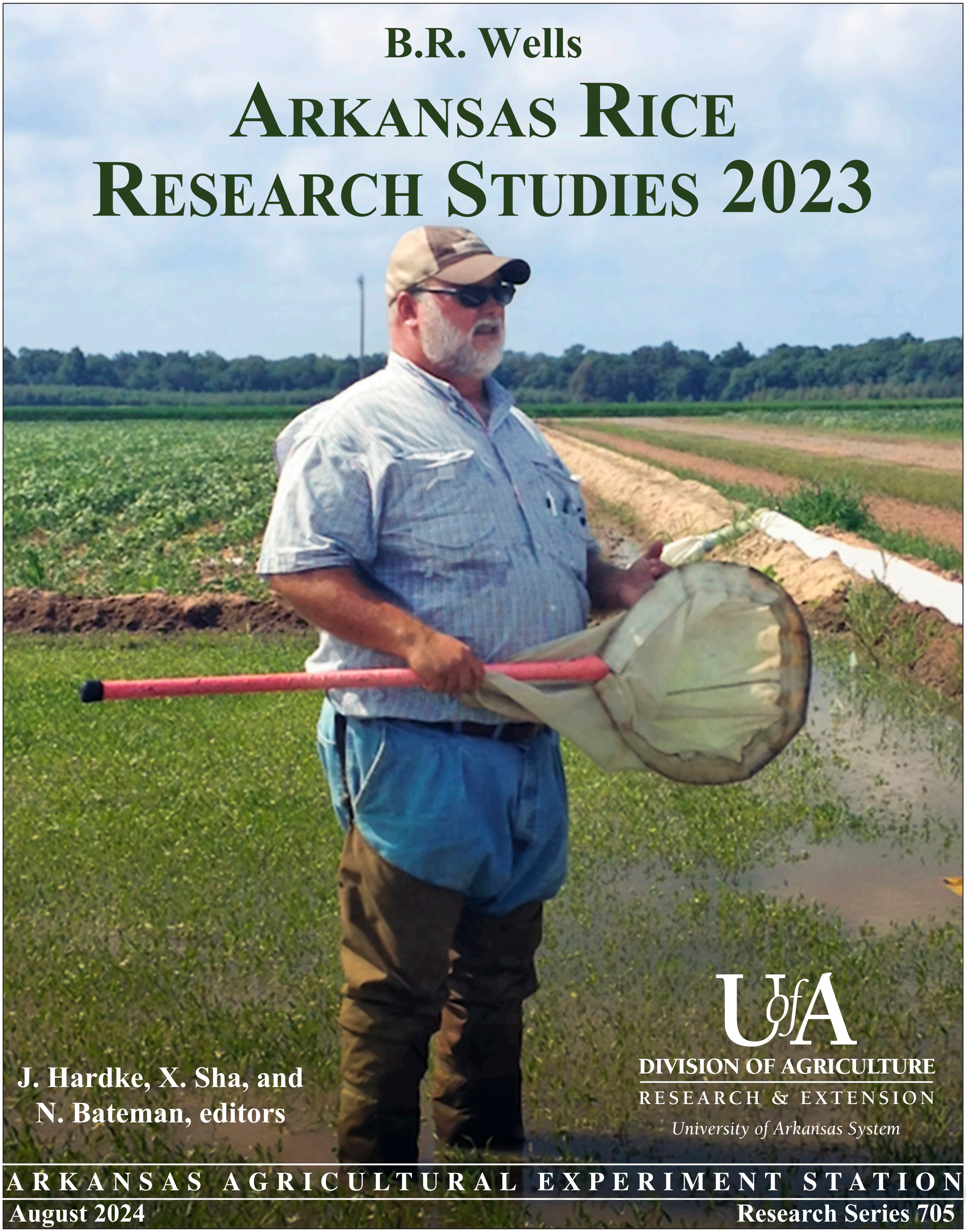
B.R. Wells
Arkansas Rice Research Studies 2023



J. Hardke, X. Sha, and
N. Bateman, editors

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Cover Photo: Gus Lorenz, retired extension entomologist and associate department head for Entomology and Plant Pathology, conducts a training session on how to scout fields for crop pests. (Undated photo). University of Arkansas System Division of Agriculture.

Layout and editing by Gail Halleck

Arkansas Agricultural Experiment Station (AAES), University of Arkansas System Division of Agriculture, Fayetteville. Deacue Fields, Vice President for Agriculture. Jean-François Meullenet, AAES Director and Senior Associate Vice-President for Agriculture–Research. WWW/CC2024.

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University of Arkansas System
Division of Agriculture
Arkansas Agricultural Experiment Station
Fayetteville, Arkansas 72704

DEDICATED IN MEMORY OF
Bobby R. Wells

Bobby R. Wells was born July 30, 1934, at Wickliffe, Kentucky. He received his B.S. degree in agriculture from Murray State University in 1959, his M.S. degree in agronomy from the University of Arkansas in 1961, and his Ph.D. in soils from the University of Missouri in 1964. Wells joined the faculty of the University of Arkansas in 1966 after two years as an assistant professor at Murray State University. He spent his first 16 years at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart. In 1982, he moved to the University of Arkansas Department of Agronomy in Fayetteville.

Wells was a world-renowned expert on rice production with special emphasis in rice nutrition and soil fertility. He had a keen interest in designing studies to determine how the rice plant reacted to different cultural practices and nutrient supplementation: including timing and rates of nitrogen, phosphorus, and potassium fertilization; zinc fertilization of high pH soils; irrigation methods; dates and rates of seeding and the reasons for differing responses.

Wells was a major participant in the pioneering effort by University of Arkansas System Division of Agriculture scientists in the development of the Degree-Day 50 (DD50) computer rice production program which assists growers with 26 management decisions during the season based on temperature, rice cultivar, and growth stage; including herbicide application, critical times to scout and spray for insects and diseases, and nitrogen fertilizer application. The DD50 program developed in the 1970s remains a vital program to this day in assisting growers, consultants and extension agents in making important management decisions concerning inputs to optimize rice yield and quality. Other rice-growing states have followed suit in this important development and have copied the Arkansas DD50 program.

He was the principal developer of the nitrogen fertilizer application method known famously at the time as the Arkansas 3-way split application strategy; who his successor discovered, using the isotopic tracer N-15, to be the most efficient method (i.e., as concerns nitrogen uptake) of fertilizing rice with nitrogen in the world. The application method has since been modified to a 2-way split, because of the release of new short stature and semi-dwarf cultivars, but its foundation was built on Wells' 3-way split method.

Wells was a major participant in the development of cultivar-specific recommendations for getting optimum performance from new cultivars upon their release and reporting research results at Cooperative Extension Service meetings as well as in the Extension Service publications, even though he had no extension appointment; he just did what he thought was best for the Arkansas rice farmer. He made numerous presentations at annual meetings of the Tri-Societies and Rice Technical Working Group, published many journal articles, and several book chapters. He loved being a professor and was an outstanding teacher who taught a course in soil fertility and developed a course in rice production. Both courses are still being taught today by his successors. The rice production course he developed is the only rice production course being taught in the USA to the best of our knowledge.

Wells was very active in the Rice Technical Working Group (RTWG), for which he served on several committees, chaired and/or moderated Rice Culture sections at the meetings, and was a past secretary/program chair (1982-1984) and chairman (1984-1986) of the RTWG. He was appointed head of the Department of Agronomy (later renamed the Department of Crop, Soil, and Environmental Sciences) in 1993 and was promoted to the rank of University Professor that year in recognition of his outstanding contributions to research, teaching, and service.

Among the awards Wells received were the Outstanding Faculty Award from the Department of Agronomy (1981), the Distinguished Rice Research and/or Education Award from the Rice Technical Working Group (1988), and the Outstanding Researcher Award from the Arkansas Association of Cooperative Extension Specialists (1992). He was named a Fellow in the American Society of Agronomy (1993), and posthumously, the Distinguished Service Award from the RTWG (1998) and induction into the Arkansas Agriculture Hall of Fame (2017). Wells edited this series when it was titled Arkansas Rice Research Studies from the publication's inception in 1991 until his death in 1996. Because of Wells' contribution to rice research and this publication, it was renamed the B.R. Wells Rice Research Studies in his memory starting with the 1996 publication. The name of this publication was modified in 2014 to the B.R. Wells Arkansas Rice Research Studies.

FEATURED RICE COLLEAGUE

Gus Lorenz

When Arkansas rice growers found the leaf beetle grape colaspis to be a difficult foe, then-Extension Rice Pathologist Rick Cartwright and Chuck Wilson, former director of the Rice Research and Extension Center, knew what they needed to do and had someone specific in mind.

"I wasn't always a rice entomologist," said Gus Lorenz, who retired as extension entomologist and associate department head for entomology in 2022. "I got coerced into working in rice by Rick Cartwright and Chuck Wilson.

"They came to my office one day — just showed up with no notice," Lorenz said. "They indicated that there were a lot of rice insect issues growers were facing and they needed some help to address those issues. I wished them luck in finding someone to help," Lorenz said.

Undeterred, Cartwright said, "Gus, you don't get it, we choose you."

Lorenz said he laughed, told them he appreciated their faith, but said "no thanks," considering the amount of work keeping him busy in cotton and soybeans. "Gus, you don't get it," Cartwright told him. "'We're not leaving your office until we get a commitment from you to work on rice insects.' Well, we had a lot of discussion, but suffice it to say, I started working in rice," Lorenz said.

Grape colaspis larvae feed on rice roots and can cause severe reductions in stands and yield loss. Farmers had managed the pest with Fipronil but it was pulled off the market by the Environmental Protection Agency because of effects to crawfish.

"As I was coming on board some new seed treatments were coming online and my crew and I began conducting seed treatment trials across the state," Lorenz said. "We averaged about 35-40 trials a year, mostly in grower fields, to figure out what the new seed treatments would provide in the way of control for grape colaspis and rice water weevil. "We wanted to provide our growers with the best information on which seed treatments and what rates would provide the best economic control of these pests for our growers," he said.

While working on the grape colaspis problem, Lorenz said he and his team noticed rice water weevil was also a problem in all rice-growing areas. "We started working on ways to provide best control practices for rice water weevil and letting growers know of the impact of this pest."

Lorenz said there were several years where rice stink bugs were also an issue and "we spent a lot of time working through best management practices, including determining thresholds for when to spray, what products were effective and the impact stink bugs had on growers' rice."

Lorenz said much of the work was done by Aaron Cato for his Ph.D. research. Cato is now an extension specialist-horticulture-integrated pest management.

In addition to fostering pest management solutions, Lorenz also nurtured the careers of many grad students including Jarrod Hardke, who is now extension rice agronomist for Arkansas; and Chase Floyd, assistant professor/crop protection specialist for the University of Missouri extension service. "When you signed up to get a degree with Gus, it wasn't because you wanted an easy path to a degree," Floyd said. "You signed up to get a degree with Gus because you wanted to be challenged."

Floyd, who worked with rice billbugs under Lorenz's tutelage, said "Gus was very good at figuring out how to get the best out of you. He could figure out where you needed to improve on and push you to step out of your comfort zone and unlock your potential." "If your degree project involved rice you got thrown in the truck to go on grower calls," Floyd said. "I loved that. Gus was never afraid to turn you loose and let you talk to the growers about pest issues. He was always at an arm's length to make sure you were accurate, but he let you be involved in the problem solving."

"I remember him saying how important it was to find a solution and we don't back down from a challenge here," Floyd said, "I can promise you, myself, Dr. Cato and Mallory Everett all were impacted by his passion for rice entomology." In addition to her involvement in the rice industry, Everett is an award-winning singer/songwriter.

"In Arkansas rice, Gus left quite a large boot print," Floyd said. "Whether it was the impact of seed treatments, proper sweeping techniques, or emerging pests in new rice systems, Gus had his hand in it. He was determined to find a solution."

Mary Hightower
University of Arkansas System Division of Agriculture Communications

FOREWORD

Research reports contained in this publication may represent preliminary or only a single year of results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication will appear in other Arkansas Agricultural Experiment Station publications. This duplication is the result of the overlap in research coverage between disciplines and our effort to inform Arkansas rice producers of all the research being conducted with funds from the rice check-off program. This publication also contains research funded by industry, federal, and state agencies.

Use of products and trade names in any of the research reports does not constitute a guarantee or warranty of the products named and does not signify that these products are approved to the exclusion of comparable products.

ACKNOWLEDGMENTS

Most of the research results in this publication were made possible through funding provided by the rice farmers of Arkansas and administered by the Arkansas Rice Research and Promotion Board. We express sincere appreciation to the farmers and to the members of the Arkansas Rice Research and Promotion Board for their vital financial support of these programs.

The Arkansas Rice Research and Promotion Board

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Trends in Arkansas Rice Production, 2023

J.T. Hardke[1]

Abstract

Arkansas is the leading rice producer in the United States. The state represents 49.0% of total U.S. rice production and 49.6% of the total acres planted to rice in 2023. Rice cultural practices vary across the state and across the U.S. However, these practices are also dynamic and continue to evolve in response to changing political, environmental, and economic times. This survey was initiated in 2002 to monitor and record changes in the way Arkansas rice producers approach their livelihood. The survey was conducted by polling county extension agents in each of the counties in Arkansas that produce rice. Questions included topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Information from the University of Arkansas System Division of Agriculture DD50 Rice Management Program was included to summarize the variety acreage distribution across Arkansas. Other data was obtained from the USDA National Agricultural Statistics Service.

Introduction

Arkansas is the leading rice producer in the United States in terms of acreage planted, acreage harvested, and total production. Each year, rice planting typically ranges from late March into early June, with harvest occurring from late August to early November. Rice production occurs across a wide range of environments in the state. The diverse conditions under which rice is produced lead to variation in the adoption and utilization of different crop management practices. A survey was initiated in 2002 to record annual production practices in order to monitor and better understand changes in rice production practices, including the adoption of new practices. Information obtained through this survey helps to illustrate the long-term evolution of cultural practices for rice production in Arkansas. It also serves to provide information to researchers and extension personnel about the ever-changing challenges facing Arkansas rice producers.

Procedures

A survey has been conducted annually since 2002 by polling county agriculture extension agents in each of the counties in Arkansas that produce rice. Questions were asked concerning topics such as tillage practices, water sources and irrigation methods, seeding methods, and precision leveling. Acreage, yield, and crop progress information was obtained from the USDA National Agricultural Statistics Service (https://www.nass.usda.gov). Rice cultivar distribution was obtained from summaries generated from the University of Arkansas System Division of Agriculture DD50 Rice Management Program enrollment.

Results and Discussion

Rice acreage by county is presented in Table 1 with the distribution of the most widely-produced cultivars. RT 7521 FP was the most widely planted cultivar in 2023 at 21.3% of the acreage, followed by RT 7321 FP (14.6%), RT XP753 (12.3%), DG263L (8.1%), RT 7421 FP (6.0%), Titan (5.8%), CLL16 (4.3%), and Jupiter (4.2%). Additional cultivars of importance in 2023, though not shown in the table, were Diamond, RTv7231 MA, CLM04, RT 7401, PVL03, and RT 7301.

Arkansas planted 1,436,000 acres of rice in 2023, which accounted for 49.6% of the total U.S. rice acres (Table 2). The state-average yield of 7,550 lb/ac (167.7 bu./ac) represented a 140 lb/ac increase compared to 2022. The 2021 yield of 7,630 lb/ac (169.6 bu./ac) was a state record. Record rainfall through late March was concerning but gave way to clear early planting windows and a dramatic planting pace in certain areas through the early parts of April. Late April cool temperatures and rainfall slowed progress temporarily before a rapid resumption in early May. Persistent dry, northerly winds created difficulties for plant health and weed control through May and early June, but favorable temperatures drove crop progress. July faced a cooler period and unexpected rainfall amounts, which led to reductions in irrigation water use. Once harvest arrived, increasing heat and dry conditions led to rapid harvest progress, but also overdrying of grain that led to lower milling yields.

The final harvested acreage in 2023 totaled 1,417,000. The total rice produced in Arkansas during 2023 was 107.0 million hundredweight (cwt). This represents 49.0% of the 218.3 million cwt produced in the U.S. during 2023. Over the past three years, Arkansas has been responsible for 48.8% of all rice produced in the U.S. The largest rice-producing counties by acreage in Arkansas during 2023 included Jackson, Poinsett, Lawrence, Cross, and Lonoke, representing 35.4% of the state's total rice acreage (Table 1).

Planting in 2023 exceeded the 5-year average through mid-April as favorable dry weather occurred (Fig. 1). Planting progress had reached 33% by 16 April compared to 20% averaged across

[1] Professor and Rice Extension Agronomist, Department of Crop, Soil, and Environmental Sciences, Rice Research and Extension Center, Stuttgart.

the previous 5 years. Planting progress improved considerably through the end of April. As of 30 April, 68% of acres had been planted compared with an average of 47% by this date across the 5 previous seasons. By 4 June, 99% of acres had been planted compared to the 5-year average of 95%. Planting progress in 2023 appeared to progress even faster in late March and early April than official data suggests.

As harvest began, dry conditions and heat sped crop maturity. By 17 September, harvest progress had reached 58% compared to 43% for the 5-year average (Fig. 2). About 81% of the crop had been harvested by 1 October compared with 72% harvest progress on the same date in previous years. Harvest progress was complete (100%) by 5 November.

More rice is produced on silt loam soils (49.2%) than any other soil texture (Table 3). Rice production on clay or clay loam soils (22.3% and 20.5%, respectively) has become static over recent years after steadily increasing through 2010. These differences in soil type present unique challenges in rice production, such as tillage practices, seeding rates, fertilizer management, and irrigation.

Approximately 40% of the rice produced in Arkansas was planted using conventional tillage methods in 2023 (Table 3). This usually involves fall tillage when the weather cooperates, followed by spring tillage to prepare the seedbed. The remainder of rice acres are planted using stale seedbed (45.3%) or no-till (14.8%) systems. True no-till rice production is not common but is practiced in a few select regions of the state.

Rice most commonly follows soybean in rotation, accounting for 68.6% of the rice acreage (Table 3). Approximately 21.4% of the acreage in 2023 was planted following rice, with the remainder made up of rotation with other crops, including cotton, corn, grain sorghum, wheat, and fallow. The majority of the rice in Arkansas is produced in a dry-seeded, delayed-flood system, with only 2.0% using a water-seeded system. Annually, approximately 88% of all the Arkansas rice acreage is drill-seeded, with the remaining acreage broadcast-seeded (dry-seeded and water-seeded).

Irrigation water is one of the most precious resources for rice producers in Arkansas. Reports of diminishing supplies have prompted many producers to develop reservoir and/or tailwater recovery systems to reduce the “waste” by collecting all available water and re-using it. Simultaneously, producers have tried to implement other conservation techniques to preserve the resource vital to continued production. Groundwater is used to irrigate 79.3% of the rice acreage in Arkansas, with the remaining 20.7% irrigated with surface water obtained from reservoirs or streams and bayous (Table 3).

During the mid-1990s, the University of Arkansas System Division of Agriculture began educating producers on multiple-inlet rice irrigation, which uses poly-tubing to irrigate rice and conserve water and labor. As of 2023, rice farmers utilize this practice on 31.9% of the rice acreage (Table 3). Most remaining acreage is still irrigated with conventional levee and gate systems. Intermittent flooding is another means of irrigation that has been increasing in interest recently as a means to reduce pumping costs and water use, but the practice accounts for only 3.4% of acreage at this time. Additional interest has risen in growing rice in a furrow-irrigated system (row rice) as is common with soybean or corn as a means to simplify crop rotation and management and currently accounts for 17.4% of acreage compared to 18.0% and 20.2% in 2022 and 2021, respectively.

Stubble management is important for preparing fields for the next crop, particularly in rice following rice systems. Several approaches are utilized to manage the rice straw for the next crop, including burning, tillage, rolling, and winter flooding. In 2023, 51.3% of the acreage was burned, 58.1% was tilled, 29.8% was rolled, and 27.5% was winter flooded (Table 3). Combinations of these systems are used in many cases. For example, a significant amount of the acreage that is flooded during the winter for waterfowl will also be rolled. Some practices are inhibited by fall weather, and the wet fall weather from 2018 to 2020 resulted in a decrease in burning and tillage, but a subsequent rise in rolling and winter flooding; whereas drier falls in recent years have shown an increase in burning and tillage.

Contour levee fields accounted for 49.6% of rice acres in 2023 (Table 3). Precision-leveled, or straight levee, fields represented 38.0% and zero-graded fields 12.4%. Each year, growers attempt land improvement where possible to improve overall rice crop management, particularly related to water management. Modifying the slope, and subsequently the levee structure and arrangement in fields, can have a profound impact on the efficiency of rice production. Straight levees and zero-grade fields have been shown to significantly reduce water use in rice production in Arkansas.

The use of yield monitors at harvest (81.6%) and grid soil sampling (32.0%) have increased slightly in recent years (Table 3). However, only 24.4% of rice acres are fertilized using variable-rate equipment. Urea stabilizers (products containing NBPT) are currently used on 90.8% of rice acres in Arkansas to limit nitrogen losses due to ammonia volatilization. The use of the Nitrogen Soil Test for Rice (N-STaR) remains low at 6.0% of acres, but additional tools are being developed to improve the confidence in and adoption of this practice. In addition, programs such as Pipe Planner, PHAUCET, and MIRI Rice Irrigation were used on 29.9% of rice acres in 2023. A GreenSeeker handheld was utilized to monitor in-season nitrogen condition on 2.4% of acres. The use of cover crops in rice rotations remains limited but was a practice used on 4.5% of acres. Harvest aid applications, primarily sodium chlorate, are currently used on 41.8% of acres to improve harvest efficiency.

Pest management is vital to preserve both yield and quality in rice. Foliar fungicide applications were made on 56.9% of rice acres in 2023 (Table 3). Conditions appeared more favorable for disease development in 2023, but the need to treat fields was variable. Approximately 42% of rice acres received a foliar insecticide application due to rice stink bug infestation levels, which were low to moderate overall. Insecticide seed treatments were used on 75% of rice acreage as producers continue to utilize this technology each year due to its early-season benefits for both insect control and improved plant growth and vigor.

The use of herbicide-tolerant rice cultivars continues to play a significant role in rice production in Arkansas. The technologies include Clearfield® (tolerant to imidazolinone herbicides), FullPage™ (tolerant to imidazolinone herbicides), Provisia® (tolerant to ACCase herbicides), and MaxAce™ (tolerant to ACCase herbicides). Herbicide-tolerant cultivars (all technologies combined) accounted for 57% of the total rice acreage in 2023 (Fig. 3). Clearfield acres increased rapidly from 2001 to 2011 but have gradually declined since then. In 2018, Provisia became available on limited acres and in 2023, it was planted on 2.15% of acres. FullPage, similar to Clearfield, was launched in 2020 and in 2023 was planted on 41.9% of acres. MaxAce became available beginning in 2022, and in the 2023 season, it was planted on 4.9% of acres. Acres of these and other herbicide technologies will likely increase in the coming years. Proper stewardship of these technologies will be the key to their continued success in rice. In areas where stewardship has been poor, imidazolinone-resistant barnyardgrass has been discovered.

Practical Applications

State average yields over the past 20 years in Arkansas have increased from an average of 143.7 bu./ac in 2001–2003 to an average of 167.3 bu./ac in 2021–2023, an increase of 23.6 bu./ac. This increase can be attributed to the development and adoption of more productive cultivars and improved management practices, including better herbicides, fungicides, and insecticides, improved water management through precision-leveling and multiple-inlet irrigation, improved fertilizer efficiency via timing and the use of urease inhibitors, and increased understanding of other practices such as seeding dates and tillage. Collecting this kind of information regarding rice production practices in Arkansas is important for researchers to understand the adoption of certain practices as well as to understand the challenges and limitations faced by producers in field situations.

Acknowledgments

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Table 1. 2023 Arkansas harvested rice acreage summary.

	Harvested Acreage[a]		Medium-Grain			Long-Grain						
County	2022	2023	Jupiter	Titan	Others[b]	CLL16	DG263L	RT 7321 FP	RT 7421 FP	RT 7521 FP	RT XP753	Others[b]
Arkansas	65,448	70,789	1,050	158	1,590	2,863	4,064	9,590	9,778	25,059	6,761	9,876
Ashley	4,563	8,305	0	0	0	0	0	4,146	0	4,160	0	0
Chicot	18,186	27,299	305	305	0	0	611	106	0	909	13,684	11,379
Clay	62,298	71,081	3,790	1,555	0	7,307	6,148	11,809	5,006	10,878	13,567	11,020
Craighead	50,276	62,733	9,437	0	0	2,944	13,123	11,683	394	6,520	8,876	9,755
Crittenden	29,139	41,762	0	0	2,719	1,639	8,533	4,524	2,904	5,008	12,427	4,008
Cross	54,413	90,053	11,325	7,908	9,192	1,370	2,176	15,989	2,768	25,917	7,001	6,407
Desha	18,447	27,513	0	2,378	0	11	390	7,532	0	3,948	1,286	11,968
Drew	10,267	13,380	523	523	0	0	0	805	0	8,123	1,770	1,636
Greene	55,281	67,612	1,399	3,964	0	7,424	5,023	3,768	0	4,075	6,279	35,679
Independence	8,904	12,396	224	448	2,395	2,352	0	2,138	0	540	1,557	2,741
Jackson	84,101	112,566	5,614	8,450	17,395	4,308	3,658	19,301	5,573	18,106	8,066	22,096
Jefferson	54,861	67,254	1,238	3,376	0	4,084	10,238	18,466	0	13,731	17	16,104
Lafayette	5,439	5,552	0	0	0	389	389	0	0	1,665	333	2,776
Lawrence	75,582	104,302	2,864	20,121	823	1,377	4,474	9,877	0	7,391	32,836	24,538
Lee	12,749	18,938	463	1,251	0	0	2,666	4,738	450	5,452	2,056	1,863
Lincoln	20,060	30,112	5,682	0	0	0	1,245	7,771	1,176	11,788	1,960	490
Lonoke	84,168	86,562	7,393	0	2,856	2,959	508	0	16,722	30,354	10,307	15,462
Miller	6,216	8,225	1,295	1,295	0	394	394	0	0	1,690	338	2,817
Mississippi	43,194	64,865	702	702	0	1,490	3,368	18,118	8,942	16,623	13,650	1,269
Monroe	40,834	53,611	0	0	7,878	3,989	7,326	2,321	6,674	11,725	6,932	6,765
Phillips	19,955	33,306	0	2,632	0	0	6,489	7,626	0	10,885	0	5,674
Poinsett	81,464	107,482	1,265	8,466	11,560	11,920	13,099	7,870	2,509	20,412	2,864	27,517
Prairie	50,771	56,930	794	1,309	1,011	1,682	5,730	11,487	8,265	14,844	6,971	4,837
Randolph	28,629	40,153	0	10,697	1,465	0	2,739	4,454	1,073	2,388	7,001	10,335
St. Francis	26,630	34,553	373	1,395	13	399	5,745	7,577	90	7,772	4,042	7,147
White	6,086	8,303	245	0	0	230	0	3,234	0	3,403	851	340
Woodruff	46,662	65,229	1,806	3,612	0	0	5,297	11,509	12,807	24,449	0	5,749
Others[c]	17,871	20,810	1,243	1,243	0	1,273	1,340	827	438	3,250	2,482	8,715
Unaccounted[d]	1,505	5,327										5,327
2023 Total		1,417,000	59,028	81,787	58,897	60,404	114,775	207,266	85,571	301,065	173,915	274,291
2023 Percent		100.00	4.17	5.77	4.16	4.26	8.10	14.63	6.04	21.25	12.27	19.36
2022 Total	1,084,000		49,146	29,702	11,088	53,560	117,623	158,421	0	322,737	193,247	148,476
2022 Percent	100.00		4.53	2.74	1.02	4.94	10.85	14.61	0.0	29.77	17.83	13.70

[a] Harvested acreage. Source: USDA-NASS, 2024a.

[b] Other varieties: AddiJo, ARoma17, ARoma22, CLL17, CLL18, CLM04, Diamond, Lynx, Ozark, ProGold1, ProGold2, PVL03, RTv7231 MA, RT 7301, RT 7302, RT 7331 MA, RT 7401, RT 7801, and Taurus.

[c] Other counties: Clark, Conway, Faulkner, Franklin, Hot Springs, Johnson, Little River, Logan, Perry, Pope, Pulaski, and Yell.

[d] Unaccounted for acres is the total difference between USDA-NASS harvested acreage estimate and estimates obtained from each county's Farm Service Agency.

Table 2. Acreage, grain yield, and production of rice in the United States from 2021 to 2023.[a]

	Area Planted			Area Harvested			Yield			Production		
State	2021	2022	2023	2021	2022	2023	2021	2022	2023	2021	2022	2023
	--------------(1,000 ac)--------------			-------------(1,000 ac)-------------			---------------(lb/ac)---------------			-----------------(1,000 cwt[b])-----------------		
AR	1,211	1,104	1,436	1,188	1,080	1,417	7,630	7,410	7,550	90,680	80,051	106,968
CA	407	254	515	405	252	512	9,050	8,770	8,590	36,653	22,103	43,971
LA	420	422	468	413	412	462	6,870	6,660	6,800	28,380	27,453	31,431
MS	104	87	121	98	86	120	7,540	7,370	7,470	7,388	6,338	8,964
MO	199	157	205	194	151	200	8,040	7,940	7,990	15,599	11,991	15,985
TX	190	195	149	180	186	143	6,860	6,510	7,670	12,352	12,105	10,972
US	2,531	2,219	2,894	2,478	2,167	2,854	7,710	7,385	7,649	191,052	160,041	218,291

[a] Source: USDA-NASS, 2024a.
[b] cwt = hundredweight.

Table 3. Acreage distribution of selected cultural practices for Arkansas rice production from 2021 to 2023[a].

	2021		2022		2023	
Cultural Practice	**Acreage**	**% of Total**	**Acreage**	**% of Total**	**Acreage**	**% of Total**
Arkansas Rice Acreage	1,194,000	100.00	1,084,000	100.00	1,417,000	100.00
Soil Texture						
Clay	268,075	22.5	204,721	18.9	315,321	22.3
Clay Loam	220,061	18.4	208,746	19.3	290,101	20.5
Silt Loam	650,536	54.5	617,210	56.9	697,850	49.2
Sandy Loam	43,517	3.6	48,746	4.5	89,473	6.3
Sand	11,810	1.0	4,578	0.4	24,256	1.7
Tillage Practices						
Conventional	674,053	56.5	545,565	50.3	565,348	39.9
Stale Seedbed	424,978	35.6	425,376	39.2	642,068	45.3
No-Till	177,783	8.0	136,278	10.4	164,503	14.8
Crop Rotations						
Soybean	793,231	66.4	725,512	66.9	971,860	68.6
Rice	260,971	21.9	214,026	19.7	303,894	21.4
Cotton	1,591	0.1	5,705	0.5	13,227	0.9
Corn	68,557	5.7	71,449	6.6	76,439	5.4
Grain Sorghum	3,262	0.3	1,362	0.1	0	0.0
Wheat	3,093	0.3	1,391	0.1	0	0.0
Fallow	63,295	5.3	50,909	4.7	51,581	3.6
Other	0	0.0	13,643	1.3	0	0.0
Seeding Methods						
Drill Seeded	1,016,217	85.1	947,722	87.4	1,252,497	88.4
Broadcast Seeded	138,767	11.6	95,891	8.8	135,699	9.6
Water Seeded	39,016	3.3	40,387	3.7	28,804	2.0
Irrigation Water Sources						
Groundwater	921,097	77.1	852,733	78.7	1,123,215	79.3
Stream, Rivers, etc.	122,157	10.2	91,759	8.5	147,608	10.4
Reservoirs	150,747	12.6	139,508	12.9	146,178	10.3
Irrigation Methods						
Flood, Levees	519,261	43.5	533,558	49.2	662678	46.8
Flood, Multiple Inlet	391,693	32.8	313,590	28.9	452,224	31.9
Intermittent (AWD)	41,668	3.5	41,350	3.8	48,841	3.4
Furrow	241,379	20.2	195,501	18.0	246,945	17.4
Sprinkler	0	0.0	0	0.0	4,734	0.3
Other	0	0.0	0	0.0	1,578	0.1
Stubble Management						
Burned	447,282	37.5	534,972	49.4	726,696	51.3
Tilled	528,258	44.2	516,699	47.7	823,033	58.1
Rolled	377,364	31.6	298,430	27.5	422,132	29.8
Winter Flooded	328,079	27.5	246,632	22.8	389,032	27.5
Land Management						
Contour levees	588,246	49.3	574,233	53.0	703,464	49.6
Precision-level	461,713	38.7	403,266	37.2	538,181	38.0
Zero-grade	144,040	12.1	106,501	9.8	175,356	12.4
Precision Agriculture						
Yield Monitors	971,576	81.4	887,218	81.8	1,156,773	81.6
Grid Sampling	489,135	41.0	351,429	32.4	453,633	32.0
Variable-rate Fertilizer	254,690	21.3	188,631	17.4	345,464	24.4
Use Pipe Planner, Phaucet	400,686	33.6	336,484	31.0	423,681	29.9
Use urea stabilizer (NBPT)	1,101,177	92.2	961,794	88.7	1,287,309	90.8
N-STaR	101,868	8.5	55,538	5.1	85,153	6.0
Use GreenSeeker handheld	42,480	3.6	36,827	3.4	33,558	2.4
Use Cover Crops	35,781	3.0	61,664	5.7	64,136	4.5
Use Sodium Chlorate	378,421	31.7	404,777	37.3	592,876	41.8
Pest Management						
Insecticide Seed Treatment	1,153,642	80.1	997,633	83.6	1,062,155	75.0
Fungicide (foliar app.)	868,717	60.3	719,455	60.3	806,237	56.9
Insecticide (foliar app.)	574,373	39.9	544,079	45.6	589,921	41.6

[a] Data generated from surveys of county agriculture extension agents.

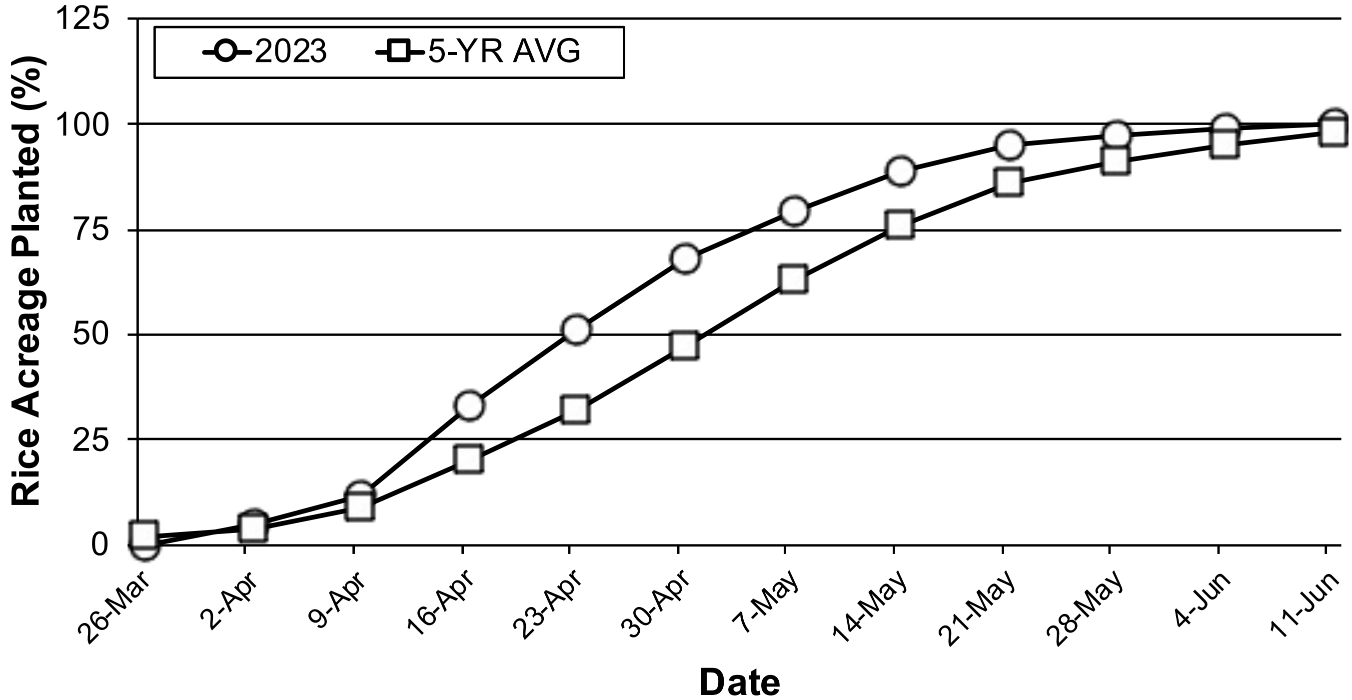

Fig. 1. Arkansas rice planting progress during 2023 compared to the five-year state average (USDA-NASS, 2024b).

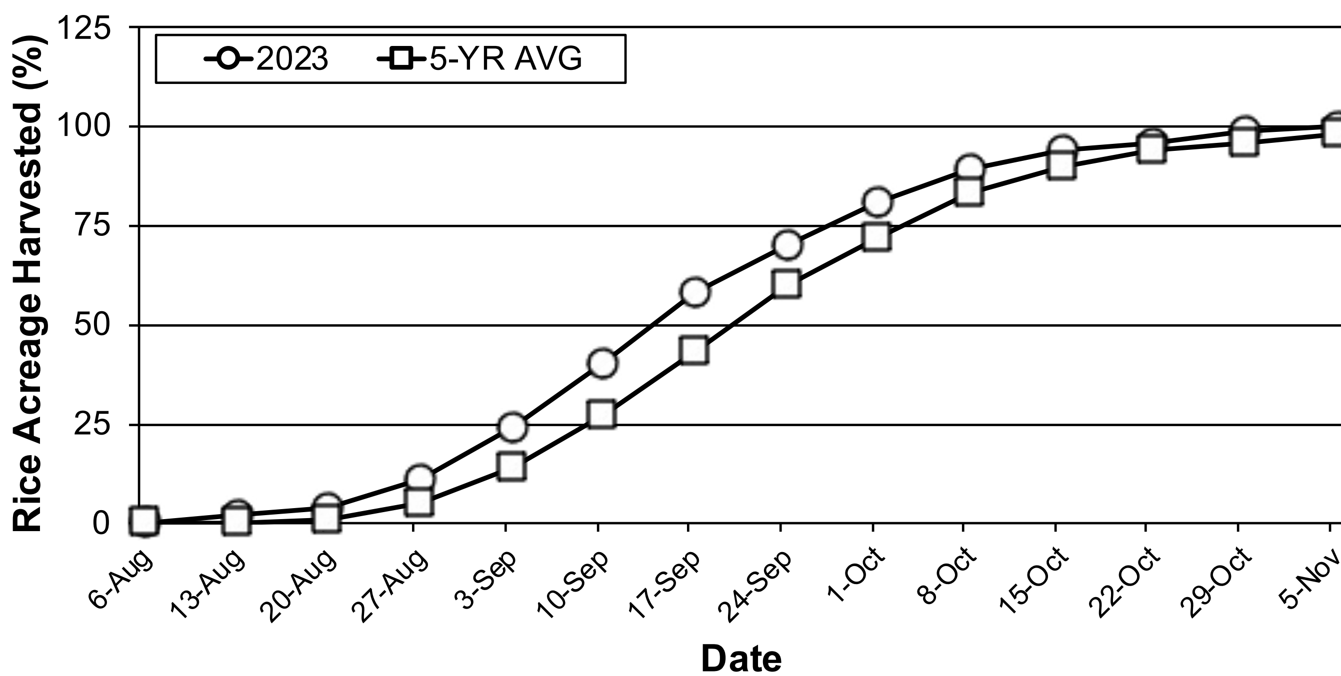

Fig. 2. Arkansas rice harvest progress during 2023 compared to the five-year state average (USDA-NASS, 2024b).

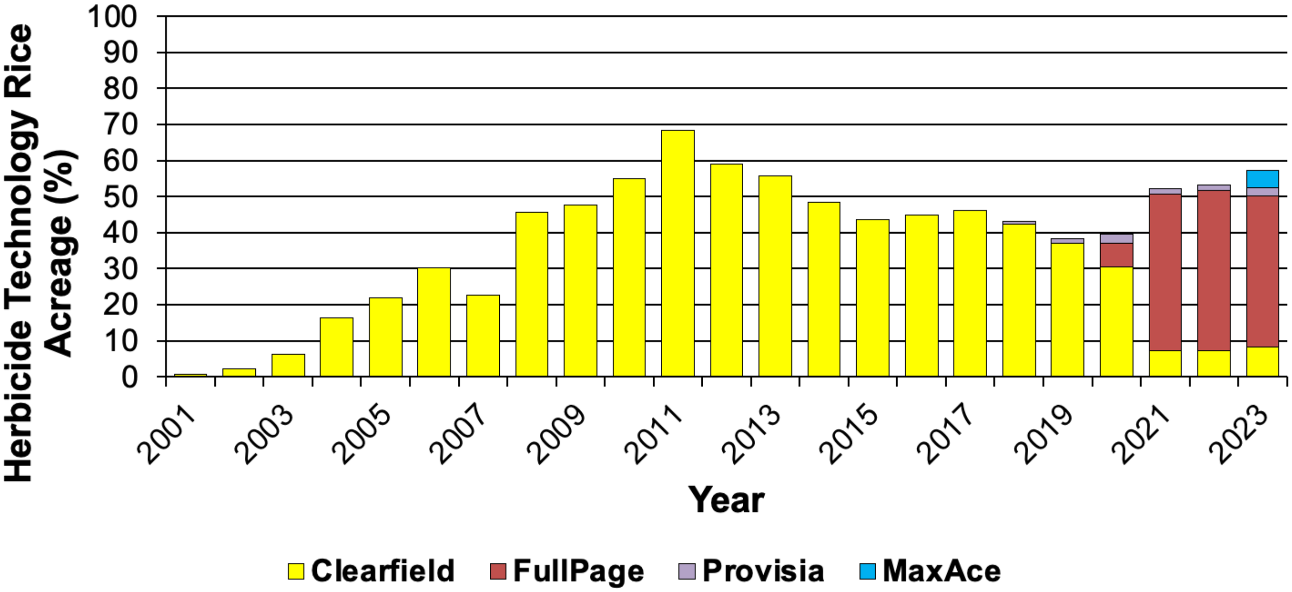

Fig. 3. Percentage of rice planted in Arkansas with herbicide technology including Clearfield, FullPage, and Provisia, and MaxAce rice cultivars between 2001 and 2023.

2023 Rice Research Verification Program

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Abstract

The 2023 Rice Research Verification Program (RRVP) was conducted on 9 commercial rice fields across Arkansas. Counties participating in the program included Clark, Cross, Drew, Jefferson, Mississippi, Pulaski, Phillips, Woodruff, and White for a total of 615 acres. Grain yield in the 2023 RRVP averaged 190 bu./ac, ranging from 136 to 236 bu./ac. The 2023 RRVP average yield was 22 bu./ac greater than the estimated Arkansas state average of 168 bu./ac. The highest yielding field was White County, with a yield of 236 bu./ac. The lowest yielding field was Clark, producing 136 bu./ac. Milling quality in the RRVP averaged 48/67 (% head rice/% total milled rice). The Phillips Co. field had the greatest returns to operating costs of $1182.75/ac, while the Clark Co. field had the lowest returns to operating costs of $51.09/ac.

Introduction

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service established an interdisciplinary rice educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Rice Research Verification Program (RRVP) was to verify the profitability of Cooperative Extension Service (CES) recommendations in fields with less than optimum yields or returns.

The goals of the RRVP are to 1) educate producers on the benefits of utilizing CES recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, and 5) incorporate data from RRVP into CES educational programs at the county and state level. Since 1983, the RRVP has been conducted on 501 commercial rice fields in 33 rice-producing counties in Arkansas. Since the program's inception 37 years ago, RRVP yields have averaged 18 bu./ac better than the state average. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

Procedures

The RRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement CES recommendations in a timely manner, from planting to harvest. A designated county agent from each county assists the RRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents are made to monitor the growth and development of the crop, determine what cultural practices need to be implemented, and monitor the type and level of weed, disease and insect infestation for possible pesticide applications.

An advisory committee, consisting of CES specialists and university researchers with rice responsibility, assists in decision-making, development of recommendations, and program direction. Field inspections by committee members are utilized to assist in fine-tuning recommendations.

Counties participating in the program during 2023 included Clark, Cross, Drew, Jefferson, Mississippi, Pulaski, White, and Woodruff. The 9 rice fields totaled 615 acres enrolled in the program. Six different cultivars were seeded: RT 7521 FP (2 fields), RT 7321 FP (4 fields), DG263L (2 fields), and Titan (1 field). University of Arkansas System Division of Agriculture recommendations were used to manage the RRVP fields. Agronomic and pest management decisions were based on field history, soil test results, rice cultivar, and data collected from individual fields during the growing season. An integrated pest management philosophy was utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, dates for specific growth stages, midseason nitrogen levels, grain yield, milling yield, and grain quality.

Results and Discussion

Yield

The average RRVP yield was 190 bu./ac with a range of 136 to 236 bu./ac (Table 1). All grain yields of RRVP fields are reported in dry bushels corrected to 12% moisture. A bushel of rice is 45 lb. The RRVP average was 22 bu./ac more than the estimated state average yield of 168 bu./ac. Similar yield differences have been observed since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The White County field, seeded with RT 7321 FP, was the highest-yielding RRVP field at 236 bu./ac. Eight fields enrolled in the program met or exceeded the 168 bu./ac state average yield. Clark County resulted in the lowest yield of 136 bu./ac.

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Milling data was recorded on all the RRVP fields. The average milling yield for the 9 fields was 48/67 (% head rice/% total milled rice). The highest milling yield was 62/72 with RT 7321 FP in Cross County (Table 1). The lowest milling yield was 37/64 in Clark County. The milling yield of 55/70 is considered the standard used by the rice milling industry.

Planting and Emergence

Planting began with Jefferson County on 29 March and ended with Pulaski County on 12 May (Table 1). Five of the verification fields were planted in April, 3 in May, and 1 in March. An average of 58 lb of seed/ac was planted for pure-line varieties and 22 lb of seed/ac for hybrids. Seeding rates were determined using the CES RICESEED program for all fields. An average of 14 days was required for emergence. Stand density averaged 11 plants/ft^2 for pure-line varieties and 7 plants/ft^2 for hybrids. The seeding rates in some fields were slightly higher than average due to soil texture and planting date. Clay soils generally require an elevated seeding rate to achieve desired plant populations.

Fertilization

The Nitrogen Soil Test for Rice (N-STaR) was utilized for 7 RRVP fields and reduced the total nitrogen (N) recommendation by an average of 15 lbs N/ac when compared with the standard N recommendation. However, row rice fields call for additional N in 2 fields during the season. The recommendations prompting the N additions are described in the field reviews, and the amounts are included in Table 2.

As with standard N recommendations for rice, N-STaR N recommendations consider a combination of factors, including soil texture, previous crop, and cultivar requirements (Tables 1 and 2). The GreenSeeker hand-held crop sensor was used at least weekly in all fields after panicle initiation through late boot stage to verify that N levels were adequate for the targeted yield potential.

Phosphorus (P), potassium (K), and zinc (Zn) fertilizers were applied based on soil test analysis recommendations (Table 2). Phosphorus was applied pre-plant to Clark, Cross, Drew, Mississippi, Phillips, and St. Francis County fields. Potassium was applied to Arkansas, Drew, Lonoke, Mississippi, Monroe, Phillips, Pulaski, White, and Woodruff County fields. Zinc was applied as a pre-plant fertilizer to the Clark, Cross, Phillips, and White County fields, while zinc seed treatment was used with all hybrids and pure-line rice cultivars at a rate of 0.5 lb Zn/cwt. The average per-acre cost of fertilizer across all fields was $153.66.

Weed Control

Clomazone (e.g., Command) herbicide was utilized as either a stand-alone, premix, or tank mix application in all 9 program fields for early-season grass control (Table 3). Quinclorac (e.g., Facet) was utilized in 4 of 9 fields, again, as either a stand-alone, premix, or tank mix application for both pre-emergence and early post-emergence treatments. Overlapping residuals proved to be an effective strategy utilized in all fields. A combination of both grass and broadleaf residuals was used in each field. Six fields (Clark, Cross, Drew, Mississippi, Pulaski, and White Counties) were seeded in imidazolinone (IMI) tolerant cultivars, either Clearfield or FullPage technologies (Table 1).

Disease Control

A foliar fungicide was applied in 4 of the 9 program fields (Clark, Cross, Pulaski, and White Counties). These were preventive treatments applied for kernel smut and false smut diseases (Table 4). Generally, fungicide rates are determined based on cultivar, growth stage, climate, disease incidence/severity, and disease history. However, preventative treatments for kernel or false smut and rice blast require specific rates depending on the product used. Nine fields had a seed treatment containing a fungicide.

Insect Control

Two fields (Jefferson and White Counties) were treated with a foliar insecticide application for rice stink bug (Table 4). All 9 fields received an insecticide seed treatment.

Irrigation

Well water was used exclusively for irrigation in 8 of the fields in the 2023 RRVP. Two fields (Drew and Phillips Counties) were grown under furrow irrigated rice (FIR; row rice) management. Multiple Inlet Rice Irrigation (MIRI) was utilized in the 5 conventionally flooded fields. Typically, a 25% reduction in water use is observed when using MIRI, which employs polytube irrigation and a computer program to determine the size of tubing required plus the correct number and size of holes punched into it to achieve uniform flood-up across the field. Flow meters were used in 6 fields to record water usage throughout the growing season (Table 5). In 3 fields where flow meters for various reasons could not be utilized, the average across all irrigation methods (30 inches) was used. The difference in irrigation water used was due in part to rainfall amounts, which ranged from a low of 6.25 inches to a high of 16.3 inches.

Economic Analysis

This section provides information on production costs and returns for the 2023 Rice Research Verification Program (RRVP). Records of field operations on each field provided the basis for estimating production costs. The field records were compiled by the RRVP coordinators, county Extension agents, and cooperators. Production data from the 9 fields were applied to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel indicate the commodity price needed to meet each cost type.

Operating costs are those expenditures that would generally require annual cash outlays and would be included on an annual operating loan application. Actual quantities of all operating inputs, as reported by the cooperators, are used in this analysis. Input prices are determined by data from the 2023 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the cooperating producers. Fuel and repair costs for machinery are calculated using a budget calculator based on parameters and standards established by the American Society of Agricultural and Biological Engineers. Machinery repair costs should be regarded as estimated values for full-service repairs, and actual cash outlays could differ as producers provide unpaid labor for equipment maintenance.

Fixed costs of machinery are determined by a capital recovery method, which determines the amount of money that should be set aside each year to replace the value of equipment used in production. Machinery costs are estimated by applying engineering formulas to representative prices of new equipment. This measure differs from typical depreciation methods, as well as actual annual cash expenses for machinery.

Operating costs, fixed costs, costs per bushel, and returns above operating and total specified costs are presented in Table 6. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. Operating costs ranged from $568.05/ac for Phillips County to $968.16 for Cross County, while operating costs per bushel ranged from $2.76/bu. for Phillips County to $6.27/bu. for Clark County. Total costs per acre (operating plus fixed) ranged from $717.80/ac for Phillips County to $1,129.01/ac for Cross County, and total costs per bushel ranged from $3.48/bu. for Phillips County to $7.05/bu. for Clark County. Returns above operating costs ranged from -$54.48/ac for Clark County to $1032.99/ac for Phillips County, and returns above total costs ranged from -$54.48/ac for Clark County to $1032.99/ac for Phillips County.

A summary of yield, rice price, revenues, and expenses by expense type for each RRVP field is presented in Table 7. The average rice yield for the 2023 RRVP was 190 bu./ac but ranged from 136 bu./ac for Clark County to 236 bu./ac for White County. An Arkansas average long grain and medium grain cash price of $7.19/bushel and $8.76/bushel, respectively, were estimated using USDA, National Agricultural Statistics Service (NASS) U.S. long-grain prices and medium-short grain prices (for rice states other than California) for the months of August through October. A premium or discount was given to each field based on the milling yield observed for each field, based on a standard milling yield of 55/70 for long-grain rice and 58/69 for medium-grain rice, and 2023 loan values for whole kernels ($11.13/cwt for medium-grain; $10.45/cwt for long-grain) and broken kernels ($6.74/cwt for both long-grain and medium-grain). Estimated long-grain prices adjusted for milling yield varied from $6.63/bu. in Jefferson County to $7.38/bu. in Cross County (Table 7). Phillips County was the only county producing medium grain rice, and the estimated milling yield adjusted price for Phillips County was $8.50/bushel.

The average operating expense for the 9 RRVP fields was $803.97/acre (Table 7). Fertilizer and nutrient expenses accounted for the largest share of operating expenses on average (19.1%), followed by chemicals (17.5%), seed (18.1%), and post-harvest expenses (14.3%). Although seed's share of operating expenses was 18.1% across the 9 fields, its average cost and share of operating expenses varied depending on whether a proprietary non-herbicide tolerant pure-line cultivar was used ($45.75/ac; 8.1% of operating expenses), a non-herbicide tolerant hybrid was used ($83.00/ac; 12.21% of operating expenses), or a herbicide-tolerant hybrid was used ($178.46/ac; 20.73% of operating expenses).

The average return above operating expenses for the 9 fields was $557.74/ac and ranged from $51.09/ac for Clark County to $1182.75/ac for Phillips County. The average return above total specified expenses for the 9 fields was $429.92/ac and ranged from -$54.48/ac for Clark County to $1032.99/ac for Phillips County. Table 8 provides select variable input costs for each field and includes a further breakdown of chemical costs into herbicides, insecticides, and fungicides. Table 8 also lists the specific rice cultivars grown on each RRVP field.

Field Summaries

Clark County

The Clark County field was located south of Arkadelphia on an Una and Gurdon silty clay loam soil. The field is zero grade with continuous rice, and no tillage practices were used for spring preparation. The field consisted of 41 acres. The chosen cultivar was RT 7321 FP, which was treated with the company's standard seed treatment. The field was drill-seeded at 25 lb/ac on 17 April. Emergence was observed on May 1 with a stand count of 3.2 plants/ft^2. According to the soil test, a 0-40-90-5 (lb/ac N-P_2O_5-K_2O) was applied in the spring. A 21-21-21 blend was applied for soil maintenance as litter. Command, Sharpen, First Shot, and Glyphosate were applied as pre-emergence and burndown herbicides at planting. Postscript, Command, and Facet L were applied as overlapping and post-emergence herbicides on 19 May. Regiment and RiceBeaux herbicides were applied on 30 May for weed escapes. Nitrogen Soil Test for Rice (N-STaR) was taken on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 240 lb/ac on 20 May, followed by 70 lb/ac urea on 12 July. Surface water was adequately maintained with the use of a re-lift pump. Using Trimble GreenSeeker technology, the N response levels remained adequate throughout the growing season. Having a kernel smut history, Quilt Xcel was applied on 18 July. The field was harvested on 4 September, yielding 136 bu./ac and a milling yield of 37/64. The disappointing yield was believed to be due to competition from weedy rice. The average harvest moisture was 18%. Total irrigation was 5.5-ac-in., and total rainfall was 18.57 inches.

Cross County

The contour Cross County field was located just north of Hickory Ridge on a Henry silt loam soil. Conventional tillage practices were used in the spring by running a disc and land plane. The field consisted of 116 acres, and the previous crop grown was soybean. The cultivar chosen was RT 7321 FP, which was treated with the company's standard seed treatment. The field was drill-seeded at 22 lb/ac planted on 12 April. Command, Preface, Roundup, and League herbicides were applied at planting on 12 April. Emergence was observed on 1 May with a stand count of 6 plants/ft^2. According to the soil test, a 12-42-85-10 (lb/ac N-P_2O_5-K_2O-Zn) was applied in the spring. Preface and Propanil were applied as post-emergence herbicides on May 5. N-STaR was utilized on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 300 lb/ac on 15 May, followed by 65 lb/ac on 14 July. Using Trimble GreenSeeker, the N response levels remained adequate throughout the season. An adequate flood was maintained throughout the growing season. Propiconazole fungicide was applied on 10 July due to a history of smut. The field was harvested on 24 August, yielding 195 bu./ac with a milling yield of 62/72. The average harvest moisture was 18%. Total irrigation was 28.4 ac-in., and rainfall totaled 21.1 inches.

Drew County

The Drew County furrow-irrigated field was located just west of Winchester on a Perry and Portland clay soil. The field consisted of 112 acres, and the previous crop was soybean. The cultivar chosen was RT 7521 FP, treated with the company's standard seed treatment in the spring; no tillage practices were used. The field was drill-seeded at 26 lb/ac on 4 May. Emergence was observed on 13 May with a stand count of 11 plants/ ft^2. According to the soil test, an 18-46-0 (lb/ac N-P_2O_5-K_2O) was applied on 23 May. Glyphosate, Command, Sharpen, and Preface herbicides were applied at planting. Facet and Propanil herbicides were applied as post-emergence herbicides on 7 June. N-STaR was taken on the field. Nitrogen in the form of urea plus an approved NBPT was applied at 100 lb/ac on 25 May, followed by 100 lb/ac on 1 June, followed by 100 lb/ac on 7 June. The late-boot N application was made on 20 July at 70 lb/ac. Using Trimble GreenSeeker, the N response levels remained adequate throughout the season. Intermittent flushing was utilized for irrigation. The field was harvested on 15 September, yielding 175 bu./ac and a milling yield of 48/69. The average harvest moisture was 14%. Total irrigation was 28.8 ac-in./ac, and total rainfall was 10.9 inches.

Jefferson County

The 128-acre Jefferson County field was located just north of Reydell on a Dundee silt loam soil. No tillage practices were done in the spring. No pre-plant fertilizer was necessary, according to the soil sample analysis. The field was drill-seeded on 29 March with DG263L at 45 lb/ac. The seed was treated with the company's standard seed treatment. Rice emergence was observed on 18 April at 9 plants/ft^2. Command, Sharpen, and Roundup were used as pre-emergence and burndown herbicides on 1 April. Command was applied as an overlapping residual on 11 April. Propanil and Facet were applied as post-emergence herbicides on 22 May. Using the N-STaR recommendation, N fertilizer in the form of urea plus NBPT was applied at 200 lb/ac on 23 May. The midseason N application was applied on 19 June at 100 lb/ac. GreenSeeker technology was utilized during midseason growth stages to monitor the crop's N level. Multiple-inlet rice irrigation (MIRI) was utilized to achieve a more efficient permanent flood. Endigo insecticide was applied for stink bugs on 14 July. The field was harvested on 5 September. The yield was 190 bu./ac. The milling yield was 36/64, and average harvest moisture was 15%. Total irrigation use was 32.6 ac-in., and rainfall totaled 15.1 inches.

Mississippi County

The 32-acre furrow-irrigated field was located just north of Denwood on an Alligator Clay soil. No tillage practices were utilized. Gramoxone was applied on 20 March as a burndown herbicide. The cultivar RT 7321 FP treated with the company's standard seed treatment was drill-seeded at 22 lb/ac on 19 April. Glyphosate, Command, Sharpen, and Facet were applied as burndown and pre-emergence herbicides at planting. Stand emergence was observed on 5 May with 5 plants/ft^2. Nitrogen fertilizer in the form of urea plus NBPT was applied at 200 lb/ac on 15 May. Phosphorus 0-46-0 (lb/ac N-P_2O_5-K_2O) was applied according to the soil test. The second application of urea plus NBPT was applied at 100 lb/ac on 25 May. GreenSeeker technology was utilized during midseason growth stages to monitor the crop's N level. The late-boot urea application was made on 27 July at 70 lb/ac. The field required no treatments for disease or insects. The field was harvested on 12 September, yielding 193 bu./ac and a milling yield of 48/69. Total irrigation was 28.4 ac-in./ac, and total rainfall was 14.9 inches.

Phillips County

The 29-acre furrow irrigated field was located north of Marvell. The soil classification is a Callaway silt loam. Pre-plant fertilizer 0-60-60-10 (lb/ac N-P_2O_5-K_2O-Zn) was applied in the spring. No tillage practices were used for field preparation. Titan, a conventional medium-grain variety, was chosen and treated with zinc and CruiserMaxx Rice. The field was drill-seeded at 75 lb/ac on 6 April. Command, Sharpen, and Glyphosate were applied at planting as pre-emergence and burndown herbicides. Emergence was observed on 12 April with 19.4 plants/ft^2. Command was applied as an overlapping residual on 16 May. Sharpen herbicide was applied on 31 May. N-STaR was taken on the field. Nitrogen fertilizer in the form of urea was applied at 100 lb/ac on 22 May, followed by 100 lb/ac on 31 May. Another 100 lb/ac was applied at midseason on 10 July. GreenSeeker technology was utilized during growth stages to monitor the crop's N level. The field was harvested on 7 September, yielding 206 bu./ac. The milling yield was 46/67 and the average harvest moisture was 19%. Total irrigation for the season was 63.4 ac-in./ac and total rainfall was 12.45 inches.

Pulaski County

Pulaski County field was located just west of England on a Dewitt silty clay loam soil. The field was no-till, and based on soil test analysis, pre-plant fertilizer was applied at 0-50-60 (lb/ac N-P_2O_5-K_2O). On 30 April, RT 7321 FP treated with the company's standard seed treatment was drill-seeded at 23 lb/ac. Command and Roundup were applied at planting as pre-emergence and burndown herbicides. Stand emergence was observed on 11 May with 8.3 plants/ft^2. Preface and Facet herbicides were applied on 20 May. Nitrogen fertilizer in the form of urea plus NBPT was applied at 270 lb/ac on 20 May, according to the N-STaR recommendation. The late-boot urea application of 80 lb/ac was made on 11 July. Due to a history of smuts, Amistar Top was applied on 5 June. Stink bugs reached treatment level, and the field was sprayed with Endigo insecticide on 16 August. The field was harvested on 23 September, yielding 187 bu./ac with a milling yield of 43/64. The harvest moisture was 13%. Total irrigation use was 30 ac-in./ac, and rainfall totaled 12.0 inches.

White County

The 40-acre contour field was located southeast of Higginson on a Calhoun silt loam soil. Conventional tillage practices were utilized, and pre-plant fertilizer was applied at 0-30-90-7.5 Zn lb/ac (N-P_2O_5-K_2O-Zn) according to the soil test. Command, Sharpen, and Preface were applied as pre-emergence herbicides on 13 April. The cultivar RT 7321 FP treated with the company's standard seed treatment was drill-seeded at 22 lb/ac on 12 April. Stand emergence was observed on 26 April at 6 plants/ft^2. Duet herbicide was applied on 9 May. Command and Preface were applied as overlapping and post-emergence herbicides on 24 May. Nitrogen fertilizer in the form of urea plus NBPT was applied on 26 May at 300 lb/ac according to the N-STaR recommendation. Multiple-inlet rice irrigation (MIRI) was utilized to achieve a more efficient permanent flood. GreenSeeker technology was utilized during mid-season growth stages to monitor the crop's N level. The late-boot N fertilizer application was made on 6 July at 70 lb/ac. Sheath blight reached treatment level, and Amistar Top fungicide was applied on 2 July. Stink bugs exceeded threshold levels, and Endigo insecticide was applied on 2 August. The field was harvested on 4 September, yielding 236 bu./ac and a milling yield of 51/67. The harvest moisture averaged 18%. Total irrigation usage was 12.4 ac-in., and total rainfall was 13.65 inches.

Woodruff County

The contour field was located south of McCrory. The soil type is a McCrory fine sand soil. Spring conventional tillage practices were used for field preparation, and based on soil analysis, a 0-46-120 lb/ac (N-P_2O_5-K_2O) was applied on 10 April based on soil test analysis. On 20 April, DG263L, treated with the company's standard seed treatment, was drill-seeded at 55 lb/ac. Command and Facet L were applied at planting as pre-emergence herbicides. Stand emergence was observed on 5 May with 7.6 plants/ft^2. Permit Plus and Propanil herbicides were applied on 22 May. Nitrogen fertilizer in the form of urea plus NBPT was applied at 260 lb/ac on 25 May in accordance with the N-STaR recommendation. The midseason urea application of 100 lb/ac was made on 29 June. No disease or insect treatments were necessary. The field was harvested on 15 September yielding 194 bu./ac with a milling yield of 58/69. The harvest moisture was 14%. Total irrigation use was 60.5 ac-in./ac, and rainfall totaled 12.1 inches.

Practical Applications

Data collected from the 2023 RRVP reflects the continued general trend of improved rice yields and returns. Analysis of this data showed that the average yield was significantly higher in the RRVP compared to the state average, and the cost of production was equal to or less than the Cooperative Extension Service-estimated rice production costs.

Acknowledgments

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Table 1. Agronomic information for fields enrolled in the 2023 Rice Research Verification Program.

Field Location by County	Cultivar	Field size	Previous crop	Seeding rate	Stand density	Planting date	Emergence date	Harvest date	Yield	Milling yield[a]	Harvest Moisture
		(ac)		(lb/ac)	(plants/ft^2)				(bu./ac)	(%HR/%TR)	(%)
Clark	RT 7321 FP	40	Rice	25	3	17-April	1-May	4-Sept	136	37/64	18
Cross	RT 7321 FP	116	Soybean	22	6	12-April	1-May	24-Aug	195	62/72	18
Drew	RT 7521 FP	112	Soybean	22	11	4-May	13-May	15-Sept	175	48/69	14
Jefferson	DG263L	128	Soybean	45	9	29-March	18-April	5-Sept	190	36/64	15
Mississippi	RT 7321 FP	32	Soybean	22	8	12-April	27-April	26-Sept	193	48/69	18
Phillips	Titan	29	Soybean	75	19	6-May	12-May	7-Sept	206	46/67	19
Pulaski	RT 7521 FP	56	Rice	22	10	12-May	28-May	29-Aug	187	43/64	18
White	RT 7321 FP	40	Soybean	22	6	12-April	26-April	4-Sept	236	51/67	18
Woodruff	DG263L	61	Corn	55	7	20-April	5-May	15-Sept	194	58/69	14
Average		**68**	------	**34[b]**	**9[c]**	**20-April**	**4-May**	**7-Sep**	**190**	**48/67**	**17**

[a] Milling yield: %HR = % Head rice (whole white grains)/%TR = % Total white rice (whole grains + broken grains).
[b] Seeding rates averaged 78 lb/ac for conventional cultivars and 24 lb/ac for hybrid cultivars.
[c] Stand density averaged 18 plants/ft^2 for conventional cultivars and 7 plants/ft^2 for hybrid cultivars.

Table 2. Soil test results, fertilization, and soil classification for fields enrolled in the 2023 Rice Research Verification Program.

Field Location by County	pH	Soil Test P	Soil Test K	Soil Test Zn	Applied Fertilizer: Mixed Fertilizer[a] N-P-K-Zn[b]	Applied Fertilizer: N-Star Urea (46%N) rates and timing[c, d]	Applied Fertilizer: Total N rate	Soil Classification
		--------------(lb/ac)--------------			---------------------(lb/ac)---------------------		(lb N/ac)	
Clark	5.5	20	160	3.6	0-40-90-5	240-0-70	143	Una-Gurdon Silt Clay Loam
Cross	6.9	70	154	9.5	12-42-85-10	300-0-60	166	Henry Silt Loam
Drew	6.2	24	842	6.4	18-46-0-0	(100-100-100)-0-70[e]	170	Perry-Portland Clay
Jefferson	7.8	67	519	5.6	0-0-0-0	200-100-0	138	Dundee Silt Loam
Mississippi	7.0	38	786	6.2	0-46-0-0	(200-100)-0-70[e]	170	Alligator Clay
Phillips	7.4	30	236	4.2	0-60-60-10	(100-100)-100-0[e]	138	Loring-Memphis-Collins
Pulaski	6.1	36	516	5.0	0-50-60-0	270-0-80	161	Perry Clay
White	6.2	68	249	9.3	0-30-90-7.5	300-0-70	170	Calhoun-Henry Silt Loam
Woodruff	6.5	44	106	11.0	0-46-120-0	260-100-0	166	McCrory Fine Sand

[a] Column represents regular pre-plant applications.
[b] N = nitrogen, P = phosphorus, K = potassium, Zn = zinc.
[c] Timing: preflood – midseason – boot. Each field was fertilized according to its N-STaR recommendation.
[d] N-Star preflood N recommendation in all fields was treated with an approved N-(n-butyl) thiophosphoric triamide (NBPT) product to minimize N loss due to ammonia volatilization.
[e] Row rice fields received additional seasonal N exceeding the N-Star recommendation by 46 lb.

Table 3. Herbicide rates and timings for fields enrolled in the 2023 Rice Research Verification Program.

Field Location by County	Pre-emergence Herbicide Applications	Post-emergence Herbicide Applications
	(Product trade name and rate/ac)[a]	
Clark	Command (16 oz) + Glyphosate (32 oz) + Sharpen (2 oz) + FirstShot (5 oz)	Postscript (5 oz) + Command (16 oz) + Facet L (43 oz) fb Regiment (0.6 oz) + RiceBeaux (3 qt) + Triple Play (1 pt)
Cross	Preface (5 oz) + Command (16 oz) + Roundup (32 oz) + League (6.4 oz)	Propanil (3 qt) + Postscript (5 oz)
Drew	Command (24 oz) + Roundup (26 oz) + Sharpen (3 oz) + Preface (4 oz)	Command (10 oz) + Preface (5 oz)
Jefferson	Command (16 oz) + Sharpen (2 oz) + Glyphosate (32 oz)	Facet L (32 oz) + Propanil (4 qt)
Mississippi	Command (16 oz) + Glyphosate (32 oz) + Sharpen (2 oz) + Quinstar (12 oz)	Propanil (4 qt) + Prowl (2.1 pt)
Pulaski	Command (16 oz) + Glyphosate (32 oz) + Sharpen (2 oz)	Prowl (2.1 pt) + Bolero (4 pt) + Clincher (15 oz)
Phillips	Command (12.8 oz) + Sharpen (2 oz) + Glyphosate (32 oz) fb Command (16 oz)	Sharpen (1 oz)
Woodruff	Command (12.8 oz) + Facet L (32 oz)	Permit Plus (0.75 oz) + Propanil (4 qt)
White	Command (16 oz) + Sharpen (2 oz) + Preface (4 oz) fb Duet (3 qt)	Command (16 oz) + Preface (5 oz)

[a] fb = followed by and is used to separate herbicide application events; COC = crop oil concentrate; MSO = methylated seed oil.

Table 4. Seed treatments, foliar fungicide, and insecticide applications made in the 2023 Rice Research Verification Program.

	Seed treatments	Foliar fungicide and insecticide applications			
Field Location by County	Fungicide and/or insecticide seed treatment for control of diseases and insects of seedling rice	Fungicide applications for control of sheath blight/kernel smut/false smut	Fungicide applications for control of rice blast	Insecticide Applications for Control of Rice Water Weevil	Insecticide Applications for Control of Rice Stink Bug/Chinch Bug
	(Product trade name and rate/cwt seed)	(Product trade name and rate/ac)			
Clark	RTST[a]	Quilt Xcel (15 oz)	------	------	------
Cross	RTST	Propiconazole (6 oz)	------	------	------
Drew	RTST	------	------	------	------
Jefferson	DGST[b]	------	------	------	Endigo (5 oz)
Mississippi	RTST	------	------	------	------
Pulaski	RTST	Amistar Top (14 oz)	------	------	------
Phillips	CruiserMaxx Rice + Zinc	------	------	------	------
Woodruff	RTST	------	------	------	------
White	DGST	Amistar Top (15 oz)	------	------	Endigo (5 oz)

[a] RTST = RiceTec Seed Treatment. This abbreviation defines those fields with seed treated by RiceTec, Inc. prior to seed purchase. RTST seed is treated with zinc compounds intended to enhance germination and early-season plant growth.

[b] DGST = Nutrien Dyna-Gro Seed Treatment. This abbreviation defines those fields with seed treated by Nutrien Ag Solutions prior to seed purchase. DGST seed is treated with zinc compounds intended to enhance germination and early-season plant growth.

Table 5. Rainfall and irrigation information for fields enrolled in the 2023 Rice Research Verification Program.

Field location by county	Rainfall	Irrigation[a]	Rainfall + Irrigation
	(in.)	(ac-in.)	(in.)
Clark	18.6	5.5	24.1
Cross	21.2	28.4	49.6
Drew	10.95	30.0*	40.95
Jefferson	15.1	32.6	47.7
Mississippi	14.9	26.4	41.3
Pulaski	15.7	26.7	42.4
Phillips	12.45	63.4	75.85
Woodruff	12.1	60.5	72.6
White	13.65	12.4	26.05

[a] Not all fields were equipped with flow meters to monitor water use for irrigation. Therefore, the historical average irrigation amount in fields with flow meters was used for fields with no irrigation data. Irrigation amounts using this calculated average are followed by an asterisk (*).

Table 6. Operating costs, total costs, and returns for fields enrolled in the 2023 Rice Research Verification Program.

County	Operating Costs	Operating Costs	Returns to Operating Costs	Fixed Costs	Total Costs	Returns to Total Costs	Total Costs
	($/ac)	($/bu.)	----------($/ac)----------				($/bu.)
Clark	852.74	6.27	51.09	105.57	958.31	-54.48	7.05
Cross	968.16	4.96	471.83	160.85	1,129.01	310.98	5.79
Drew	915.98	5.23	311.78	115.06	1,031.04	196.72	5.89
Jefferson	617.55	3.25	641.38	110.72	728.27	530.66	3.83
Mississippi	872.93	4.52	481.11	84.39	957.32	396.73	4.96
Phillips	568.05	2.76	1,182.75	149.75	717.80	1,032.99	3.48
Pulaski	794.45	4.25	470.59	120.64	915.09	349.95	4.89
White	904.05	3.83	751.40	145.74	1,049.79	605.66	4.45
Woodruff	741.84	3.82	657.71	157.67	899.52	500.04	4.64
Average	**803.97**	**4.32**	**557.74**	**127.82**	**931.79**	**429.92**	**5.00**

Table 7. Summary of revenue and expenses per acre for fields enrolled in the 2023 Rice Research Verification Program.

Receipts	Clark	Cross	Drew	Jefferson	Mississippi
Yield (bu.)	136	195	175	190	193
Price Received ($/bu.)	6.65	7.38	7.02	6.63	7.02
Total Crop Revenue	**903.83**	**1439.99**	**1227.76**	**1258.93**	**1354.04**
Operating Expenses					
Seed	204.44	179.91	192.98	74.70	179.91
Fertilizers and Nutrients	177.88	191.93	137.72	93.75	192.68
Chemicals	236.18	145.44	164.98	124.44	133.07
Custom Applications	27.20	56.00	56.00	40.00	88.00
Diesel Fuel	19.65	35.84	16.07	17.67	13.11
Repairs and Maintenance	21.50	26.27	26.90	24.58	23.20
Irrigation Energy Costs	5.39	129.14	136.42	57.26	49.88
Labor, Field Activities	48.77	52.54	48.13	50.46	47.51
Other Inputs and Fees, Pre-harvest	29.64	33.41	31.17	20.04	29.09
Post-harvest Expenses	82.08	117.68	105.61	114.67	116.48
Total Operating Expenses	**852.74**	**968.16**	**915.98**	**617.55**	**872.93**
Returns to Operating Expenses	**51.09**	**471.83**	**311.78**	**641.38**	**481.11**
Capital Recovery and Fixed Costs	105.57	160.85	115.06	110.72	84.39
Total Specified Expenses[a]	**958.31**	**1,129.01**	**1,031.04**	**728.27**	**957.32**
Returns to Specified Expenses	**-54.48**	**310.98**	**196.72**	**530.66**	**396.73**
Operating Expenses/bu.	6.27	4.96	5.23	3.25	4.52
Total Expenses/bu.	7.05	5.79	5.89	3.83	4.96

Continued

Table 7. Continued.

Receipts	Phillips	Pulaski	White	Woodruff	Average
Yield (bu.)	206	187	236	194	190
Price Received ($/bu.)	8.50	6.76	7.01	7.21	7.13
Total Crop Revenue	**1750.79**	**1265.03**	**1655.45**	**1399.56**	**1361.71**
Operating Expenses					
Seed	45.75	163.29	179.91	91.30	145.80
Fertilizers and Nutrients	97.13	152.53	173.55	165.76	153.66
Chemicals	74.29	156.60	140.19	92.77	140.88
Custom Applications	0.00	64.00	72.00	36.80	48.89
Diesel Fuel	20.73	17.60	30.99	27.68	22.15
Repairs and Maintenance	27.65	29.82	24.61	27.55	25.79
Irrigation Energy Costs	111.35	24.08	56.20	106.26	75.11
Labor, Field Activities	49.77	47.47	54.17	51.93	50.08
Other Inputs and Fees, Pre-harvest	17.07	26.22	29.99	24.73	26.82
Post-harvest Expenses	124.32	112.85	142.43	117.08	114.80
Total Operating Expenses	**568.05**	**794.45**	**904.05**	**741.84**	**803.97**
Returns to Operating Expenses	**1,182.75**	**470.59**	**751.40**	**657.71**	**557.74**
Capital Recovery and Fixed Costs	149.75	120.64	145.74	157.67	127.82
Total Specified Expenses[a]	**717.80**	**915.09**	**1,049.79**	**899.52**	**931.79**
Returns to Specified Expenses	**1,032.99**	**349.95**	**605.66**	**500.04**	**429.92**
Operating Expenses/bu.	2.76	4.25	3.83	3.82	4.32
Total Expenses/bu.	3.48	4.89	4.45	4.64	5.00

[a] Does not include land costs, management, or other expenses and fees not associated with production.

Table 8. Selected variable input costs per acre for fields enrolled in the 2023 Rice Research Verification Program.

County	Rice type	Seed	Fertilizers and nutrients	Herbicides	Insecticides	Fungicides and other inputs	Diesel fuel	Irrigation energy costs
Clark	RT 7321 FP	204.44	177.88	221.18	---	15.00	19.65	5.39
Cross	RT 7321 FP	179.91	191.93	139.44	---	6.00	35.84	129.14
Drew	RT 7521 FP	192.98	137.72	164.98	---	---	16.07	136.42
Jefferson	DG 263 L	74.70	93.75	113.94	10.50	---	17.67	57.26
Mississippi	RT 7321 FP	179.91	192.68	126.61	---	6.46	13.11	49.88
Phillips	Titan	45.75	97.13	74.29	---	---	20.73	111.35
Pulaski	RT 7521 FP	163.29	152.53	122.86	---	33.74	17.60	24.08
White	RT 7321 FP	179.91	173.55	117.64	10.50	36.15	30.99	56.20
Woodruff	DG 263 L	91.30	165.76	92.77	---	---	27.68	106.26
Average	**---**	**145.80**	**153.66**	**130.41**	**10.50**	**14.65**	**22.15**	**75.11**

Evaluation of Conventional, Herbicide Tolerant, and Aromatic Advanced Rice Lines in the Arkansas Rice Breeding Program

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Abstract

The Arkansas Long Grain and Aromatic Rice breeding program is actively developing and improving rice varieties that are widely adapted in the U.S. mid-South. Strict evaluations of desirable characteristics are conducted in different phases of the breeding program. Characteristics that are important include high yield potential, excellent milling yields, good plant stature, pest and disease resistance, and superior grain quality (i.e., low percent chalk, cooking, processing, and eating). We conducted an advanced yield trial of Conventional and Clearfield long grains at four locations in Arkansas and one location for Aromatic and Provisia Long Grain lines to identify potential lines to be advanced and possibly released as varieties in the future. We have identified several lines that are comparable or better in grain yield, milling yield, grain quality, and other agronomic characteristics than existing checks at one or all four locations. These lines will be advanced to another multi-location yield test in the following year to confirm stability across years and locations.

Introduction

The rice breeding and variety development program in Arkansas evaluates lines with good agronomic characteristics, high grain yields, excellent milling yields, and good grain qualities. Successful varietal release necessitates extensive testing across years and locations. All varieties released from the breeding program have undergone similar testing during early and late-stage yield tests. Similarly, before a breeding line is moved to the pre-commercial release trials such as in Arkansas Rice Variety Advancement Trials (ARVAT) and Arkansas Rice Performance Trials (ARPT), up to one hundred lines are evaluated at late generation testing at multiple locations in Arkansas. These experimental lines are in the F_5 generation or later while simultaneously advanced and seed increased. The top 10% of the best lines are identified based on high grain yield with acceptable agronomic characteristics as well as better milling yield.

Procedures

A total of 62 advanced conventional lines and a check were planted in the 2023 Long Grain Advanced Yield Trial (23LGAYT), while 41 advanced Clearfield lines and 3 checks were planted in the 2023 Clearfield Advanced Yield Trial (23CLAYT) in 4 different locations in Arkansas. The locations are: Rice Research and Extension Center (RREC) at Stuttgart, Ark.; Pine Tree Research Station (PTRS) at Colt, Ark.; Northeast Rice Research and Extension Center (NERREC) at Harrisburg, Ark.; and Northeast Research and Extension Center (NEREC) at Keiser, Ark. Two of the lines in 23LGAYT and 2 lines in 23CLAYT were concurrently tested in the 2023 uniform regional rice nursery (URRN), while 8 lines in 23LGAYT and 8 lines in 23CLAYT were also part of the 2023 ARVAT. The Provisia Advanced Yield Trial is composed of 37 entries and 2 checks, while the Aromatic Advanced Yield Trial is composed of 29 entries and 6 checks and was planted at the RREC location. The experimental design used in all trials is a randomized block design (RBD) in three replications. The plots measured 20 ft long with 7.5-in. row spacing and drill seeded at 70 lb/ac seeding rate using an Almaco 8-row planter. Seeds were not treated with any chemicals, and plants were not sprayed with fungicides to allow natural infection and performance in a natural environment. A single preflood of 130 lb/ac of nitrogen in the form of urea was applied to dry soil when the plants reached the 4- to 5-leaf stage before permanent flood was established after 1–2 days. Before harvesting, the plots were trimmed on both ends to 16 ft, and only the middle 6 rows were harvested to minimize border effects using the Wintersteiger Quantum plot combine (Wintersteiger Inc., USA. Salt Lake City, Utah). The plot combine integrated HarvestMaster system automatically measured plot weights and moisture. Grain yields were calculated as bushels per acre adjusted at 12% moisture content. Plant height was measured from soil surface to the panicle tip. Days to 50% heading were also collected by counting the number of days from emergence to 50% of the plants in the plots headed.

Approximately 300 g of seeds were collected from the combine as the milling sample, and a subsample of 100 g from cleaned seeds was milled using a Zaccarria PAZ-100 sample mill

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(Zaccaria, Limeira, Brazil). Grain dimensions such as length, width, thickness, and chalk impact (% chalk) were obtained using SeedCount SC6000R (Next Instruments, Australia). Means were analyzed in each and across locations using the analysis of variance (ANOVA) of multi-environment trials in IciMapping (www.isbreeding.net), and the means were separated by least significant difference (LSD) at a probability of ≤0.05.

Results and Discussion

2023 Conventional Long Grain Advanced Yield Trial (23LGAYT)

Overall, grain yields of the top 15 entries are higher in all locations compared to the check variety Ozark. The top 3 high yielding entries include entries 153, 115, and 162 with 182, 177, and 175 bu./ac, respectively. The check variety Ozark was ranked 20th out of 63 lines evaluated with 164 bu./ac mean across all locations. The top yielding line 153 is significantly higher compared to the check Ozark. Notably, yields at the NEREC location for both 23LGAYT and 23CLAYT were low due to early flood drain. Days to heading showed entries 153 and 162 having 88 days to heading compared to entry 115 with 86 days and Ozark with 87 days. In terms of height, entry 153 is the shortest, with 100 cm compared to 107, 105, and 104 cm for entries 115, 162, and Ozark, respectively (Table 1). Entries 153, 115, 162, and Ozark have milling % totals of 76, 75, 76, 77, and the milling % head of 60, 56, 61, and 61, respectively. The percent chalk of entry 165 is significantly lower at 11.8% when compared to Ozark (16.7%; Table 2). Grain length, width, and thickness are not significantly different among the top 3 entries and the check Ozark (Table 3). Overall, in terms of yield and grain quality, the top 3 entries are superior in yield and comparable grain quality to the check variety Ozark.

2023 Clearfield Long Grain Advanced Yield Trial (23CLAYT)

The yield at each location, as well as across environments, showed significant differences among entries in 23CLAYT using ANOVA. The top three lines in terms of yield are entries 1320, 1330, and 1339, with 165, 162, and 162 bu./ac, respectively. The check varieties CLL18 (rank 3rd) and CLL16 (rank 5th) have yields of 161 and 158 bu./ac, respectively, which are not significantly different from the top three experimental lines based on LSD values. Entry 1320 is similar in height to CLL18 and 1339 but shorter than 1330. Entry 1339 is 2 days earlier than CLL18 and 4 days earlier than CLL16 (Table 4). Milling yields (% total and % head rice) do not significantly differ across all locations of the top three lines and check CLL18. Percent chalk does not significantly differ between the top 3 and check CLL18 across all locations based on LSD values (Table 5).

Grain length data showed that entry 1320 is significantly shorter than 1330, 1339, and CLL18. Entries 1320 and 1339 have significantly wider grain than CLL18 across all locations. For grain thickness, entry 1330 does not differ from CLL18 (Table 6).

2023 Provisia Long Grain Advanced Yield (23PVAYT)

All agronomic trait measurements showed significant differences using ANOVA in 23PVAYT. The top 3 entries in terms of yield are 2513, PVL03, and 2512 with 167, 165, and 164 bu./ac, respectively. No significant differences in grain yield were detected among the top entries based on LSD values. Entries 2513 and 2512 headed 3 and 5 days earlier than PVL03, respectively. The total milled rice yield is not significantly different among the three, but head rice yield is significantly higher in PVL03 than in 2513 and 2512. Percent chalk was also significantly higher in 2513 and 2512 compared to PVL03, with 21.4%, 19.9%, and 6.9% chalk, respectively. The grain length of entry 2512 is significantly longer than PVL03 but not 2513. The grain width and thickness of the top three entries do not show significant differences based on LSD (Table 7).

2023 Aromatic Advanced Yield Trial (23AROAYT)

Analysis of variance on all traits in 23AROAYT conducted at RREC showed significant differences among entries. The highest yielding entries that are significantly different from the check variety ARoma 22 are entries 3736, 3703, and 3735, with grain yields of 196, 188, and 186 bu./ac, respectively, while Aroma 22 ranked 7th with 170 bu./ac. The heading date showed that entry 3736 is 3 days later than ARoma 22, and 3735 is 1 day later than 3703. Entries 3736, 3703, and 3735 have heights of 110, 112, and 106 cm, respectively, which are shorter than ARoma22 (116 cm). The milled % total rice yield is higher in 3703 and ARoma 22 compared to 3736 and 3735. The top three entries do not significantly differ from ARoma 22 for the head rice yield. Entry 3736 has 8.8% chalk, which is significantly lower than ARoma 22 (14.8%). Grain dimensions showed entry 3736 to have significantly longer grains but smaller widths compared to ARoma22. Entry 3703 has thicker grains than ARoma22 based on LSD value (Table 8).

Practical Applications

The best-performing lines and data from this study will help make decisions in advancing lines for the breeding program targets in conventional, herbicide-tolerant and aromatic rice. The selected lines have the potential to be released as future varieties or will be recycled back to the breeding program as elite parents to generate new populations.

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Table 1. Yield, days to heading, and height of the top 20 entries in the 2023 Long Grain Advanced Yield Trial (23LGAYT) conducted at the Rice Research and Extension Center (RREC), Pine Tree Research Station (PTRS), Northeast Rice Research and Extension Center (NERREC), and Northeast Research and Extension Center (NEREC).

		Yield					Days to heading					Height				
Entry	**Pedigree**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**
		-----------------(bu./ac)-----------------										--------------------(cm)--------------------				
153	19991516/19951094//….	216	197	205	112	182	90	85	90	85	88	103	99	104	94	100
115	ROYJ/2/KBNT/Q36194/7	208	201	191	108	177	88	83	89	83	86	104	108	110	106	107
162	TGRT/6/91642//KATY/….	210	176	197	116	175	90	85	90	87	88	108	98	108	107	105
160	LGRU//KATY/STBN/3/….	205	193	175	113	171	89	84	89	84	87	103	103	106	112	106
150	IRGA409/RXMT/5/NWBT.	210	178	185	104	169	88	82	89	82	85	105	100	108	101	103
116	IRGA409/RXMT/5/NWBT.	200	184	198	92	169	87	83	89	84	86	116	109	111	108	111
133	ROYJ/2/KBNT/Q36194/7.	205	177	193	97	168	92	86	90	87	89	113	104	108	104	107
151	IRGA409/RXMT/5/NWBT.	197	186	188	98	167	88	83	89	81	85	101	97	110	97	101
112	DMND/5/RPG/WLLS//…..	195	180	188	105	167	91	85	89	86	88	107	103	105	107	106
155	KATY/NWBT//L201…	200	187	175	106	167	91	84	90	87	88	103	99	104	106	103
161	DMND/8/19991516…	203	178	184	102	167	92	84	90	84	88	111	107	112	111	110
158	19991516/19951094/…	188	174	192	112	167	86	83	88	81	85	107	107	116	112	111
117	ROYJ/2/KBNT/Q36194…	205	179	190	93	166	88	82	89	78	84	111	110	114	106	110
152	19991516/19951094/…	208	172	186	99	166	90	84	90	87	88	107	101	105	100	103
145	IRGA409/RXMT/5/…	187	184	192	103	166	90	83	90	88	88	111	104	112	105	108
132	ROYJ/2/KBNT/Q36194/…	198	178	186	99	165	89	84	89	85	87	108	101	113	101	106
126	JEWL/DMND	207	172	186	94	165	89	84	89	86	87	111	110	114	109	111
147	IRGA409/RXMT/5/NWBT.	190	176	189	105	165	92	86	90	86	88	111	105	110	103	107
154	LGRU//LMNT/RA73…	207	179	177	97	165	90	84	90	85	87	110	103	106	100	105
Ozark		187	170	193	110	165	89	85	89	84	87	110	95	105	107	104
$LSD_{0.05}$		12	20	18	21	13	2	3	1	5	2	7.2	7.2	6.6	9.2	4.5

Table 2. Milling (% total, % head rice) and % chalk of the top 20 entries in the 2023 Long Grain Advanced Yield Trial (23LGAYT) conducted at the Rice Research and Extension Center (RREC), Pine Tree Research Station (PTRS), Northeast Rice Research and Extension Center (NERREC), and Northeast Research and Extension Center (NEREC).

		Milling (% total)					Milling (% head)					% Chalk				
Entry	Pedigree	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean
153	19991516/19951094//….	89	70	70	75	76	74	59	50	58	60	20.1	8.1	20.7	10.4	14.8
115	ROYJ/2/KBNT/Q36194/7	89	70	70	70	75	65	57	46	55	56	18.7	8.6	19.0	8.0	13.5
162	TGRT/6/91642//KATY/….	88	71	69	76	76	69	63	48	66	61	15.6	6.5	21.3	3.9	11.8
160	LGRU//KATY/STBN/3/….	91	70	71	77	77	56	53	36	64	52	18.9	5.8	20.0	3.3	12.0
150	IRGA409/RXMT/5/NWBT.	91	70	70	76	77	71	49	40	49	52	21.5	13.1	22.3	10.9	16.9
116	IRGA409/RXMT/5/NWBT.	89	70	69	69	74	60	52	43	50	51	28.0	17.2	32.4	19.2	24.2
133	ROYJ/2/KBNT/Q36194/7.	90	71	70	71	76	62	59	39	60	55	19.4	8.6	25.1	5.1	14.6
151	IRGA409/RXMT/5/NWBT.	90	70	71	75	77	72	53	50	45	55	21.4	11.7	18.5	11.1	15.7
112	DMND/5/RPG/WLLS//…..	91	72	71	70	76	67	61	47	58	58	14.7	5.8	15.6	4.7	10.2
155	KATY/NWBT//L201…	88	70	69	75	75	71	56	46	63	59	17.5	10.2	24.3	6.8	14.7
161	DMND/8/19991516…	87	70	70	75	76	63	60	47	62	58	18.5	8.8	15.6	9.1	13.0
158	19991516/19951094/…	92	72	72	78	78	71	55	49	58	58	19.8	10.2	21.2	6.4	14.4
117	ROYJ/2/KBNT/Q36194…	90	70	70	69	75	69	56	45	42	53	17.6	7.7	17.5	13.1	14.0
152	19991516/19951094/…	90	70	71	76	77	72	56	47	60	59	22.8	10.3	26.1	9.1	17.1
145	IRGA409/RXMT/5/…	91	73	71	77	78	79	63	48	65	63	12.3	6.1	17.3	6.8	10.6
132	ROYJ/2/KBNT/Q36194/…	89	71	70	70	75	64	59	40	55	55	19.4	6.7	19.2	8.6	13.5
126	JEWL/DMND	89	71	70	69	75	66	61	45	56	57	14.8	5.0	13.1	4.3	9.3
147	IRGA409/RXMT/5/NWBT.	91	73	71	77	78	76	63	50	58	62	14.8	6.0	17.6	7.4	11.4
154	LGRU//LMNT/RA73…	89	70	64	75	75	76	62	59	62	65	17.0	6.8	18.6	5.7	12.0
Ozark		90	72	70	77	77	71	64	46	63	61	24.6	7.0	28.0	7.2	16.7
$LSD_{0.05}$		1.6	1.7	4.9	9.6	3.1	4.5	5.0	8.5	12.8	6.5	3.1	2.9	4.3	5.1	3.7

Table 3. Grain dimensions (length, width, and thickness) of the top 20 entries in the 2023 Long Grain Advanced Yield Trial (23LGAYT) conducted at the Rice Research and Extension Center (RREC), Pine Tree Research Station (PTRS), Northeast Rice Research and Extension Center (NERREC), and Northeast Research and Extension Center (NEREC).

		Length					Width					Thickness				
Entry	**Pedigree**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**
		---------------------(mm)---------------------					---------------------(mm)---------------------					---------------------(mm)---------------------				
153	19991516/19951094//…	6.7	6.6	6.6	6.5	6.6	1.9	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
115	ROYJ/2/KBNT/Q36194/7	6.7	6.8	6.6	6.7	6.7	1.8	1.9	1.9	1.9	1.9	1.8	1.9	1.9	1.8	1.9
162	TGRT/6/91642//KATY/..	6.8	6.6	6.7	6.6	6.7	1.9	2.0	1.9	2.0	1.9	1.9	1.9	1.9	1.9	1.9
160	LGRU//KATY/STBN/3/….	7.0	7.0	6.9	6.9	6.9	1.8	1.9	1.9	2.0	1.9	1.8	1.9	1.8	1.9	1.8
150	IRGA409/RXMT/5/NWB.	6.4	6.3	6.4	6.3	6.4	2.0	1.9	2.1	2.0	2.0	1.9	1.9	1.9	1.9	1.9
116	IRGA409/RXMT/5/NWB.	6.6	6.7	6.6	6.6	6.6	1.9	2.0	1.9	2.0	2.0	1.8	1.9	1.9	1.9	1.9
133	ROYJ/2/KBNT/Q36194/.	6.7	6.7	6.6	6.6	6.6	1.7	1.9	1.8	1.9	1.8	1.7	1.8	1.8	1.9	1.8
151	IRGA409/RXMT/5/NWB.	6.4	6.4	6.4	6.3	6.4	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
112	DMND/5/RPG/WLLS//….	6.8	6.7	6.7	6.7	6.7	1.8	1.9	1.9	2.0	1.9	1.8	1.9	1.9	1.9	1.9
155	KATY/NWBT//L201…	6.6	6.6	6.5	6.6	6.6	1.8	2.0	1.9	2.0	1.9	1.8	1.9	1.9	1.9	1.9
161	DMND/8/19991516…	6.8	6.7	6.7	6.6	6.7	1.9	2.0	1.9	2.0	2.0	1.9	1.9	1.9	1.8	1.9
158	19991516/19951094/…	6.7	6.6	6.5	6.5	6.6	1.8	1.9	1.9	2.0	1.9	1.8	1.9	1.9	1.9	1.9
117	ROYJ/2/KBNT/Q36194…	6.9	6.9	6.9	6.8	6.9	1.9	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
152	19991516/19951094/…	6.6	6.6	6.6	6.6	6.6	1.9	2.0	1.9	2.1	2.0	1.8	1.9	1.9	1.9	1.9
145	IRGA409/RXMT/5/…	6.6	6.5	6.5	6.5	6.5	1.9	2.0	2.0	2.1	2.0	1.9	1.9	1.9	1.9	1.9
132	ROYJ/2/KBNT/Q36194..	6.6	6.5	6.4	6.5	6.5	1.8	1.9	1.9	2.0	1.9	1.8	1.9	1.9	1.9	1.9
126	JEWL/DMND	6.7	6.8	6.6	6.7	6.7	1.9	2.0	1.9	2.0	2.0	1.8	1.9	1.9	1.9	1.9
147	IRGA409/RXMT/5/NWB.	6.6	6.5	6.6	6.4	6.5	1.9	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
154	LGRU//LMNT/RA73…	6.5	6.5	6.5	6.5	6.5	2.0	2.1	2.0	2.1	2.1	1.9	1.9	1.9	1.9	1.9
Ozark		6.6	6.6	6.6	6.6	6.6	1.9	1.9	2.0	2.0	1.9	1.9	1.9	1.9	1.9	1.9
$LSD_{0.05}$		0.1	0.07	0.16	0.10	0.08	0.05	0.05	0.07	0.06	0.04	0.05	0.05	0.05	0.05	0.03

Table 4. Yield, days to heading, and height of the top 20 entries in the 2023 Clearfield Long Grain Advanced Yield Trial (23CLAYT) conducted at the Rice Research and Extension Center (RREC), Pine Tree Research Station (PTRS), Northeast Rice Research and Extension Center (NERREC), and Northeast Research and Extension Center (NEREC).

		Yield					Days to heading					Height				
Entry	Pedigree	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean
		----------------------(bu./ac)----------------------										-------------------------(cm)-------------------------				
1320	ProGold 1/5/DREW/….	181	188	185	106	165	91	87	93	88	90	106	107	106	106	106
1330	ROYJ/CL142-AR	188	164	188	108	162	88	87	91	84	87	113	118	113	114	114
1339	248DREW16C-1-3/6/LG….	190	176	181	99	162	87	82	89	80	85	109	115	112	104	110
CLL18		202	164	182	98	161	89	85	91	84	87	116	108	107	101	108
1334	LAKAST/7/248DREW16C..	193	182	173	97	161	87	80	89	77	83	114	114	117	106	113
1303	ROYJ/CLL16	171	183	178	105	159	93	86	94	87	90	114	116	106	108	111
1314	JEWL/CLL16	187	173	175	97	158	89	86	90	86	88	105	114	105	107	108
CLL16		180	177	178	97	158	90	87	92	86	89	111	109	111	104	109
1340	DMND/3/248FRA….	169	174	180	107	158	87	82	89	78	84	119	111	119	113	116
1310	ProGold 2/4/TMPT….	175	175	177	95	156	89	87	90	84	88	119	126	123	109	119
1338	DREW/CL161/6/…	179	170	164	108	155	88	85	91	82	86	102	100	102	98	101
1331	DREW/CL161/6/…	188	161	170	98	154	88	84	90	83	86	101	100	102	93	99
1324	JEWL/CLL16	188	164	161	101	153	91	87	94	87	90	98	101	98	98	99
1315	ROYJ/CLL16	173	163	166	108	153	90	88	91	84	88	113	115	110	111	112
1304	ProGold 2/4/CL172/…	177	167	165	92	150	93	88	96	90	92	96	94	93	89	93
1316	ProGold 2/5/ DREW/CL…	153	162	170	101	147	94	91	94	91	92	125	121	121	117	121
1336	DREW/CL161/6/LGRU…	193	147	162	83	146	86	83	90	80	85	99	96	96	90	95
1305	ProGold 2/4/TMPT…	161	158	168	96	146	89	84	91	86	87	109	112	114	108	111
1311	ProGold 2/5/DREW/CL…	172	147	169	93	145	90	86	90	86	88	110	109	110	109	109
1333	CL172/3/19991516…	151	162	167	99	145	86	82	89	79	84	114	116	112	104	111
$LSD_{0.05}$		14	25	15	10	16	1	3	2	3	3	5.6	7.5	6.0	7.4	4.4

Table 5. Milling (% total, % head rice) and % chalk of the top 20 entries in the 2023 Long Grain Advanced Yield Trial (23LGAYT) conducted at the Rice Research and Extension Center (RREC), Pine Tree Research Station (PTRS), Northeast Rice Research and Extension Center (NERREC), and Northeast Research and Extension Center (NEREC).

		Milling (% total)					Milling (% head)					% Chalk				
Entry	Pedigree	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean	RREC	PTRS	NERREC	NEREC	Mean
1320	ProGold 1/5/DREW/….	89	72	68	75	76	61	59	33	60	53	25.0	10.3	22.5	10.0	16.9
1330	ROYJ/CL142-AR	86	70	71	74	75	66	59	51	55	58	19.7	7.0	17.2	6.5	12.6
1339	248DREW16C-1-3/6/LG….	88	68	69	75	75	72	58	53	58	60	17.6	10.6	16.5	9.9	13.6
CLL18		88	65	68	74	74	67	58	48	55	57	24.0	7.2	16.1	7.7	13.7
1334	LAKAST/7/248DREW16C..	89	68	69	74	75	64	48	44	45	50	18.2	11.4	18.9	13.8	15.6
1303	ROYJ/CLL16	87	71	69	75	75	65	62	53	60	60	15.5	5.2	11.1	4.3	9.0
1314	JEWL/CLL16	89	71	68	76	76	68	61	46	61	59	14.0	5.5	11.0	5.4	9.0
CLL16		88	72	69	74	76	66	62	49	55	58	16.4	5.0	14.5	7.1	10.8
1340	DMND/3/248FRA….	88	68	69	74	74	66	48	42	50	52	22.4	13.2	21.1	15.4	18.0
1310	ProGold 2/4/TMPT….	86	65	66	73	72	55	59	32	43	47	20.9	9.3	19.2	9.4	14.7
1338	DREW/CL161/6/…	86	69	68	74	75	69	60	50	58	59	14.4	4.8	12.5	6.9	9.7
1331	DREW/CL161/6/…	86	69	66	73	73	66	58	51	58	58	14.8	6.4	12.0	3.8	9.3
1324	JEWL/CLL16	91	69	71	77	77	70	63	56	66	64	10.3	3.4	12.1	2.8	7.1
1315	ROYJ/CLL16	89	71	69	75	76	62	62	43	57	56	13.5	4.4	13.7	4.2	8.9
1304	ProGold 2/4/CL172/…	86	71	70	75	75	48	58	46	58	52	20.2	7.1	12.3	8.7	12.1
1316	ProGold 2/5/ DREW/CL…	90	72	70	77	77	69	66	53	68	64	13.2	3.8	9.2	3.3	7.3
1336	DREW/CL161/6/LGRU…	88	70	71	75	76	66	51	48	48	53	19.9	8.8	16.4	10.2	13.9
1305	ProGold 2/4/TMPT…	88	69	68	75	75	60	45	35	46	47	15.3	6.8	13.8	4.2	10.0
1311	ProGold 2/5/DREW/CL…	87	70	69	78	76	61	52	33	53	50	22.0	9.7	16.4	7.6	13.9
1333	CL172/3/19991516…	86	67	69	75	74	62	48	45	54	52	20.8	10.0	16.0	6.9	13.4
$LSD_{0.05}$		2	4	3	ns	ns	5	5	8	8	6	3.3	2.4	6.2	2.9	3.1

ns = not significantly different at $LSD_{0.05}$.

Table 6. Grain dimensions (length, width, and thickness) of the 2023 Clearfield Long Grain Advanced Yield Trial (23CLAYT) conducted at the Rice Research and Extension Center (RREC), Pine Tree Research Station (PTRS), Northeast Rice Research and Extension Center (NERREC), and Northeast Research and Extension Center (NEREC).

		Length					Width					Thickness				
Entry	**Pedigree**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**	**RREC**	**PTRS**	**NERREC**	**NEREC**	**Mean**
		---------------------(mm)---------------------					---------------------(mm)---------------------					---------------------(mm)---------------------				
1320	ProGold 1/5/DREW/….	6.5	6.3	6.6	6.2	6.4	2.1	2.3	2.1	2.3	2.2	1.9	1.8	1.8	1.9	1.8
1330	ROYJ/CL142-AR	6.7	6.7	6.7	6.6	6.7	2.0	2.0	2.0	2.1	2.0	1.9	1.9	1.9	1.9	1.9
1339	248DREW16C-1-3/6/L…	6.8	6.7	6.7	6.6	6.7	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.8	1.8
CLL18		6.7	6.7	6.7	6.5	6.7	1.8	1.9	1.8	1.9	1.9	1.8	1.9	1.9	1.9	1.9
1334	LAKAST/7/248DREW1..	6.8	6.7	6.7	6.6	6.7	1.8	1.8	1.9	1.9	1.9	1.8	1.9	1.9	1.9	1.9
1303	ROYJ/CLL16	6.8	6.8	6.7	6.7	6.7	1.9	2.0	2.0	2.0	2.0	1.8	1.9	1.9	1.9	1.9
1314	JEWL/CLL16	6.6	6.5	6.6	6.5	6.5	2.0	2.1	2.0	2.1	2.1	1.9	1.9	1.9	1.8	1.9
CLL16		6.7	6.7	6.8	6.6	6.7	1.9	2.1	2.0	2.1	2.0	1.9	1.9	1.9	1.8	1.9
1340	DMND/3/248FRA….	6.7	6.6	6.5	6.5	6.6	1.9	1.9	1.8	1.9	1.9	1.8	1.8	1.8	1.8	1.8
1310	ProGold 2/4/TMPT….	6.8	6.7	6.5	6.7	6.7	1.9	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
1338	DREW/CL161/6/…	7.1	7.0	6.9	6.9	6.9	1.8	1.9	1.8	1.9	1.9	1.8	1.9	1.9	1.8	1.8
1331	DREW/CL161/6/…	7.0	7.0	7.0	6.8	6.9	1.8	1.9	1.8	1.9	1.9	1.8	1.9	1.8	1.9	1.8
1324	JEWL/CLL16	6.6	6.5	6.6	6.5	6.6	1.9	2.1	2.0	2.1	2.0	1.9	2.0	1.9	1.9	1.9
1315	ROYJ/CLL16	7.0	7.1	6.9	7.0	7.0	1.8	2.0	1.9	2.0	1.9	1.8	1.9	1.9	1.9	1.9
1304	ProGold 2/4/CL172/…	6.7	6.8	6.7	6.7	6.7	2.0	2.2	2.1	2.2	2.1	1.8	1.9	1.9	1.9	1.9
1316	ProGold 2/5/ DREW/…	6.8	6.7	6.7	6.6	6.7	1.9	2.1	2.0	2.1	2.1	1.9	1.9	1.9	1.9	1.9
1336	DREW/CL161/6/LGRU…	6.7	6.6	6.6	6.6	6.6	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.9	1.9	1.8
1305	ProGold 2/4/TMPT…	6.7	6.6	6.6	6.5	6.6	2.0	2.0	2.1	2.1	2.0	1.8	1.9	1.9	1.9	1.9
1311	ProGold 2/5/DREW/C..	6.6	6.5	6.6	6.4	6.5	2.0	2.1	2.1	2.2	2.1	1.9	1.9	1.9	1.9	1.9
1333	CL172/3/19991516…	6.9	6.8	6.8	6.8	6.8	1.9	2.0	1.9	2.0	1.9	1.9	1.9	1.9	1.9	1.9
$LSD_{0.05}$		0.08	0.10	0.23	0.08	0.09	0.04	0.05	0.12	0.05	0.05	0.06	0.06	0.07	0.06	0.04

Table 7. Agronomic and grain quality traits of the top 10 entries in the 2023 Provisia Long Grain Advanced Yield Trial (23PVAYT) conducted at the Rice Research and Extension Center.

Entry	Pedigree	Yield	Days to heading	Height	Milling % total	Milling % head	% Chalk	Length	Width	Thickness
		(bu./ac)		(cm)				------------------(mm)------------------		
2513	Provisia/JEWL-PLT97//''	168	87	97	67	45	21.4	7.1	1.8	1.8
PVL03		165	90	106	71	60	12.6	7.0	1.9	1.8
2512	Provisia/JEWL-PLT97//..	164	85	101	68	39	20.0	7.2	1.9	1.8
2534	Provisia/DMND-PLT32//..	164	84	110	67	49	18.7	6.7	1.8	1.8
2535	Provisia/DMND-PLT32//..	164	84	122	69	53	20.1	6.8	1.9	1.8
2526	Provisia/DMND-PLT32//..	162	84	111	71	50	13.3	6.3	1.8	1.8
2532	Provisia/DMND-PLT32//..	146	82	105	67	55	11.0	6.4	1.9	1.8
2503	Provisia/JEWL-PLT97//..	143	90	130	68	44	8.7	6.6	1.7	1.7
2527	Provisia/DMND-PLT32//..	139	85	116	66	53	13.0	6.5	1.8	1.8
2511	Provisia/JEWL-PLT97//..	139	85	96	67	43	15.7	7.3	1.8	1.8
$LSD_{0.05}$		30	2	9	4	7	4.3	0.17	0.1	0.05

Table 8. Agronomic and grain quality traits of the top 10 entries in the 2023 Aromatic Advanced Yield Trial (23AROAYT) conducted at the Rice Research and Extension Center.

Entry	Pedigree	Yield	Days to heading	Height	Milling % total	Milling % head	% Chalk	Length	Width	Thickness
		(bu./ac)		(cm)				------------------(mm)------------------		
3736	Jazzman/RU0701124//D..	196	91	110	80	68	8.8	7.2	1.9	1.8
3703	STG05F5-08-104/STG03..	188	89	112	82	69	18.9	6.2	2.0	1.9
3735	Jazzman/PI597046//Dia..	186	88	106	80	65	33.4	6.5	2.0	1.9
3724	JZMN//DREW/UA99-16..	184	89	114	82	62	8.1	7.3	1.9	1.9
3734	JZMN/RU0701124//JZM..	184	87	119	82	71	14.8	6.7	2.1	1.9
3709	Jazzman/PI597046//Dia..	178	87	111	83	56	16.0	6.2	1.9	1.8
3711	JZMN/RU0701124//JZM..	173	88	110	82	73	14.9	6.9	2.1	1.9
ARoma22		170	88	116	82	68	14.8	6.9	2.0	1.9
3727	JZMN/LGRU12//RU0802..	169	88	104	83	76	9.4	6.6	2.0	1.9
3712	JZMN/RU0701124//JZM..	168	88	125	82	70	13.4	6.9	2.1	1.8
$LSD_{0.05}$		14	2	6	1	4	3.2	0.09	0.05	0.06

Arkansas Rice Variety Advancement Trials, 2023

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Abstract

The Arkansas Rice Variety Advancement Trials (ARVAT) are conducted each year to evaluate promising experimental lines from the Arkansas rice breeding program compared to commercially available cultivars from public and private breeding programs. ARVATs are planted on experiment stations and cooperating producer's fields in a diverse range of environments, soil types, and agronomic and pest conditions. The ARVATs were conducted at 6 locations during 2023. Grain yields, averaged across locations, among conventional long-grains, were highest for 22AR147 at 182 bu./ac and 22LG136 at 179 bu./ac compared to the commercial checks RT XP753 (203 bu./ac), Ozark (176 bu./ac), DG263L (189 bu./ac), and Diamond (163 bu./ac). Among Clearfield long-grains, grain yields were highest for 22AR1121 at 180 bu./ac, RU2301024 at 178 bu./ac, and 23AR1131 at 177 bu./ac compared to the commercial checks RT 7321 FP (205 bu./ac), CLL18 (174 bu./ac), CLL16 (173 bu./ac), and CLL19 (167 bu./ac). Among medium grains, grain yields were highest for 21AR1217 at 186 bu./ac compared to the commercial checks Taurus (183 bu./ac), Titan (159 bu./ac), and CLM04 (154 bu./ac). Among long-grain aromatics, grain yields were highest for 21AR3708 at 167 bu./ac compared to the commercial check ARoma22 (133 bu./ac). Among Provisia long-grains, grain yields were highest for 22AR2106 at 172 bu./ac and 23AR2112 at 171 bu./ac compared to the commercial check PVL03 (154 bu./ac). Among hybrid long-grains, grain yields were highest for 22HX105CL at 189 bu./ac and 22HX101CL at 187 bu./ac compared to the commercial checks Ozark (176 bu./ac) and RT XP753 (205 bu./ac).

Introduction

Cultivar selection is likely the most important management decision made each year by rice producers. This choice is generally based on past experience, seed availability, agronomic traits, and yield potential. When choosing a rice cultivar, grain yield, milling yield, lodging potential, maturity, disease susceptibility, seeding date, field characteristics, the potential for quality reductions due to pecky rice, and market strategy should all be considered. Data averaged over years and locations are more reliable than a single year of data for evaluating rice performance for such important factors as grain and milling yields, kernel size, maturity, lodging resistance, plant height, and disease susceptibility.

The Arkansas Rice Variety Advancement Trials (ARVAT) are conducted each year to compare promising new experimental lines from the Arkansas breeding program with established cultivars currently grown in Arkansas. Multiple locations each year allow for continued reassessment of the performance and adaptability of advanced breeding lines and commercially available cultivars to such factors as environmental conditions, soil properties, and management practices.

Procedures

The 6 locations for the 2023 ARVATs included the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark.; the Pine Tree Research Station (PTRS) near Colt, Ark.; the Northeast Research and Extension Center (NEREC) near Keiser, Ark.; the Northeast Rice Research and Extension Center (NERREC) near Harrisburg, Ark.; the Trey Bowers farm in Clay County (CLAY) near McDougal, Ark.; and the Jim Whitaker farm in Desha County (DESHA) near McGehee, Ark. Seventy-three entries, including established cultivars and promising breeding lines, were grown across a range of maturities.

The studies were seeded at CLAY, DESHA, NEREC, PTRS, RREC, and NERREC on 4 April, 19 April, 4 May, 3 May, 10 April, and 24 April, respectively. Pure-line cultivars (varieties) were drill-seeded at a rate of 33 seed/ft^2 in plots 8 rows (7.5-in. spacing) wide and 17.5-ft in length. Hybrid cultivars were drill-seeded into the same plot configuration using a seeding rate of 11 seed/ft^2. Cultural practices varied somewhat among the ARVAT locations but, overall, were grown under conditions for high yield.

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Nitrogen was applied to ARVAT studies located on experiment stations at the 5- to 6-leaf growth stage in a single preflood application of 130 lb N/ac at RREC, 130 lb N/ac at NERREC, 145 lb N/ac at PTRS, and 160 lb N/ac at NEREC using urea as the N source. The permanent flood was applied within 2 days of preflood N application and maintained throughout the growing season. Trials conducted in commercial fields (CLAY and DESHA) were managed by the grower with the rest of the field in regard to fertilization, irrigation, and weed and insect control.

Percent lodging notes were taken immediately prior to harvest. At maturity, the center four rows of each plot were harvested, the moisture content and weight of the grain were determined, and a subsample of harvested grain was removed for grain quality and milling determinations. Grain yields were adjusted to 12% moisture and reported on a bushels per acre (bu./ac) basis. The dried rice was milled to obtain percent head rice (%HR; whole kernels) and percent total white rice (%TR) presented as %HR/%TR. Each location and group of the study was arranged in a randomized complete block design with 4 replications. Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separation using Fisher's least significant difference test ($P = 0.10$).

Results and Discussion

Selected agronomic traits, grain yield, and milling yields for the conventional long-grain trial are shown in Table 1. Twenty-one experimental lines and 4 checks were included. The checks Ozark, DG263L, Diamond, and RT XP753 averaged 176, 189, 163, and 203 bu./ac, respectively. The experimental lines 22AR147 and 22LG136 averaged 182 and 179 bu./ac, respectively, the only lines to outperform Ozark.

Selected agronomic traits, grain yield, and milling yields for the Clearfield long-grain trial are shown in Table 2. Twenty-one experimental lines and 4 checks were included. The checks CLL16, CLL18, CLL19, and RT 7321 FP averaged 173, 174, 167, and 205 bu./ac, respectively. The experimental lines 22AR1121 (180 bu./ac), RU2301024 (178 bu./ac), and 23AR1131 (177 bu./ac) performed higher than the CLL16, CLL18, and CLL19 checks.

Selected agronomic traits, grain yield, and milling yields for the medium-grain trial are shown in Table 3. Eight experimental lines and 3 checks were included. The checks Titan, CLM04, and Taurus averaged 159, 154, and 183 bu./ac, respectively. The Clearfield experimental line 21AR1217 (186 bu./ac) performed higher than all checks.

Selected agronomic traits, grain yield, and milling yields for the conventional and Clearfield long-grain aromatic trials are shown in Table 4. Five experimental lines and 1 check were included. The check ARoma22 averaged 133 bu./ac. All experimental lines performed higher than the check, with 21AR3708 (167 bu./ac) and RU2301046 (165 bu./ac) having the highest yields.

Selected agronomic traits, grain yield, and milling yields for the Provisia long-grain trial are shown in Table 5. Five experimental lines and 1 check were included. The check PVL03 averaged 154 bu./ac. The experimental line 22AR2106 had the highest yield of 172 bu./ac, followed by 23AR2112 at 171 bu./ac, and all other lines performed equal to or greater than the PVL03 check.

Selected agronomic traits, grain yield, and milling yields for the hybrid long-grain trial are shown in Table 6. Nine experimental hybrids and 2 checks were included. The checks Ozark and RT XP753 averaged 176 and 205 bu./ac, respectively. The experimental hybrids 22HX105CL and 22HX101CL had the highest yields of 189 and 187 bu./ac, respectively. These and four additional hybrids outperformed the Ozark check, but no hybrids outperformed the RT XP753 check.

Practical Applications

Data from this study will assist the rice breeding program with variety advancement and release decisions to provide rice producers with new cultivars suitable to the wide range of growing conditions found throughout Arkansas.

Acknowledgments

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Table 1. Grain yield and agronomic traits of conventional long-grain experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2023.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	----------	----------	----------	(bu./ac)	----------	----------	----------
21AR136	L	89	34	0	54/69	185	141	168	180	176	183	172
RU2201020	L	87	37	0	55/71	162	160	160	172	185	171	169
22AR147	L	87	37	0	53/71	188	180	168	180	177	198	182
22AR149	L	87	36	0	53/71	181	160	160	172	180	173	171
22AR157	L	88	35	0	52/71	177	173	153	162	166	168	168
22AR159	L	85	36	0	56/70	186	162	168	177	181	191	178
22AR160	L	87	35	0	53/70	183	159	154	165	172	183	170
22AR179	L	89	35	0	54/70	187	151	165	176	175	179	172
22AR182	L	84	38	0	50/69	166	166	165	182	180	178	173
22AR134	L	88	32	0	56/70	176	151	153	169	149	176	163
22AR131	L	88	35	0	56/69	168	145	169	170	177	186	169
RU2301023	L	90	35	0	57/69	192	170	177	169	175	172	176
22LG136	L	90	36	0	54/68	187	146	174	187	194	184	179
22LG133	L	89	34	0	47/70	184	158	164	169	177	187	173
22LG135	L	90	37	0	52/68	171	152	153	172	182	166	167
22LG130	L	90	36	0	56/70	178	166	171	162	167	165	168
22LG144	L	90	35	0	56/70	188	158	163	152	168	162	165
22LG125	L	88	37	0	56/71	172	157	172	175	180	165	170
22LG108	L	88	37	0	53/70	181	156	173	159	177	171	169
22LG140	L	87	37	0	56/71	181	150	162	157	173	172	166
22LG142	L	90	38	0	53/69	181	157	152	174	180	159	168
Ozark	L	88	36	0	55/69	193	155	176	169	175	191	176
DG263L	L	84	33	0	54/68	206	161	173	192	201	195	189
Diamond	L	89	36	0	53/69	185	154	155	157	165	161	163
RT XP753	LH	83	36	0	48/71	216	216	187	179	213	201	203
$LSD_{(0.10)}$[c]		0.4	0.3	0	1.1/0.2	16	10	NS	12	9	15	3

[a] Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, PL = Provisia long-grain, PM = Provisia medium-grain, LA = long-grain aromatic, and CLA = Clearfield long-grain aromatic.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 2. Grain yield and agronomic traits of Clearfield long-grain experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2023.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	-----------------	-----------------	-----------------	(bu./ac)	-----------------	-----------------	-----------------
RU2101101	CL	83	33	0	58/69	170	162	152	170	164	166	165
22AR1121	CL	89	35	0	59/70	206	173	167	170	184	173	180
22AR1122	CL	90	31	0	60/71	181	162	142	176	167	168	167
22AR1123	CL	87	34	0	58/70	191	164	149	176	177	155	170
22AR1129	CL	88	32	0	60/71	174	172	171	168	168	166	170
22AR1117	CL	85	34	0	57/71	185	155	150	170	168	167	167
RU2101221	CL	88	35	0	62/70	186	167	141	169	156	163	166
21AR1112	CL	85	32	0	57/70	197	167	161	162	154	153	166
RU2201019	CL	86	35	0	57/71	190	174	149	167	158	158	168
RU2301022	CL	89	32	0	61/71	200	168	156	163	153	166	168
RU2301024	CL	85	37	0	53/70	206	177	148	171	181	179	178
23CL1325	CL	89	40	0	62/71	209	186	149	163	166	161	173
22CL1329	CL	89	33	0	58/69	198	171	142	166	180	152	169
22CL1330	CL	85	37	0	61/70	190	174	172	176	177	159	175
22CL1314	CL	87	37	0	56/70	202	181	147	164	172	153	170
22CL1320	CL	88	33	0	53/71	169	165	138	155	152	148	156
22CL1319	CL	89	35	0	45/70	181	161	140	137	156	143	154
22CL1308	CL	90	34	0	57/69	198	173	148	162	174	149	169
22CL1309	CL	90	36	0	58/71	197	171	159	160	167	158	169
23AR1131	CL	88	35	0	55/70	210	169	150	172	180	174	177
RU2001121	CL	85	34	0	59/71	186	169	140	160	163	154	163
CLL19	CL	85	33	0	57/70	191	167	137	169	167	162	167
RT 7321 FP	FLH	85	37	0	48/71	225	210	183	191	217	199	205
CLL18	CL	90	36	0	56/69	193	175	156	167	181	169	174
CLL16	CL	90	37	0	54/69	192	169	163	172	175	165	173
$LSD_{(0.10)}$[c]		2	0.3	NS	0.6/0.2	11	7	22	12	8	14	3

[a] Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, PL = Provisia long-grain, PM = Provisia medium-grain, LA = long-grain aromatic, and CLA = Clearfield long-grain aromatic.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 3. Grain yield and agronomic traits of conventional and Clearfield medium-grain experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2023.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	----------	----------	----------	(bu./ac)	----------	----------	----------
RU2101234	CM	88	34	0	61/68	205	167	170	178	148	189	176
21AR1217	CM	89	32	0	59/69	206	176	200	178	172	186	186
21AR1226	CM	91	36	0	62/70	184	172	169	179	166	163	172
22AR1228	CM	86	32	0	57/69	178	160	173	165	149	161	164
22AR241	M	90	31	0	65/69	172	161	181	175	167	178	172
22AR242	M	89	30	0	62/71	186	158	187	181	164	163	173
22AR343	M	87	35	0	64/68	175	138	158	137	112	161	147
23AR2205	PM	87	36	0	63/68	182	168	174	165	147	179	169
Titan	M	83	35	0	58/69	184	146	167	159	129	170	159
CLM04	CM	89	38	0	64/69	175	158	145	167	116	168	154
Taurus	M	85	32	2	60/70	199	171	198	181	172	179	183
$LSD_{(0.10)}$[c]		1	1	3	1.6/0.5	12	11	19	8	11	14	7

[a] Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, PL = Provisia long-grain, PM = Provisia medium-grain, LA = long-grain aromatic, and CLA = Clearfield long-grain aromatic.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 4. Grain yield and agronomic traits of conventional and Clearfield long-grain aromatic experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2023.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	(bu./ac)						
RU2101208	CLA	87	34	0	58/68	--	--	154	172	141	160	157
RU2101109	LA	87	41	0	61/69	--	--	160	159	146	162	157
21AR2931	LA	90	38	0	55/69	--	--	157	165	149	149	155
RU2301046	LA	86	33	0	53/68	--	--	172	176	151	162	165
21AR3708	LA	85	34	0	53/68	--	--	169	172	160	166	167
ARoma22	LA	87	38	0	56/68	--	--	138	144	112	140	133
$LSD_{(0.10)}$[c]		1	1	NS	2.6/0.5	--	--	14	10	7	10	7

[a] Grain type: CL = Clearfield long-grain, CM = Clearfield medium-grain, FLH = FullPage long-grain hybrid, L = conventional long-grain, LH = long-grain hybrid, M = conventional medium-grain, ML = MaxAce long-grain, PL = Provisia long-grain, PM = Provisia medium-grain, LA = long-grain aromatic, and CLA = Clearfield long-grain aromatic.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 5. Grain yield and agronomic traits of Provisia long-grain experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2023.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	(bu./ac)						
22AR2106	PL	90	34	1	55/69	165	158	182	172	175	184	172
RU2201021	PL	89	32	0	56/69	172	129	158	161	134	168	154
23AR2110	PL	88	31	0	57/69	164	149	166	165	143	177	160
23AR2111	PL	89	35	0	57/69	178	170	164	157	161	176	168
23AR2112	PL	88	35	0	54/69	186	169	174	161	161	177	171
PVL03	PL	89	34	0	55/70	174	165	137	156	147	146	154
$LSD_{(0.10)}$[c]		1	1	NS	1.5/0.5	NS	11	6	7	13	15	5

[a] Grain type: PL = Provisia long-grain.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

Table 6. Grain yield and agronomic traits of conventional, Clearfield, and Provisia long-grain hybrid experimental lines and commercial checks in the Arkansas Rice Variety Advancement Trials (ARVAT) by location in 2023.

Entry	Grain Type[a]	50% Heading	Plant Height	Lodging	Milling Yield	Clay[b]	Desha	NEREC	PTRS	RREC	NERREC	Mean
		(days)	(in.)	(%)	(%HR/%TR)	---------------	---------------	---------------	(bu./ac)	---------------	---------------	---------------
21HX113	LH	84	33	0	49/70	192	167	160	175	143	185	170
22HX101CL	CLH	88	38	0	43/70	210	187	168	192	164	200	187
22HX105CL	CLH	88	39	0	52/70	209	173	184	186	175	202	189
22HX108CL	CLH	89	38	0	58/69	207	176	169	186	154	186	180
22HX109	LH	85	37	0	52/70	197	179	175	190	142	178	177
22HX110	LH	85	33	0	49/69	192	158	165	180	141	172	168
22HX113	LH	86	38	6	50/70	208	171	170	194	158	185	182
22HX115CL	CLH	88	39	0	53/69	209	159	176	184	148	178	176
22HX112PV	PLH	88	38	0	58/69	182	159	163	171	138	173	164
Ozark	L	88	34	0	57/70	204	153	176	174	151	192	176
RT XP753	LH	85	37	0	51/71	219	206	189	206	194	219	205
$LSD_{(0.10)}$[c]		1.6	0.8	4.5	NS/0.4	11	17	12	9	25	15	5

[a] Grain type: L = conventional long-grain, LH = long-grain hybrid, PLH = Provisia long-grain hybrid, and CLH = Clearfield long-grain hybrid.

[b] Clay = Clay Co., McDougal, Ark.; Desha = Desha Co., McGehee, Ark.; NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.; and NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.

[c] LSD = least significant difference.

University of Arkansas System Division of Agriculture Hybrid Rice Breeding Progress in 2023

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Abstract

Efforts in 2023 were made by the University of Arkansas System Division of Agriculture's (UADA) Rice and Research Extension Center's (RREC) hybrid rice breeding program in developing hybrid rice (*Oryza sativa* L.) varieties, which include developing environmentally sensitive male sterile (EGMS) lines, cytoplasmic male sterile (A) lines, maintainer (B) lines, restorer (R) lines, and competitive hybrids. As parental line development was being attempted, test crosses were also made to evaluate both parents and the experimental hybrids. Parents were planted as panicle rows to select based on phenotypes while simultaneously being crossed with other parental lines to produce test crosses to be evaluated in the following year. Efforts for hybrid variety development with Provisia® and Clearfield® herbicide technologies were also attempted.

Introduction

A hybrid rice breeding program requires a multiple pipeline scheme compared to a more straightforward conventional rice breeding approach. This scheme is required due to the need for multi-parental line development and a male sterility system for the production of hybrid seed. Hybrid seed is first-generation (F_1) only; thus, when grown, the selfed seed (F_2) produced by the hybrid plants will not perform the same if grown due to segregating genes affecting traits among the plants (Virmani et al., 1997). There is also an added level of difficulty because the required genes for incorporating both male sterility and fertility restoration are found in *Indica* type rice varieties (Virmani et al., 1997), which are not suitable for growing in the Arkansas climate where *Japonica* type rice is grown. On top of that, most of these lines are not accessible due to the protection of intellectual property. These unique male sterility genes were originally found in rice fields that experienced spontaneous mutations, while some were created by making wide crosses among genetically diverse rice varieties (Li et al., 2007).

Hybrid seed can be produced by using either a 2-line or a 3-line method. The names of the methods are the required number of parents needed for hybrid seed production, but the same is true for both methods: a male sterile parent is needed that serves as the female parent. For the 2-line method, the sterility of a female parent is induced by environmental conditions such as high daily temperatures, long daylengths, or a combination of both; and it can be self-fertilized at lower daily temperatures, shorter daylengths, or a combination of both (Virmani et al., 2003). The pollen parent can be any rice variety, but additional flowering traits such as good anther dehiscence, good anther protrusion, large anther size, and high pollen load are needed for successful hybrid rice production, which may not be prevalent in all rice varieties. For the 3-line method, the female parent (A-line) is male sterile due to a genetic interaction between cytoplasm and nucleus in which its seed can only be re-produced when crossing with its genetically similar maintainer line (B-line). The B line serves as the male parent for the propagation of the female parent (A-line). The third line (R-line) requires specific restorer gene(s) that serves as the male parent for hybrid seed production (Virmani et al., 1997).

Because the magnitude of the objectives involved in handling both methods is too great, most international hybrid rice breeding programs divide the two methods into separate breeding programs, sometimes even having multiple projects within the already divided programs. Both methods are required, however, to completely approach all the possibilities for developing a hybrid rice variety. This results in the need to develop five parental lines (S, A, B, and R lines and pollen parents). Even after developing the parents, thousands of testcrosses must be made among the parents, the resulting testcrosses must be evaluated, and the best testcrosses must be re-produced and further tested until a hybrid variety is identified.

Procedures

2-Line Method

The 2-line method of hybrid rice production requires S-line development, pollen parent selection, testcrossing, testcross evaluation, and advanced hybrid testing. S-line development consisted of 19 advanced lines derived from the University of Arkansas System Division of Agriculture's (UADA) hybrid rice breeding program's temperature genic male sterile (TGMS) lines (North et al., 2019). Eight of the S-lines were used for testcrossing, while 11 were used for large hybrid seed production. These lines were evaluated based on combining ability and flowering characteristics used for testcrossing. Individual plants were harvested from the previous season and separated as individual lines (66 total) to purify sterility and uniformity. These lines were planted separately in the greenhouse by single seed and later transplanted to the field during the first week of May to evaluate their sterility and uniformity later in July (at heading). Four to five plants of each line were transplanted in 4 ft rows, 2 ft apart, to allow for space between plants. Selected plants were ratooned, urea fertilizer applied, and dug up to be placed in the cool shed for temperature treatment about 10 days after ratooning.

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The cool shed is a 12 ft x 20 ft storage shed custom built in which the program added insulation and interior walls. Six Mars Hydro TSW 2000 grow lights were installed along with a window air conditioning unit (10,000 BTU) for proper growing conditions. Two benches (16 ft x 4 ft, 30 in. height) were placed inside to allow for up to 250 plants for treatment at a time. After 14 days of treatment, the plants are brought into the greenhouse to finish maturing, and the seeds are collected when ready.

S-line development included the continuation of lines from the program's predecessors before 2021. These lines were in development from 2014 through 2020. In total, there were 70 F_2 populations and 2,140 F_3-6 lines. S-line development with Provisia® technology was initiated in 2019. In 2023, there were 9 F_2 populations and 300 F_3-5 progenies. These populations and lines were planted as panicle rows (5-ft length and 10-in. row spacing) and selected based on sterility, desirable phenotypes, and Provisia® herbicide tolerance. Selected plants were later dug up, placed into pots, treated with cooler temperatures, and placed inside a greenhouse for seed production in the fall.

New testcrosses were made by digging up females from the field and then bringing them to the greenhouse for crossing. Panicles from male parents were used for pollinating. Parents selected for crossing were planted in a crossing block design: 2 rows/parents (10-in. spacing) 5-ft length. Nine S-lines were crossed with 50 elite UADA lines/varieties.

Testcrosses made in 2022 were evaluated in two ways: 1) preliminary yield trial (SIT) that consisted of 3 hybrids that were planted 7 rows wide with 8 in spacing and 15 ft length, with 2 replications; 2) observation trial (OBT) consisting of 331 testcrosses (111 with Clearfield® trait, and 19 with Provisia® trait) planted as rows with 10-in. row spacing and 5 ft length. Method 1 results concluded with the combine harvesting of selected hybrid plots that displayed uniformity, and method 2 concluded with the evaluation of hybrid rows based on plant uniformity, desirable phenotypes, and maturity, resulting in bulk row harvesting of the best-looking testcrosses for evaluating milling quality.

Thirteen advanced hybrids (11 with Clearfield® trait and 1 with Provisia® trait) were tested in the Hybrid Advanced Yield Trial (HAYT). The design of the HAYT is 7 rows wide with 7.5-in. spacing and 15 ft length, with 3 replications at 4 locations in Arkansas – Northeast Research and Extension Center at Keiser (NEREC), Pine Tree Research Station (PTRS) near Colt, Northeast Rice Research and Extension Center (NERREC) near Harrisburg, and 2 plantings (1 month apart) at RREC. The Arkansas Rice Variety Advancement Trials (ARVAT) included 9 hybrids (4 with Clearfield® trait and 1 with Provisia® trait) that were planted 8 rows wide with 7.5 in spacing and 18 ft length, with 4 replications at 6 locations in Arkansas – RREC, NEREC, PTRS, NERREC, a grower's field in Clay county near McDougal, and a grower's field in Desha county near McGehee.

3-Line Method

The 3-line method of hybrid rice production requires A, B, and R line development; testcrossing; testcross evaluation; and advanced hybrid testing. The hybrid rice breeding program started A and B line development previously, with lines accessible through the USDA world collection. Currently, the program has 1 developed A-line and 6 advanced A-lines for 3-line hybrid combinations. A total of 1,896 B lines from F_3 to F_7 generations were planted as panicle rows and selected based on desirable phenotypes. Testcrosses were made with A-lines, and the progeny were evaluated in the 2023 season to determine complete sterility for the development of new A-lines. A total of 6,210 R lines spanning F_3 to F_6 generations were planted as panicle rows and selected based on desirable phenotypes. Fifteen advanced R lines were tested in the SIT. New testcrosses were made following the same procedure for the 2-line system. Three A-lines were crossed with 37 UADA R-lines.

Testcrosses and experimental hybrids made in 2022 were evaluated using the same two procedures and the same yield trials as for the 2-line method. One hybrid was tested in the SIT, two advanced hybrids with Clearfield® trait were tested in the AYT, and 1 advanced hybrid with Clearfield® trait was tested in the ARVAT. The OBT consisted of 179 testcrosses (10 with Clearfield® trait).

Results and Discussion

2-Line Method

For S-line purification, 63 lines were selected and 126 plants were harvested from those lines. Upon the results of the marker assisted selection (MAS) data, some of the plants will be discarded if any of the traits are still segregating or undesirable. The seeds were sent to the Puerto Rico winter nursery as head rows to be further purified and harvested in spring 2024.

For the development of S-lines (Table 1), 10 F_2 populations and 200 lines (F_3–F_6) were selected to advance and be further evaluated in 2024. For the Provisia® S-line development, 9 F_2 populations and 45 lines (F_3–F_6) were selected, temperature-treated in the cool shed, and harvested in the greenhouse. From these selected lines, additional selection will occur based on MAS results collected from the plants' leaves. The final selected lines will be grown in 2024 as panicle rows.

The program continues to grow, producing 138 testcrosses and 8 experimental hybrids in 2023 (Table 2). These 8 experimental hybrids will be tested in the 2024 AYT and ARVAT. The 138 testcrosses will be tested in the 2024 OBT to evaluate for desirable phenotypes, maturity, seed setting, yield potential, milling, and grain and cooking quality.

Of the 331 testcrosses (Table 2) evaluated in the 2023 OBT, 87 (31 with Clearfield® trait) were harvested based on desirable phenotypes. The seed from the selections will be used to check milling quality. Upon these results, if any are selected, then hybrid seed production of these combinations will be made in 2024. There were no hybrids that outperformed the hybrid check 'RT XP753' (270 bu./ac) in the 2023 SIT; however, 2 performed better (228 and 249 bu./ac) than the conventional check 'Ozark' (204 bu./ac).

The results from the 2023 AYT revealed 2 well-performing experimental hybrids—one yielding 242 bu./ac and another (with Clearfield® trait) yielding 226 bu./ac. This is compared to the pure-line check Ozark yielding 205 bu./ac. The highest yielding experimental hybrid compared closely to the hybrid check 'RT XP753' (250 bu./ac). The 2 best experimental hybrids have slightly greater plant heights at 46 and 48 in. compared to 'RT XP753's height of 43 in.

The last of the yield trial results concludes with the 2023 ARVAT. Two of the nine experimental hybrids showed a slight yield potential compared to the pure-line check 'Ozark' but was not comparable to the hybrid check 'RT XP753'. The purpose of having all of these yield trials is to verify the experimental hybrids' performance and determine what does great in some trials and performs poorly in others. The variability of environments and management practices will reduce the risk of releasing a poor-performing hybrid that would hurt both the Arkansas rice growers and the reputation of the UADA breeding program. At all costs, the program will avoid this.

3-Line Method

For A-line development, the 6 advanced lines had successful seed production and will be used in 2024 for a large-scale seed increase. For B-line development, there were 200 panicle rows selected and then harvested to advance as 600 panicle rows in 2024. There were 600 panicle rows selected for R-line development and then harvested to advance as 1,800 panicle rows in 2024 (Table 1). Of the 15 advanced R lines tested in the 2023 SIT, none showed any yield potential compared to the pure-line check 'Ozark.'

The program produced 58 testcrosses (Table 2) to be used in the 2024 OBT and 1 experimental hybrid to be used in the 2024 AYT. In the OBT trial, 55 (8 with Clearfield® trait) testcrosses were selected based on desirable phenotypes. The seed from the selections will be used to check milling quality. Based upon these results, if any are selected, then hybrid seed production of these combinations will be made in 2024. None of the hybrids performed well in the 2024 SIT, AYT, or ARVAT trials.

Practical Applications

After further evaluation of the 63 S-lines harvested in Puerto Rico in spring 2023, the program will decide which ones to select as the prominent females to be crossed with in the summer of 2024 for 2-line hybrid seed production. Efforts are being made to develop S-lines with Provisia® technology that will later be used for the development of Provisia® hybrid varieties. There were 138 (2-line) testcrosses made that will be evaluated in 2024. The OBT and yield trial results reveal that some experimental hybrids have potential but are not quite at commercial hybrid standards. The testcrosses made in 2023 will help lead to the right combinations to produce a commercial-scale hybrid, as it appears the yield potential is present in the program's germplasm. Multiple A, B, and R lines are in development and being simultaneously used to cross with the A lines to check maintainer and restorer ability while evaluating their agronomic characteristics, grain quality, and yield potential. With 57 (3-line) testcrosses made, there will be an ample amount to evaluate in 2024 to lead to the right combination for high-yielding hybrids. Sufficient amounts of hybrid seeds were produced in 2023, which enables us to have 9 new experimental hybrids. Of the 9, 4 are conventional, and 5 are Clearfield® (one of which is a 3-line). These hybrids will be evaluated in the 2024 AYT, and 4 of them will also be simultaneously tested in the 2024 ARVAT.

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Table 1. The number of parental lines tested and selected in 2023.

Parental Line Development	Number of Lines Tested	Number of Lines Selected
S-line (2-line system)	2,434	308
A-line (3-line system)	6	6
B-line (3-line system)	1,896	200
R-line (3-line system)	6,210	600

Table 2. The number of 2-line and 3-line hybrids in 2023.

Hybrid Development	Number of 2-line Hybrids	Number of 3-line Hybrids	Total Number of Hybrids
2023 Test Crosses (to be tested in 2024)	138	57	195
2023 OBT (first-year hybrids)	331 (111 CL,[a] 19 PRV[b])	179 (10 CL)	699
2023 SIT	3	1	4
2023 AYT	13 (11 CL, 1 PRV)	2 CL	15
2023 ARVAT	8 (4 CL)	1 CL	9

[a] Number of hybrids with Clearfield herbicide technology.
[b] Number of hybrids with Provisia herbicide technology.

University of Arkansas System Division of Agriculture Hybrid Rice Seed Production in 2023

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Abstract

Part of the hybrid rice breeding program's efforts at the University of Arkansas System Division of Agriculture's (UADA) Rice and Research Extension Center (RREC) is to produce hybrid rice seed. This includes not only the production of hybrid seed but also the production of the female parental lines which must undergo temperature treatment (2-line system) or be crossed with an isogenic maintainer line (3-line system). Different field designs and management strategies were implemented for ample hybrid seed production, monitoring growth stages to improve synchronization of both parents and testing temperature treatments for increased female seed production. Successful hybrid seed (F_1) production of 9 hybrid combinations was achieved, which enables the program to test these new hybrids in the Advanced Elite Line Yield Trials (AYT) or the Arkansas Rice Variety Advancement Trials (ARVAT) across the state in 2024. Treating 2-line female parents at R1 + 10 days (when internode elongation is approximately 1.2 inches) leads to better seed production. Increasing the number of days for temperature treatment did not improve 2-line female seed production.

Introduction

The greatest difficulty following the development of a hybrid rice (*Oryza sativa* L.) variety for commercialization is the efforts and costs of producing the hybrid seed. To produce hybrid rice seeds, one rice plant must be pollinated from a different rice variety or line (Virmani et al.,1993). Pollen sterility was discovered in Asia and further developed, leading to the 2-line and 3-line systems to achieve the production of hybrid seed. For the 2-line method, the sterility of a female parent is induced by environmental conditions such as high daily temperatures, long daylengths, or a combination of both; and it can be self-fertilized at lower daily temperatures, shorter daylengths, or a combination of both (Virmani et al., 2003). The pollen parent can be any rice variety. Still, additional flowering traits such as good anther dehiscence, good anther protrusion, large anther size, and high pollen load are needed for successful hybrid rice production, which may not be prevalent in all rice varieties. For the 3-line method, the female parent (A-line) is male sterile due to a genetic interaction between cytoplasm and nucleus in which its seed can only be re-produced when crossing with its genetically similar maintainer line (B line). The B line serves as the male parent for the propagation of the female parent (A line). The third line (R line) requires specific restorer gene(s) that serves as the male parent for hybrid seed production (Virmani et al., 1997).

When discussing hybrid rice production, this includes not only the production of hybrid seed but also the production of the female parental lines which must undergo temperature treatment (2-line system) or be crossed with an isogenic maintainer line (3-line system). Each system has its advantages and disadvantages, but the key factor is that the 2-line female's (S-line) pollen sterility depends on the environment (primarily temperature) and must be grown in certain environments for S-line seed production. The 3-line female (A-line) is produced by crossing with its maintainer line (B-line), so the environment does not affect pollen sterility for A-line seed production. This makes the 3-line system applicable at any geographic location. The advantage of the 2-line system, while not as largely applicable as the 3-line system, is that it has more potential to develop a hybrid variety because any rice variety or line can be used as the male parent. As mentioned previously, the male parent used for hybrid seed production in the 3-line system must possess restorer genes that are exclusive to *Indica*-type rice. Ideally, a hybrid rice breeding program starting relatively new, such as the University of Arkansas System Division of Agriculture's (UADA) hybrid rice breeding program, could benefit from a quicker approach by developing a hybrid rice variety utilizing the 2-line system.

The UADA hybrid rice breeding program at RREC has made efforts to produce a hybrid rice variety since its inception in 2009. More recently, the program has looked into hybrid seed production by exploring different field designs and management strategies, monitoring growth stages to improve synchronized flowering of both parents, and testing temperature treatments for increased female seed production.

Procedures

Hybrid Seed Production

For hybrid seed production, two different designs were implemented for planting: 1) 5–6 passes (160 ft length) of 3 male parents (7 rows, 8 in spacing) and 4–5 passes of 8 S-lines and 1 A-line within a block 65–75 ft wide to allow for 13 hybrid combinations; and 2) one male parent and 11 S-lines with ratios of 2:3 and 3:8 male to female alternating rows (10-in. row spacing) within a block dimension of 280 ft by 64 ft. Corn was planted on the levees to serve as pollen barriers of alternating male parents and nearby rice fields to improve hybrid seed purity.

Management of the hybrid production blocks included three herbicide applications (one pre-emerge, one post-emerge, and one pre-flood), flood establishment once plants were approximately 6

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inches, an application of 125 units of urea at flood, and removal of off-type rice plants. Additional management necessary for hybrid seed production was also implemented, such as two applications (9.7 grams a.i./ac) of gibberellic acid (first at 5% heading, then the second application four days after), and supplemental pollination in which rope was pulled across the male parents five times daily between 10:00 AM and 1:30 PM for 10 days (starting one day after 5% heading). Harvesting the hybrid seed was accomplished by machine (Mitsubishi mini-combine harvester) or by hand (sickle cutting rows) and threshed with an Almaco Vogel thresher.

Female Seed Production

Female seed production includes producing A (CMS) and S (TGMS) lines. A-line seed production was implemented using an alternating row design in which the A-lines were planted in the centermost rows, and their corresponding maintainer lines (B-lines) were planted in the outermost rows. The ratio of A:B rows varied depending on the amount of A-line seed available. A Wintersteiger cell planter was used, and each A/B pair was planted 5 ft with 10-in. row spacing. An additional 7 ft spacing was added in between pairs to allow for isolation. Pollen cages were utilized at flowering to allow for pure A-line production. The pollen cages were made with PVC framing and special pollen fabric designed by Diatex that covered each A/B pair (5 ft x 10 ft). Supplemental pollination was accomplished by using a leaf blower five times daily between 10:00 AM and 1:30 PM for 10 days (starting one day after 5% heading). The A-line rows were bulked.

S-line seed production (Table 1) includes two parts in which head rows for maintaining purification are grown at RREC, and large-scale production is grown at the University of Puerto Rico's Lajas Substation. In 2023, there were 66 advanced S-lines grown as head rows. Head rows begin as transplants in which individual seeds of each female line are grown in the greenhouse in Jiffy peat pots (2 in by 3 in). About 3 weeks following emergence, five plants of each S-line are transplanted to the field, which is specially designed using flags arranged as 4 ft rows with 2 ft spacing. Once internode elongation occurs and is approximately 3/4 inches elongated (R1 stage), two plants from each row are dug and placed into six-inch pots to undergo a lower temperature treatment (76 °F) in a controlled chamber. The controlled chamber, referred to as the cool shed, is a 12 ft x 20 ft insulated building with an air conditioner and 6 grow lights designed by the UADA hybrid breeding program. After 10 days in the cool shed, the plants are brought to a greenhouse with temperatures similar to that of the field to produce the S-line seed. After nearly two months in the greenhouse, the mature seed is hand-harvested and prepared for shipment to Puerto Rico.

In Puerto Rico, the S-lines are planted with a Wintersteiger cell planter (10-in. row spacing and 7 ft planting length). One trip is made to observe the lines at the time of flowering to note uniformity. Off-types are removed, and the best-looking rows are selected. A second trip is made once it is ready for harvesting. Any additional off-types are removed, and best-looking rows are bulk-harvested.

S-line Temperature Treatment Trial

To determine an efficient method of producing a 2-line system female (S-line) seed, the program looked closely at different points during the reproductive stage to undergo temperature treatment along with testing different numbers of days for treatment. To do this, a sample of 14 UADA S-lines were used from head row seeds. Two variables (Table 2) were measured—the bulk seed weight of each plant and the seed set percentage of 5 panicles from each plant taken as an average. The number of blank spikelets and seeds was counted for each panicle to provide a total amount of spikelets on the panicle. The number of seeds was divided by the total amount to provide the seed set percentage. Each plant was treated at 5 growth stages (Table 3): R0, R1, R1 + 10, R2, R2 + 10. The R growth stage is the reproductive phase in which panicle initiation begins (R0). This is also referred to as the green ring stage due to the visible green band above the top node. The next stage is R1, which is observed when internode elongation is ½ to ¾ inches. The R2 stage is observed once the flag leaf sheath begins swelling, referred to as booting. This is the last stage in panicle formation. The R3 stage is observed once the panicles exert, referred to as heading (Moldenhauer et al., 2013).

Along with monitoring growth stages, internode elongation was measured for each plant treated. The following 6 measurements (Table 4) were categorized as <0.6 in., 0.6 in., 0.8 in., 1.2 in., 1.6 in., and >1.6 in. Measuring internode elongation provides a more defined method of determining when to treat the plant rather than gauging plant growth development by observance. The timing of treatment is what determines maximum seed production, and since the number of days between growth stages varies depending on the environment and the genotypes of the lines, it is best to measure a plant characteristic that can be associated with proper treatment timing.

Three of the 14 UADA S-lines were also used in an additional study to determine if increasing the number of days undergoing temperature treatment would increase female seed production. The same variables (bulk seed weight of each plant and seed set percentage of 5 panicles per plant) were measured for each line. Three different numbers of days for treatment were tested: 8, 11, and 13. It is important to determine if there is any increase in S-line seed production from more days treated because of the yield potential, but it is also important to determine if there is no yield advantage that would lead to a quicker seed production by reducing the number of days treated.

Results and Discussion

Hybrid Seed Production

Eight experimental hybrids were selected and harvested for advanced testing in 2024. These 8 hybrids were selected based on the flowering synchronization of the male and female parents, the uniformity of the female lines, and the amount of hybrid seeds observed. In total, 6 S-lines and 3 male lines served as the parental combinations. Two of these hybrids have the Clearfield herbicide trait. The other 6 hybrids are conventional. All 8 hybrids have smooth plant leaves and non-pubescent seeds. The highest hybrid combination produced 22 lb seed, and the lowest had 3 lb, altogether averaging 8.5 lb. These advanced experimental hybrids will be tested in the 2024 AYT and ARVAT.

Female Seed Production

For 3-line female (A-line) seed production, 6 successful pairs were made. This resulted in approximately 200 seeds of each A-line produced. Continuous backcrossing of A/B pairs is required to further purify and establish uniformity of the A-lines. These lines are in the 7th generation and must undergo a few more generations before being used for large-scale hybrid seed production. The harvested A-line seed will be advanced in 2024, and with more seed being available, this will allow for larger female seed production.

For 2-line female (S-line) seed production, 140 plants were selected from panicle rows of 62 lines. Approximately 100 seeds were harvested from each plant. To ramp up seed production, these lines were sent to Puerto Rico in October to be harvested in February 2024. In Puerto Rico, each of the 140 plants is planted as small seed increase plots (7 rows with 10-in. spacing and 7 ft planting length) approximately 40.8 ft^2. For an even greater attempt at S-line seed production, 18 of the selected 62 lines were planted as seed increase plots ranging from 150 to 500 ft^2. The seed collected will be planted as head rows, and selected lines will be used for hybrid seed production at RREC in 2024.

S-line Temperature Treatment Trial

Treatment of the S-lines at different growth stages resulted in the R1 + 10 days stage being significantly greater than the other growth stages at both bulk weight and seed set percentage (Table 5). The worst timing for treatment is at the R0 stage. This stage is too early and panicle development is just being initiated. Treatment at other growth stages is not significantly different.

Treatment of the S-lines at different internode lengths resulted in 1.2 in. being significantly greater than the other internode measurements at both bulk weight and seed set percentage (Table 6). The measurement of <0.6 in. was significantly less than the other measurements. This again, is too early for treatment, being that is it at the R0 stage. Seed set for plants treated at 0.6-in. internode was significantly less than that treated at 1.2 and 0.8-in. internode; however, there was no significant difference for bulk weight. As for a measurable plant characteristic, it may be best to treat once the internode elongates to approximately 1 inch.

The different number of days of treatment resulted in no significant difference for both bulk weight and seed set percentage (Table 7). This is important to determine as it could result in quicker seed production. This is a first-time trial for the number of days of treatment. Based on this test, for 2024, the program can look into fewer days of treatment with the knowledge that 8 days is still enough to maximize seed production.

Practical Applications

Successful hybrid seed production of 8 experimental hybrids (2 with Clearfield herbicide trait, 6 conventional) was accomplished. A range of 3 lb to 22 lb was produced and will be plentiful for testing in multi-location yield trials in 2024. Field design and management are optimum for efficient hybrid seed production. The number of hybrid combinations in 2024 will be determined by available field space for isolation and parent seed availability.

Successful female seed production of 6 A-lines and 62 S-lines was accomplished. A large-scale seed production of the S-lines will be harvested in February 2024 in Puerto Rico. This should produce an ample amount of female seed for hybrid testcrossing and for hybrid seed production in 2024.

Further testing will be conducted to determine the most efficient method of producing a 2-line system female (S-line) seed. The S-line temperature treatment trial in 2023 determined that the R1+10 days growth stage is the best time for temperature treatment. Furthermore, looking at internode elongation as a better means of measuring the appropriate time for treatment, elongation at 1 inch is the best time. Overall, any treatment at R1 until R2 + 10 days (internode elongation of 0.8–1.6 in.) will produce seed. Lastly, the greater amount of days for treatment did not increase seed production. This will be further investigated by testing fewer number of days to determine a minimum number of days for treatment.

Acknowledgments

We want to express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture. We thank Emily Carr for her technical support.

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Table 1. The process of developing temperature-sensitive male sterile S-line seed during a year at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center and Lajas, Puerto Rico.

Month	Process
April	Plant S-lines in the greenhouse
May	Transplant to the field
July	Treat in the cool shed for 10 days, then move to the greenhouse
September	Harvest seeds in the greenhouse
October	Plant for large-scale production in Puerto Rico
February	Harvest at Puerto Rico

Table 2. The description of variables measured for the S-line temperature treatment trial procedures to determine male sterile S-line yield and seed set.

Variable	Description
Bulk Weight	Amount of total seed harvested from each plant
Blank Spikelet Count	Number of spikelets in which seed did not form on a panicle
Seed Count	Number of seeds on a panicle
Total Count	Sum of the blank spikelet and seed count on a panicle
Seed Set Percentage	Seed count divided by total count on a panicle

Table 3. The description of rice growth stages during the reproductive phase from panicle initiation until 10 days after the booting stage.

Growth Stage	Description
R0	Panicle initiation, visible green ring
R1	Internode elongation 0.5–0.8 inches
R1 + 10 days	Approximately 10 days after R1
R2	Visible swelling of flag leaf sheaths, referred to as booting
R2 + 10 days	Approximately 10 days after R2, slight panicle exertion just before heading

Table 4. The description of rice growth stages during the reproductive phase when measured by the length of elongating internodes.

Internode Elongation	Description
(in.)	
<0.6	R0 growth stage – panicle initiation, visible green ring
0.6	Approximately R1
0.8	Approximately 5 days after R1
1.2	Approximately 10 days after R1
1.6	Approximately R2 - visible swelling of flag leaf sheaths, referred to as booting
>1.6	Approximately 10 days after R2, slight panicle exertion just before heading

Table 5. Effects of growth stage on yield and seed set of male sterile S-lines when treated at 70 °F and under 12 h day length.

Growth Stage	Bulk Weight	Seed Set
	(g)	**(% of seed set)**
R0	0.3 c†	2.7 c
R1	4.4 b	28.6 b
R1 + 10 days	12.3 a	45.8 a
R2	6.2 b	27.3 b
R2 + 10 days	4.7 b	26.8 b
$LSD_{0.05}$‡	3.5	9.4

† Means within a column followed by the same letter are not significantly different ($P > 0.05$).
‡ LSD = least significant difference.

Table 6. Effects of growth stage measured by the length of elongating internode on yield and seed set of male sterile S-lines when treated at 70 °F and under 12 h day length.

Internode Elongation	Bulk Weight	Seed Set
(in.)	(g)	(% of seed set)
<0.6	1.4 b[†]	7.0 d
0.6	3.6 b	22.1 c
0.8	4.4 b	32.5 b
1.2	12.3 a	45.8 a
1.6	6.2 b	27.3 bc
>1.6	4.7 b	26.8 bc
$LSD_{0.05}$[‡]	5.4	7.9

[†] Means within a column followed by the same letter are not significantly different ($P > 0.05$).
[‡] LSD = least significant difference.

Table 7. Effects of the number of days on yield and seed set of male sterile S-lines when treated at 70 °F and under 12 h day length.

Number of Days	Bulk Weight	Seed Set
	(g)	(% of seed set)
8	7.0 a[†]	24.9 a
11	6.3 a	30.8 a
13	4.3 a	24.8 a
$LSD_{0.05}$[‡]	4.8	9.5

[†] Means within a column followed by the same letter are not significantly different ($P > 0.05$).
[‡] LSD = least significant difference.

Evaluation of Advanced Medium-Grain and Long-Grain Breeding Lines at Four Arkansas Locations

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Abstract

It is critical to have a yield trial under the most representative soil types and environmental conditions for rice breeders to identify the ideal breeding lines for potential varietal releases. To bridge the gap between the single location and 2–3 replication preliminary yield trials with over 1,500 breeding lines and statewide multi-location Arkansas Rice Variety Advancement Trials (ARVAT), which only accommodate a small number of entries, an advanced elite line yield trial (AYT) was initiated in 2015. The trial is conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark.; the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), near Colt, Ark.; the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), in Keiser, Ark., and the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center (NERREC), in Harrisburg, Ark. This trial will help us to select the best and the most uniform breeding lines for advancement into the ARVAT and other advanced yield trials, and ultimately will improve the quality of those yield trials.

Introduction

Complex traits, such as yield and quality, can only be evaluated effectively in replicated yield trials. Once reaching a reasonable uniformity, rice breeding lines are bulk-harvested and tested in a single location and 2–3 replication preliminary yield trials, which include the Clearfield® (CL) Stuttgart Initial Test (CSIT), Provisia® (PV) Stuttgart Initial Test (PSIT), and Conventional Stuttgart Initial Test (SIT). Each year, about 1,500 new breeding lines are tested in CSIT, PSIT, or SIT trials. About 10% of the tested breeding lines, which are expected to yield statistically or numerically higher than commercial checks and possess desirable agronomical characteristics, need to be tested in replicated and multi-location advanced yield trials. However, the current advanced yield trials, including statewide Arkansas Rice Variety Advancement Trials (ARVAT) and the multi-state Uniform Regional Rice Nursery (URRN), only can accommodate about 37 entries from each rice breeding project. Obviously, a new replicated and multi-location trial is needed to accommodate those additional breeding lines. In addition to the verification of the findings in the previous preliminary trials, the new trial will result in purer and more uniform seed stock for ARVAT and URRN trials.

Procedures

A total of 60 entries were tested in the 2023 advanced elite line yield trial (AYT), which included 48 experimental long-grain and 8 medium-grain lines, and 4 commercial check varieties. Fourteen of the experimental lines were also concurrently tested in 2023 ARVAT and/or URRN trials. As companion tests, a 115-entry CL AYT (CAYT) and a 40-entry PV AYT (PAYT) were also carried out, and a 2X recommended rate of NewPath and Provisia herbicides were applied, respectively. The CAYT included 100 CL long-grain and 7 CL medium-grain experimental lines, and 8 commercial checks, while the PAYT was made up of 37 PV long-grain lines, 1 PV medium-grain line, and 2 commercial checks. The experimental design is a randomized complete block with three replications. Plots measuring 4.38 feet wide (7 rows with a 7.5-in. row spacing) and 14.25 feet long were drill-seeded at 85 pounds per acre rate. All seeds were treated with AV-1011 (18.3 fl oz/cwt) and CruiserMaxx Rice (7 fl oz/cwt) for blackbirds, seedling diseases, and insect pests. The soil types at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Northeast Rice Research and Extension Center (NERREC), Pine Tree Research Station (PTRS), and Rice Research and Extension Center are Sharkey clay, Henry-Calloway silt loam, Calloway silt loam, and DeWitt silt loam, respectively. Trials at NEREC were planted on 4 May, NERREC on 25 April, and PTRS on 19 April. Planting dates at RREC were 29 March (AYT RREC1, CAYT RREC1, and PAYT RREC1), 8 May (CAYT RREC2 and PAYT RREC2), and 23 May (AYT RREC2). A single pre-flood application of 135 lb (160 lb for NEREC) nitrogen in the form of urea was applied to a dry soil surface at the 4- to 5-leaf stage, and a permanent flood was established 1–2 days later. At maturity, all trials were harvested by

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using a Wintersteiger Quantum plot combine (Wintersteiger AG, 4910 Ried, Austria), and the moisture content and plot weight were determined by the automated weighing system Harvest Master that is integrated into the combine. A small sample of seed was collected off the combine from each plot for later milling yield determination. Milling evaluations were conducted in-house on a Zaccaria PAZ-100 sample mill (Zaccaria, Limeira, Brazil). Grain yields were calculated as bushel per acre at 12% moisture content.

Data were analyzed using the General Linear Model procedure of SAS software, v. 9.4 (SAS Institute, Inc., Cary, N.C.). A combined analysis of variance across all locations was performed for grain yield, milling yields, days to 50% heading, plant height, and seedling vigor. The means were separated by Fisher's protected least significant difference (LSD) test at the 0.05 probability level.

Results and Discussion

The average AYT grain yield of all entries across 4 locations and 5 planting dates is 214 bu./ac, which is higher than the 2022 average of 198 bu./ac but lower than the 232 bu./ac of 2021 (Table 1). The PTRS has the highest average yield at 228 bu./ac, followed by 225 and 215 bu./ac at NERREC and the first planting at RREC, respectively. Medium-grain rice yield rebounded from 2022 with an average of 216 bu./ac, which is much higher than the 2022 average of 179 bu./ac. The top 6 highest-yielding entries are commercial hybrid 23AYT03 (RT XP753), long-grain lines 23AYT15 (22AR182), 23AYT22 (23AR122), 23AYT10 (22AR151), 23AYT43 (23AR143), and medium-grain check 23AYT04 (Taurus), with average grain yields of 269, 231, 226, 225, 225, and 226 bu./ac, respectively. Similar to those reported by rice mills, the average head rice and total rice yield across all locations are much lower at 47% and 66%, as compared with 63% and 68% in 2022, respectively.

The five highest-yielding conventional medium-grain entries are 23AYT04 (Taurus), 23AYT59 (23AR259), 23AYT38 (23AR238), 23AYT19 (23AR219), and 23AYT58 (23AR258) with average yields of 226, 224, 217, 215, and 211 bu./ac, respectively. Of 48 conventional experimental long-grain lines, 22 out-yielded Ozark, and 37 outperformed DG263L. Top-performing lines include 23AYT15, 23AYT22, 23AYT10, 23AYT43, and 23AYT29, with average yields of 231, 226, 225, 225, and 225 bu./ac, respectively. Most of these top-yielding experimental lines will be advanced or re-tested in the 2024 ARVAT and/or URRN trials.

The average grain yield of CAYT across all locations/planting dates is 192 bu./ac as compared with 204 and 214 bu./ac in 2022 and 2021, respectively (Table 2). The lower yield may be attributed to the delayed planting of entries harvested from the Puerto Rico winter nursery. The average milling yield (%head rice/%total rice) is 50/64, which is lower than 62/68 and 59/66 in 2022 and 2021, respectively. CL medium-grain 21AR1217 continues showing the outstanding yield potential, followed by CLL18, 23AR1212, 23AR1125, and 22AR1129, with average yields of 238, 226, 223, 218, and 215 bu./ac, respectively. Among CL long-grain entries, CLL18 had the highest yield of 226 bu./ac. However, 40 out of a total of 100 experimental lines outperformed the predominant check CLL16. The top 5 lines are CLL18, 23AR1125, 22AR1129, 23CAYT241, and 23CAYT237, with an average yield of 226, 218, 215, 212, and 212, respectively. The top-performing CL medium-grain lines include 21AYT1217, 23AR1212, 23AR1217, 22AR1226, and 22AR1228 with average yields of 238, 223, 211, 209, and 206 bu./ac, respectively, as compared with the 193 bu./ac of CLM04.

Our Provisia rice breeding program was launched in February 2019. Through extensive crossing/backcrossing, rapid generation advancement, and intensive selection and re-selection, more PV long-grain lines were developed in a very short period of time and tested in our new PAYT trial (Table 3). The average grain yield is 203 bu./ac as compared with 190 and 183 bu./ac in 2022 and 2021, respectively. The average milling yields (% head rice/% total rice) are 53/67, as compared with 63/68 and 55/65 in 2022 and 2021, respectively. The PTRS had the highest yield of 225 bu./ac, followed by 209 and 207 bu./ac of the first planting at RREC and at NERREC, respectively. All but one experimental line yielded significantly ($P < 0.01$) higher than check PVL03, while 28 of the total 38 lines outperformed the newly released PVL04. 23AR2134, 23AR2114, 23AR2133, 23AR2109, and 23AR2104 are top-performing PV long-grain lines with average grain yields of 225, 221, 220, 218, and 217 bu./ac, respectively, as compared with 181 and 196 bu./ac of PVL03 and PVL04 checks, respectively.

Practical Applications

The new AYT trials successfully bridged the gap between the single location preliminary yield trials with numerous entries and the multi-state or statewide advanced yield trial that can only accommodate a very limited number of entries by offering opportunities for the trial of additional elite breeding lines. Our results enable us to confirm the findings from other yield trials and identify the outstanding breeding lines that were otherwise excluded from ARVAT and/or URRN trials due to insufficient space.

Acknowledgments

We would like to express our appreciation for funding and support from the Arkansas rice growers administered through the Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture. Technical support from Emily Carr was greatly appreciated.

Table 1. Grain and milling yield of 60 long- and medium-grain breeding lines and commercial checks in the advanced elite line yield trial (AYT) conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Ark.; Northeast Rice Research and Extension Center (NERREC) in Harrisburg, Ark.; Pine Tree Research Station (PTRS) near Colt, Ark.; and Rice Research and Extension Center (RREC) near Stuttgart, Ark., 2023.

			Grain Yield						
Entry	Pedigree	GT[a]	NEREC	NERREC	PTRS	RREC1[b]	RREC2[b]	Mean	%HR/%TR[c]
			--------------------------------(bu./ac)--------------------------------						
23AYT01	Ozark	L	202	232	236	215	179	216	49/65
23AYT02	DG263L	L	176	212	217	211	186	207	50/64
23AYT03	RT XP753	L	216	285	299	265	229	269	37/66
23AYT04	Taurus	M	184	237	243	233	193	226	49/66
23AYT05	RU1201111/DMND	L	195	231	243	220	200	223	47/65
23AYT06	DMND/LKST	L	188	228	243	209	189	217	49/65
23AYT07	RU1501030/DMND	L	179	210	235	210	186	210	48/65
23AYT08	17AYT06/FRNS	L	175	219	225	214	185	211	50/66
23AYT09	RU1201111/DMND	L	194	220	229	213	204	216	42/65
23AYT10	17AYT06/RU1601010	L	185	230	238	228	206	225	42/66
23AYT11	17AYT06/FRNS	L	174	206	218	214	181	205	51/67
23AYT12	17AYT06/RU1601010	L	201	233	240	221	195	222	51/65
23AYT13	17AYT06/RU1601070	L	168	216	228	202	176	205	45/64
23AYT14	RU1401050/DMND	L	188	236	242	209	178	216	47/65
23AYT15	17AYT06/RU1401099	L	191	244	232	233	217	231	37/64
23AYT16	16ARPT269/16ARPT272	M	197	226	226	233	159	211	56/65
23AYT17	16ARPT272/RU1501050	M	216	194	241	223	181	210	42/66
23AYT18	TITN/Norin 50	S	164	191	200	201	148	185	56/64
23AYT19	16ARPT255/17AYT060	M	198	222	231	233	173	215	43/65
23AYT20	DMND/LKST	L	189	226	230	219	175	212	47/65
23AYT21	DMND/RU1201111	L	201	243	205	225	210	221	44/66
23AYT22	DMND/RU1201111	L	184	243	226	224	212	226	48/66
23AYT23	DMND/RU1201111	L	185	232	223	212	207	218	48/67
23AYT24	RU1201111/DMND	L	215	232	218	234	204	222	50/67
23AYT25	RU1201111/DMND	L	199	231	226	211	219	222	48/66
23AYT26	RU1201111/DMND	L	172	228	228	221	196	218	49/67
23AYT27	RU1201111/DMND	L	166	221	226	216	184	212	46/65
23AYT28	RU1201111/DMND	L	178	227	224	193	184	207	50/66
23AYT29	17AYT06/DMND	L	192	235	239	219	205	225	45/66
23AYT30	17AYT06/DMND	L	180	234	229	203	211	219	49/66
23AYT31	17AYT06/DMND	L	187	216	220	189	192	204	50/67
23AYT32	17AYT06/DMND	L	174	234	226	216	206	220	51/66
23AYT33	17AYT06/FRNS	L	170	206	205	210	196	205	52/68
23AYT34	17AYT06/FRNS	L	188	232	231	225	202	223	50/68
23AYT35	17AYT06/RU1601070	L	186	230	214	204	201	212	50/66
23AYT36	RU1701185/DMND	L	202	221	224	211	178	209	50/66
23AYT37	16AYT058/16ARPT255	M	199	219	227	229	173	212	42/64
23AYT38	16AYT058/17AYT060	M	188	216	238	231	184	217	42/64
23AYT39	RU0801093/MRMT//RU1201111	L	181	204	216	191	174	196	45/67
23AYT40	RU1401142/RU1201108	L	180	232	222	184	190	207	55/68

Continued

Table 1. Continued.

Entry	Pedigree	GT[a]	Grain Yield NEREC	NERREC	PTRS	RREC1[b]	RREC2[b]	Mean	%HR/%TR[c]
			--------------------------------(bu./ac)--------------------------------						
23AYT41	RU1701084/JEWL	L	196	215	238	211	191	214	48/67
23AYT42	RU1701084/RU1601070	L	151	216	223	202	165	202	49/66
23AYT43	RU1701084/17SIT556	L	189	241	244	227	187	225	43/66
23AYT44	JEWL/TGRT	L	188	241	231	217	191	220	49/66
23AYT45	JEWL/TGRT	L	198	228	228	213	199	217	43/66
23AYT46	RU1601070/DMND	L	193	243	227	228	199	224	50/66
23AYT47	RU1601070/DMND	L	184	224	218	176	181	200	41/65
23AYT48	RU1601070/DMND	L	193	236	228	214	174	213	48/67
23AYT49	RU1601070/JEWL	L	198	228	226	196	190	210	47/67
23AYT50	RU1601070/RU1201108	L	175	220	212	193	188	203	40/66
23AYT51	RU1601070/18AYT58	L	171	233	227	228	199	222	50/67
23AYT52	RU1601070/18AYT58	L	195	221	232	202	198	213	46/67
23AYT53	RU1601070/18AYT58	L	185	212	231	215	204	215	44/65
23AYT54	RU1401142/DMND	L	196	214	224	210	187	209	47/66
23AYT55	RU1401142/LKST	L	187	213	205	202	172	198	47/65
23AYT56	17SIT556/RU1601145	L	179	223	221	213	151	202	50/66
23AYT57	17SIT556/RU1201111	L	195	216	215	221	179	208	52/65
23AYT58	18AYT77/RU1801237	M	196	220	227	211	190	212	49/66
23AYT59	18AYT79/18AYT76	M	194	236	235	239	187	224	41/65
23AYT60	RU1601070/18AYT58//JEWL/…	L	173	208	202	201	162	193	48/67
c.v.(%)[d]			7.4	4.2	5.2	4.9	4.4	6.4	5.1/1.4
$LSD_{0.05}$			30.8	15.4	19.1	16.9	13.6	10.2	2.8/0.9

[a] Grain type, L = conventional long-grain, M = conventional medium-grain, and S = conventional short-grain.
[b] RREC1 = planted on 29 March and RREC2 = planted on 23 May.
[c] Milling yield, HR = head rice and TR = total rice yield.
[d] c.v. = Coefficient of variance.

Table 2. Performance of selected Clearfield® (CL) long- and medium-grain breeding lines and commercial checks in the CL advanced elite line yield trial (CAYT) conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, and Northeast Rice Research and Extension Center (NERREC), Harrisburg, Ark., or Pine Tree Research Station (PTRS) near Colt, Ark. 2023.

Variety/Line	Pedigree	Grain type[a]	Days to 50% heading	Plant height	Yield	Milling[b]
				(in.)	(bu./ac)	(%HR/%TR)
21AR1217[†]	RU1501050/RU1501027	CM	94	38	238	54/65
23AR1212[†]	TITN/RU1501096	CM	89	38	223	57/64
23AR1125[†]	RU1801169/RU1201111	CL	91	39	213	50/65
22AR1129[†]	RU1201111/CL172	CL	91	40	210	53/65
23AR1115[†]	RU1201111/CL172	CL	91	36	203	52/67
23AR1124[†]	RU1801169/LKST	CL	90	43	198	46/66
CLL16[†]	CLL16	CL	95	41	210	50/64
CLL18[†]	CLL18	CL	93	42	226	48/62
CLM04[†]	CLM04	CM	92	41	193	56/64
23CAYT126[‡]	RU1801145/20SIT1051	CL	83	44	204	46/63
23CAYT113[‡]	RU1801145/RU1201111	CL	83	45	203	51/64
23CAYT121[‡]	RU1801145/20SIT1049	CL	84	43	203	52/64
23CAYT123[‡]	RU1801145/20SIT1049	CL	83	44	202	52/64
23CAYT135[‡]	ROYJ/RU1501127//RU1801145	CL	83	44	200	48/64
23CAYT133[‡]	ROYJ/RU1501127//RU1801145	CL	84	42	199	49/64
23CAYT106[‡]	CLL16/RU1801093	CL	83	42	197	45/63
23CAYT125[‡]	RU1801145/20SIT1051	CL	84	41	196	52/63
23CAYT136[‡]	ROYJ/RU1501127//RU1801145	CL	84	44	195	43/62
CLL16[‡]	CLL16	CL	86	43	185	52/64
CLL18[‡]	CLL18	CL	85	43	207	49/63
23CAYT241[‡]	RU2001125/RU1801145	CL	88	44	212	53/66
23CAYT237[‡]	RU2001125/RU1801145	CL	92	43	212	49/62
23CAYT232[‡]	RU2001125/CLL16	CL	88	44	212	49/66
23CAYT240[‡]	RU2001125/RU1801145	CL	88	46	210	53/65
23CAYT242[‡]	RU2001125/RU1801145	CL	88	47	208	51/65
23CAYT238[‡]	RU2001125/RU1801145	CL	89	43	204	51/63
23CAYT239[‡]	RU2001125/RU1801145	CL	89	44	203	52/63
23CAYT218[§]	CLL16/RU1901065	CL	80	44	197	43/63
23CAYT217[§]	CLL16/RU1801145	CL	78	44	195	46/61
CLL16[§]	CLL16	CL	83	40	187	48/63
CLL18[§]	CLL18	CL	82	40	219	50/64

[a] CL = Clearfield long-grain and CM = Clearfield medium-grain.
[b] Milling yield HR = head rice and TR = total rice.
[†] Planted at RREC on March 29 and PTRS on April 19.
[‡] Planted at NERREC on 24 April and RREC on 8 May.
[§] Planted at NERREC on 24 April and RREC on 8 May.

Table 3. Grain and milling yield of 40 Provisia® (PV) long-grain breeding lines and commercial checks in the advanced PV elite line yield trial (PAYT) conducted at Northeast Rice Research and Extension Center (NR) in Harrisburg, AR., Northeast Research and Extension Center (NE) at Keiser, AR, Pine Tree Research Station (PT) near Colt, AR, and Rice Research and Extension Center (RB) near Stuttgart, AR, 2023.

Variety	GT [a]	Days to 50% heading	Height	Grain Yield						%HR/%TR [c]
				NEREC	NERREC	PTRS	RREC1[b]	RREC2 [b]	Mean	
			(in.)	---------------------------(bu./ac)---------------------------						
22AR2106	PVL	91	41	170	188	222	185	175	188	55/66
23AR2104	PVL	93	43	190	234	232	224	205	217	55/68
23AR2205	PVM	90	41	201	231	237	213	195	215	58/65
23AR2106	PVL	92	42	165	194	208	202	180	190	57/68
23AR2107	PVL	92	41	166	181	198	187	154	177	54/69
23AR2108	PVL	90	43	182	197	222	197	189	197	54/67
23AR2109	PVL	92	44	200	236	231	221	203	218	51/66
23AR2110	PVL	90	39	198	215	231	230	210	217	56/66
23AR2111	PVL	93	42	185	226	226	217	206	212	56/67
23AR2112	PVL	92	42	182	216	232	225	221	215	52/67
23AR2113	PVL	92	46	173	217	240	209	211	210	53/66
23AR2114	PVL	90	45	182	239	249	224	212	221	49/67
23AR2115	PVL	90	46	171	216	230	205	200	204	48/67
23AR2116	PVL	97	42	183	204	228	211	196	205	55/65
23AR2117	PVL	93	44	172	208	223	212	206	204	52/67
23AR2118	PVL	93	43	176	195	219	205	196	198	51/67
23AR2119	PVL	90	44	174	205	207	191	201	196	55/68
23AR2120	PVL	90	43	169	218	236	203	186	202	44/64
23AR2121	PVL	94	44	161	190	206	197	173	185	52/68
23AR2122	PVL	92	40	167	216	217	209	196	201	56/67
23AR2123	PVL	86	40	170	191	219	199	173	190	46/65
23AR2124	PVL	95	41	186	197	214	207	202	201	57/68
23AR2125	PVL	95	43	179	221	235	215	214	213	54/67
23AR2126	PVL	93	44	169	206	216	220	201	202	54/67
23AR2127	PVL	93	42	177	213	234	223	208	211	55/67
23AR2128	PVL	91	44	184	212	235	226	210	213	55/67
23AR2129	PVL	96	44	150	200	220	202	176	190	52/65
23AR2130	PVL	94	42	163	183	224	204	185	192	49/66
23AR2131	PVL	94	43	164	175	218	202	187	189	53/66
23AR2132	PVL	93	43	199	226	234	222	198	216	50/66
23AR2133	PVL	92	42	203	220	239	236	203	220	48/65
23AR2134	PVL	91	43	208	238	244	225	211	225	49/65
23AR2135	PVL	92	43	172	198	233	197	190	198	54/66
23AR2136	PVL	93	40	173	188	202	186	172	184	53/67
23AR2137	PVL	87	43	183	210	240	214	201	210	53/66

Continued

Table 3. Continued.

Variety	GT[a]	Days to 50% heading	Height	Grain Yield NEREC	NERREC	PTRS	RREC1[b]	RREC2[b]	Mean	%HR/%TR[c]
			(in.)	---------------------------(bu./ac)---------------------------						
23AR2138	PVL	94	43	187	210	231	215	212	211	50/66
23AR2139	PVL	93	42	194	217	226	225	199	212	55/68
23AR2140	PVL	95	44	181	199	217	205	183	197	57/67
PVL03	PVL	92	41	175	164	209	182	173	181	53/68
PVL04	PVL	94	41	181	198	222	202	179	196	58/68
c.v.(%)[d]		1.6	3.6	5.4	5.5	4.0	4.2	4.3	4.98	3.6/1.2
$LSD_{0.05}$		1.2	1.4	15.6	18.6	14.8	14.3	13.7	7.2	2.2/0.9

[a] Grain type, PVL = PV long-grain and PVM = PV medium-grain.
[b] RREC1 = planted on 29 March and RREC2 = planted on 8 May.
[c] Milling yield, HR = head rice and TR = total rice yield.
[d] c.v. = coefficient of variance.

Development of Superior Medium-Grain and Long-Grain Rice Varieties for Arkansas and the Mid-South

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Abstract

In order to reflect changes in the Arkansas rice industry and streamline the delivery of new and improved rice varieties to Arkansas rice growers, the medium-grain rice breeding project has expanded its research areas and breeding populations to include conventional, Clearfield®, and Provisia® medium-grain and long-grain rice. The newest elite breeding lines/varieties from our own and collaborating programs, as well as lines with diverse genetic origins, will be actively collected, evaluated, and incorporated into current crossing blocks for programmed hybridization. To improve the efficiency and effectiveness of the program, maximum mechanized-operation, multiple generations grown in the winter nursery, and new technologies such as genomic selection are vigorously pursued.

Introduction

Medium-grain rice is an important component of Arkansas rice. Arkansas ranks second in medium-grain rice production in the United States, only behind California. During 2013–2022, an average of 0.163 million acres of medium-grain rice was grown annually, making up about 13% of total state rice acreage (USDA-ERS, 2023). Even with the rapid adoption of hybrid rice from the private sector during the last 2 decades, about 20% of Arkansas rice acreage was planted to long-grain pure-line varieties, such as DG263L, Diamond, Ozark, CLL16, CLL18, and PVL03. Improved semi-dwarf long-grain rice can also be directly adopted by the hybrid breeding program. Since genetic potential still exists for further improvement of current varieties, rice breeding efforts must continue to maximize yield and quality for the future.

Procedures

Potential parents for the breeding program are evaluated for the desired traits. Cross combinations are programmed that combine desired characteristics to fulfill the breeding objectives. Marker-assisted selection (MAS) will be carried out on backcross or top-cross progenies for simply inherited traits such as herbicide traits, blast resistance, and physicochemical characteristics. Meanwhile, genomic selection will be attempted on mid-generation breeding lines that are reasonably uniform. Segregating populations are planted, selected, and advanced at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. and the winter nursery near Lajas, Puerto Rico. Pedigree and modified single-seed descent will be the primary selection technologies employed. A great number of traits will be considered during this stage of selection, including grain quality (shape and appearance), plant type, short stature, lodging resistance, disease (blast, sheath blight, and panicle blight) resistance, earliness, and seedling vigor. Promising lines with a good combination of these characteristics will be further screened in the laboratory for traits such as kernel size and shape, grain chalkiness, and grain uniformity. Initial milling evaluation will be conducted on bulked panicle rows prior to their inclusion in the preliminary yield trial to eliminate ones with evident quality problems in order to maintain the standard U.S. rice quality of different grain types/market classes. Yield evaluations include the preliminary Stuttgart Initial Yield Test (conventional SIT, Clearfield® CSIT, and Provisia® PSIT) at RREC and the Advanced Elite Line Yield Trial (conventional AYT, Clearfield® CAYT, and Provisia® PAYT at RREC, Pine Tree Research Station (PTRS) near Colt, Ark., Northeast Research and Extension Center (NEREC) in Keiser, Ark., and Northeast Rice Research and Extension Center (NERREC) in Harrisburg, Ark. Advanced yield trials also include the Arkansas Rice Variety Advancement Trials (ARVAT) and on-farm Arkansas Rice Performance Trials (ARPT) conducted by Dr. Jarrod Hardke, the Arkansas rice agronomy specialist, at 6–10 locations in rice growing regions across the state, and the Uniform Regional Rice Nursery (URRN) conducted in cooperation with public rice breeding programs in California, Louisiana, Mississippi, and Texas. Promising advanced lines will be further evaluated in the new Pre-commercial (PC) trial conducted at 25–30 locations in Arkansas, Louisiana, and Texas, as well as by cooperating projects for their resistance to sheath blight, blast, and panicle blight, grain and cooking/processing quality, and nitrogen fertilizer requirements. All lines entered in the SIT, CSIT, or PSIT and beyond will be planted as head rows for purification and increase purposes.

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Results and Discussion

The field research in 2023 included 951 transplanted or drill-seeded F_1 populations, 945 space-planted F_2 populations, and 85,400 panicle rows ranging from F_3 to F_7. Visual selection on over 1 million individual space-planted F_2 plants resulted in a total of 55,000 panicles that will be individually processed and grown as F_3 panicle rows in 2024. A total of 4,500 panicle rows were selected for advancement to the next generation, while 2,174 rows appeared to be uniform and superior to others and, therefore, were bulk-harvested by hand as candidates for 2024 SIT, CSIT, and PSIT trials. In the 2023 CSIT trial, we evaluated 445 new breeding lines, which included 405 CL long-grain and 40 CL medium-grain breeding lines. Of 551 new conventional breeding lines tested in the 2023 SIT trial, 424 were long-grain lines and 127 medium-grain lines. A total of 443 new Provisia lines were tested in the PSIT trial, which included 440 PV long-grain and 3 PV medium-grain lines. A 60-entry Advanced Elite Line Yield Trial (AYT) and 40-entry PV AYT (PAYT) were conducted at NEREC, NERREC, PTRS, and RREC, while a 115-entry CAYT was tested at NERREC, PTRS and RREC. A number of breeding lines showed yield potential similar to or better than the check varieties in the 2023 SIT, CSIT, and PSIT trials (Tables 1–4). Thirty-seven advanced experimental lines were evaluated in the statewide ARVAT trial, and results can be found in the article "Arkansas Rice Variety Advancement Trials, 2023" in this publication. Three Puerto Rico winter nurseries consisting of 13,500 7-foot rows were planted, selected, and turned around during off-season 2023. The first nursery was harvested in early November and turned around, and the remaining two will be harvested in spring 2024. A total of 853 new crosses were made to incorporate desirable traits from multiple sources into adapted Arkansas rice genotypes.

Three new varieties were officially released in 2023, which included the first ever Arkansas-developed Provisia long-grain variety PVL04 (RU2201021), CL medium-grain CLM05 (RU2101234), and medium-grain commercial variety ProGold 3M (RU1901165). One hundred ninety-one breeding lines that outperformed commercial check varieties in AYT, CAYT, PAYT, CSIT, PSIT, and SIT trials were selected and further evaluated in the laboratory as candidates for 2024 advanced yield trials, including ARVAT, AYT, CRT, PC, and URRN.

Practical Applications

Successful development of medium-grain varieties CLM05, Taurus, Titan, CLM04, and Lynx, and long-grain varieties PVL04, Ozark, 21AR136, and CLL15 offers producers options for variety and management systems in Arkansas rice production. Continued utilization of new germplasm through exchange and introduction remains important for Arkansas rice improvement.

Acknowledgments

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Table 1. Performance of selected Clearfield experimental lines and check varieties in the Clearfield® Stuttgart Initial Test (CSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2023.

Variety/Line	Pedigree	Grain type[a]	Days to 50% heading	Plant height	Yield	Milling[b]
				(in.)	(bu./ac)	(%HR/%TR)
23CSIT1052[†]	RU1801221/17AYT026	CL	91	39	224	55/68
23CSIT1165[†]	17AYT067/RU1801137	CM	96	38	223	58/68
23CSIT1017[‡]	17AYT070/RU1501099	CM	94	39	213	47/65
23CSIT1007[†]	DMND/CLL15	CL	90	40	210	48/69
23CSIT1209[‡]	RU1501096/16ARPT269	CM	81	36	203	56/67
23CSIT1233[‡]	RU1601070/CLL16	CL	76	43	198	50/69
23CSIT1237[‡]	RU1601070/CLL16	CL	77	43	193	57/69
23CSIT1381[‡]	RU1801145/RU1701081	CL	82	44	193	52/69
23CSIT1365[‡]	RU1701081/RU1801145	CL	83	44	193	54/68
23CSIT1383[‡]	RU1801145/RU1601070	CL	82	43	189	64/70
23CSIT1385[‡]	RU1801145/RU1601070	CL	81	43	188	49/69
CLL16[†]	CLL16	CL	95	41	199	50/64
CLM05[†]	CLM04	CM	92	41	189	56/64
CLL16[‡]	CLL16	CL	84	41	175	n/a
CLM04[‡]	CLM04	CM	82	40	162	n/a

[a] CL = Clearfield long-grain and CM = Clearfield medium-grain.

[b] Milling yield HR = head rice and TR = total rice; n/a = not available.

[†] Planted on March 29.

[‡] Planted on May 23.

Table 2. Performance of selected conventional medium-grain experimental lines and check varieties in the Stuttgart Initial Test (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2023.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling[b]
				(in.)	(bu./ac)	(%HR/%TR)
23SIT356[†]	18AYT77/17SIT804	3.0	94	39	258	63/67
23SIT292[†]	LYNX/18AYT76	4.0	93	39	241	57/67
23SIT347[†]	18AYT75/LYNX	4.0	93	37	237	58/67
23SIT409[†]	CFFY/17SIT730	4.0	94	40	230	n/a
23SIT290[†]	16ARPT271/18AYT80	3.5	95	37	229	58/65
23SIT357[†]	18AYT77/17SIT978	4.0	96	40	226	62/66
23SIT350[†]	18AYT75/17SIT925	4.0	92	39	222	62/66
23SIT295[†]	RU1801237/17SIT978	4.0	94	37	220	52/68
23SIT422[‡]	16ARPT269/RU1801237	4.0	88	36	220	57/66
Taurus[†]	Taurus	3.0	89	36	242	n/a
Titan[†]	Titan	3.0	89	41	210	n/a
Taurus[‡]	Taurus	3.0	83	34	213	n/a

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.

[b] Milling yield HR = head rice and TR = total rice; n/a = not available.

[†] Planted on April 11.

[‡] Planted on May 3.

Table 3. Performance of selected Conventional long-grain experimental lines and check varieties in the Stuttgart Initial Test (SIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2023.

Variety/Line	Pedigree	Seedling vigor[a]	Days to 50% heading	Plant height	Yield	Milling[b]
				(in.)	(bu./ac)	(%HR/%TR)
23SIT133†	DMND/17AYT006	3.0	96	44	246	48/68
23SIT332‡	DMND/RU1601145	3.5	93	43	238	50/67
23SIT087†	RU1601070/18AYT58	3.0	97	43	236	50/68
23SIT341‡	RU1401142/ROYJ	3.0	94	44	235	49/67
23SIT201†	RU1401142/RU1201111	3.5	99	45	235	46/68
23SIT128†	DMND/RU1701084	4.0	101	44	235	48/67
23SIT324‡	DMND/FRNS	4.0	92	42	235	55/68
23SIT104†	18AYT53/DMND	3.5	95	41	233	49/65
23SIT129†	DMND/RU1701084	3.5	101	44	232	57/68
23SIT376‡	CTHL/FRNS//DMND*2/RU1201111	4.0	96	45	232	51/66
23SIT153†	FRNS/LKST	3.5	95	44	231	55/69
23SIT040†	17AYT06/RU1601010	4.0	98	41	231	57/68
Ozark†	Ozark	3.0	98	43	222	n/a
Ozark‡	Ozark	3.0	94	41	205	n/a
DG263L†	DG263L	3.0	96	38	234	n/a

[a] A subjective 1–7 rating taken at emergence, 1 = perfect stand and 7 = no stand.

[b] Milling yield HR = head rice and TR = total rice; n/a = not available.

† Planted on March 29.

‡ Planted on April 17.

Table 4. Performance of selected Provisia® (PV) experimental lines and check varieties in the PV Stuttgart Initial Test (PSIT) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., 2023.

Entry	Pedigree	Days to 50% heading	Plant height	Yield	Milling[a]
			(in.)	(bu./ac)	(%HR/%TR)
23PSIT2071	19AYT64/5/RU1701084/4/…//HPHI2/3/…	107	46	228	58/70
23PSIT2007	DMND/4/RU1201145/3/ …//HPHI2	98	41	228	38/67
23PSIT2089	RU1901193/5/RU1701084/4/…//HPHI2/3/…	102	47	224	48/67
23PSIT2177	RU1901065/6/RU1701081/5/…//HPHI2	97	47	224	57/69
23PSIT2070	19AYT64/5/RU1701084/4/…//HPHI2/3/…	102	44	223	52/68
23PSIT2125	RU1701081/5/RU1701084/4/…//HPHI2/3/…	101	43	222	56/69
23PSIT2027	RU1601070/4/JEWL/RU1601070//HPHI2/3/…	105	43	221	50/66
23PSIT2114	DMND*2/4/RU1601070/…//HPHI2/3/…	103	42	221	55/67
23PSIT2014	RU1701081/4/JEWL/3/RU1601070/…//HPHI2	101	41	221	56/68
23PSIT2022	RU1701084/4/…//HPHI2/3/17SIT556/JEWL	105	44	220	49/69
23PSIT2097	RU1701081/5/DMND/4/…/3/…//HPHI2	103	43	219	49/66
23PSIT2059	RU1701084/4/…//HPHI2/3/17SIT556/JEWL	102	46	219	53/67
PVL03	PVL03	102	41	193	56/69
PVL04	PVL04	103	44	187	58/68

[a] Milling yield: HR = head rice and TR = total rice.

Grain Quality Improvement under High Nighttime Temperature Using Functional Gene Markers

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Abstract

The global rice crop production is being affected worldwide due to the increase in nighttime temperature caused by climate change. The rice (*Oryza sativa* L.) crop is vulnerable to increased nighttime temperatures (HNT), especially during the grain-filling stage, which leads to a decline in grain quality. For several years, there has been major concern by rice growers and industry regarding the prevalence of grain chalk and the reduction of grain dimensions affected by HNT stress. Therefore, improving heat stress tolerance for rice grain quality will increase market rice value. In this study, 185 F_5 recombinant inbred lines (RILs) derived from two U.S. rice cultivars, Cypress (HNT-tolerant) and LaGrue (HNT-sensitive) were screened for percent chalkiness (%chalk) under control and HNT stress conditions. The aim was to identify the genomic regions that are linked to grain quality traits, specifically %chalk, under both normal and HNT stress conditions. In total, 4 QTLs under HNT on chromosomes 1, 6, 7, and 10 were identified for grain chalk with LOD values ranging from 2.61 to 4.86 and phenotypic variation (PVE) ranging from 28.76 to 51.52. A total of 213 differentially expressed (DE) genes in 4 QTL regions for developing caryopsis tissue in parents "Cypress" and "LaGrue" were mapped, with 30 potential candidate genes on different chromosomes indicating quantitative traits contribution for grain chalk. QTL 10 contains many unannotated genes that are expressed differently and have single nucleotide polymorphisms (SNPs) and the presence and absence of variation (PAV) in the Cypress parent compared to LaGrue contributing to hotspot region for grain quality improvement. The study of mapping QTLs and genetic dissection in U.S.-grown japonica rice provides insights into genetic differences, assisting rice breeders and geneticists in comprehending the genetic mechanism of grain chalkiness under HNT.

Introduction

Rice (*Oryza sativa* L.), a staple crop, provides 35–60% of the dietary calories for three billion people and contributes to food security and sustainability in Asia, the Americas, and Africa (Fageria et al., 2016). To meet the demands of an increasing world population, rice breeders and geneticists have been working on developing high-yielding rice varieties and improving grain quality. A study conducted by Shi et al. revealed that specific rice genotypes were more susceptible to chalkiness, changed amylose concentration, and decreased head rice yield and grain quality when subjected to high nighttime temperature (HNT) stress. The amount of amylose is less under HNT stress (16.1%) compared to control nighttime temperature conditions (19.1%), indicating that chalk formation could be influenced by a decreased rate of amylose synthesis. Chalky grains have opaque spots in the endosperm varied in size on the dorsal side (white belly) or in the middle (white core), causing rice grain quality differences. Multiple studies have documented that HNT stress impacts physiochemical characteristics, leading to increased chalk production, reduced amylose content, and smaller grain size (Muttayya et al., 2014), including flour protein variations, enzyme activity changes, and poor rice grain starch packing.

The chalkiness trait has been linked to more than 100 quantitative (QTLs), including 30 QTLs for the percentage of grain that contains white core (PGWC) and 26 QTLs for the degree of endosperm chalkiness (DEC: %chalk), 12 QTLs for the area of endosperm chalkiness (AEC), 11 QTLs for white-backed kernel, and 3 QTLs for basal white (BW), all distributed across 12 chromosomes and cataloged in the Gramene database (Sreenivasulu et al., 2015). As HNT stress significantly degrades rice grain quality, limited research has identified a few QTLs/loci related to chalkiness under heat stress worldwide (Wada et al., 2015).

Grain quality traits are polygenic quantitative traits (Sreenivasulu et al., 2015). Recent revolutionary genomic advances—QTL mapping employing bi-parental recombinant inbred lines (RILs) and genome-wide association studies (GWAS) on various populations—can resolve complex trait genetic architecture. The genetic underpinnings of grain quality in the presence of heat stress remain poorly comprehended. The primary objective is to examine and establish connections between the genetic and environmental factors that influence quantitative trait loci in response to stress. This will be achieved through the utilization of modern genetic tools and extensive omics datasets, including genomic and transcriptome data, and will facilitate the advancement of genomics-assisted breeding.

The genetic loci regulating grain quality traits and HNT stress resistance in tropical japonica rice were examined in the RIL population of two U.S. rice cultivars, "Cypress" and "LaGrue"

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under HNT stress. The study includes screening and evaluating RIL populations with both parents for grain quality traits (% chalk) under HNT stress to identify QTLs with SNP markers using Inclusive Composite Interval Mapping (IM-Add and IM-EPI) (Kumar et al., 2023). The current study uses transcriptomics to discover potential genes for grain quality attributes under HNT stress tolerance, further extrapolating the QTL regions derived from the Kumar et al. studies. The identification of differentially expressed candidate genes and non-synonymous (SNPs) and the (PAV) in the genomic sequence of these genes confirms the presence of candidate genes on the chromosomes that could contribute to HNT tolerance for grain quality.

Procedures

Plant Materials and HNT Stress Conditions

The "MY2" population consists of 185 F5-derived bulk recombinant inbred lines (RILs) at the F_{12} generation. These RILs were developed by crossing two U.S. long-grain rice types, "Cypress" and "LaGrue." The development of this population was undertaken as a component of the RiceCap project. LaGrue is susceptible to heat stress and shows poor grain quality (high chalkiness) when subjected to HNT stress, whereas Cypress is tolerant to heat stress and maintains good grain quality (low chalkiness) (Lanning et al., 2012). The MY2 RIL population was originally obtained from the USDA ARS Dale Bumpers National Rice Research Center, Stuttgart, Ark., and each line was purified using a single plant (F_{10}) and further rederived from a single panicle in the 2016 field trial at H. Rouse Cafey Rice Research Station, Louisiana State University Agricultural Center, Rayne, La.

HNT Phenotyping and Data Analysis

Each RIL and both parents were tagged with three main panicles/plants from 6 plants at the grain-filling stage (R5), as described by Counce et al., 2012. Three plants with tagged panicles were then moved to HNT stress treatment at 86 °F (30 °C)/ 82.4 °F (28 °C) for 10 h (20:00–6:00), while the other three plants were treated as control until harvest maturity (approximately 18–20% grain moisture content). The phenotype data was analyzed using R statistical packages v. 4.1.0 and JMP Genomics Pro 12.0. An analysis of variance (ANOVA) was performed with a statistical model that comprised RIL, treatment (control and HNT stress), and their interactions (Kumar et al., 2023). Tukey's honestly significant difference (HSD) test was used to compare the means of treatments among all the RILs for significant effects (Tukey's HSD, $P < 0.05$) using the HSD function in R packages and JMP version 12, as Tukey's HSD can determine slight differences between the means (Kumar et al., 2023).

Genotyping and Construction of Genetic Map

The MY2 RIL population with both parents was genotyped using the 1K Agriplex platform on single plants that were rederived from single panicles in the field trial in collaboration with Adam Famoso (H. Rouse Cafey Rice Research Station, La.). In addition, allele-specific primer (KASP) data was designed to genotype the RIL population. For genotyping of the MY2 RIL population, DNA was extracted from the young leaf tissue of each individual plant of each RIL using a modified CTAB method, and KASP assays were designed by LGC genomics. After removing the SNPs that were monomorphic, heterozygous, and had more than 30% of their data missing, a collection of 1178 (1042 SNPs + 136 KASP) was chosen to conduct additional genetic analysis. Using logarithms of the odds (LOD) threshold values, binned markers were grouped to create 12 linkage groups, which correspond to the rice chromosomes. The RECORD (Recombination Counting and ORDering) method ordered 1178 SNP markers across 12 chromosomes in linkage groups. Kosambi mapping converted marker recombination frequencies into cM. MapChart 2.0 was used to generate the physical map containing 1178 SNP markers and their placements (IRGSPv1.0: http://rice.uga.edu/).

Quantitative Trait Loci (QTL) Analysis

The QTL analysis for the grain chalkiness trait was conducted using IciMapping v. 4.2 software with the BIP feature (https://www.isbreeding.net/) in the MY2 RIL population. The LOD criteria for identifying significant QTLs were determined by 1000 permutations and a Type I error rate of less than 0.05. Significant QTLs were those that explained ≥10.0% of the phenotypic variance with LOD ≥2.5. The rice chromosome QTLs were graphically represented using the MapChart v2.0 program.

Characterization of the QTLs regions and Identification of Candidate Genes and Functions Using Transcriptome and Genomic Analyses

We identified candidate genes involved in % chalk under HNT by integrating genomic QTLs and expression QTL (eQTL) analyses of both Cypress and LaGrue. RNA-Seq data from caryopsis tissues at R6 stage (milky endosperm) under control and HNT conditions with three replicates were used for differential gene expression analyses using the DESeq2 R package. The differentially expressed (DE) genes were investigated using the ratio Cypress-Control (CypC) vs. LaGrue-Control (LagC) and Cypress-HNT (CypHNT) vs. LaGrue-HNT (LagHNT) in a Genotype-Treatment dependent manner. Genes with a threshold value of $|\text{Log}_2\text{fold change}| \geq 2$ and *padj* < 0.05 were assigned as DE and used for subsequent analyses.

Results and Discussion

Phenotyping of Cypress and LaGrue under Control and HNT

Among the many factors that contribute to poor grain quality in rice grain, HNT stress is one of the most harmful and primarily affects grain characteristics. Enhancing HNT stress tolerance while minimizing poor grain quality in U.S. rice cultivars is one of the evolving targets in rice breeding programs. It is extremely challenging for plant breeders to attain improvement in grain quality traits through the use of conventional breeding methods. With the application of genomics-assisted breeding and the completion of rice genome sequencing, the identification and mapping of quantitative trait loci (QTLs) for rice grain quality traits have been made possible. Phenotyping of the MY2 RIL population derived from Cypress × LaGrue cross for grain quality traits (% chalk) under HNT stress and control conditions (Fig. 1) allowed us to map and identify the genomic loci linked with grain quality traits under HNT stress response (Kumar et al., 2023). The phenotypic variance and frequency distribution for the percentage grain chalk traits distribution among the RIL population and the parents, Cypress and LaGrue, under both control and HNT stress conditions, are shown (Fig. 2a and b). Additionally, the values distribution shown in the histogram for grain chalkiness trait among the RIL population extends beyond both parents, hence showing transgressive variation under control and HNT stress conditions (Kum.

Four quantitative trait loci (QTLs) associated with the trait of % chalk were identified: q%chalk-HNT-1, q%chalk-HNT-6, q%chalk-HNT-7, and q%chalk-HNT-10. The LOD scores for these quantitative trait loci (QTLs) are 4.33, 4.86, 4.42, and 2.61, respectively. The percentage of phenotypic variance explained by each QTL is as follows: 49.87%, 51.47%, 51.53%, and 28.77%. The size of these four QTLs in cM, as well as the physical distance (in base pairs and cM) between the Left and Right Flanking Markers (location position of marker in cM and marker name), are shown in Table 1.

Genomic and Transcriptomic Characterization of the QTLs Regions and Identification of Candidate Genes for Grain Quality under HNT Stress

The QTL-wise distribution and order of these genes were also determined by a genomic scan of the ~41 Mb region spanning the 4 QTLs for grain chalk using the IRGSP 1.0 genome feature file (gff3) as a reference; we identified a total of 7117 genes in this region, of which 213 genes were significantly differentially expressed. QTL regions (*q%Chalk-HNT-1* on chromosome 1 had 34 DE genes; *q%Chalk-HNT-6* on chromosome 6 had 41DE genes, *q%Chalk-HNT-7* on chromosome 7 had 94 DE genes, and *qChalk-HNT-10* on chromosome 10 had 44 DE genes. In Cypress, a total of 31 genes were induced by HNT, in comparison to LaGrue. Some of these genes are annotated, while others are categorized as unknown hypothetical proteins. Out of these, five genes are absent in LaGrue but present in Cypress when aligned against IRGSP 1.0 genomic Fasta sequence. There are 15 genes that have SNP non-synonymous differences (Table 2). These SNPs and PAV associated with the QTL regions must contribute to HNT-induced chalkiness in LaGrue compared to Cypress (Fig. 3 and Table 2).

In QTL1 region, LOC_Os01g59410, which encodes the VQ motif controlling grain weight and grain length, and the gene LOC_Os01g62100, which encodes a conserved putative protein, showed increased expression in Cypress compared to LaGrue. Conversely, the gene LOC_Os01g55630, which is similar to Glutelin type-A 3, was shown to be downregulated in Cypress. Furthermore, the genes LOC_Os01g59420 and LOC_Os01g59420, which encode a conserved putative protein, showed a decrease in expression, possibly due to two SNPs in the coding region contributing to lower expression under HNT conditions.

In QTL6, induced genes LOC_Os06g18850 (Single SNP in LaGure) and LOC_Os06g32600 (conserved hypothetical protein and Thionin, antimicrobial peptide) showed high expression in Cypress compared to LaGrue, while LOC_Os06g33690 (Polyketide cyclase, positive regulator of ABA signally pathways) and LOC_Os06g33490 (encode conserved hypothetical protein) showed low expression in Cypress, suggesting that Cypress didn't activate the ABA pathway under heat stress and it is buffered unlike LaGrue.

Six HNT-induced genes were identified at QTL7. These genes encode conserved putative protein (LOC_Os07g20164, LOC_Os07g19410, and LOC_Os07g23390), alpha-amylase inhibitor protein, drought-tolerant Synaptotagmin-5 protein, and Prolamin precursor. Although LOC_Os07g20164 showed high expression (Log2FC >14), LOC_Os07g23390 showed significantly lower expression (Log2FC < -10) in Cypress compared to LaGrue. The genes LOC_Os07g18750 and LOC_Os07g22640 were absent in LaGure and hence showed high expression of Log2FC> 2.00 in Cypress. Compared to Cypress, LaGrue had one nucleotide change in LOC_Os07g19410 and LOC_Os10g35100, according to SNP data.

A total of sixteen genes that are responsive to HNT were discovered in QTL10. These genes comprise both putative proteins and proteins with functional annotations. All these genes displayed overexpression in the HNT condition, except for LOC_Os10g34500, which showed downregulation in Cypress compared to LaGrue. The expression of mostly hypothetical protein-encoded genes remained consistently high under control and HNT in Cypress vs. LaGrue. The gene LOC_Os10g36160 showed high expression, indicating its role as a lipid transfer protein. Among the genes that have been studied for their function, LOC_Os10g40570 is a member of the Flavin-containing monooxygenase FMO family protein and has shown the highest level of upregulation (Log2FC > 14). LOC_Os10g39470 and LOC_Os10g40250 encode a protein containing the DUF domain, and LOC_Os10g34710 encodes a protein containing the motor region domain. These genes have all shown upregulation with a Log2FC > 7 in Cypress compared to LaGure under HNT conditions. Additionally, the genes LOC_Os10g34020 (which codes for Glutathione S-transferase) and LOC_Os10g35870 (which codes for Cytochrome b5 domain containing protein) had significant expression levels in the presence of HNT conditions. The PAV results showed the absence of genes for putative protein and a nonspecific lipid transfer protein in LaGrue, which may be involved in carbohydrate storage and packing. In addition, the analysis of single nucleotide polymorphisms (SNPs) revealed that LOC_Os10g35604, LOC_Os10g34710, LOC_Os10g34020, and LOC_Os10g34500 exhibited 5, 4, 3, and 3 SNPs, respectively, in LaGrue compared to the Cypress (as shown in Table 2). The variation in expression between Cypress and LaGrue is caused by the presence or absence of specific genes. Additionally, post-transcriptional regulation of these genes may also have a role in producing translucent and high-quality grains in Cypress under HNT circumstances.

Practical Applications

This study aimed to measure the impact of HNT stress on the Cypress-LaGrue biparental population. The phenotypic screenings revealed that the MY2 RIL population, consisting of both U.S. rice cultivars as parents, exhibited significant variation in the percentage of chalk formation during high night temperature (HNT) compared to the control. This variation was shown in relation to grain quality attributes under HNT stress. Four significant QTL regions were identified from the RIL population and precisely matched with probable candidate genes by overlaying these regions with transcriptomics data from parents. SNPs and PAV, with a greater positive impact on gene expression, can be valuable in the rice breeding program. These markers can aid in the selection of favorable alleles in U.S. rice cultivars, particularly in tropical japonica rice. Additionally, they can contribute to QTL mapping and enhance our comprehension of the mechanism behind HNT tolerance in rice, offering valuable insights into genetic variations. These findings are accessible to rice breeders and geneticists, aiding the understanding of the mechanisms underlying heat stress tolerance and its impact on rice grain quality.

Acknowledgments

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Table 1. Quantitative trait loci (QTLs) with the genomic regions of 4 QTLs related to grain % chalk under control and high nighttime temperature (HNT) stress.

QTL	Chr	Position (cM)	Left Flaking Marker	Pos(cM)	Right Flaking Marker	Position (cM)	LOD	PVE%	Phy_Pos (bp)	Size(bp)	#genes
q%Chalk1	1	12	SNP1203_1203	6.5	SNP99_1	16.5	4.33	49.8735	30498826-38418739	7868Kb	1242
q%Chalk6	6	98	SNP0603_603	73.2981	SNP0640_640	107.5	4.86	51.4703	10049864-29142501	18MB	2804
q%Chalk7	7	12	SNP1163_1163	1.0959	SNP0652_652	17.5	4.42	51.5266	4001958-15703246	11MB	1670
q%Chalk10	10	70	SNP0923_923	69.5	SNP212_10	72.5	2.61	28.7753	17908351-21817967	3884Kb	624

Table 2. Quantitative trait loci (QTLs) associated with grain % chalk under control and high nighttime temperature (HNT) stress conditions in the MY2 RIL population derived from the cross of two U.S. rice cultivars (Cypress and LaGrue) showing type of mutations, SNPs, and PAV in candidate genes.

QTLs	MSU	Gene_ name	Start	End	Type pf mutation	Position	REF_ Nipponbare	ALT_ Cypress	ALT_ Lagrue	PAV_ Cypress	PAV_ Lagrue
1	LOC_Os01g59410	OsVQ4	34356640	34357450	-	-	-	-	-	1	1
1	LOC_Os01g62100		35939939	35949979	-	-	-	-	-	1	1
1	LOC_Os01g55630	OsEnS-15	32052568	32054302	synon. SNV	32052645	A	G	G	1	1
					nonsynon. SNV	32052749	G	A	A	1	1
					synon. SNV	32052762	C	A	A	1	1
					synon. SNV	32052810	G	A	A	1	1
					nonsynon. SNV	32052884	T	C	C	1	1
					nonsynon. SNV	32053026	C	G	G	1	1
1	LOC_Os01g59420		34364097	34367570	synon. SNV	34366755	A	-	G	1	1
					nonsynon. SNV	34367080	A	-	G	1	1
6	LOC_Os06g18850		10711028	10714423	synon. SNV	10712549	A	C	C	1	1
					nonsynon. SNV	10712649	T	C	C	1	1
					nonsynon. SNV	10712451	T	A	-	1	1
6	LOC_Os06g32600		18955486	18956519	-	-	-	-	-	1	1
6	LOC_Os06g33690	OsPYL/RCAR8	19604360	19606116	-	-	-	-	-	1	1
6	LOC_Os06g33490	OsEnS-89/OsPYL13	19508718	19511234	-	-	-	-	-	1	1
7	LOC_Os07g20164		11642552	11644280	-	-	-	-	-	1	1
7	LOC_Os07g18750	OsLTPd3	11090524	11091253	-	-	-	-	-	1	1
7	LOC_Os07g19410		11485815	11487161	synon. SNV	11486603	C	-	T	1	1

Continued

Table 2. Continued.

QTLs	MSU	Gene_ name	Start	End	Type pf mutation	Position	REF_ Nipponbare	ALT_ Cypress	ALT_ Lagrue	PAV_ Cypress	PAV_ Lagrue
7	LOC_Os07g22640	OsNTMC2T4.1	12747743	12760653	-	-	-	-	-	1	0
7	LOC_Os07g11920	Prol-22	6613136	6613762	Stop gain	6613545	G	A	A	1	1
7	LOC_Os07g23390	OsFAD2-4	13180808	13182551	nonsynon. SNV	13181978	G	-	T	1	1
10	LOC_Os10g35100		18723961	18725462	-	-	-	-	-	1	0
10	LOC_Os10g40570		21724435	21727179	synon. SNV	21726939	C	T	-	1	1
10	LOC_Os10g36260		19379767	19382017	synon. SNV	19380453	C	T	-	1	0
10	LOC_Os10g35604		19045236	19046259	nonsynon. SNV	19045440	T	-	G	1	1
					nonsynon. SNV	19045511	G	-	A	1	1
					nonsynon. SNV	19045530	T	-	C	1	1
					nonsynon. SNV	19045568	T	-	C	1	1
					stopgain	19045569	G	-	A	1	1
10	LOC_Os10g39470		21066730	21074892	-	-	-	-	0	1	1
10	LOC_Os10g34795		18579905	18580739	nonsynon. SNV	18580211	G	-	-	1	0
10	LOC_Os10g34710	OSMYOVIIIB	18532794	18539779	nonsynon. SNV	18534819	A	-	G	1	1
					synon. SNV	18538311	A	-	G	1	1
					nonsynon. SNV	18538754	C	-	T	1	1
					synon. SNV	18539265	C	-	T	1	1
10	LOC_Os10g40250		21558186	21563384	-	-	-	-	-	1	1
10	LOC_Os10g36160	OsLTP2.11	19330390	19330970	nonsynon. SNV	19330694	G	-	-	1	0
10	LOC_Os10g35870	OsMSBP2	19171760	19174055	-	-	-	-	-	1	1
10	LOC_Os10g34020	OsGSTU47	18145792	18149595	nonsynon. SNV	18146069	C	-	G	1	1
					nonsynon. SNV	18146137	G	-	A	1	1
					synon. SNV	18149236	T	-	A	1	1
10	LOC_Os10g37870		20278007	20278573	-	-	-	-	-	1	1
10	LOC_Os10g36340		19413262	19414196	synon. SNV	19413274	A	-	-	1	0
10	LOC_Os10g34670		18475042	18484780	-	-	-	-	-	1	1
10	LOC_Os10g37860		20271867	20272423	-	-	-	-	-	1	1
10	LOC_Os10g34500		18403982	18404841	nonsynon. SNV	18404303	C	-	G	1	1
					nonsynon. SNV	18404519	G	-	C	1	1
					nonsynon. SNV	18404528	C	-	A	1	1

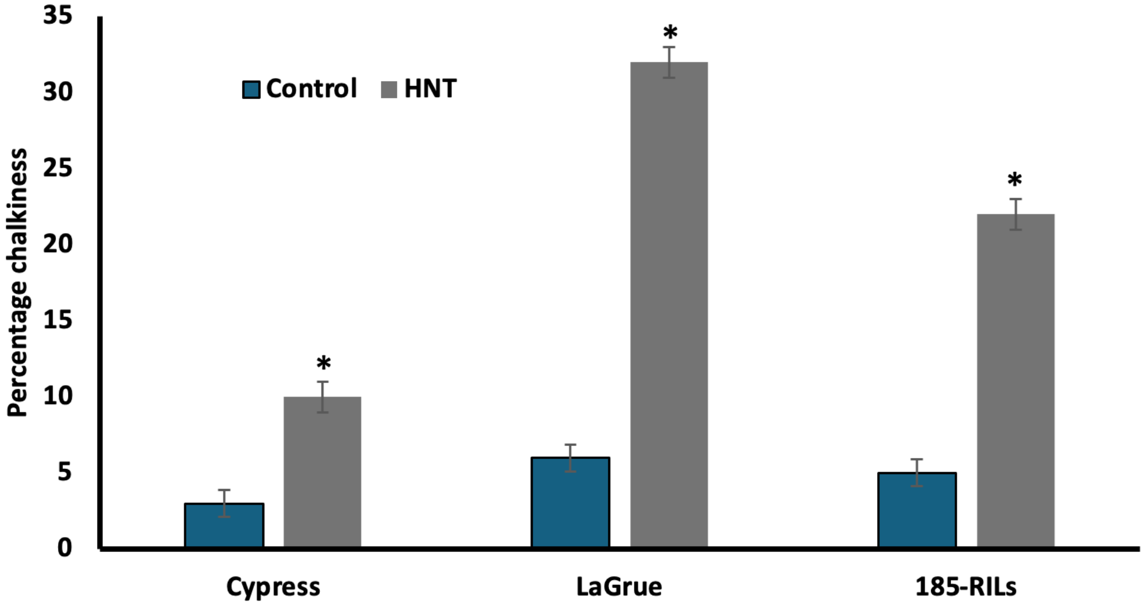

Fig. 1. Bar plots showing the phenotypic variation in percent chalkiness in 185-MY2 RIL population with both parents, "Cypress and LaGrue," under high nighttime temperature (HNT) stress condition compared to the control condition. The significance level (*) *P* < 0.05 indicates that the chalk % under HNT is statistically significant as compared to the control condition.

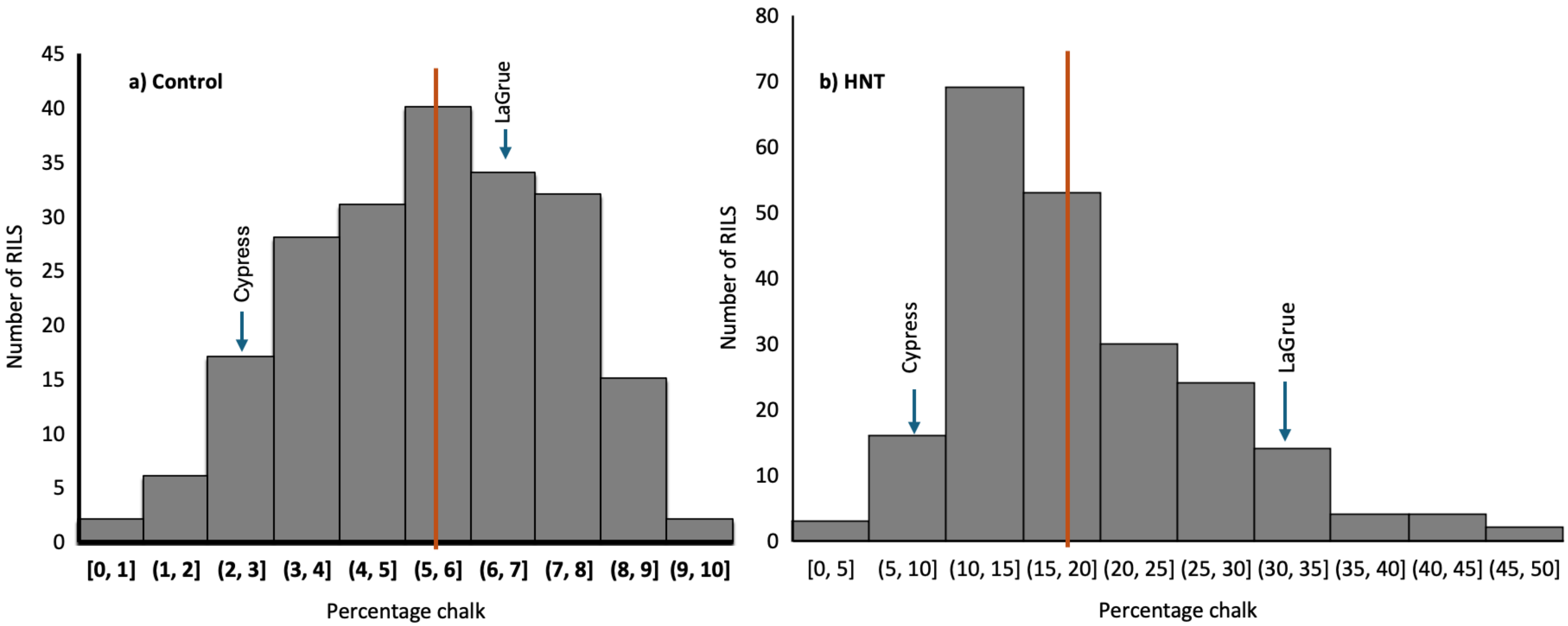

Fig. 2. Frequency distribution showing a broad range of variation for percent chalkiness and response to control (a) and HNT stress (b). The vertical line (red) indicates the mean of the recombinant inbred lines (RIL) population. Arrows show the mean of both parents "Cypress and LaGrue."

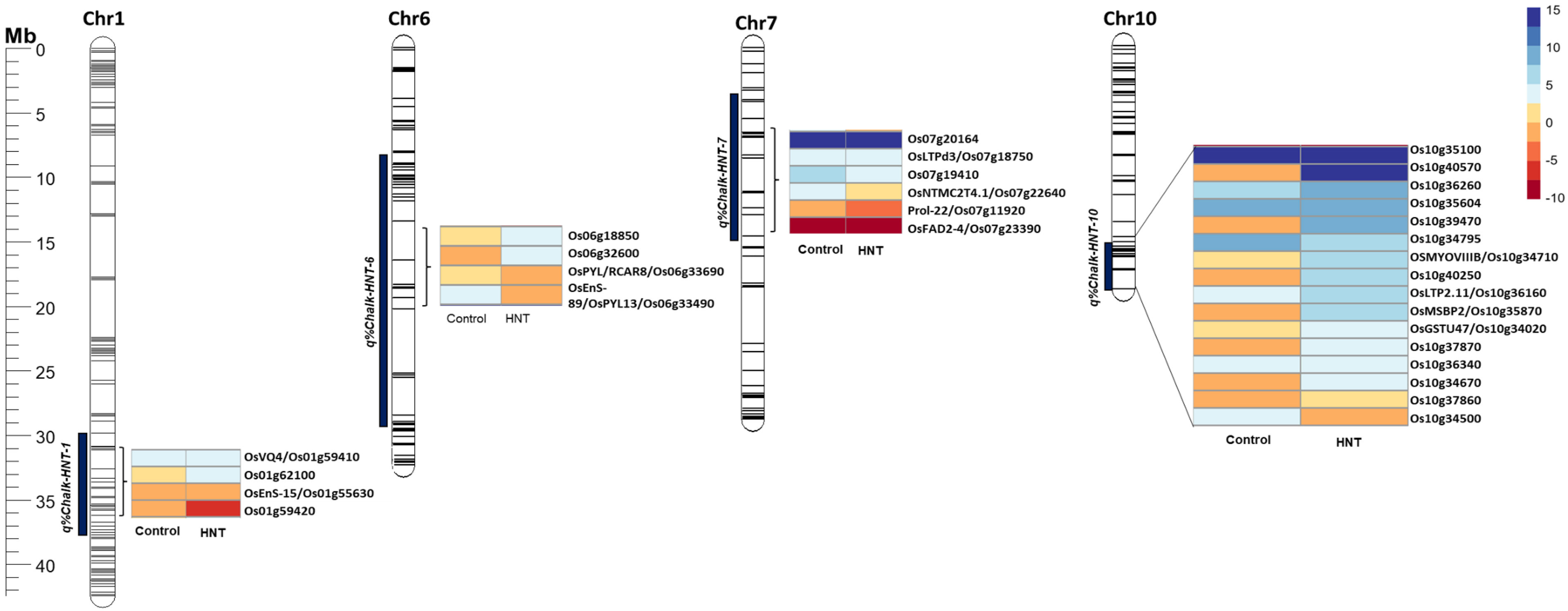

Fig. 3. Graphic representation of molecular mapping of quantitative trait loci (QTLs) for grain chalkiness traits with the physical position of potential candidate genes on rice chromosomes in the MY2 RIL population identified by ICIM mapping.

Monitor Fungicide Resistance of Rice Sheath Blight to Maximize the Efficacy of Management Decisions to Reduce Yield Losses

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Abstract

Sheath blight, caused by *Rhizoctonia solani*, poses a significant threat to rice production, particularly in Arkansas's conducive warm and humid climate. This study aimed to assess the efficacy of Azoxystrobin (Quadris®) against *R. solani* isolates collected from rice fields across Arkansas, given the concerns raised by growers that applied fungicides do not seem to be controlling the disease. A collaborative effort between Arkansas county agents and the University of Arkansas System Division of Agriculture's Plant Pathology and Extension Program facilitated the collection and isolation of *R. solani* from affected rice fields during the 2023 growing season. Molecular techniques were employed to identify and classify the isolates, all of which belonged to the AG1-IA anastomosis group. Fungicide resistance assays revealed variable sensitivity among the isolates, with some demonstrating reduced susceptibility to Azoxystrobin, indicating potential resistance issues. This study highlights the importance of ongoing monitoring for fungicide resistance and provides valuable insights for the development of integrated disease management strategies. It underscores the critical need for judicious fungicide use and the adoption of resistance management practices to ensure the sustainable production of rice in Arkansas. The collaboration between researchers, extension agents, and rice producers is pivotal in addressing the challenges posed by sheath blight and in safeguarding the rice industry from significant economic losses.

Introduction

During the rice crop growing season, sheath blight, attributed to the fungus *Rhizoctonia solani*, emerges as a notable disease with an economic impact on rice production worldwide. This is especially true in regions with warm and humid climates, where conditions foster the proliferation of the fungus. In Arkansas, summer months provide an ideal environment for the development and spread of sheath blight, often resulting in substantial yield losses when susceptible cultivars are grown without adequate disease control measures (Wamishe et al., 2020). Among the control management options available for sheath blight, fungicide application is adopted by many producers. There are few fungicides available for managing sheath blight in rice, including Azoxystrobin, a broad-spectrum fungicide belonging to the strobilurin group (Hardke et al., 2024). These fungicides may be applied preventively or curatively depending on the severity of the disease and the growth stage of the crop. Whenever fungicides are used, not only should the labeled rate be followed, but the applicator should also consider factors of resistance management, application timing, and potential environmental impacts (Groth, 2005). In recent years, Arkansas growers have started to notice that some of the fungicides they are using no longer provide the disease control of the past. Given the importance of responsible fungicide use to prevent resistance and provide environmental stewardship, our primary objective was to map sheath blight resistance in Arkansas to commonly used fungicides in rice fields, particularly focusing on azoxystrobin as the active ingredient.

Procedures

Sampling Rice Plants with Sheath Blight Symptoms to Obtain *Rhizoctonia solani* Isolates

In Arkansas, the quest to isolate *Rhizoctonia solani* from rice fields is a collaborative effort between county agents and the Rice Crop Care Plant Pathology Program laboratory. County agents diligently record the location of the field when plant samples suspected of having sheath blight are collected. These samples from across the state could provide vital insights into the prevalence and distribution of the pathogen. For each sample that arrived at the laboratory at Rice Crop Care, expert researchers employ isolation techniques to identify and characterize *Rhizoctonia solani* isolates. This collaborative process underscores a proactive approach to safeguarding Arkansas's rice industry against the detrimental impacts of plant pathogens, ensuring the resilience and productivity of rice fields throughout the region.

Molecular Identification and Classification of *Rhizoctonia* sp. Isolates

To identify and classify the isolates of *Rhizoctonia*, the DNA extraction was performed using mycelium from 1-2 weeks old cultures from each fungal isolate. The ITS (Internal Transcribed Spacer) region refers to the non-coding DNA sequence found between the small subunit (18S) and large subunit (28S) ribosomal RNA genes in eukaryotic organisms. This region of the genome was amplified using the primers ITS1F and ITS4 (Gónzalez et al., 2016). Amplicons

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were cleaned up and sequenced at the Research Technology Support Facility at Michigan State University by Sanger sequencing.

Fungicide Resistance Assay

The sensitivity of isolates to Azoxystrobin (Quadris®) was conducted using amended media with various concentrations of the fungicide, ranging from the commercial product concentration 22900 ppm to 10 ppm, 1 ppm, 0.1 ppm, 0.01 ppm, and 0.001 ppm. Untreated media was used as controls (media without fungicide). Plates were incubated at 25 °C, and daily measurements of mycelial growth were taken to assess the isolates' growth rates. After four days, the EC50 was determined based on the final measurements. The Effective Concentration 50% (EC50) for a fungal isolate refers to the fungicide concentration at which 50% inhibition of fungal growth is observed. In other words, it represents the fungicide concentration required to achieve half of the maximum inhibitory effect against the fungal isolate being tested. Determining the EC50 involves building a dose-response curve where the fungicide concentration is plotted against the percentage of inhibition of fungal growth (Lunos, 2016). The concentration at which the inhibition reaches 50% corresponds to the EC50. The EC50 value provides valuable information about the sensitivity of the fungal isolate to the fungicide being tested. Lower EC50 values indicate greater sensitivity, while higher values suggest reduced sensitivity or potential resistance of the fungal isolate to the fungicide. In fungicide resistance assays, calculating the EC50 helps researchers and agricultural professionals understand the effectiveness of different fungicides against specific fungal isolates and determine appropriate concentrations for disease management strategies.

Results and Discussion

Thirty-nine samples were collected from symptomatic plants in 12 Arkansas counties during the 2023 rice season. One soybean sample with aerial blight symptoms caused by *R. solani* was also collected, and the pathogen was isolated from soybean symptomatic tissues and tested in this study as well. From those 39 samples, a total of 17 isolates were obtained and subjected to molecular testing to confirm the anastomoses group of the *R. solani* isolates (Table 1). They were all identified as AG1-IA group. After the molecular characterization, all the isolates were subjected to fungicide resistance bioassay in laboratory conditions. The isolates, PP058, PP064, and PP071, collected from Jefferson, Miller, and Arkansas counties, displayed lower sensitivity to the Azoxystrobin (Quadris®) fungicide (Fig. 1).

The remaining isolates exhibited sensitivity to Azoxystrobin, which effectively controlled mycelial growth compared to the water-mock-control. Among the sensitive isolates, PP060, PP061, and PP065 were the most sensitive to the fungicide tested (Fig. 1). The results of the fungicide resistance assay conducted on *R. solani* isolates collected from rice and soybean crops in Arkansas during the 2023 season provide valuable insights into the dynamics of sheath blight resistance in the region. Among the 39 rice samples collected from 12 counties, all isolates were identified as *R. solani* of the AG1-IA group anastomoses, indicating low variability of group anastomoses presence in Arkansas rice fields.

The isolate PP070, from a soybean sample with aerial blight symptoms, underscores the versatility of the pathogen and its potential impact on multiple crops within the region. Notably, the fungicide resistance assay revealed distinct sensitivity profiles among the *R. solani* isolates, with isolates from Jefferson, Miller, and Arkansas counties displaying lower sensitivity to the fungicide than isolates from Clay and Lafayette counties. Conversely, isolates from Clay and Lafayette counties exhibited higher sensitivity to the fungicide and effectively controlled mycelial growth. These results highlight the variability in fungicide response among *R. solani* populations currently present in Arkansas rice-growing fields.

These findings underscore the importance of continued monitoring and surveillance of Azoxystrobin resistance sheath blight isolates in Arkansas rice fields. Researchers can further elucidate resistance patterns and inform targeted disease management strategies by sampling rice fields in the upcoming 2024 season and monitoring disease response to fungicides. Understanding the factors contributing to fungicide resistance, such as geographical variability and pathogen dynamics, is crucial for developing effective control measures and preserving the long-term sustainability of rice production in the state. Moreover, including soybean samples in the surveillance efforts emphasizes the need for integrated disease management approaches that address the potential cross-host spread of *R. solani* during crop rotation practices. Overall, these data contribute to a comprehensive understanding of the fungicide resistance of sheath blight in Arkansas and provide valuable insights for stakeholders involved in rice and soybean production within the region.

Practical Applications

The findings from this study on sheath blight offer valuable insights and practical applications for rice farms in Arkansas. This collaborative effort between county agents and specialized laboratories in isolating *Rhizoctonia solani* underscores the importance of proactive disease management strategies. The fungicide resistance assay, mainly focused on the effectiveness of Azoxystrobin (Quadris®), highlights the importance of responsible fungicide use. By understanding the sensitivity of *Rhizoctonia* isolates to different fungicides, farmers can make informed decisions regarding fungicide selection, application timing, and dosage, thereby reducing the risk of resistance development and environmental damage. Lastly, the ongoing monitoring and sampling efforts planned for the 2024 season underscores our commitment to continual improvement and adaptation in disease management practices. By systematically mapping and monitoring disease response to fungicides, we aim to provide rice farmers with up-to-date information and recommendations for combating sheath blight effectively. In summary, our research not only enhances our understanding of fungicide resistance of sheath blight in Arkansas but also offers practical solutions and recommendations for rice farms to mitigate the impact of this economically damaging disease, ensuring the resilience and productivity of rice fields throughout the region.

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Bedoya for her contributions in conducting the molecular work to confirm the presence of *R. solani* AG-1A.

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Table 1. Details and geographic distribution of *Rhizoctonia solani* isolates collected from rice and soybean fields in Arkansas, 2023.

Number of Isolate	Lab ID	Origin ID	Host	Species identification	Anastomosis group	Arkansas County
1	PP057	sample 1	rice	*R. solani*	AG1-IA	White
2	PP058	sample 2	rice	*R. solani*	AG1-IA	Jefferson
3	PP059	sample 8	rice	*R. solani*	AG1-IA	Lincoln
4	PP060	sample 9	rice	*R. solani*	AG1-IA	Clay
5	PP061	sample 10	rice	*R. solani*	AG1-IA	Clay
6	PP062	sample 11	rice	*R. solani*	AG1-IA	Clay
7	PP063	sample 12	rice	*R. solani*	AG1-IA	Pulaski
8	PP064	sample 13	rice	*R. solani*	AG1-IA	Miller
9	PP065	sample 14	rice	*R. solani*	AG1-IA	Lafayette
10	PP066	sample 18	rice	*R. solani*	AG1-IA	Greene
11	PP067	sample 20	rice	*R. solani*	AG1-IA	Greene
12	PP068	sample 21	rice	*R. solani*	AG1-IA	Lawrence
13	PP069	sample 22	rice	*R. solani*	AG1-IA	Drew
14	PP070	sample 31	soybean	*R. solani*	AG1-IA	Drew
15	PP071	sample 5	rice	*R. solani*	AG1-IA	Arkansas
16	PP072	sample 29	rice	*R. solani*	AG1-IA	Desha
17	PP073	sample 30	rice	*R. solani*	AG1-IA	Desha

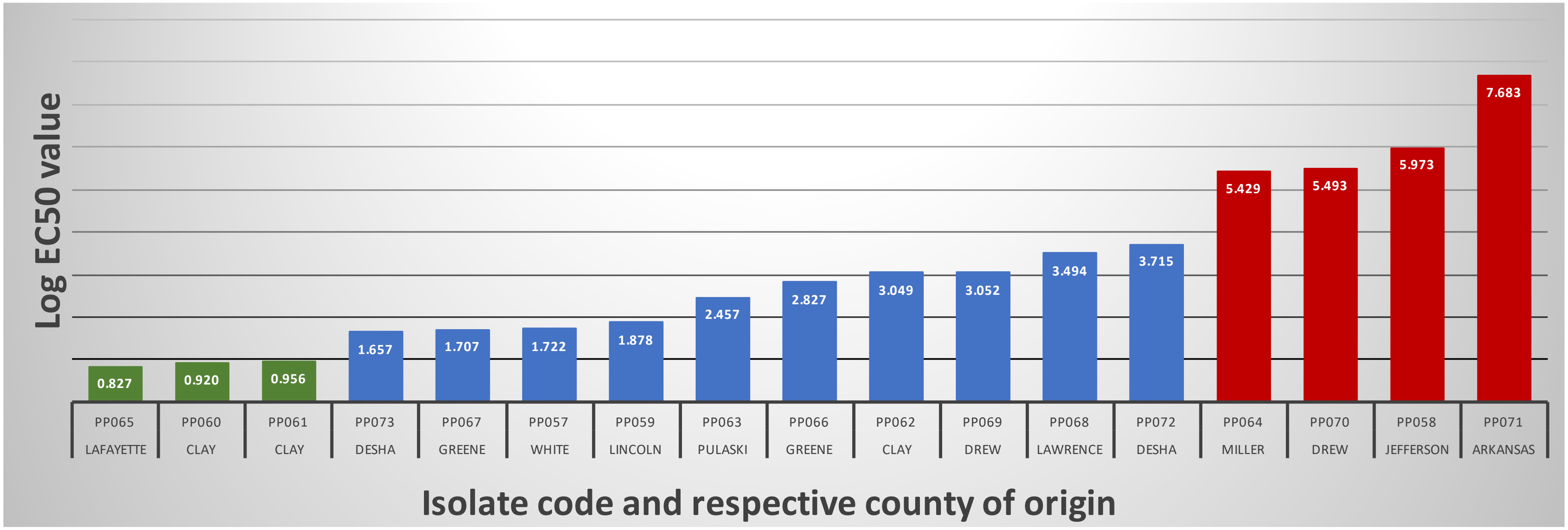

Fig. 1. Sensitivity of *Rhizoctonia solani* isolates to Azoxystrobin (Quadris®) across different Arkansas Counties during the 2023 rice growing season.

Rice Breeding and Pathology Technical Support

J. Stalter,[1] S.B. Belmar,[1] B. Ronning,[1] R. Pedrozo,[2] C.T. De Guzman,[3] X. Sha,[3] J.T. Hardke,[3] and C. Nicolli[4]

Abstract

Collaboration between pathologists and rice breeders is pivotal for developing rice varieties with desired agronomic traits and disease resistance. Rice blast and sheath blight, caused by *Magnaporthe grisea* and *Rhizoctonia solani*, respectively, pose significant threats to rice production. At the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), assessments are conducted to evaluate resistance levels against these diseases. Greenhouse evaluations focus on leaf blast resistance using different *Magnaporthe grisea* races, while field assessments target sheath blight and neck blast. Results show promising levels of resistance in breeding lines, with approximately 70% showing resistance to leaf blast and 80% showing tolerance to sheath blight. Further refinement of evaluation methodologies is ongoing to enhance accuracy. The collaboration between pathologists and breeders has facilitated applied research and supported breeding programs to develop disease-resistant rice varieties, ultimately contributing to sustainable rice production.

Introduction

Collaboration between pathologists and rice breeders is crucial in the development of rice varieties with desirable agronomic traits and resistance to diseases. Disease evaluation begins early in the plant selection process and is essential for the success of breeding programs. Lines showing potential disease resistance, even if they do not meet desired agronomic standards for release, can serve as parents for developing new varieties. Rice blast, caused by *Magnaporthe grisea* (T.T. Herbert) M.E. Barr, and sheath blight, caused by *Rhizoctonia solani* Kühn, remain significant threats during severe disease years, resulting in substantial yield losses.

Therefore, at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) in Stuttgart, Arkansas, the Plant Pathology Program conducts assessments to determine resistance levels against leaf and neck blast as well as sheath blight for all advanced breeding lines and selected preliminary breeding lines (Belmar et al., 2023). This includes evaluations in controlled environments such as greenhouses (early stage) for leaf blast, where precise conditions can be maintained. Additionally, field assessments involve both artificial inoculations, allowing for targeted testing, such as neck blast and sheath blight, and natural infection scenarios to mimic real-world conditions. These diverse evaluation methods cater to different goals, ensuring a thorough understanding of the plant's resistance across a spectrum of environments and challenges. The following section will detail the tests carried out in the greenhouse and in the field using artificial inoculation.

Procedures

Assessment of Breeding Materials for Blast Resistance in the Greenhouse

Entries of Uniform Regional Rice Nursery (URRN), Arkansas Rice Variety Advancement Trials (ARVAT), the Advanced Yield Trials (AYT) for Long Grain (LG), Clearfield (CL), Aromatics (Aro), and Provisia (PV), and the Preliminary Yield Trial (PYT) for Long Grain (LG), Clearfield (CL), High Night Temperature (HNT) and additional checks of susceptibility and resistance varieties were evaluated for resistance to leaf blast. Tests were replicated to generate three disease observations per entry to ensure the quality of data. URRN and ARVAT tests were individually assessed with individual spore suspensions of *M. grisea* races: IB-1, IB-17, IB-49, IC-17, and IE-1K. All AYT and PYT tests were sprayed with a mixture of IB-1, IB-17, IB-49, and IC-17 races, while the IE-1K race was tested separately due to its aggressiveness in producing large and elongated lesions on the leaves. Disease ratings were collected 10 days post-infection using the leaf blast disease severity rating scale (Table 1). The scale ranges from 0, indicating healthy tissue, to 9, representing elongated necrotic tissue. Additionally, the incidence (%) of plants with lesion coverage was assessed.

Assessment of Breeding Materials for Sheath Blight and Neck Blast in the Field

Entries of URRN, ARVAT, the AYT for Long Grain, Clearfield, Aromatics, and Provisia, and the PYT for Long Grain, Clearfield, High Night Temperature and additional checks of susceptibility and resistance varieties were evaluated for resistance to neck blast and sheath blight in the field.

The sheath blight nursery, located at the RREC, was planted on 30 May 2023, and five replications were planted to establish 2,425 hill plots. On 20 July, plants (at panicle initiation stage) were inoculated with growing pathogenic *Rhizoctonia solani* isolates at the rate of 24g (~1 oz) per 6 hill plot rows. About 6 weeks later, vertical disease progress was visually scored in proportion to the height of each entry using a 0 to 9 sheath blight scale (Table 2) where 0 was no vertical disease progress and 9 showed infection of flag leaf and head.

The neck blast nursery, located at the Pine Tree Research Station (PTRS) was planted on 3 May 2023, in a secluded area with a forested

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border on three sides of the test. The study included 485 entries with 5 replicated hill plots, totaling 2,425 hill plots with checks. The nursery was planted surrounded by a mixture of susceptible lines used as a spreader to encourage spore multiplication and disease spread to adjacent rice plants. The hill plots were started as a flooded paddy, but for purposes of inoculation, they were later changed to upland conditions. Approximately 125 gallons of corn chops/rough rice media was prepared using a mixture of four of the pathogen races (IB-1, IB-17, IB-49, and IC-17), the same as those used in the greenhouse leaf blast assessment that are common to Arkansas. IE-1K was omitted since there has not been any recorded evidence of this race in St. Francis County. The nursery was inoculated 2 times over the course of the season, on 23 June and 5 July. The disease assessment was made by counting the number of panicles appearing with neck blast, when entries reached full heading.

Results and Discussion

Of the 461 experimental lines tested for leaf blast in the greenhouse with five individual races of the pathogen *Magnaporthe grisea,* 70% of the entries received scores between 0 (no disease) to 4 (small diamond-shaped lesion with ashy center), which is categorized as resistant/tolerant to leaf blast (Fig. 1). The screening for leaf blast is a crucial step in identifying the susceptibility and resistance of breeding lines. Additionally, it serves to identify entries as seed mixtures or potential segregation of resistance genes. The neck blast nursery in the field displayed zero to low disease incidence in the susceptible checks varieties, making the evaluation of these entries for neck blast in the field invalid. The inoculations in the 2024 season will be conducted using a new methodology to increase the chance of finding susceptible and resistant rice breeding lines for neck blast.

In terms of sheath blight disease screening, 481 experimental lines were assessed for resistance/tolerance, with roughly 80% of the entries classified as tolerant breeding lines to sheath blight (Fig. 2). In sheath blight screening, an average score of 6.3 or lower indicates disease progression covering approximately 60% of the plant, thus being considered tolerant to sheath blight disease.

Practical Applications

The Rice Breeding and Pathology Technical Support Group aided in the successful applied research of the extension rice pathology program. Activities were completed for all funded research programs which included field activities of rice planting to harvest; laboratory of inoculum production and preparation of two-liter chemical spray solutions for Mud Master spray equipment; and greenhouse with production of rice seedlings and inoculation with pathogenic fungal spores for leaf blast screening evaluation.

Acknowledgments

The authors extend sincere gratitude to the Arkansas rice producers for their cooperation and to the Arkansas Rice Research and Promotion Board for their unwavering support and funding. Additionally, we appreciate the assistance and continued support of the University of Arkansas System Division of Agriculture Research Stations located throughout Arkansas.

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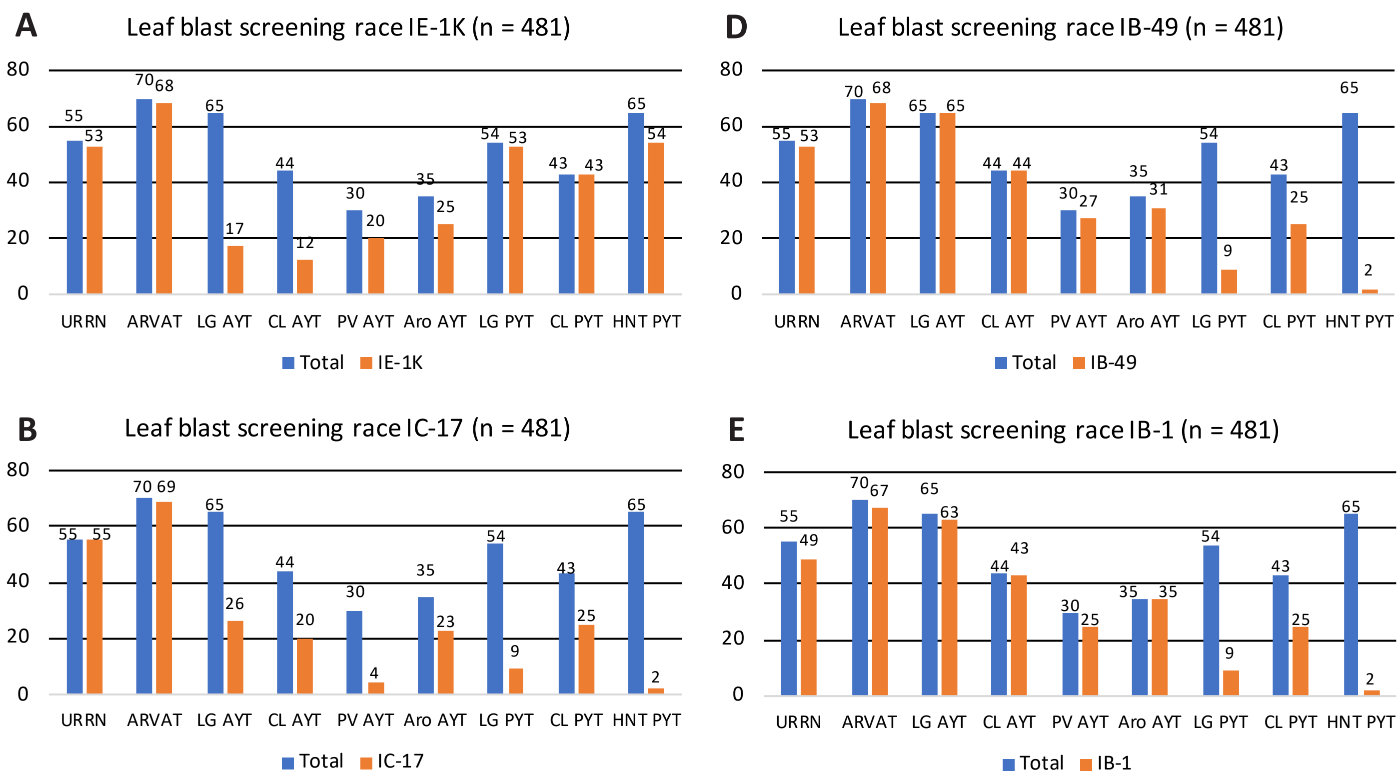
Table 1. Leaf Blast Scale (IRRI, 2013).

Scale	Description
0	No lesions observed
1	Small brown specks of pin-point size or larger brown specks without sporulating center
2	Small roundish to slightly elongated, necrotic gray spots, about 1–2 mm in diameter, with a distinct brown margin
3	Lesion type is the same as in scale 2, but a significant number of lesions are on the upper leaves
4	Typical susceptible blast lesions 3 mm or longer, infecting less than 4% of the leaf area
5	Typical blast lesions infecting 4–10% of the leaf area
6	Typical blast lesions infection 11–25% of the leaf area
7	Typical blast lesions infection 26–50% of the leaf area
8	Typical blast lesions infection 51–75% of the leaf area and many leaves are dead
9	More than 75% leaf area affected

Table 2. Sheath Blight Scale, based on relative lesion height (IRRI, 2013).

Scale	Description
0	No infection observed
1	Lesions limited to lower 20% of the plant height
3	20–30% of the plant height
5	31–45% of the plant height
7	46–65% of the plant height
9	More than 65% of the plant height



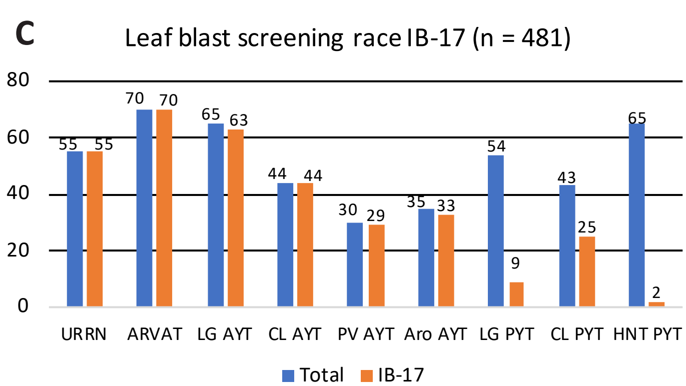


Fig. 1. Number of entries rated tolerant for 2023 greenhouse leaf blast testing. (A) leaf blast screening race IE-1K, (B) leaf blast screening race IC-17, (C) Leaf blast screening race IB-17, (D) Leaf blast screening race IB-49, (E) Leaf blast screening race IB-1. Disease severity rating scale of 0 (no disease) to 4 (small diamond-shaped lesion with ashy center). URRN = Uniform Regional Rice Nursery; ARVAT = Arkansas Variety Advancement Trial; LG AYT = Advanced Yield Trial for Long Grain; CL AYT = Advanced Yield Trial for Clearfield; Aro AYT = Advanced Yield Trial for Aromatics. LG PYT = Preliminary Yield Trial for Long Grain; CL PYT = Preliminary Yield Trial for Clearfield; HNT PYT = Preliminary Yield Trial for High Night Temperature.

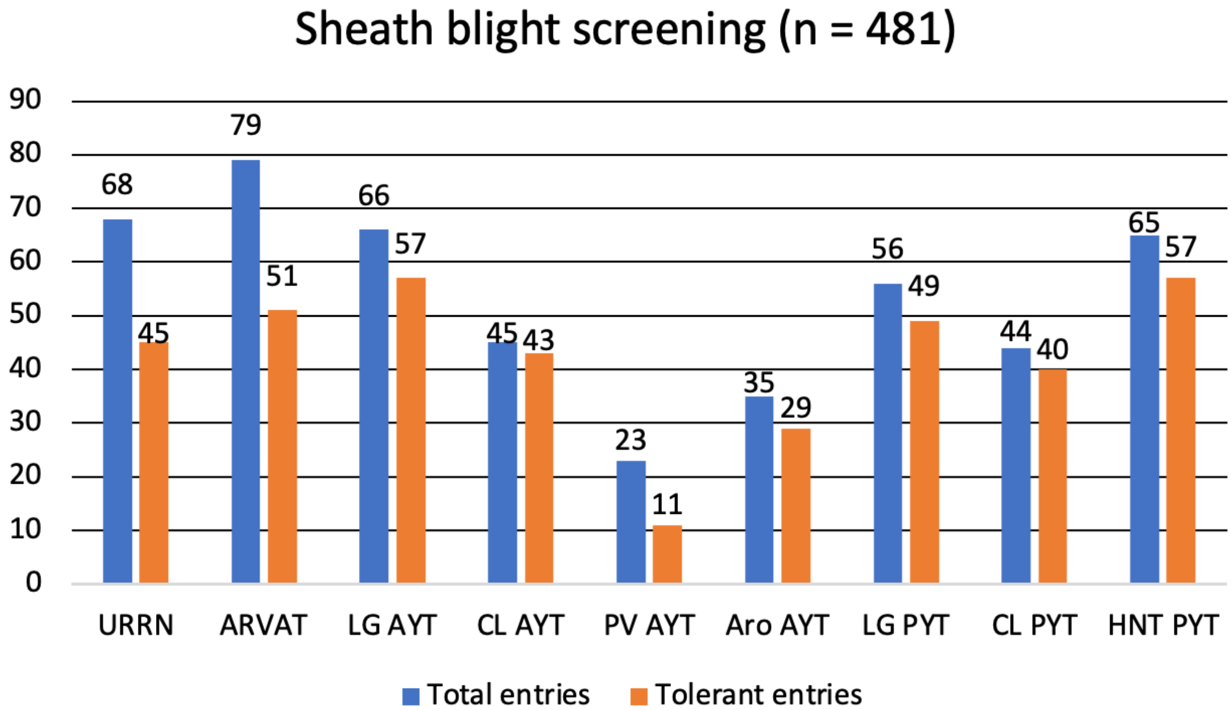


Fig. 2. The number of entries rated sheath blight tolerant in 2023 field nursery. A rating scale of 0 (no disease) to 9 (severe disease) was used. A "6" represents disease progression about 60% up the plant and is considered tolerant for average scores of 6.3 or less. URRN = Uniform Regional Rice Nursery; ARVAT = Arkansas Variety Advancement Trial; LG AYT = Advanced Yield Trial for Long Grain; CL AYT = Advanced Yield Trial for Clearfield; Aro AYT = Advanced Yield Trial for Aromatics. LG PYT = Preliminary Yield Trial for Long Grain; CL PYT = Preliminary Yield Trial for Clearfield; HNT PYT = Preliminary Yield Trial for High Night Temperature.

Impact of Rice Stink Bug on Rice Grain Quality

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Abstract

Rice stink bug (RSB) is a major pest of rice, feeding on developing grain, which can lead to yield and quality losses. Few insecticides are currently available to rice producers for rice stink bug management. Lambda-cyhalothrin (lambda) is the most common insecticide used to manage RSB due to its low cost. Over 50% of Arkansas rice acreage is treated with lambda for control of RSB annually. Other options, such as Tenchu (dinotefuran), are effective for control but not at a competitive price point. The dependency on lambda for RSB control, and control issues observed in Louisiana and Texas, raises concern for RSB resistance in Arkansas. New options for RSB need to be evaluated to determine effective alternatives to lambda. Foliar efficacy field trials were performed in 2021 and 2022 to compare insecticides for efficacy and residual control of rice stink bug. Sweep net samples were taken at 3, 7, 10, and 14 days after treatment (DAT) to monitor RSB efficacy. In general, Tenchu and either rate of Endigo ZCX performed better than Lambda-Cy, Mustang Maxx, and Malathion with respect to RSB control, peck, total rice, head rice, and return on investment.

Introduction

Rice stink bug (RSB), *Oebalus pugnax* F., is a major pest of rice in Arkansas. Rice stink bug can cause yield loss if feeding occurs during the flowering and milk growth stages, or quality loss if feeding occurs during the soft or hard dough growth stages (Swanson and Newsom, 1962). Growers in Arkansas average one insecticide application per year to manage for RSB. However, multiple applications may be warranted to keep RSB densities below threshold in very early or very late heading rice. Thresholds for RSB in Arkansas during weeks 1 and 2 after 75% heading are 5 RSB per 10 sweeps and 10 RSB per 10 sweeps during weeks 3 and 4 after 75% heading.

Limited insecticide options are currently available for RSB control (Lorenz et al., 2018). Lambda-cyhalothrin (Warrior II and generics), a pyrethroid, has been the standard for RSB control for the past 15 years. Contrary to the findings of Way and Tindall (2009), products are now available with longer residual than pyrethroid products such as Tenchu, but it is considerably more expensive ($12/ac) than lambda ($2/ac). Concerns with resistance due to the lack of chemistry rotation are still possible threats to mid-southern U.S. rice producers. The objective of this study was to compare the efficacy and residual control of insecticides for control of RSB.

Procedures

Foliar efficacy trials were conducted in 2021 and 2022 to compare multiple insecticides for efficacy and residual for RSB control, as well as the impact RSB can have on grain quality. Locations were selected when RSB densities exceeded threshold. Applications of insecticides were made with a backpack sprayer and a 12.5 ft hand boom calibrated to 10 GPA at 2.5 MPH using TeeJet flat fan nozzles. Treatments were arranged in a randomized complete block design with four replications and a plot size of 12 ft by 35 ft (Table 1). Sweep net sampling was performed at 3, 7, 10, and 14 days after treatment (DAT) by conducting 1 set of 10 sweeps per plot to monitor RSB populations. Sampling was conducted until plots reached 60% hard dough.

When plots reached harvest maturity and moisture, grain samples were collected from each plot. A 162-g rough rice sample was processed using a McGill #2 laboratory grain mill and shaker table to determine total rice (TR) and head rice (HR). Furthermore, a 100-g sample of rough rice was processed through a McGill Dehuller. After dehulling, the brown rice samples were evaluated for pecky rice. Once all grain quality samples were processed, the grade and milling yields were put into a USDA Farm Service Agency calculator to determine net returns. Yield was standardized across all plots to 166 bu./ac, based on the current state record. Return on investment was standardized as dollars over the untreated.

Results and Discussion

At 3 DAT, Endigo ZCX (both rates), Tenchu, and Carbaryl provided better control of RSB nymphs than Lambda-Cy or Mustang Maxx (Fig. 1). Similar trends were observed at 7 and 10 DAT. Also, at 14 DAT, Lambda-Cy, Mustang Maxx, and Malathion all had negative control, or more RSB nymphs than the untreated, compared to 70% or greater control for Tenchu and Endigo ZCX.

Efficacy studies focused on nymph numbers rather than adult numbers due to plot sizes being relatively small and the rest of the field not receiving an insecticide treatment. Adult RSBs migrate from field to field; therefore, selecting RSB nymphs is the most

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appropriate indicator for insecticide efficacy. Nymphs also continuously feed on rice plants due to their inability to take flight and enter surrounding fields.

In general, Tenchu and both rates of Endigo ZCX performed better than all other treatments with respect to total rice, head rice, net returns, and return on investment (Table 2). Tenchu performed better than Endigo at 5 oz for total rice yields. This was the only time there was a difference between these products. Malathion, Lambda-Cy, and Mustang Maxx had negative returns compared to all other products.

Practical Applications

Currently, pyrethroids (Lambda-Cy or Mustang Maxx) and Malathion are not suitable for rice stink bug control. If growers do choose to use these products, they need to prepare for reduced efficacy and the need for multiple applications. The current data suggest that a single application of these products will not pay for themselves. Tenchu and Endigo ZCX both performed very well in all the metrics recorded. Of these two, only Tenchu has a section 3 label. Currently, growers should consider using Tenchu as their standard RSB treatment. Labels are currently being pursued for Endigo ZCX.

Acknowledgments

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Table 1. Insecticide names, rates, and insecticide class included foliar rice stink bug efficacy studies conducted throughout Arkansas in 2021 and 2022.

Insecticide Name	Rate (oz/ac)	Active Ingredient	Insecticide Class
Lambda-Cy	3.65	Lambda-cyhalothrin	Pyrethroid
Mustang Maxx	4	Zeta-cypermethrin	Pyrethroid
Tenchu	8	Dinotefuran	Neonicotinoid
Carbaryl 4L	32	Bifenthrin	Carbamate
Malathion 57	32	Malathion	Organophosphate
Endigo ZCX	5–6	Thiamethoxan + Lambda-cyhalothrin	Neonicotinoid + Pyrethroid

Table 2. Total rice yields (TR), head rice yields (HR), net returns (Net), and return on investment (ROI) for multiple insecticides targeting rice stink bug in Arkansas from 2021 and 2022.

Insecticide Name	Rate (oz/ac)	TR	HR	Net (US$)	ROI (US$)
Untreated		67.5 d[†]	57.8 c	1177.57 cd	
Lambda-Cy	3.65	67.8 cd	58.0 c	1177.22 cd	-1.58 c
Mustang Maxx	4	67.6 d	58.2 c	1174.77 d	-2.75 c
Malathion 57	32	67.7 d	57.1 c	1171.61 d	-5.98 c
Carbaryl 4L	32	68.6 ab	59.0 ab	1158.47 bc	7.88 b
Tenchu	8	68.9 a	59.8 a	1201.83 a	24.24 a
Endigo ZCX	5	68.3 bc	58.4 a	1197.35 ab	17.33 a
Endigo ZCX	6	68.6 ab	59.0 a	1194.00 ab	16.4 ab
P-value		<0.01	<0.01	<0.01	<0.01

[†] All means followed by the same letter are not significantly different according to Fisher's protected least significant difference α = 0.05.

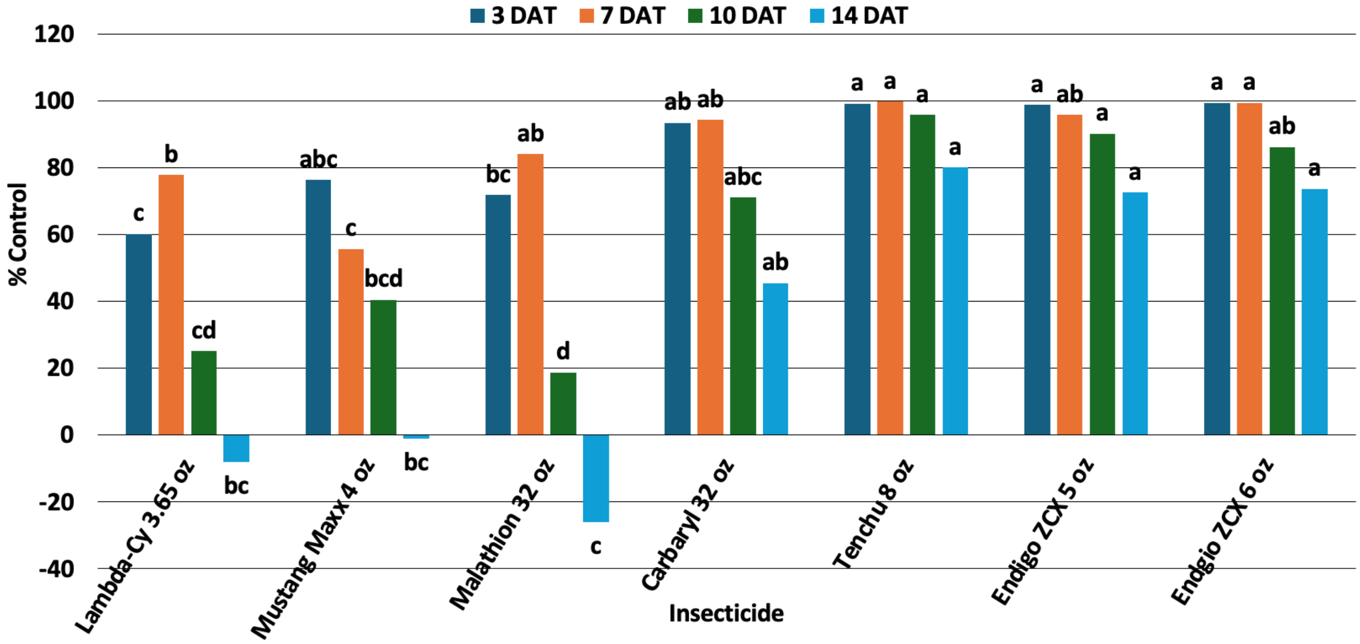

Fig. 1. Percent control of rice stink bug nymphs 3, 7, 10, and 14 days after treatment (DAT) for foliar insecticide efficacy studies conducted in 2021 and 2022 at multiple locations throughout Arkansas. All means followed by the same letter are not significantly different according to Fisher's protected least significant difference α = 0.05.

Water Management and Cultivar Strategies for Rice Water Weevil Management

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Abstract

Rice water weevils (RWW) are the most economically important insect pest of rice in the mid-South. Currently, insecticide seed treatments are the primary control tactic used to manage this pest. Other control measures, such as irrigation strategy and cultivar selection, have not been explored in recent years. Studies were conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., in 2023 to determine what impact irrigation regime and cultivar selection have on RWW densities. Higher densities of RWW were observed in the mid-May planting compared to the April planting. Generally, higher densities were also observed in hybrid cultivars as well as in alternating wetting and drying plots compared to pure-line or deep flood plots.

Introduction

In Arkansas, there are multiple soil pests that affect rice plants. Of these pests, rice water weevil (*Lissorhoptrus oryzophilus;* RWW) is the most economically important (Lorenz et al., 2018). In Arkansas, 70–80% of the total rice acres utilize insecticide seed treatments (ISTs) for RWW management. Previous research has proven that 80% of the time, an IST treatment will improve stand counts, decrease soil pest damage, and increase yields. (Taillon et al., 2016). Insecticide seed treatments provide higher efficacy and are more convenient than foliar insecticide applications as well (Taillon et al., 2013). The damaging life stage of RWW is the larval stage. The RWW larvae feed on rice roots after the flood is established, causing root pruning and, in extreme cases, plant death (Lorenz et al., 2018). While seed treatments are extremely effective and economical for RWW management, other factors such as cultivar choice and water management strategies could aid in further control of RWW. The objective of this study was to determine the impact cultivar selection and water management strategy has on RWW larvae.

Procedures

Small plot studies were conducted in 2023 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., to determine the impact cultivar selection and water management strategy have on RWW larvae. Multiple cultivars, including CLL16, Diamond, Dynagro 263, RT753, and RT7521FP, were planted on 7 April and 14 May. At each planting date, two separate plantings were made for each cultivar, one for the flooded bay and the other for the alternating wetting and drying (AWD) bay. The experimental plot design was a randomized complete block with 4 replications for each cultivar, water regime, and planting date. The plot size was 5 ft (8 rows) by 16.5 ft. The flooded bays held between 3 to 5 inches of water from flood establishment to drain timing. The AWD bays were initially flooded to a 4 in. flood, and the flood was allowed to recede to where the soil surface was still muddy but little to no standing water was present.

The RWW larvae were evaluated by taking 3 core samples per plot with a 4-in. core sampler approximately 21 days after permanent flood establishment. Samples were evaluated at the University of Arkansas System Division of Agriculture's Lonoke County Extension Center in Lonoke, Ark. Each core was washed into a 40-mesh sieve with water to loosen soil and remove larvae from the roots. The sieve was immersed in a warm, saturated saltwater solution, which caused the larvae to float for counting. Data were processed in Agriculture Research Manager v. 10, with an analysis of variance and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

Across both planting dates, a general trend was observed that plots that kept a deep flood all season had reduced RWW larvae compared to the AWD plots (Fig. 1). Additionally, The hybrid cultivars in the mid-May planting had higher RWW densities compared to the pure-line cultivars. Similar results were observed in the April planting; however, densities were closer across cultivars. Overall pressure was higher with the later planting compared to the earlier planting. In general, this data suggests that growers could decrease RWW densities with early planting, deep floods, and the use of pure-line cultivars.

Practical Applications

While water management and cultivar are not replacements for seed treatments when it comes to RWW control, they could aid in the further management of RWW. Growers should consider deep floods and pure-line cultivars for the best reduction in RWW larvae. While not applicable in all situations, where possible, this can help further increase RWW efficacy.

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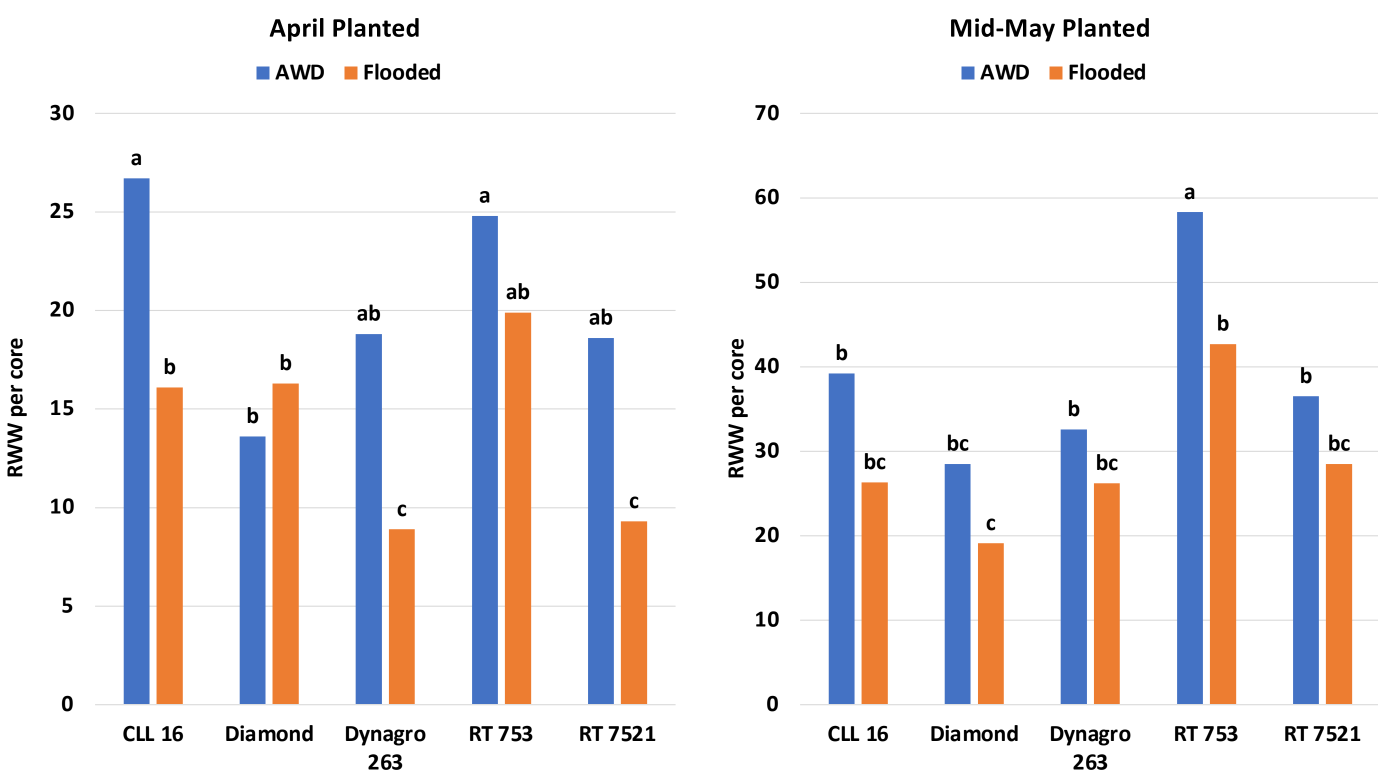

Fig. 1. Rice water weevil densities for studies conducted in 2023 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., in April and mid-May planted rice for multiple pure-line (CLL16, Diamond, and Dynagro 263) and hybrid (RT 753, RT 7521) cultivars with two different irrigation regimes (AWD-alternating wetting and drying, flooded-constant flood of 3–5 inches). All means followed by the same letter are not significantly different according to Fisher's protected least significant difference α = 0.05.

Development of Defoliation Thresholds for Hybrid and Pure-Line Rice Cultivars

S.G. Felts,[1] N.R. Bateman,[1] B.C. Thrash,[2] W.A. Plummer,[2] P.G. Maris,[3] and T. Harris[2]

Abstract

Armyworms are commonly found in rice fields in the mid-southern U.S. and have the potential to cause severe defoliation to the rice crop. Infestations can occur at all growth stages of rice. A defoliation threshold was developed in pure-line rice recently; hybrid cultivars need to be evaluated. Studies were conducted in 2023 where both pure-line and hybrid rice were mechanically defoliated at 100% with a weed eater at the two-three leaf, early tiller, late tiller, and green ring growth stages across three planting dates. Similar yield loss trends were observed at the two to three leaf and early tiller growth stages between hybrid cultivars and pure-line cultivars at all planting dates. The hybrid cultivar had less yield loss compared to the pure-line cultivar at the late tiller and green ring growth stages for May and Jun plantings. These data suggest that thresholds could potentially be increased in hybrids compared to conventional cultivars.

Introduction

Armyworms are an occasional pest of rice in the mid-South. The 2 most common species of armyworms in rice production are true armyworms (*Psuedoletia unipuncta*) and fall armyworms (*Spodoptera frugiperda*) (Lorenz et al., 2018). Infestations of armyworms can cause substantial damage to rice plants. Typically, this damage is isolated to field edges, but in some cases, large portions of fields can experience high levels of defoliation. Armyworms can infest rice at any point during the growing season. When infestations occur at early growth stages, it is common to see rice plants defoliated all the way to the soil line, or water level if the permanent flood is established. The current threshold for armyworms in rice is based on the number of larvae per square foot, which can be difficult to determine for growers and consultants. A defoliation threshold was developed in pure-line cultivars (Studebaker et al., 2023) but needs to be verified in hybrid cultivars. The objective of this study was to determine the impact of defoliation on hybrid rice yields compared to pure-line rice yields across multiple planting dates and growth stages.

Procedures

Studies were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., in 2023 to determine the impact defoliation has on rice across multiple planting dates. RT 7521 FP and Diamond were drill seeded at 22 and 70 lb/ac, respectively, on 7 April, 3 May, and 2 June. Plots were 8 rows (7.5-in. spacing) by 16.5 ft. Plots were defoliated to 100% using an electric weedeater at the 2–3 leaf, early tiller, late tiller, and green ring growth stages. Defoliations occurring at the 2 to 3 leaf growth stage were defoliated all the way to the soil line, but for all other growth stages, plants were defoliated to the water line. Plots were arranged in a randomized complete block design with 7 replications within each planting date. Data was analyzed with PROC GLIMMIX SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with an alpha level of 0.05.

Results and Discussion

For the April planting, similar levels of yield loss were observed for both the hybrid and pure-line cultivar at all timings except the green ring timing, where the hybrid cultivar had less yield loss (Fig. 1). At the May planting, the conventional cultivar had higher yields when defoliation occurred at the 2–3 leaf growth stage; however, the hybrid cultivar had higher yields when defoliation occurred at the green ring timing (Fig. 2). Higher yields were observed for the hybrid cultivar when defoliation occurred at the green ring growth stage for the June planting (Fig. 3).

Overall, trends suggest that the defoliation threshold could potentially be increased for a hybrid cultivar compared to a conventional cultivar, particularly in later plant growth stages. While trends are similar to each other in most cases, this study needs to be replicated in the future to verify that different thresholds are needed.

Practical Applications

For now, growers should use the current threshold in the MP144 for both conventional and hybrid rice; however, with further research, these recommendations may change.

Acknowledgments

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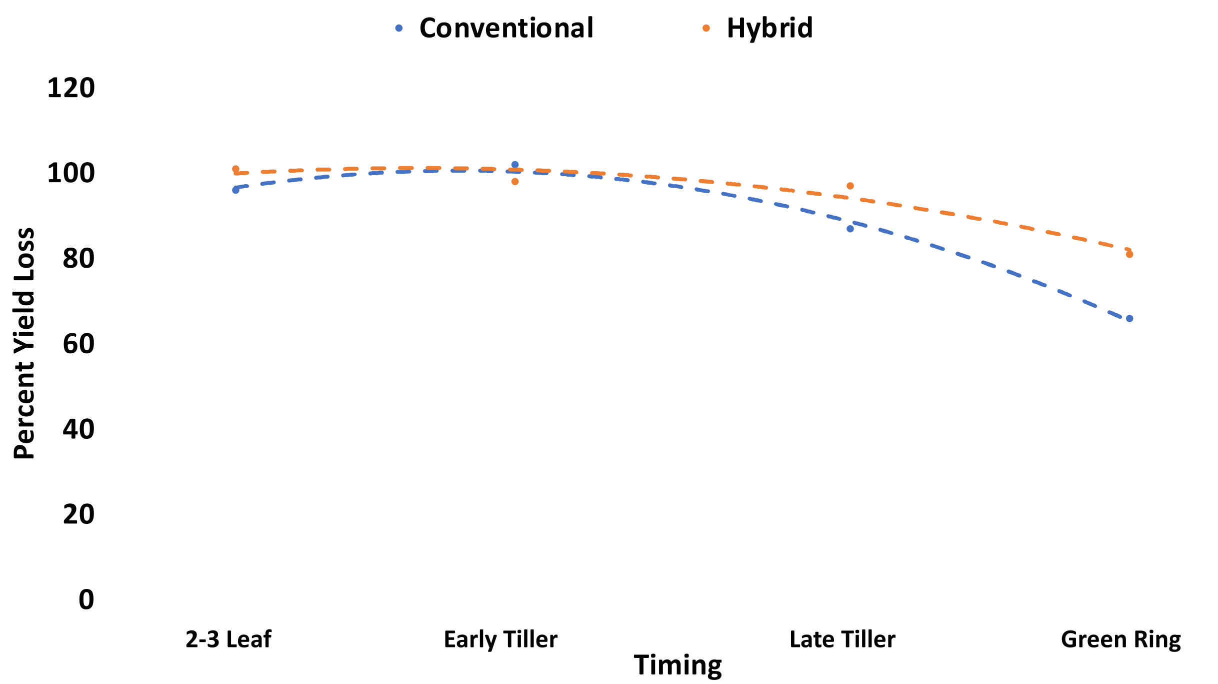

Fig. 1. Yield impacts caused by 100% defoliation at varying growth stages in a pure-line (Diamond) and hybrid (RT7521FP) cultivar for April-planted rice in 2023.

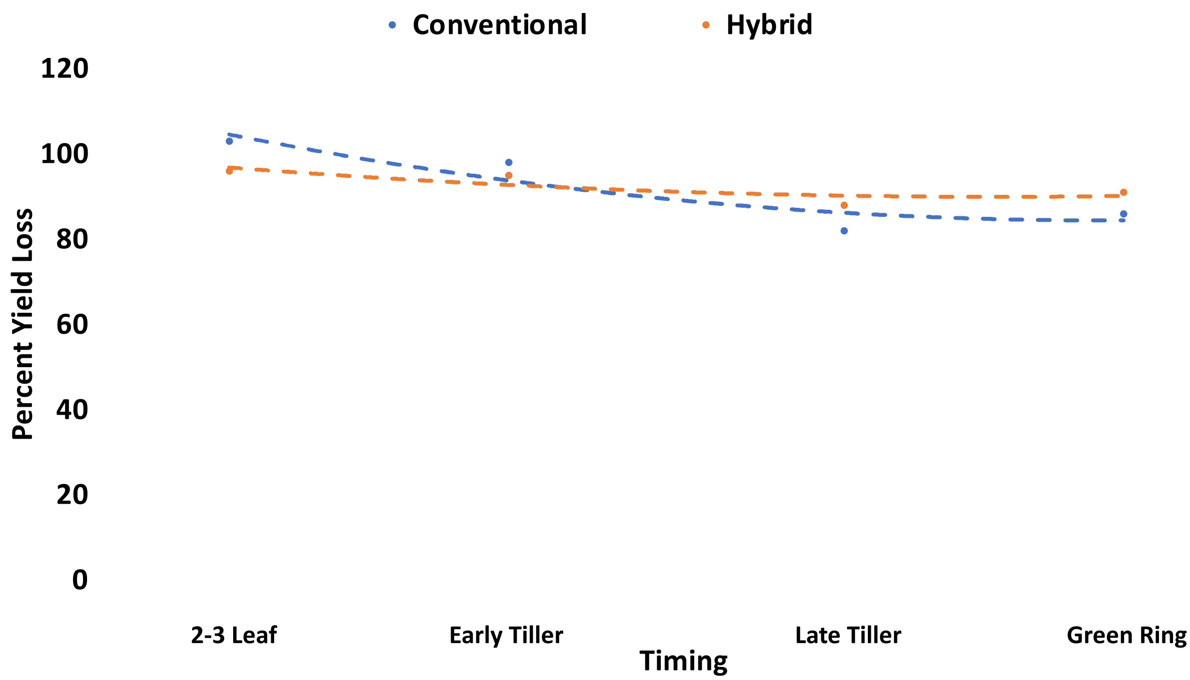

Fig. 2. Yield impacts caused by 100% of defoliation at varying growth stages in a pure-line and hybrid cultivar for May-planted rice in 2023.

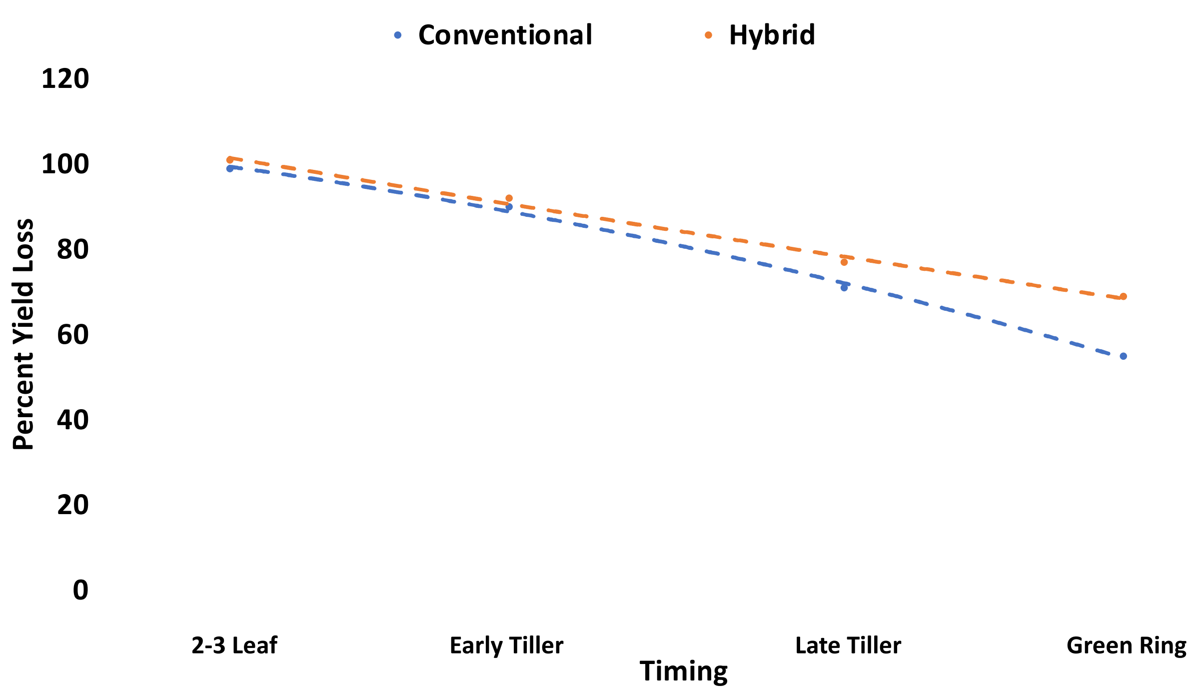

Fig. 3. Yield impacts caused by 100% of defoliation at varying growth stages in a pure-line and hybrid cultivar for June-planted rice in 2023.

Comparing CruiserMaxx Rice, Dermacor, and Warrior II Insecticide Treatments and Combinations for Control of Rice Water Weevils

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Abstract

Rice water weevil is the most economically important insect pest of flooded rice production in the southern United States. Rice water weevil larvae prune and hollow out roots, which can result in significant yield loss if not controlled. The most common method of control for rice water weevil is the use of insecticide seed treatments and foliar insecticide applications. In 2023, research was conducted at two locations to compare CruiserMaxx Rice and Dermacor X-100 seed treatments as well as foliar applications of Warrior II for management of rice water weevil in conventional and hybrid rice cultivars. All insecticide treatments reduced the number of larvae found in a soil core in hybrid and conventional rice across both locations when compared to the untreated check. Yield was increased by CruiserMaxx Rice at both locations in conventional rice. No yield differences were observed between treatments at either location in hybrid rice.

Introduction

In Arkansas, there are multiple soil insect pests in flooded rice, *Oryza sativa*. Of these pests, rice water weevils, *Lissorhoprus oryzophilus* Kuschel, are the most economically important in the southern United States (Lorenz et al., 2018). Approximately 70–80% of the total rice acres in Arkansas utilize an insecticide seed treatment (IST) for rice water weevil (RWW) control. Previous research shows that 80% of fields planted with an IST will see increased stand counts and yield (Talion et al., 2013). The damaging life stage of RWW is the larval stage, when they feed on the roots of the rice plant (Lorenz et al., 2018). Feeding by RWW larvae causes reduced water and nutrient uptake by the plant, resulting in stand reduction, reduced grain fill, and plant death.

Foliar insecticide applications target adult RWW that feed on rice foliage before mating and ovipositing in leaf sheaths (Lorenz et al., 2018). There are approximately 5–10 days after the flood is established to scout and make a foliar application before oviposition begins. In order for foliar insecticides to be effective, applications need to be made before females oviposit 7–14 days after flood (Everett and Trahan, 1967). This makes accurate scouting and good insecticide coverage highly important to avoiding larval infestations. If the preoviposition window is missed, the only effective control option for growers is to drain the field until soil cracks after larvae have hatched and moved to the root zone (Lorenz et al., 2018). This is an effective control option; however, with the added cost of fuel or electricity required to reflood the field and an application of fertilizer to replace nutrients lost during draining, this method is not economically feasible.

Diamide seed treatments such as Dermacor X-100 provide residual control for RWW up to 70–80 days after planting, and neonicotinoid treatments such as CruiserMaxx provide residual control for 28- 35 days (Taillon et al., 2018). Though neonicotinoid seed treatments have shorter residual activity, they have been proven to be effective in controlling early seedling pests such as grape colaspis (*Colaspis brunnea*) (Thrash et al., 2020). Studies have confirmed that the combination of diamide and neonicotinoid ISTs improves control of the soil-dwelling insect pest complex (Bateman et al., 2022). Though ISTs provide long-lasting and effective control for RWW, they are a proactive treatment that anticipates a larval infestation. Proactive treatments are against the principles of Integrated Pest Management. The use of foliar applications allows the grower to administer a treatment only when it is needed, saving the input cost of an IST and avoiding the possibility of making an unnecessary insecticide application. Despite these benefits, foliar applications as a primary control method are not as efficacious as ISTs. In Arkansas, due to consistently high RWW populations, it is recommended that a combination of a diamide and a neonicotinoid IST be used. In areas of heavy RWW pressure, ISTs may be overwhelmed, and a subsequent foliar insecticide application will be justified (Lorenz et al., 2018).

Procedures

Trials were conducted in 2023 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., and the Rohwer Research Station (RRS) in Rowher, Ark. The experimental plot design was a randomized complete block with four replications and plot size was 5 ft (8 rows) by 16.5 ft. RiceTec 7521FP (hybrid cultivar) and Horizon CLL16 (conventional cultivar) were planted at PTRS on 3 May and at RRS on 20 April at 20 lb/ac for the hybrid cultivar and 60 lb/ac for the conventional cultivar. Dermacor X-100 (chlorantraniliprole) seed treatment was applied at 5 oz/cwt for hybrid rice and 2.5 oz/cwt on conventional rice; CruiserMaxx (thiamethoxam) treatments were applied at 7 oz/cwt for both cultivars, and Warrior

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II (lambda-cyhalothrin) applications were made at 1.82 oz/ac. Warrior II applications were made five days after the permanent flood was established. Before the flood was applied (24 h), an 8-in.-tall barrier was placed around plots that would receive a foliar application and designated untreated control plots to eliminate insecticide wash-off during foliar application (Fig. 1). Treatments included a fungicide-only seed treatment (untreated check), fungicide-only with a barrier, Dermacor X-100, CruiserMaxx Rice, CruiserMaxx Rice plus Dermacor X-100, Warrior II, CruiserMaxx Rice plus Warrior II, Dermacor X-100 plus Warrior II, and CruiserMaxx Rice plus Dermacor X-100 plus Warrior II (Table 1).

The RWW larval populations were assessed by taking three core samples per plot with a 4 × 4 × 4 in core sampler 21 days after the permanent flood was established. Samples were evaluated at the University of Arkansas System Division of Agriculture's Lonoke Extension Center in Lonoke, Ark. Each core was washed into a 40-mesh sieve with water to loosen soil and remove larvae from the roots. The sieve was then immersed in a warm saturated saltwater solution, which causes larvae to float to the surface, where they can be counted and removed. Yield was collected in bushels/acre. Data were processed using the PROC GLIMMIX function in SAS v. 9.4 using a significance level of $P = 0.5$.

Results and Discussion

All treatments reduced the number of RWW larvae found in a soil core across both locations and cultivars. At PTRS, all treatments with an IST provided greater larval control than Warrior II except for CruiserMaxx (Table 1). The combination of CruiserMaxx plus Warrior II had greater larval control than CruiserMaxx and Warrior II used individually. Dermacor X-100 plus Warrior II and CruiserMaxx plus Dermacor X-100 plus Warrior II reduced larval populations below the threshold of 5 larvae per core. At the RRS location, all insecticide treatments and combinations had greater control of larvae compared to CruiserMaxx (Table 2). All treatments containing Dermacor X-100 provided greater control than Warrior II. CruiserMax plus Dermacor X-100, Dermacor X-100 plus Warrior, and CruiserMaxx plus Dermacor X-100 plus Warrior II reduced larval populations below the threshold of 5 larvae per core. There were no yield differences between treatments at the PTRS location (Table 1). At the RRS, CruiserMaxx was the only treatment that increased yield when compared to the untreated check (Table 2).

Overall, treatments containing Dermacor X-100 or a combination of CruiserMaxx and Warrior II provided the greatest control of RWW larvae. CruiserMaxx provided the greatest yield protection.

Practical Applications

In areas where RWW pressure is a concern, combinations of Dermacor X-100 and CruiserMaxx, along with a supplementary Warrior II application, if needed, are recommended. Dermacor X-100 provides effective and long-lasting RWW control. CruiserMaxx provides control of early seedling pests such as grape colaspis and early RWW infestations. Warrior II applications should be used in conjunction with scouting up to ten days post flood in the case of severe RWW infestations.

Acknowledgments

The authors would like to thank the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board for funding this work and the University of Arkansas System Division of Agriculture's Entomology team for their help in conducting this research.

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Table 1. Insecticide treatments, rates, the average number of larvae per core, and yield in bushels per acre in rice water weevil studies conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., in 2023.

	Cultivar Rate		RWW Larvae	
Insecticide Treatment	**RiceTec RT7521FP**	**Horizon CLL16**	**per Core**	**Yield**
				(bu./ac)
Untreated Check			13.54 A†	185.76 A
Untreated Check with Barrier			14.21 A	190.12 A
CruiserMaxx Rice	7 oz/cwt	7 oz/cwt	8.58 CB	194.91 A
Dermacor X-100	5 oz/cwt	2.5 oz/cwt	6.65 CDE	191.27 A
CruiserMaxx Rice + Dermacor X-100	7 oz/cwt + 5 oz/cwt	7 oz/cwt + 2.5 oz/cwt	7 CD	193.35 A
Warrior II	1.8 oz/ ac	1.82 oz/ac	9.31 B	194.39 A
CruiserMaxx Rice + Warrior II	7 oz/cwt + 1.8 oz/ac	7 oz/cwt + 1.8 oz/ac	6.17 DE	191.85 A
Dermacor X-100 + Warrior II	5 oz/cwt + 1.8 oz/ac	2.5 oz/cwt + 1.8 oz/ac	4.45 E	193.84 A
CruiserMaxx Rice + Dermacor X-100 + Warrior II0	7 oz/cwt + 5 oz/cwt + 1.8 oz/ac	7 oz/cwt + 2.5 oz/cwt + 1.8 oz/ac	5 DE	192.21 A

† Treatments with the same letter are not significantly different at *P*-value < 0.05.

Table 2. Insecticide treatments, rates, the average number of larvae per core, and yield in bushels per acre in rice water weevil studies conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., in 2023.

	Cultivar Rate		RWW Larvae	
Insecticide Treatment	**RiceTec RT7521FP**	**Horizon CLL16**	**per Core**	**Yield**
				(bu./ac)
Untreated Check			13.81 A†	212.97 B
Untreated Check with Barrier			8.60 C	217.43 AB
CruiserMaxx Rice	7 oz/cwt	7 oz/cwt	10.77 B	231.92 AB
Dermacor X-100	5 oz/cwt	2.5 oz/cwt	5.60 E	226.23 AB
CruiserMaxx Rice + Dermacor X-100	7 oz/cwt + 5 oz/cwt	7 oz/cwt + 2.5 oz/cwt	5.06 E	229.39 AB
Warrior II	1.8 oz/ ac	1.82 oz/ac	8.06 DC	219.21 AB
CruiserMaxx Rice + Warrior II	7 oz/cwt + 1.8 oz/ac	7 oz/cwt + 1.8 oz/ac	6.1 DE	228.46 AB
Dermacor X-100 + Warrior II	5 oz/cwt + 1.8 oz/ac	2.5 oz/cwt + 1.8 oz/ac	4.26 E	220.33 AB
CruiserMaxx Rice + Dermacor X-100 + Warrior II	7 oz/cwt + 5 oz/cwt + 1.8 oz/ac	7 oz/cwt + 2.5 oz/cwt + 1.8 oz/ac	4.44 E	227.89 AB

† Treatments with the same letter are not significantly different at *P*-value < 0.05.

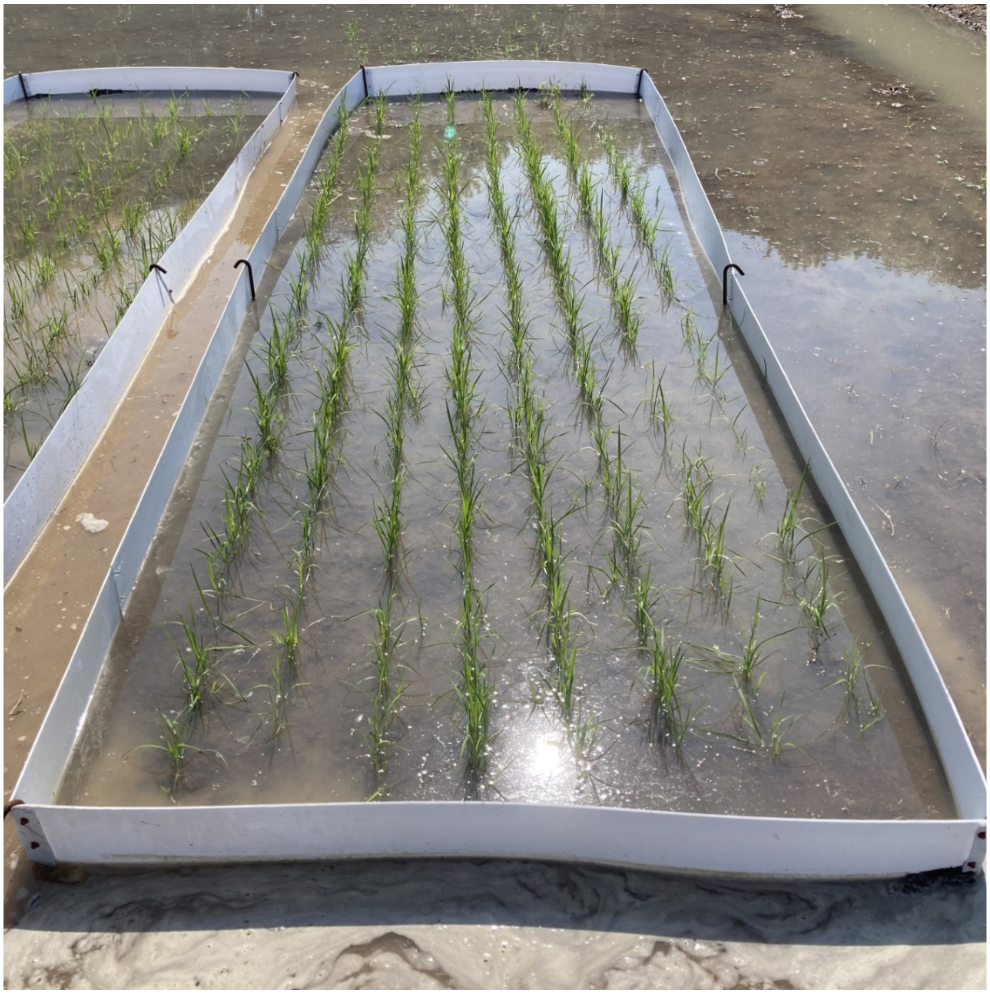

Fig. 1. Image of splash barrier used to reduce wash-off during application and increase insecticide coverage. Barriers were 18 ft x 5 ft x 8 in. and held in place by 6 metal stakes.

Comparing Foliar Insecticide Treatments Pre and Post Flood for Control of Rice Water Weevils

P.G. Maris,[1] N.R. Bateman,[2] B.C. Thrash,[3] S.G. Felts,[2] W.A. Plummer,[3] and T. Davis[3]

Abstract

Rice Water Weevil (RWW) is the most economically important insect pest of flooded rice production in the southern United States. Feeding by rice water weevil larvae prunes and hollows out roots, which can result in significant yield loss if not controlled. Though the most common method of control for rice water weevils is insecticide seed treatments (ISTs), foliar insecticide applications are another option as solo applications or as supplemental applications to ISTs. In 2023, a study was conducted to compare the efficacy of four foliar insecticides applied pre- or postflood for management of RWW in hybrid rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., and the Rohwer Research Station in Rohwer, Ark. Insecticides tested include Warrior II, Vantacor, Belay, and Endigo ZCX. Most treatments reduced larvae when compared to the untreated check, with Warrior II post flood, Vantacor pre and post flood, and Endigo ZCX post flood having the greatest control. Vantacor preflood and Belay preflood provided an increase in yield when compared to the untreated check.

Introduction

Rice water weevil (RWW), *Lissorhoprus oryzophilus* Kuschel, is the most economically important insect pest of rice, *Oryza sativa*, in the southern United States (Lorenz et al., 2018). Both adults and larvae feed on rice plants but the larval stage is the most damaging life stage. Feeding by adult RWW will leave narrow white scars on rice leaves, but this damage is superficial and will not lead to yield loss. RWW larvae feed on the roots of the rice plant, causing reduced water and nutrient uptake by the plant, resulting in stand reduction, reduced grain fill, and plant death. The current action threshold for RWW in Arkansas is 5 larvae per 4 cubic inch of soil core.

The most popular control strategy for RWW in Arkansas is the use of an insecticide seed treatment (IST) due to its efficacy and convenience (Taillon et al., 2014). Over 70% of the total rice acres in Arkansas utilize an IST for RWW control. In areas of heavy RWW pressure, ISTs may be overwhelmed, and a subsequent foliar insecticide application will be justified. Foliar insecticide applications target adult RWW that live and feed on rice foliage before mating and ovipositing in leaf sheaths (Lorenz et al., 2018). For foliar insecticides to be the most effective, applications need to be made before females oviposit 7–14 days after flood (Everett and Newsom, 1964). This makes accurate scouting and good insecticide coverage imperative to avoiding larval infestations. If the preoviposition window is missed, the only effective control option for growers is to drain the field until cracking after larvae have hatched and moved to the root zone (Lorenz et al., 2018). Though this is an effective control option, with the added cost of fuel or electricity required to reflood the field and an application of fertilizer to replace nutrients lost during draining, this method is not economically feasible.

Procedures

Trials were conducted in 2023 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., and the Rohwer Research Station (RRS) in Rowher, Ark. Experimental plot design was a randomized complete block with four replications. Plots were five feet (8 rows) by 16.5 feet. RiceTec 7521FP was planted at PTRS on 3 May and at RRS on 20 April at 20 lb/ac. Treatments included an untreated check, untreated check with a barrier, Warrior II (lambda-cyhalothrin) pre- and postflood with and without a barrier, Vantacor (chlorantraniliprole) pre- and postflood with and without a barrier, Belay (clothianidin) pre- and postflood with and without a barrier, and Endigo ZCX (lambda-cyhalothrin plus thiamethoxam) pre- and postflood with and without a barrier (table 1). Warrior II was applied at 1.82 oz/ac, Vantacor was applied at 1.7 oz/ac, Belay was applied at 4.5 oz/ac, and Endigo ZCX was applied at 5 oz/ac. Applications were made using a backpack sprayer with a 4.5 ft boom and TeeJet hollow cone nozzles with 15-in. spacing. The sprayer was calibrated to deliver 10 GPA at 40 PSI. Preflood applications were made 24 hours before the permanent flood was applied, and postflood applications were made 5 days after the flood was applied. Plots with a postflood application were split into 2 treatment groups. Group 1 received a splash barrier that prevented the wake and splash made during application from contacting the plant, and group 2 did not receive a barrier. This was done to test if reducing insecticide wash-off would increase the efficacy of insecticides. Barriers were 16.5 ft × 6 ft × 8 in. and were placed around the entire plot 24 hours before flood (Fig. 1).

RWW larval populations were assessed by taking three core samples per plot with a 4 × 4 × 4 in. core sampler 21 days after the permanent flood was established. Samples were evaluated at the

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University of Arkansas System Division of Agriculture's Lonoke County Extension Center in Lonoke, Ark. Each core was washed into a 40-mesh sieve with water to loosen soil and remove larvae from the roots. The sieve was then immersed in a warm saturated saltwater solution, which causes larvae to float to the surface, where they can be counted and removed. Yield was collected in bushels of rough rice per acre. Data were processed using the PROC GLIMMIX function in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) using a significance level of $P = 0.5$.

Results and Discussion

At the Pine Tree location, Warrior II postflood with a barrier, Vantacor preflood, Vantacor postflood with a barrier, and Endigo ZCX postflood with a barrier reduced larvae when compared to the untreated check (Fig. 2). All treatments other than Warrior II pre- and postflood and Vantacor postflood reduced larvae when compared to the untreated check with a barrier. No treatments reduced larval populations below the threshold of 5 larvae per core. Vantacor preflood and Endigo ZCX postflood increased yield when compared to the untreated check with and without a barrier (Fig. 3). At the Rohwer location, Belay postflood with a barrier and Endigo ZCX postflood with a barrier reduced larvae when compared to the untreated check with and without a barrier (Fig. 4). Belay postflood with a barrier and Endigo ZCX postflood with a barrier reduced larval populations below the threshold of 5 larvae per core. No treatments provided an increase in yield when compared to the untreated check (Fig. 5). Endigo ZCX postflood with and without a barrier increased yield when compared to Endigo ZCX preflood.

Overall, postflood applications with a barrier had greater control of RWW larvae at both locations. It can be concluded that the use of a barrier increased insecticide efficacy when compared to plots without a barrier. Vantacor, Belay, and Endigo ZCX had greater yield protection compared to the other treatments.

Practical Applications

Foliar insecticides serve an effective role as a supplementary treatment to ISTs in areas of heavy RWW infestations but do not provide enough efficacy to be recommended as a primary chemical control method.

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The authors would like to thank the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board for funding this work and the University of Arkansas System Division of Agriculture's Entomology team for their help in conducting this research.

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Table 1. A list of insecticide treatments, rates, insecticide class, application timing, and barrier used in rice water weevil studies conducted at the Pine Tree Research Station near Colt, Ark., and the Rohwer Research Station in Rohwer, Ark. in 2023.

Insecticide Treatment	Rate	Insecticide Class	Application Timing	Barrier (Yes or No)
Untreated Check				
Untreated Check				Yes
Warrior II	1.8 oz/ac	Pyrethroid	Preflood	No
Warrior II	1.8 oz/ac	Pyrethroid	Postflood	No
Warrior II	1.8 oz/ac	Pyrethroid	Postflood	Yes
Vantacor	1.7 oz/ac	Diamide	Preflood	No
Vantacor	1.7 oz/ac	Diamide	Postflood	No
Vantacor	1.7 oz/ac	Diamide	Postflood	Yes
Belay	4.5 oz/ac	Neonicotinoid	Preflood	No
Belay	4.5 oz/ac	Neonicotinoid	Postflood	No
Belay	4.5 oz/ac	Neonicotinoid	Postflood	Yes
Endigo ZCX	5 oz/ac	Pyrethroid + Neonicotinoid	Preflood	No
Endigo ZCX	5 oz/ac	Pyrethroid + Neonicotinoid	Postflood	No
Endigo ZCX	5 oz/ac	Pyrethroid + Neonicotinoid	Postflood	Yes

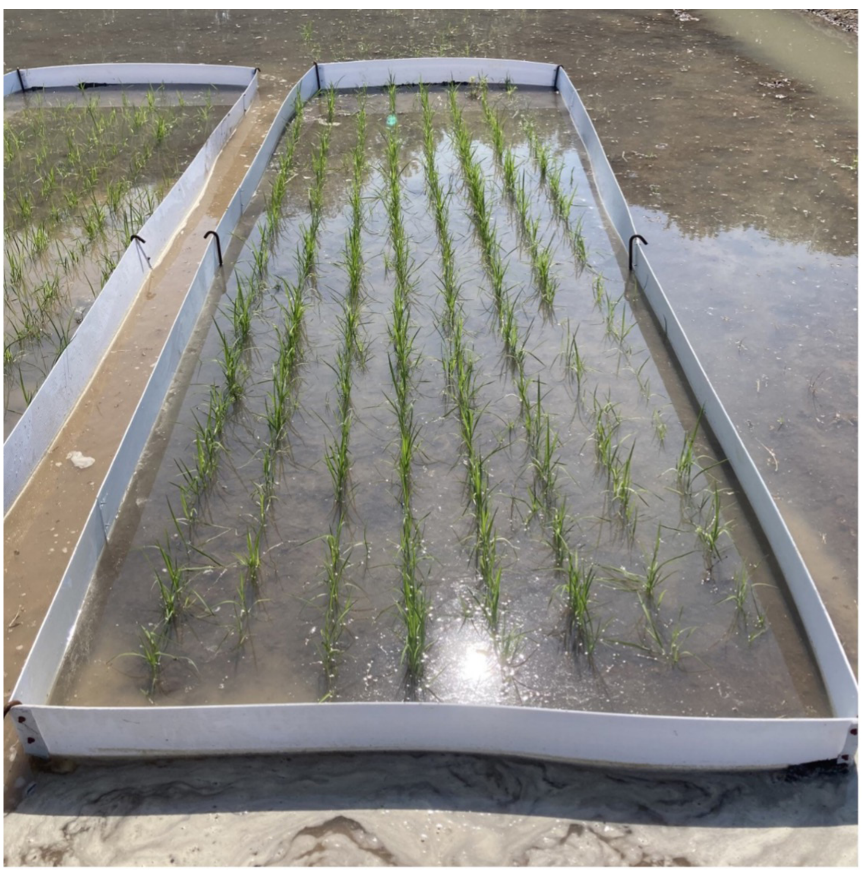

Fig. 1. Image of splash barrier used to reduce insecticide wash-off during application and increase insecticide coverage. Barriers were 18 ft × 5 ft × 8 in. and held in place by 6 metal stakes.

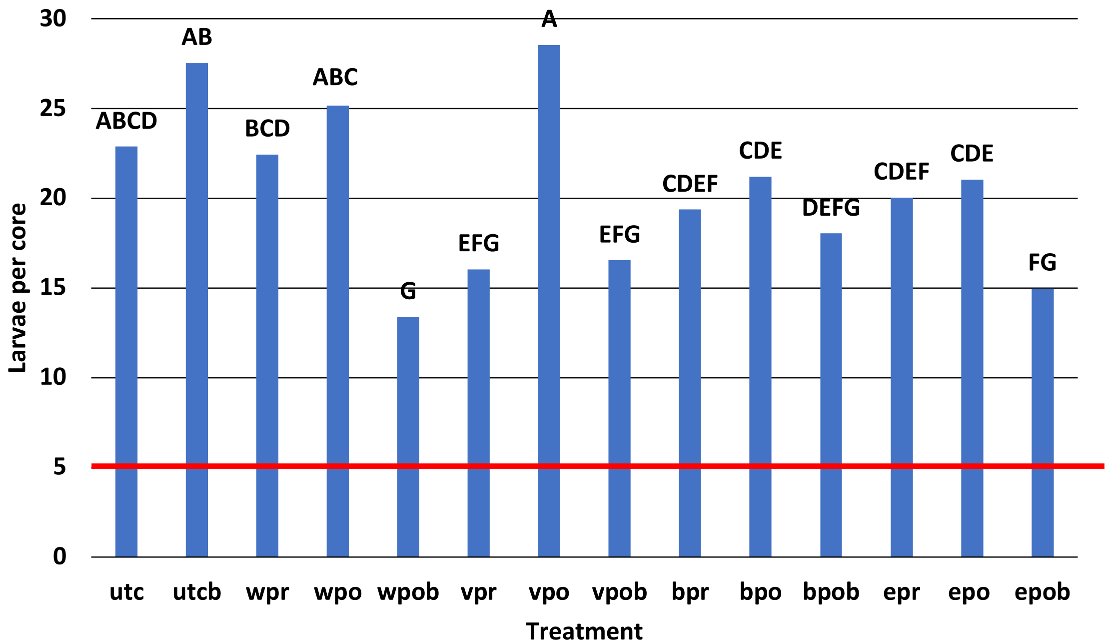

Fig. 2. Rice water weevil control demonstrated by 4 insecticides applied pre- and postflood with or without a barrier at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., in 2023. A red line represents the established threshold of 5 RWW larvae per core. Abbreviations: UTC: untreated check, UTCB: untreated check with barrier, WPR: Warrior II preflood, WPO: Warrior II postflood, WPOB: Warrior II postflood with barrier, VPR: Vantacor preflood, VPO: Vantacor postflood, VPOB: Vantacor postflood with barrier, BPR: Belay preflood, BPO: Belay postflood, BPOB: Belay postflood with barrier, EPR: Endigo ZCX preflood, EPO: Endigo ZCX postflood, EPOB: Endigo ZCX postflood with barrier. Treatments with the same uppercase letter grouping are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

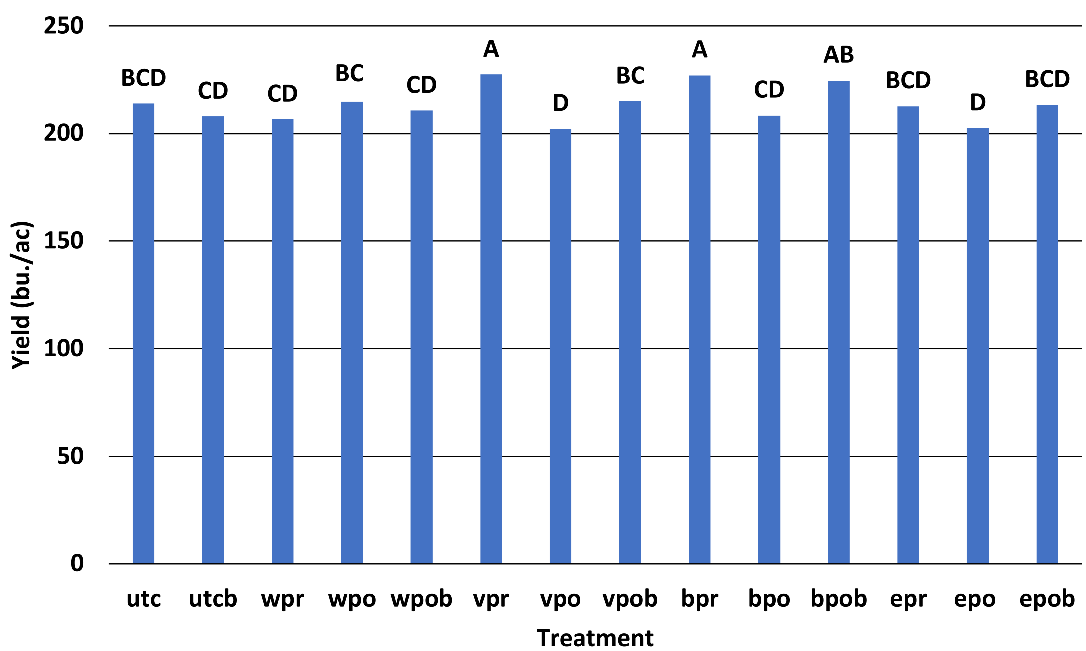

Fig. 3. Yield in bushels per acre for plots at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., in 2023. Abbreviations: UTC: untreated check, UTCB: untreated check with barrier, WPR: Warrior II preflood, WPO: Warrior II postflood, WPOB: Warrior II postflood with barrier, VPR: Vantacor preflood, VPO: Vantacor postflood, VPOB: Vantacor postflood with barrier, BPR: Belay preflood, BPO: Belay postflood, BPOB: Belay postflood with barrier, EPR: Endigo ZCX preflood, EPO: Endigo ZCX postflood, EPOB: Endigo ZCX postflood with barrier. Treatments with the same uppercase letter grouping are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

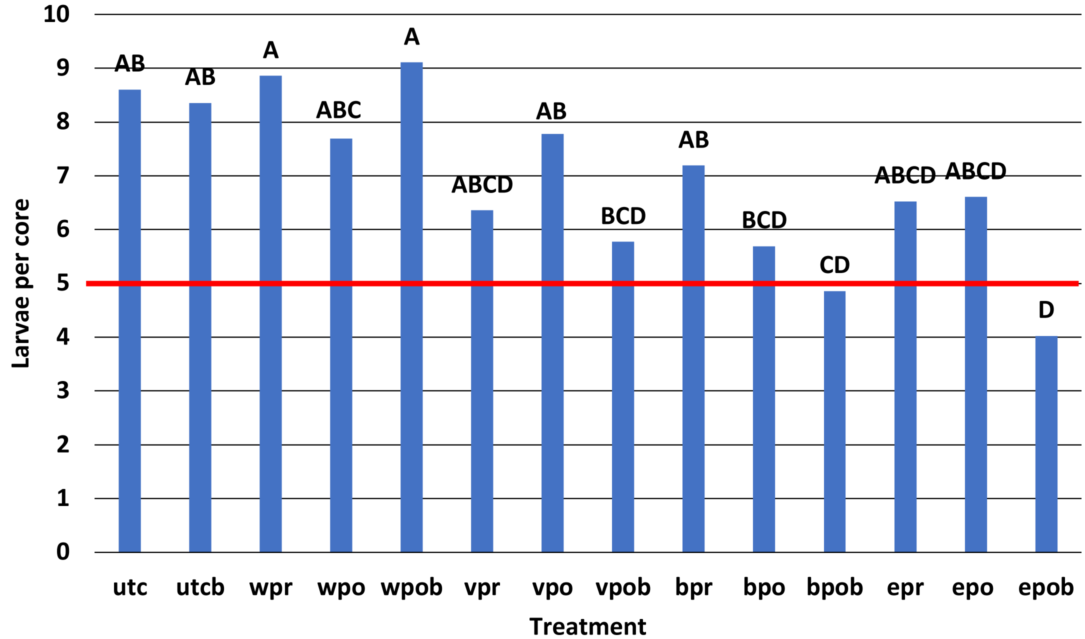

Fig. 4. Rice water weevil control demonstrated by 4 insecticides applied pre- and postflood with or without a barrier at the University of Arkansas System Division of Agriculture's Rohwer Research Station in Rohwer, Ark., in 2023. A red line represents the established threshold of 5 RWW larvae per core. Abbreviations: UTC: untreated check, UTCB: untreated check with barrier, WPR: Warrior II preflood, WPO: Warrior II postflood, WPOB: Warrior II postflood with barrier, VPR: Vantacor preflood, VPO: Vantacor postflood, VPOB: Vantacor postflood with barrier, BPR: Belay preflood, BPO: Belay postflood, BPOB: Belay postflood with barrier, EPR: Endigo ZCX preflood, EPO: Endigo ZCX postflood, EPOB: Endigo ZCX postflood with barrier. Treatments with the same uppercase letter grouping are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

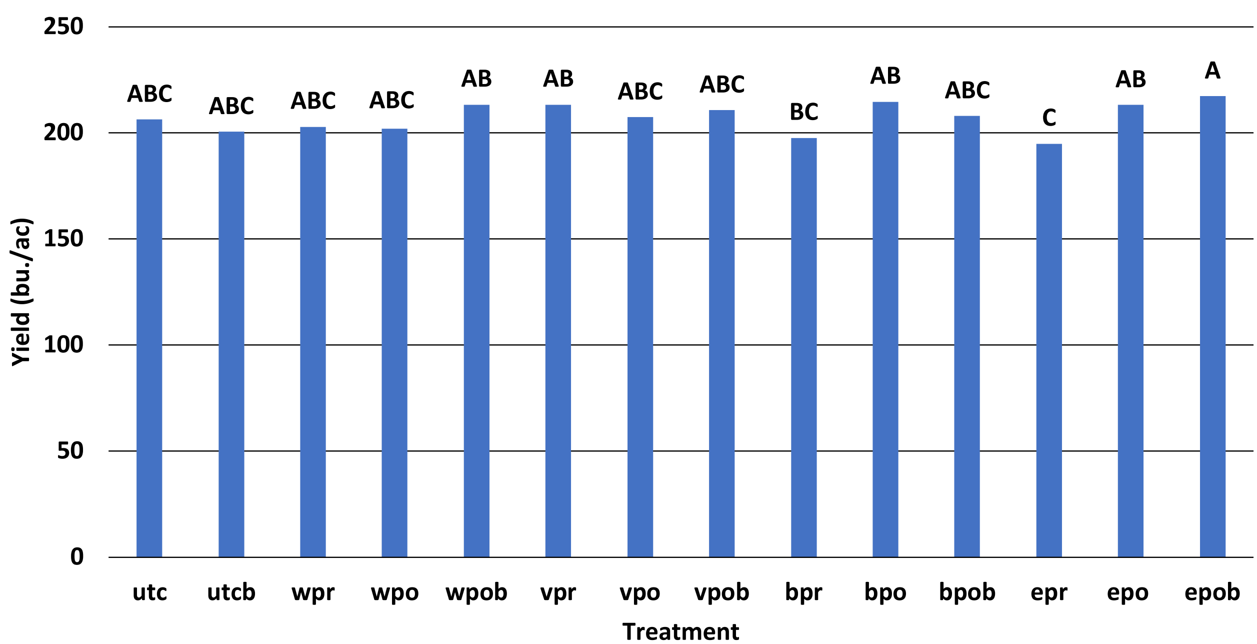

Fig. 5. Yield in bushels per acre for plots at the University of Arkansas System Division of Agriculture's Rohwer Research Station in Rohwer, Ark., in 2023. Abbreviations: UTC: untreated check, UTCB: untreated check with barrier, WPR: Warrior II preflood, WPO: Warrior II postflood, WPOB: Warrior II postflood with barrier, VPR: Vantacor preflood, VPO: Vantacor postflood, VPOB: Vantacor postflood with barrier, BPR: Belay preflood, BPO: Belay postflood, BPOB: Belay postflood with barrier, EPR: Endigo ZCX preflood, EPO: Endigo ZCX postflood, EPOB: Endio ZCX postflood with barrier. Treatments with the same uppercase letter grouping are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Rice (*Oryza sativa*) Response to Command (clomazone) Applied for Fall Residual Control of Italian ryegrass (*Lolium perenne* L.)

L.M. Collie,[1] T.R. Butts,[1] L.T. Barber,[1] and J.K. Norsworthy[2]

Abstract

Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] has become an increasingly weedy and invasive species for production agriculture in Arkansas. This poses a serious threat to Arkansas farmers economically, potentially resulting in hundreds of dollars lost per acre through crop losses and increased inputs. The objective of this experiment was to determine rice response and Italian ryegrass control using Command 3ME (clomazone) as a fall residual. In 2023, a field experiment was established at the University of Arkansas System Division of Agriculture's Jackson County Extension Center in Newport, Arkansas, on a light silt loam soil. Rice variety RT 7421 FP was planted four days after the spring application timing. Treatments consisted of Command applied at 16, 20, or 24 oz/ac alone in the fall or followed with a spring treatment of Command at 10, 12.8, and 16 oz/ac. A comparison treatment of Dual Magnum at 1.5 pt/ac was applied in the fall and followed in the spring by Command at 12.8 fl oz/ac. All treatments provided 99% control of Italian ryegrass when observed at planting. When applied alone in the fall, all rates of Command provided less than 4% injury 14 days after planting (DAP) and no visual injury 21 DAP. Command applied at 16 fl oz/ac in the fall, and followed in the spring at the same rate, provided the most injury observed at 14 DAP (37%). The higher fall rates of Command in the fall (20 and 24 fl oz/ac) and Dual Magnum (1.5 pt/ac) followed by 12.8 fl oz/ac of Command resulted in 34% or less visual injury at 14 DAP. At 21 DAP, Command applied at 16 fl oz/ac in the fall and spring had improved to 21% injury, while all other treatments resulted in less than 18% visual injury. Overall, these results demonstrate that Command applied in the fall offers crop safety and would be as effective as Dual Magnum in controlling Italian ryegrass when applied in a silt loam soil type. Fall-applied Command aids in reducing the further evolution of herbicide resistance in Italian ryegrass to postemergence applied herbicides, improves control consistency, and helps to reduce the soil seedbank for aiding long-term management and economics. Due to these results and other experiments, a Section 24C Special Local Needs label was requested and granted through the EPA and Arkansas State Plant Board for fall applications of Command to control Italian ryegrass.

Introduction

Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] has become an increasingly weedy and invasive species for production agriculture in Arkansas (Butts et al. 2022). This poses a serious threat to Arkansas farmers economically, potentially resulting in hundreds of dollars lost per acre through crop losses and increased inputs. Effective herbicides currently labeled for fall residual control of Italian ryegrass include Dual Magnum (metolachlor) and Zidua (pyroxasulfone). However, these residuals cannot be used if growers plant rice the following spring due to labeled plant-back restrictions because of potential rice stand and yield loss. Due to some populations being resistant to Select Max (clethodim) and Roundup (glyphosate), and ALS-inhibitions, this limits spring burndown control options for Italian ryegrass to a singular herbicide, Gramoxone (paraquat), which generally requires multiple applications prior to planting. The objective of this experiment was to determine rice response and Italian ryegrass control using Command 3ME (clomazone) as a fall residual.

Procedures

In 2023, a field experiment was established at the University of Arkansas System Division of Agriculture's Jackson County Extension Center in Newport, Arkansas, on a silt loam soil. Treatments were arranged in a randomized complete block with four replications. Both experiments were conducted as a randomized complete block design with plot sizes of 12.6 ft by 30 ft. Rice variety RT 7421 FP was planted four days after the spring application timing. Treatments consisted of Command applied at 16, 20, or 24 fl oz/ac alone in the fall or followed with a spring treatment of Command at 10, 12.8, and 16 oz/ac. A comparison treatment of Dual Magnum at 1.5 pt/ac was applied in the fall and followed in the spring by Command at 12.8 fl oz/ac. Applications were made using a pressurized tractor-mounted sprayer with a spray volume of 12 gallons/acre. Data collected consisted of visual injury and weed control ratings using a scale of 0% to 100%, where 0% is no visual injury and 100% is complete plant death. Visual estimations of rice injury were recorded at 14 days after planting (DAP) and 21 DAP.

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Weed control ratings were observed at planting. Data were analyzed and subjected to analysis of variance, and means were separated by Fisher's protected least significant difference test at $\alpha = 0.05$.

Results and Discussion

All treatments provided 99% control of Italian ryegrass when observed at the time of rice planting. When applied alone in the fall, all rates of Command provided less than 4% injury 14 DAP and no visual injury 21 DAP (Figs. 1 and 2). Command applied at 16 fl oz/ac in the fall and followed in the spring at the same rate provided the most injury observed at 14 DAP (37%). Additionally, the higher fall rates of Command in the fall (20 and 24 fl oz/ac) and Dual Magnum (1.5 pt/ac) followed by 12.8 fl oz/ac of Command resulted in 34% or less visual injury at 14 DAP (Fig. 1). At 21 DAP, Command applied at 16 fl oz/ac in the fall and spring had improved to 21% injury while all other treatments achieved less than 18% visual injury (Fig. 2). Visual observation of stand density revealed a significant reduction in rice stand establishment in plots where Dual Magnum was applied in the fall (data not shown). Therefore, applications of Dual Magnum should not be made in the fall to fields where rice is expected to be planted. Overall, these results demonstrate that Command applied in the fall offers crop safety and would be as effective as Dual Magnum in controlling Italian ryegrass when applied in a silt loam soil.

Practical Applications

Fall-applied Command aids in reducing the further evolution of herbicide resistance in Italian ryegrass to postemergence applied herbicides, improves control consistency, and helps to reduce the soil seedbank for aiding long-term management and economics. Due to these results and other experiments, a Section 24C Special Local Needs label was requested and granted through the EPA and Arkansas State Plant Board for fall applications of Command to control Italian ryegrass.

Acknowledgments

The authors would like to thank the Arkansas Rice Research and Promotion Board for administering Checkoff funds to support this research, and the University of Arkansas System Division of Agriculture.

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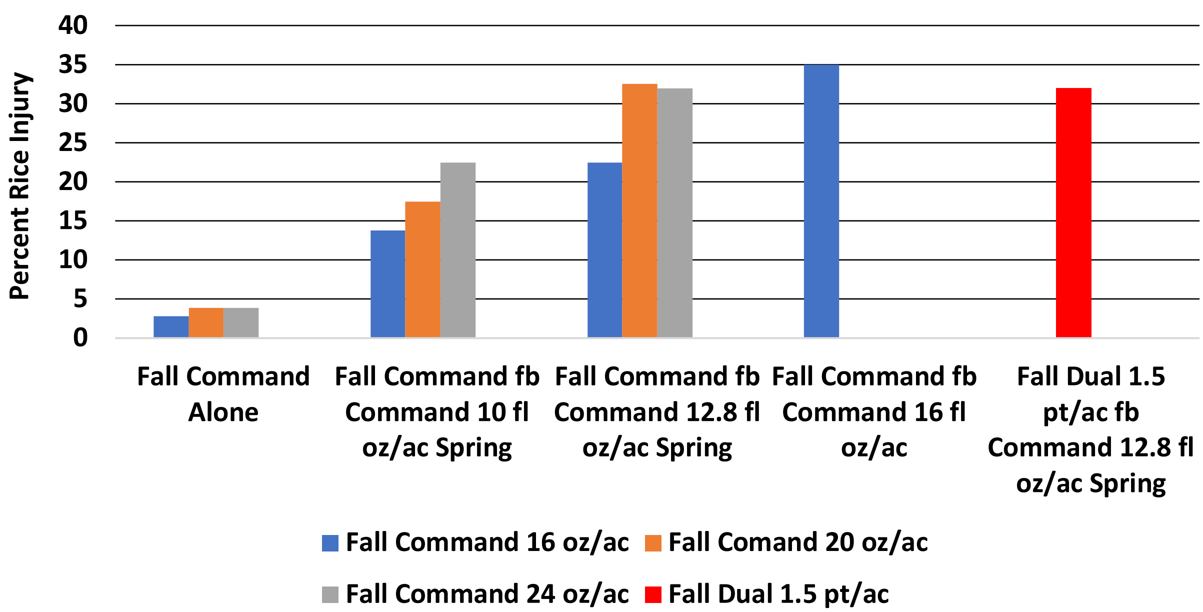

Fig. 1. Visual rice injury 14 days after planting (DAP) following residual herbicide treatments applied to a light silt loam in the fall and spring. fb = followed by.

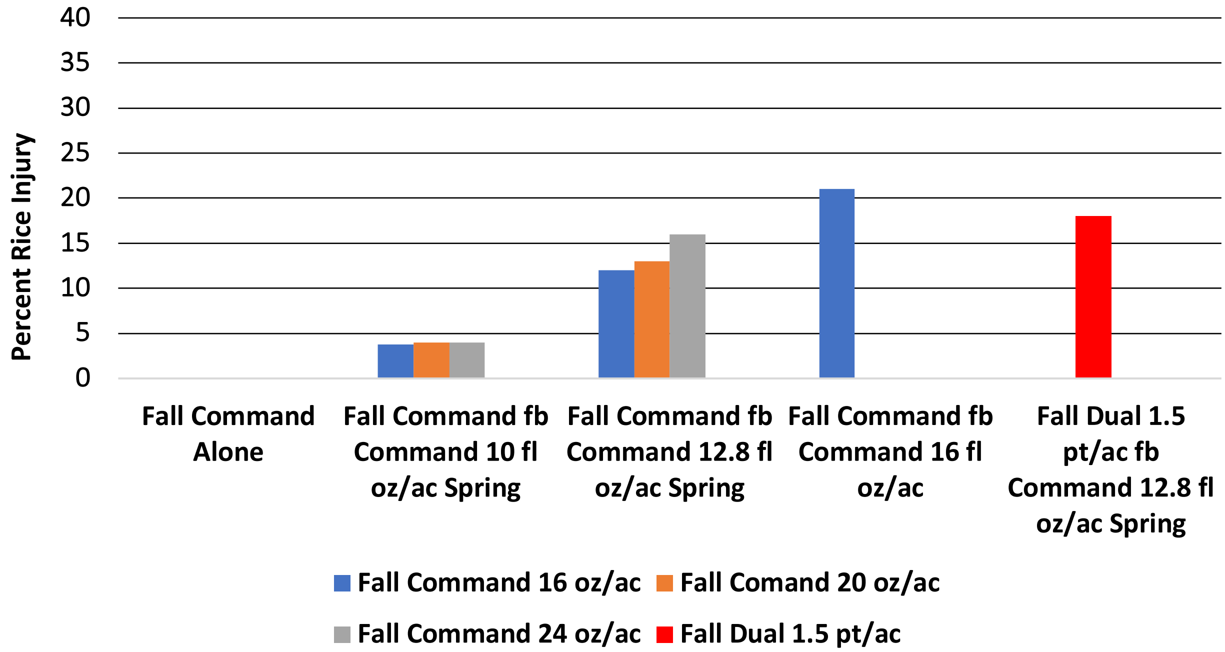

Fig. 2. Visual rice injury 21 days after planting (DAP) following residual herbicide treatments applied to a light silt loam in the fall and spring. fb = followed by.

Brake (Fluridone) Impact on Rice Following Topsoil Removal on Precision-Graded Fields

L.M. Collie,[1] T.R. Butts,[1] L.T. Barber,[1] J.T. Hardke,[2] and J.K. Norsworthy[3]

Abstract

Furrow-irrigated rice (*Oryza sativa* L.) production has increased across the mid-South; however, without the cultural strategy of a flood, weed control becomes more problematic. Additionally, weeds atypical to rice production, such as Palmer amaranth (*Amaranthus palmeri* S. Wats.), become troublesome. Precision-grading is an important aspect in mid-South rice production to maintain an effective irrigation flow-path; however, removal of topsoil can severely impact crop response from residual herbicides. In 2022, a label was granted for Brake (fluridone) herbicide use in furrow-irrigated rice production in the mid-South. The objective of this study was to evaluate the impact of Brake on rice response when applied to a precision-graded furrow-irrigated field. An on-farm field study was conducted in 2023 near Osceola, Ark., and hybrid rice cultivar RT7521FP was grown in a furrow-irrigated production system. Applications were applied to 3-leaf rice, and treatments consisted of Brake at 8 (0.5x), 16 (1x), and 32 (2x) oz/ac, Command 3ME (Clomazone) at 12.8 oz/ac, Facet L (Quinclorac) at 32 oz/ac, and a nontreated control. At 8 and 10 weeks after treatment (WAT), visual rice injury was greater than 65% and 25% for the Brake 16 (2x) and 32 (1x) fl oz/ac treatments, respectively. Rice canopy coverage was reduced by 14 and 53 percentage points for the 1x and 2x Brake treatments, respectively, compared to all other treatments (70% coverage) at 8 WAT. Rice yield in the 2x Brake treatment was reduced by 21% compared to all other treatments (172.4 bu./ac). Overall, Brake applied at a 1x and 2x label rate to a recent precision-graded field caused substantial rice injury and would not be recommended. Although an 8 fl oz/ac Brake rate (0.5x) did not severely injure rice, this rate has previously provided poor weed control on a clay soil in cotton (*Gossypium hirsutum* L.); therefore, more research is needed to evaluate whether this rate would provide adequate control of problematic weeds in rice before recommending its use on precision-graded rice fields.

Introduction

Furrow-irrigated rice (*Oryza sativa* L.) production has increased across the mid-South; however, without the cultural strategy of a flood, weed control becomes more problematic. Additionally, weeds atypical to rice production, such as Palmer amaranth (*Amaranthus palmeri* S. Wats.), become troublesome (Butts et al., 2022). Precision-grading is an important aspect in mid-South rice production for maintaining an effective irrigation flow-path; however, the removal of topsoil in deeper cut areas can severely impact the crop (Walker et al. 2003), including eliciting crop response from residual herbicides (Anonymous, 2016, 2019). In 2023, a label was granted for Brake® (fluridone) herbicide use in rice production in the Mid-south (Anonymous 2023). However, no information was available regarding rice response to Brake on precision-graded fields following topsoil removal. Therefore, the objective of this research was to evaluate the impact of Brake herbicide on rice response (injury, canopy coverage, heading, and rough rice yield) when applied to a precision-graded field following topsoil removal.

Procedures

In 2023, an on-farm field experiment was established near Osceola, Arkansas with a Sharkey-Steele clay complex soil type. Hybrid rice cultivar RT7521FP (RiceTec Inc., Alvin, Texas) was grown in a furrow-irrigated system and the field was maintained as weed-free. Treatments were arranged in a randomized complete block with six treatments and four replications. All applications were made with a CO_2-pressurized backpack sprayer equipped with AIXR110015 nozzles calibrated to deliver 10 GPA. Applications were applied to 3-leaf rice, and treatments consisted of Brake at 8 (0.5x), 16 (1x), and 32 (2x) oz/ac, Command 3ME (Clomazone) at 12.8 oz/ac, Facet L (Quinclorac) at 32 oz/ac, and a nontreated control. Irrigation occurred approximately every 2 to 3 days and was initiated approximately 10 days after the application. Urea fertilizer was applied across the entire field (including the trial area) with 5 split-timing applications of 100 lb/ac each. Finally, the entire field was desiccated 1 week prior to trial harvest with sodium chlorate at 1 gal/ac. Data collected consisted of visual injury ratings using a scale of 0% to 100%, where 0% is no visual injury and 100% is complete plant death. Remote sensing digital imagery to assess rice canopy coverage was taken using a small, unmanned aerial system (sUAS) and subsequently analyzed using FieldAnalyzer (Green Research Services, LLC., Fayetteville, Ark.) (Fig. 1). Visual injury ratings and rice canopy coverage were recorded at 4, 6, 8, 10 and 13 weeks after treatment (WAT). Visual percentage of rice heading (% of plants) was recorded at 10, 11, 12, and 13 WAT. Rice was harvested using a small plot combine, and rough rice yield was

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adjusted to 13% moisture. Data were analyzed using ANOVA with PROC GLIMMIX in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) and the appropriate distribution. Means were separated with Fisher's protected least significant difference at $\alpha = 0.05$.

Results and Discussion

At 8 and 10 weeks after treatment (WAT), visual rice injury was greater than 65% and 25% for the Brake 2x (32 oz/ac) and 1x (16 oz/ac) treatments, respectively (Fig. 1). Ten percent or less visual rice injury was observed for all other treatments. As Command and Facet are already not recommended for use on precision-graded or "cut" ground (Anonymous 2016, 2019), this increased injury from Brake at 16 and 32 oz/ac would not be commercially acceptable. Additionally, rice canopy coverage was reduced by 14 and 53 percentage points for the 1x and 2x Brake treatments, respectively, compared to all other treatments (70% coverage) at 8 WAT (Fig. 2). At 10 WAT, the 1x Brake treatment was able to recover and have similar canopy coverage to the Command, Facet, and 0.5x Brake treatments (greater than 60% coverage); however, the 2x Brake treatment still had severe canopy loss with less than 30% coverage. By 13 WAT, the 2x Brake treatment significantly regained canopy formation and was able to achieve greater than 70% coverage. Rice heading was delayed by more than 60 and 30 percentage points at 11 and 12 WAT, respectively, in the 2x Brake treatment compared to all other treatments (82 and 100% headed, respectively) (Fig. 3). By 13 WAT, the 2x Brake treatment was able to achieve greater than 90% rice heading. Rough rice yield in the 2x Brake treatment was reduced by 21% compared to all other treatments (11,080 kg/ha) (Fig. 4). Overall, these results demonstrate that when Brake is applied on-label at the 3-leaf timing, significant impacts on rice growth and development can be observed from both a 1x (16 oz/ac) and 2x (32 oz/ac) rate.

Practical Applications

This research indicates that Brake applied in a precision-graded field with clay soil at 1x and 2x label rate (16 and 32 oz/ac, respectively) will cause substantial rice injury and would not be recommended. Brake applied at 8 oz/ac (0.5x) did not severely injure rice; however, this rate has previously provided poor weed control on a clay soil in cotton (*Gossypium hirsutum* L.). More research is needed to determine if the 0.5x rate of Brake would provide adequate control of problematic weeds in rice before recommending its use on precision-graded rice fields.

Acknowledgments

The authors would like to thank the Arkansas Rice Research and Promotion Board for administering Checkoff funds to support this research. Additionally, thank you to crop consultant Tyler Hydrick and grower Ryan Sullivan for providing an on-farm field location for this research, and to Mississippi County Extension Agents Ethan Brown and Alan Beach for aiding in data collection. Support was also given by the University of Arkansas System Division of Agriculture.

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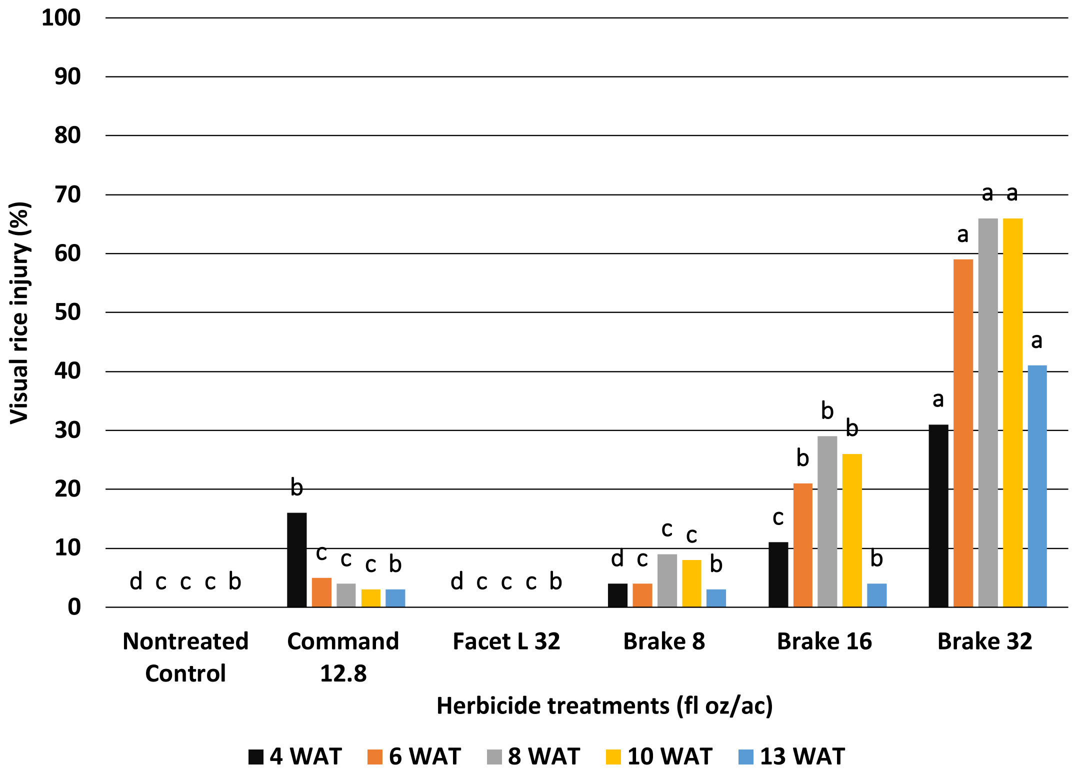

Fig. 1. Visual rice injury (%) 4, 6, 8, 10, and 13 weeks after treatment (WAT) following herbicide treatments applied at 3-leaf rice. Treatments with the same lowercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.

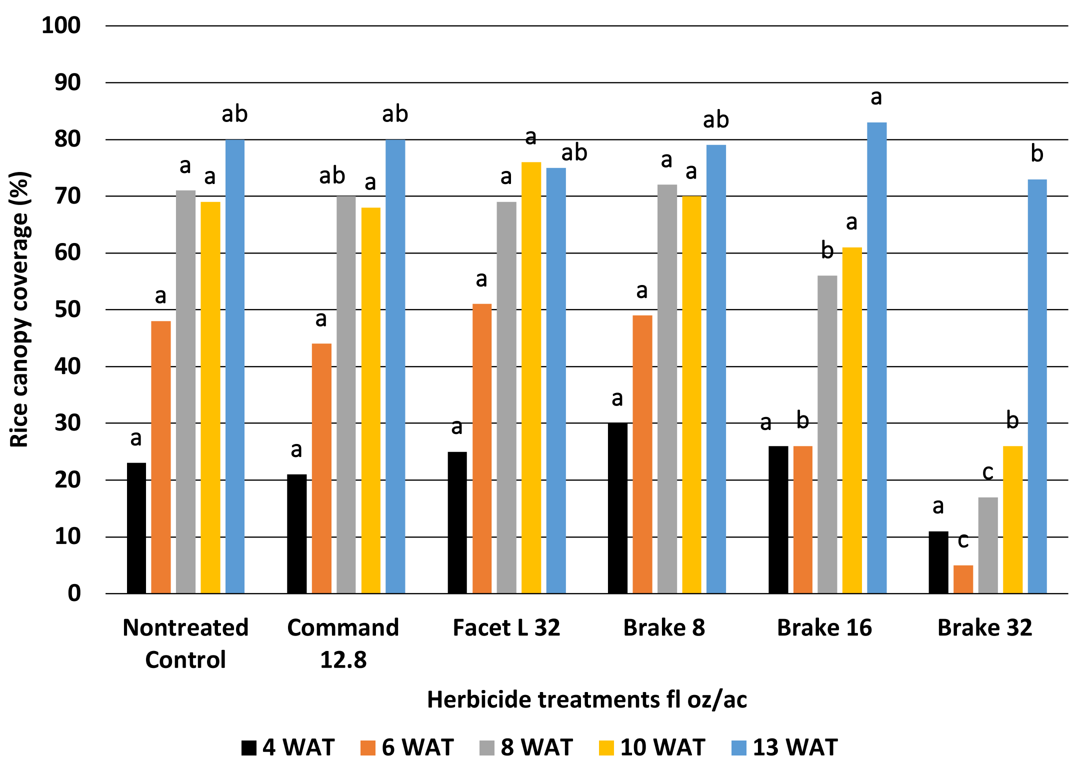

Fig. 2. Rice Canopy coverage (%) 4, 6, 8, 10, and 13 weeks after treatment (WAT) determined through remote sensing digital imagery following herbicide treatments applied at 3-leaf rice. Treatments with the same lowercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.

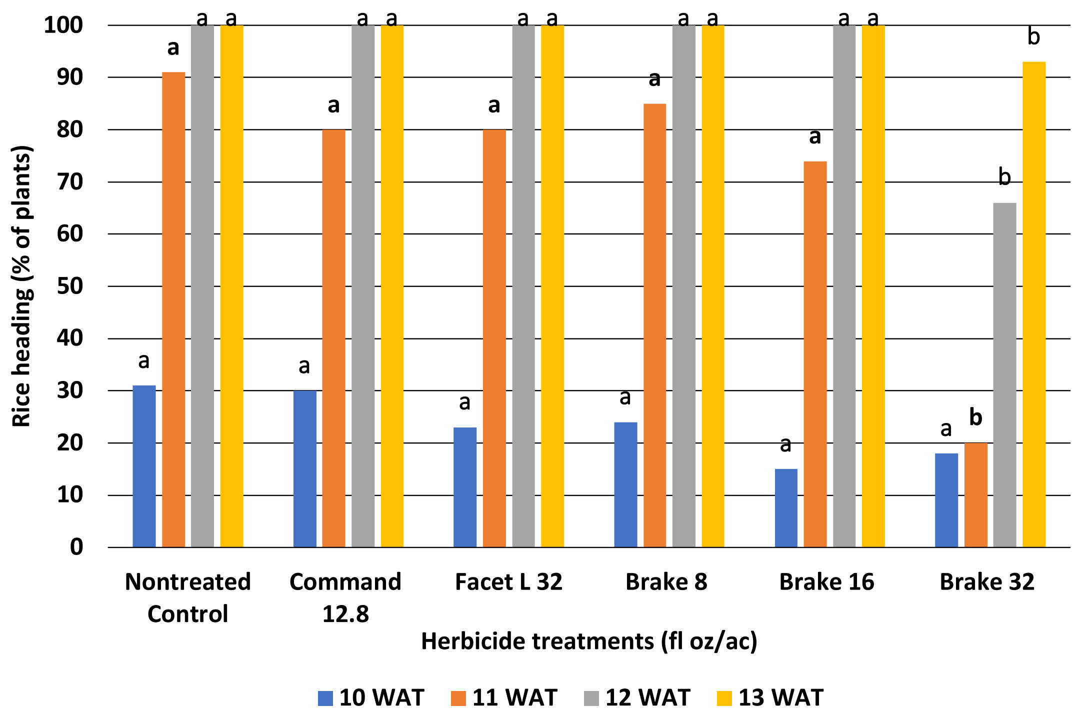

Fig. 3. Rice heading (% of plants) 10, 11, 12, and 13 weeks after treatment (WAT) following herbicide treatments applied at 3-leaf rice. Treatments with the same lowercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.

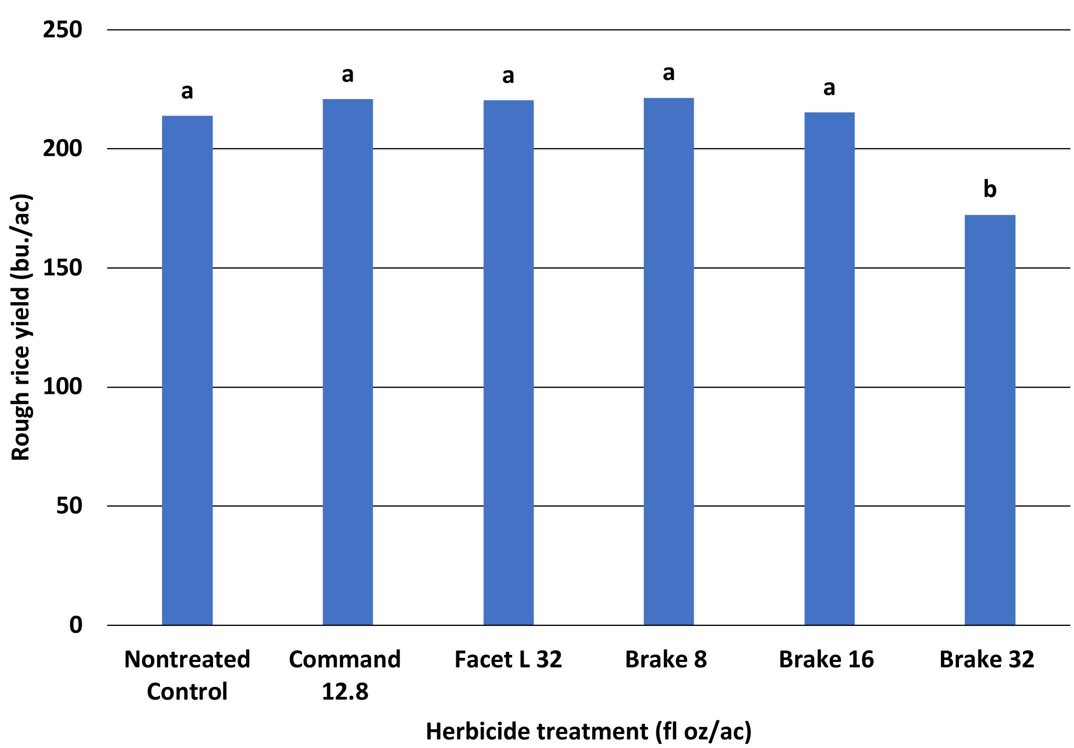

Fig. 4. Rough rice yield (bu./ac) following herbicide treatments applied at 3-leaf rice. Treatments with the same lowercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.

Coverage and Weed Control with Spray Drones

B.M. Davis,[1] T.R. Butts,[1] J.K. Norsworthy,[2] L.T. Barber,[1] T.N. Spurlock,[3] and J. Davis[4]

Abstract

Weed control has been a major concern for Arkansas producers since crops were first cultivated in the state. Failure to control problematic weeds in crops can drastically affect profitability, and with increased input costs in recent years, profit margins have narrowed further. Certain application scenarios, such as under power lines, along field tree lines where manned aircraft applicators are unable to fly, or precisely applying to rice levees, demonstrate potential fits for the use of spray drones or remotely piloted aerial application systems (RPAAS). RPAAS have increased in popularity for herbicide applications in recent years; however, a more thorough understanding of application parameters such as nozzle type and carrier volumes is needed to maximize weed control. The objective of this research was to evaluate the effects of nozzle type, spray volume, and application equipment (RPAAS versus ground-driven sprayer) on spray coverage and weed control. Three field studies were conducted in the spring of 2023 at Lonoke, Newport, and Rohwer, Ark. Treatments consisted of nozzle type (XR11002, TADF11002, and ULD12002) and three application setups (RPAAS at 2 and 5 GPA, and a Bowman MudMaster sprayer at 10 GPA), and a nontreated control. Gramoxone 3SL (32 fl oz/ac) was applied to naturally occurring populations of emerged winter annual weed species across locations. Spray coverage was the greatest from the XR11002 nozzle applied at 10 GPA from the Bowman MudMaster compared to all other nozzles and setups. The RPAAS at 5 GPA and the Bowman MudMaster at 10 GPA provided greater weed control compared to the RPAAS at 2 GPA regardless of nozzle type at 1 week after treatment (WAT). By 4 WAT, the RPAAS at 2 GPA had reduced visual weed control compared to the RPAAS at 5 GPA and Bowman MudMaster at 10 GPA. However, at 4 WAT, the Visible Atmospherically Resistant Index (VARI) and biomass reductions were equivalent for all treatments.

Introduction

Arkansas grew an estimated 1.08 million acres of rice (*Oryza sativa* L.) in 2022 and is ranked number 1 in rice production in the U.S. (Hardke, 2022). Both aerial and ground applications of pesticides are crucial for a successful crop and are used in nearly equal percentages in Arkansas (Butts et al., 2021). However, there are limiting factors affecting these more traditional application methods. Weather patterns in the spring are unpredictable and narrow planting windows between weather events could put growers in situations where applications of herbicides are not made or are partially made. New technologies are needed to aid growers in applying herbicides in a timely manner for a successful weed control program. One new avenue of aerial application is with the use of spray drones or remotely piloted aerial application systems (RPAAS). RPAAS would allow growers the ability to precisely apply herbicides to parts or all of a field that a traditional method may have been unable to due to flooding, power lines, tree field edges, etc. Of the estimated 1.08 million acres of rice grown in Arkansas, 82% of those are in flooded rice that contains either contoured or straight levees (Hardke, 2023). A potential fit for RPAAS is the application of herbicides to rice levees, where an herbicide is only applied directly to the levees and not the entire field, thereby potentially saving growers money and labor. The objectives of this research were to evaluate nozzle type, carrier volume, and application equipment (RPAAS versus ground driven sprayer) effects on spray coverage and weed control.

Procedures

Three field experiments were conducted in the spring of 2023 at Lonoke, Newport, and Rohwer, Ark. The experimental design was a randomized complete block with four replications completed at each location. Treatments consisted of three nozzles [XR11002 (TeeJet Technologies, Glendale Heights, Ill.), TADF11002 (Greenleaf Technologies, Covington, La.), and ULD12002 (Pentair Hypro, Golden Valley, Minn.)] and three application setups (RPAAS at 2 and 5 GPA, and a Bowman MudMaster at 10 GPA). Spray parameters for the RPAAS (DJI Agras T30) consisted of an 8 ft flight height at a 15 MPH flight speed for the 2 GPA treatment and an 8 ft flight height at a 6 MPH flight speed for the 5 GPA treatment. The Bowman MudMaster was calibrated to deliver 10 GPA with a boom height of 36 inches at 3 MPH. Gramoxone 3SL at 32 oz/ac was applied to naturally occurring populations of emerged winter annual weed species across locations. Some of these weed species included Italian ryegrass [*Lolium perenne* L. ssp. *Multiflorum* (Lam.) Husnot], curly dock (*Rumex crispus* L.), Carolina foxtail (*Alopecurus carolinianus* Walt.), and cutleaf evening primrose (*Oenothera laciniata* Hill).

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Data collected consisted of one water-sensitive paper placed in the horizontal position at the top of the weed canopy in each plot. Visual estimations of weed control were taken and were estimated using a scale of 0 to 100%, where 0% is no control and 100% is complete plant death. Weed biomass was harvested at 4 weeks after treatment (WAT) from a 2.7 ft^2 quadrant per plot, dried to constant mass, and subsequently weighed. Additionally, remote sensing digital imagery (RGB images) was collected using various small, unmanned aerial systems (sUAS) at an altitude of 120 m. The images were subsequently analyzed using Pix4D for the Visible Atmospherically Resistant Index (VARI). A higher VARI correlated to healthier vegetation, therefore reduced herbicide efficacy. VARI data were then converted to a percent of the nontreated control; therefore, a greater value indicated greater weed control (greater reduction from the nontreated control). Water-sensitive paper was analyzed using USDA-ARS DepositScan software to extract coverage data. All data were subjected to analysis of variance in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with a beta distribution with the exception of VARI, which was analyzed using a Gaussian distribution. Means were separated with Tukey's honestly significant difference at $P = 0.05$. Location and block nested within location were considered random effects, and nozzle type and application setup were considered fixed effects.

Results and Discussion

Spray coverage was the greatest with the XR11002 nozzle applied at 10 GPA from the ground spray equipment (Bowman MudMaster) at 26.7% compared to all other nozzles and application setups (Fig. 1). The RPAAS operated at 2 GPA did not provide greater than 5% coverage regardless of nozzle type used. However, the RPAAS operated at 5 GPA with the TADF11002 (18.1%) and ULD12002 (18.0%) nozzles provided equivalent coverage as the ground spray equipment at 10 GPA (18.3% and 19.1%, respectively). Additionally, nozzles producing the larger droplet size (TADF and ULD) provided greater coverage than the nozzles producing smaller droplet size (XR) when applied using the RPAAS at 5 GPA.

Visual weed control ratings at 1 WAT were affected by application setup as the RPAAS at 5 GPA (76%) and Bowman Mudmaster at 10 GPA (77%) had increased weed control compared to the RPAAS at 2 GPA (59%) (Table 1). This may be attributed to greater coverage of the contact herbicide (Fig. 1). The VARI reduction data 1 WAT were greater for the Bowman MudMaster at 10 GPA (75%) compared to the RPAAS at 2 GPA (70%), but the RPAAS at 5 GPA (74%) was not different when averaged across nozzle types (Table 1). Visual weed control ratings 1 WAT were greater for the XR nozzle (76%) compared to the TADF nozzle (66%) with no difference in control for the ULD nozzle (71%) (Fig. 2). This indicates the smaller droplet size producing nozzle (XR) may have improved control when averaged across application setups, particularly compared to the dual-fan, larger droplet size producing TADF nozzle. However, reduced application pressures below nozzle manufacturer recommendations may have contributed to this result.

By 4 WAT, reduced visual weed control for the RPAAS at 2 GPA (69%) remained compared to the RPAAS at 5 GPA (86%) and Bowman MudMaster at 10 GPA (83%) (Table 1). However, the VARI reduction percentages were no longer different among application setup treatments, and no biomass reduction treatment differences were observed (Table 1). Nozzle type did not influence any weed control variable 4 WAT. Overall, these data suggest that the RPAAS at 5 GPA can be considered equivalent to a ground spray application (Bowman MudMaster) at 10 GPA in almost all application facets. Additionally, there are slight indications that the RPAAS at 2 GPA may be able to achieve the same level of weed control as both the RPAAS at 5 GPA and the Bowman MudMaster at 10 GPA despite reduced levels of spray coverage (Table 1, Fig. 1).

Practical Applications

Initial findings in this study suggest that a RPAAS could be a viable option for herbicide applications in situations where conventional application equipment may not fit. RPAAS provided equivalent spray coverage and weed control at 5 GPA to the ground-driven sprayer at 10 GPA. Additionally, despite coverage reductions and initial reductions in weed control, RPAAS at 2 GPA was also able to provide similar weed control by 4 WAT, indicating there may be potential even for the low-volume applications, albeit with much less room for error within the application. Particular attention to herbicide labels and approved nozzles for some herbicides needs to be taken into account. Other parameters, such as wind speed and direction, may need to be investigated in the future for the implementation and success of an RPAAS application.

Acknowledgments

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Table 1. Biomass reduction (% of nontreated control), visual weed control (% of nontreated control) 1 and 4 weeks after treatment (WAT), and Visible Atmospherically Resistant Index (VARI) (% of nontreated control) at 1 and 4 WAT.

Application setup	Spray volume	Weed control (1 WAT)†	Weed control (4 WAT)†	VARI reduction (1 WAT)‡	VARI reduction (4 WAT)‡	Biomass reduction‡
	GPA	--------	--------	%	--------	--------
RPAAS	2	59 b§	69 b	70 b	52 a	56 a
RPAAS	5	76 a	86 a	74 ab	52 a	59 a
Mudmaster	10	77 a	83 a	75 a	52 a	59 a

† Visual weed control ratings are based on a scale of 0 to 100, where 0 is no control and 100 is plant death.

‡ Biomass and VARI are calculated as % of nontreated control.

§ Means followed by the same letter are not different according to Tukey's honestly significant difference at *P* = 0.05.

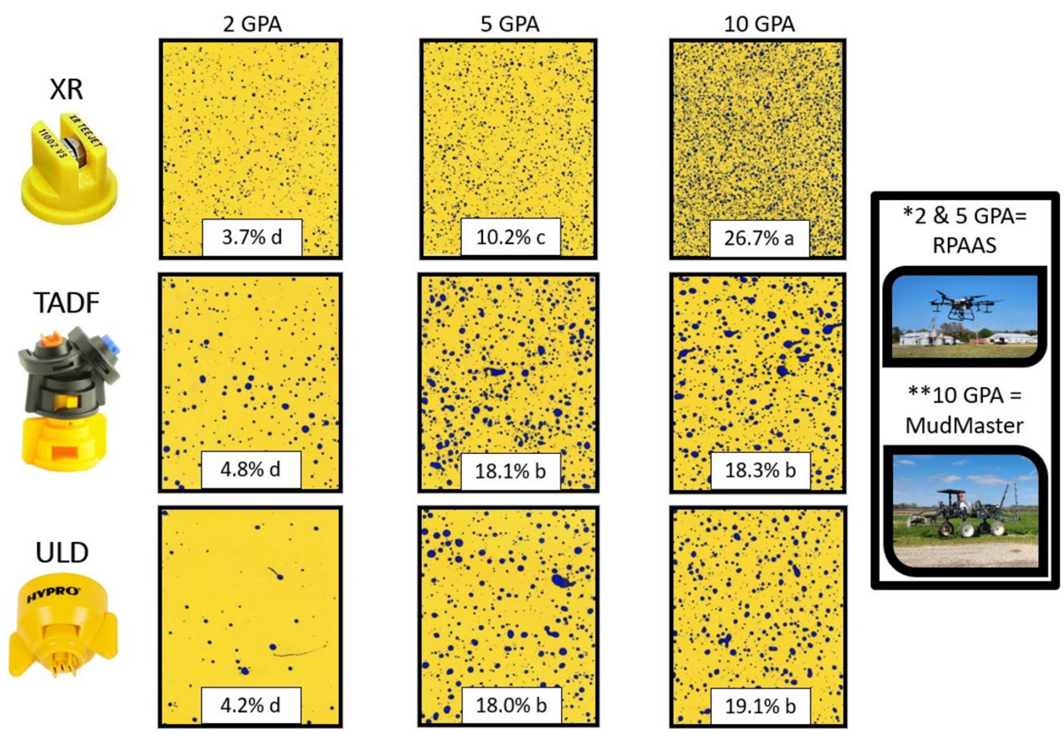

Fig. 1. Diagram of spray coverage results collected from water-sensitive paper for three nozzle types (rows) and three application setups (columns). Means followed by the same letter are not different according to Tukey's honestly significant difference at *P* = 0.05.

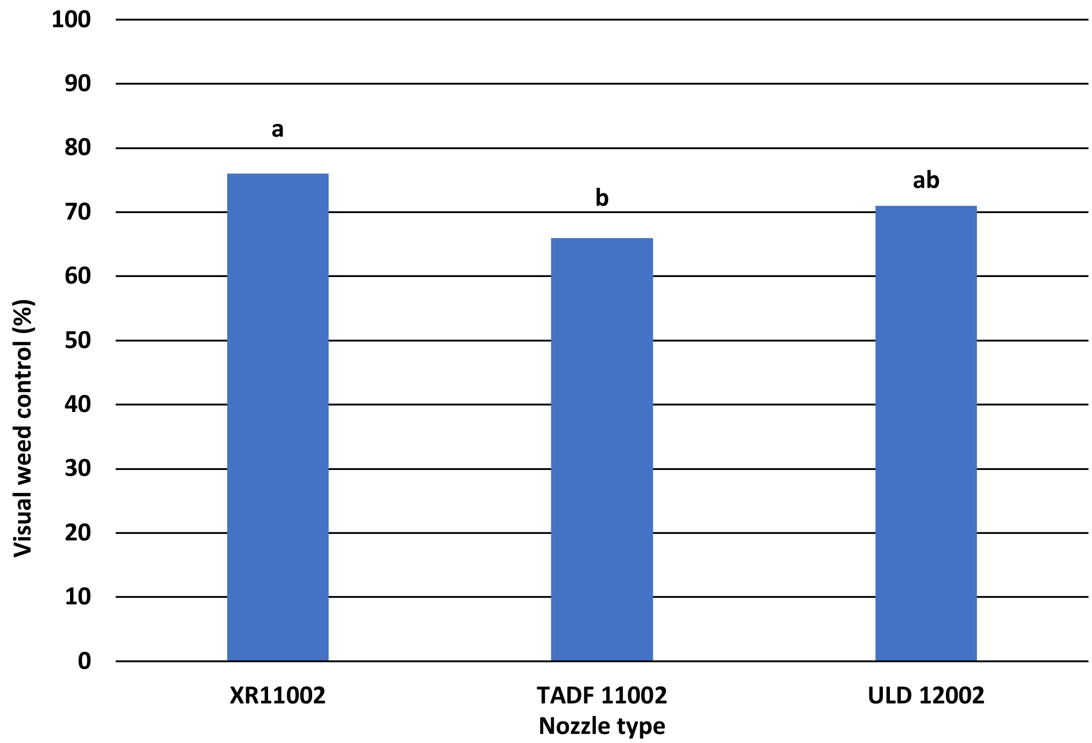

Fig. 2. Visual weed control (% control) 1 week after treatment for three nozzle types across application setups. Means followed by the same letter are not different according to Tukey's honestly significant difference at *P* = 0.05.

Evaluation of Aceto-CoA Carboxylase-Inhibiting Herbicides with Residual Herbicides to Control Grass Weed Species in Furrow-Irrigated Rice

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Abstract

In Arkansas, furrow-irrigated rice (*Oryza sativa* L.) production has increased to greater than 20% since 2020. Additionally, barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] was reported to be the most problematic weed species in furrow-irrigated rice. In 2023, an experiment was conducted in Rohwer, Ark., to evaluate the use of acetyl-CoA carboxylase-inhibiting herbicides with and without residual herbicides to effectively control grass weeds in furrow-irrigated rice. Early postemergence (EPOST) herbicide treatments consisted of fenoxaprop (Ricestar HT) at 0.068 (15 oz/ac), 0.086 (oz/ac), and 0.109 (oz/ac) pounds of active ingredient per acre (lb/ac) applied alone, in addition to being mixed with clomazone (Command®) at 0.56 lb/ac (24 oz/ac), and cyhalofop (Clincher®) at 0.28 lb/ac (15 oz/ac) plus clomazone at 0.56 lb/ac. Fourteen days after the EPOST applications, treatments with fenoxaprop at 0.068 lb/ac and fenoxaprop at 0.068 lb/ac plus clomazone at 0.56 lb/ac had a subsequent application of the same herbicides applied. At 7 days after the EPOST application, all herbicide treatments provided greater than 90% control of barnyardgrass, except for fenoxaprop at 0.068 lb/ac and cyhalofop at 0.28 lb/ac tank-mixed with clomazone at 0.56 lb/ac. By 14 days after the EPOST timing, herbicide efficacy from the higher two rates of fenoxaprop applied alone began to decrease compared to those applied with a residual herbicide. At 25 days after the mid-postemergence application, an increase in control was observed when fenoxaprop at 0.068 lb/ac was followed by a subsequent application of fenoxaprop at 0.068 lb/ac, with 92% control of barnyardgrass. These findings suggest that the use of fenoxaprop or cyhalofop herbicides can still provide effective control of herbicide-resistant barnyardgrass when incorporated into a herbicide program with multiple modes of action.

Introduction

Rice (*Oryza sativa* L.) production in Arkansas accounted for $1.3 billion in 2023, with Arkansas producing 56% to 58% of the total long-grain rice grown in the United States (USDA-ERS, 2023). Over the last several years, furrow-irrigated rice production has increased by more than 10% since 2020 (Hardke et al., 2020), which has some disadvantages, particularly an increase in weed emergence due to the lack of a standing flood to suppress weeds. In a recent survey, barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] was reported to be the most problematic weed species in furrow-irrigated rice (Butts et al., 2022), due to its resistance to multiple herbicide modes of action (Heap, 2023), in addition to the difficulty of timely herbicide applications with the prolific growth that barnyardgrass can achieve. Barnyardgrass control in a furrow-irrigated rice production system can be more difficult as a long emergence pattern can occur without a flooded environment. Studies to determine the best fit for currently labeled herbicides are needed to prevent control failures and further development of resistance.

Procedures

An experiment was conducted in 2023 in Rohwer, Ark., to evaluate the use of acetyl-CoA carboxylase inhibiting herbicides with and without residual herbicides to effectively control grass weeds in furrow-irrigated rice. Barnyardgrass control was the primary point evaluated in this experiment. The experiment was set up as a randomized complete block design, and RT7521FP rice was drilled at 35 lb/ac with four replications and plot sizes of 12.66 ft by 30 feet. Visual efficacy ratings were taken at 7 and 14 days after the early postemergence (EPOST) (2- to 3-leaf grass weeds) timing and at 7 and 25 days after the mid-postemergence (MPOST) (<4-inch grass weeds) timing. All treatments were compared to a nontreated control to determine the effectiveness of each treatment. A standard application of halosulfuron methyl + prosulfuron (Gambit®) + saflufenacil (Sharpen®) was applied preemergence across all treatments in this experiment to reduce the presence of sedges and broadleaf weeds. Herbicide treatments at the EPOST timing consisted of fenoxaprop (Ricestar HT) at 0.068 (15 oz/ac), 0.086 (19 oz/ac), and 0.109 (24 oz/ac) pounds of active ingredient per acre (lb/ac) applied alone, in addition to being tank-mixed with clomazone (Command®) at 0.56 lb/ac (24 oz/ac), and cyhalofop (Clincher®) at 0.28 lb/ac (15 oz/ac) tank-mixed with clomazone at 0.56 lb/ac as a comparison. At the MPOST timing, fenoxaprop at 0.068 lb/ac was followed by fenoxaprop at 0.068 lb/ac, and fenoxaprop at 0.068 lb/ac + clomazone at 0.56 lb/ac was followed by fenoxaprop at 0.068 lb/ac + clomazone at 0.56 lb/ac. Herbicide treatments were applied with a compressed

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air-pressurized Bowman MudMaster-mounted sprayer calibrated to deliver 15 gallons/acre using Teejet® AIXR 11002 nozzles traveling 3.5 mph. Visual herbicide efficacy data were subjected to an analysis of variance, and means were separated by Fisher's protected least significant difference test with a *P*-value of 0.05.

Results and Discussion

Generally, most herbicide treatments provided greater than 90% control of barnyardgrass at 7 DAEPOST, except for the lowest rate of fenoxaprop and cyhalofop at 0.28 lb/ac + clomazone, with 79% and 71% control, respectively (Table 1). At this evaluation, there was little to no influence from clomazone compared to fenoxaprop applied alone. By 14 DAEPOST, the control of barnyardgrass decreased to an average of 83% in fenoxaprop treatments lacking a residual herbicide tank mixture. (Table 2). Conversely, all treatments tank-mixed with clomazone continued to provide greater than 90%, which indicates a positive influence from residual activity. Following the MPOST application, herbicide efficacy from fenoxaprop at 0.086 and 0.109 lb/ac applied alone had continued to decrease to less than 70% control of barnyardgrass (Table 3). Fenoxaprop at 0.068 lb/ac followed by a subsequent application of fenoxaprop at 0.068 lb/ac had a slight increase in control over that of fenoxaprop treatments without a subsequent application. Additionally, fenoxaprop treatments tank-mixed with clomazone continued to provide greater than or equal to 90% control of barnyardgrass, regardless of the rate of fenoxaprop. When applied alone, fenoxaprop treatments continued to lack effective control of barnyardgrass at 25 DAMPOST (Table 4). An increase in control was observed with subsequent applications of fenoxaprop applied at 0.068 lb/ac, with 92% control of barnyardgrass. Additionally, comparable control was observed from all treatments tank-mixed with clomazone, with those treatments providing greater than 90% control (Table 4).

Practical Applications

Based on these data, acetyl-CoA carboxylase-inhibiting herbicides such as fenoxaprop can still provide effective control of barnyardgrass when implemented into an effective herbicide program in a furrow-irrigated rice production scenario. Although subsequent and timely applications of fenoxaprop were shown to provide comparable barnyardgrass control to fenoxaprop when mixed with a residual herbicide, the use of multiple herbicide modes of action will be more beneficial in reducing the chances of continued herbicide resistance evolving in barnyardgrass populations. Furthermore, the addition of a residual herbicide will provide flexibility in a field-scale production system and will more likely ensure a timely secondary application.

Acknowledgments

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Table 1. Visual barnyardgrass control 7 days after the early postemergence (EPOST) application in Rohwer, Ark.

Treatments[a]	Rate(s)	Rate(s)	Application timing	7 DAEPOST[b]
	lb/ac	fl. oz/ac		------------%----------
Nontreated control				0
Fenoxaprop	0.086	19	EPOST	90
Fenoxaprop	0.109	24	EPOST	90
Fenoxaprop	0.068	15	EPOST	79
Fenoxaprop + Clomazone	0.068 + 0.56	15 + 24	EPOST	91
Fenoxaprop + Clomazone	0.068 +0.56	15 + 24	EPOST	90
Fenoxaprop + Clomazone	0.109 + 0.56	24 + 24	EPOST	93
Cyhalofop + Clomazone	0.28 + 0.56	15 + 24	EPOST	71
LSD (P = 0.05)				9

[a] All herbicide treatments had a preemergence application of halosulfuron-methyl + prosulfuron plus saflufenacil. All postemergence applications were tank-mixed with a 1% v/v of crop oil concentrate.
[b] DAEPOST = days after the EPOST application.

Table 2. Visual barnyardgrass control 14 days after the early postemergence (EPOST) application in Rohwer, Ark.

Treatments[a]	Rate(s)	Rate(s)	Application timing	14 DAEPOST[b]
	lb/ac	fl. oz/ac		------------%-----------
Nontreated control				0
Fenoxaprop	0.086	19	EPOST	82
Fenoxaprop	0.109	24	EPOST	82
Fenoxaprop	0.068	15	EPOST	85
Fenoxaprop + Clomazone	0.068 + 0.56	15 + 24	EPOST	92
Fenoxaprop + Clomazone	0.068 + 0.56	15 + 24	EPOST	91
Fenoxaprop + Clomazone	0.109 + 0.56	24 + 24	EPOST	92
Cyhalofop + Clomazone	0.28 + 0.56	15 + 24	EPOST	90
LSD (P = 0.05)				8

[a] All herbicide treatments had a preemergence application of halosulfuron-methyl + prosulfuron plus saflufenacil. All postemergence applications were tank-mixed with a 1% v/v of crop oil concentrate.
[b] DAEPOST = days after the EPOST application.

Table 3. Visual barnyardgrass control 6 days after the mid postemergence (MPOST) application in Rohwer, Ark.

Treatments[a]	Rate(s)	Rate(s)	Application timing	6 DAMPOST[b]
	lb/ac	fl. oz/ac		------------%-----------
Nontreated control				0
Fenoxaprop	0.086	19	EPOST	67
Fenoxaprop	0.109	24	EPOST	65
Fenoxaprop fb Fenoxaprop	0.068 fb 0.068	15 fb 15	EPOST fb MPOST	78
Fenoxaprop + Clomazone fb Fenoxaprop + Clomazone	0.068 + 0.56 fb 0.068 + 0.56	15 + 24 fb 15 + 24	EPOST fb MPOST	91
Fenoxaprop + Clomazone fb Fenoxaprop + Clomazone	0.068 + 0.56 fb 0.068 + 0.56	15 + 24 fb 15 + 24	EPOST fb MPOST	90
Fenoxaprop + Clomazone	0.109 + 0.56	24 + 24	EPOST	90
Cyhalofop + Clomazone	0.28 + 0.56	15 + 24	EPOST	86
LSD (*P* = 0.05)				11

[a] All herbicide treatments had a preemergence application of halosulfuron-methyl + prosulfuron plus saflufenacil. All postemergence applications were tank-mixed with a 1% v/v of crop oil concentrate.
[b] DAMPOST = days after mid postemergence, EPOST = early postemergence, fb = followed by.

Table 4. Visual barnyardgrass control 25 days after the mid postemergence (MPOST) application in Rohwer, Ark.

Treatments[a]	Rate(s)	Rate(s)	Application timing	25 DAMPOST[b]
	lb/ac	fl. oz/ac		------------%-----------
Nontreated control				0
Fenoxaprop	0.086	19	EPOST	66
Fenoxaprop	0.109	24	EPOST	79
Fenoxaprop fb Fenoxaprop	0.068 fb 0.068	15 fb 15	EPOST fb MPOST	92
Fenoxaprop + Clomazone fb Fenoxaprop + Clomazone	0.068 + 0.56 fb 0.068 + 0.56	15 + 24 fb 15 + 24	EPOST fb MPOST	95
Fenoxaprop + Clomazone fb Fenoxaprop + Clomazone	0.068 + 0.56 fb 0.068 + 0.56	15 + 24 fb 15 + 24	EPOST fb MPOST	93
Fenoxaprop + Clomazone	0.109 + 0.56	24 + 24	EPOST	92
Cyhalofop + Clomazone	0.28 + 0.56	15 + 24	EPOST	91
LSD (*P* = 0.05)				7

[a] All herbicide treatments had a preemergence application of halosulfuron-methyl + prosulfuron plus saflufenacil. All postemergence applications were tank-mixed with a 1% v/v of crop oil concentrate.
[b] DAMPOST = days after mid postemergence, EPOST = early postemergence, fb = followed by.

Comparison of Highcard and Provisia Efficacy in Arkansas Rice

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Abstract

In recent years, Arkansas rice (*Oryza sativa* L.) producers have faced many challenges in reducing the evolution of weed resistance to rice herbicides. Max-Ace® and Provisia® rice systems enable the use of quizalofop-p-methyl to control problematic grass weeds like barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv]. A field experiment was conducted in 2023 in Rohwer, Ark, to evaluate the efficacy of Highcard® (quizalofop-p-ethyl plus isoxadifen) and Provisia® (quizalofop-p-ethyl) herbicides applied at varying rates and timings. Herbicide programs consisted of Provisia® and Highcard® applied at the early postemergence (EPOST), mid postemergence (MPOST), or late postemergence (LPOST) timing at rates of either 10 or 15.5 oz/ac. Seven days after the EPOST application, Provisia® at 15.5 oz/ac provided the highest control of barnyardgrass over all other treatments, with 81% control. Following the LPOST application, all herbicide programs provided greater than or equal to 85% control of barnyardgrass, except for the program containing three subsequent application rates of Highcard® at 10 oz/ac. Within three weeks, Highcard® at 15.5 oz/ac followed by Highcard® at 15.5 oz/ac failed to effectively control barnyardgrass, whereas Provisia® applied at the same rate and timings controlled barnyardgrass up to 95%. Initially, a gradual increase in control of Amazon sprangletop (*Leptochloa panicoides* L.) was observed from all herbicide programs. Twenty days after the LPOST application, all herbicide programs provided 99% control of Amazon sprangletop. Although Highcard® and Provisia® have the same active ingredient, Highcard® failed to provide season-long control of barnyardgrass over that of programs containing Provisia®. Additionally, the incorporation of Provisia® into an herbicide program containing residual herbicides would be necessary to reduce the further evolution of herbicide resistance in problematic weeds.

Introduction

In a recent survey, barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv] was reported to be the most troublesome weed observed by Arkansas rice (*Oryza sativa* L.) producers (Butts et al. 2022). This is due to the increase of herbicide-resistant barnyardgrass populations being found across the state (Heap, 2024). Herbicide-resistant rice varieties, such as Provisia® and Max-Ace® rice, are useful tools in combatting herbicide-resistant weeds (Smith et al., 2022). Provisia® and Max-Ace® rice varieties are resistant to quizalofop-ethyl, an acetyl-CoA carboxylase-inhibiting herbicide that is used to control grass species in rice. Although both rice systems are resistant to the same active ingredient, Max-Ace® utilizes the quizalofop-p-ethyl formulation Highcard®, which contains the safener isoxadifen (Shen et al., 2017), whereas the Provisia® formulation of quizalofop-p-methyl lacks the safeners.

Procedures

A field experiment was conducted in 2023 in Rohwer, Ark, to evaluate the herbicide efficacy of Highcard® and Provisia® herbicides applied at varying rates and timings. Barnyardgrass and Amazon sprangletop (*Leptochloa panicoides* L.) visual controls were evaluated in this experiment. The experiment was set up as a randomized complete block design. Provisia® PVL03 rice and MaxAce® RT7331MA rice cultivars were drilled at 35 lb/ac with four replications for their respective treatments, in plot sizes of 12.7 ft by 30 ft. Visual efficacy ratings were taken at 7 days after the early postemergence (EPOST) timing, 7 days after the mid-postemergence (MPOST) timing, and 3, 11, and 20 days after the late postemergence (LPOST) timing. All treatments were compared to a nontreated control to determine the effectiveness of each treatment. A standard application of halosulfuron-methyl + prosulfuron (Gambit®) + saflufenacil (Sharpen®) was applied preemergence across all programs in this experiment to reduce the presence of sedges and broadleaf weeds. Herbicide programs consisted of Provisia (quizalofop-p-ethyl) and Highcard (quizalofop-p-ethyl + isoxadifen) applied at the early postemergence (EPOST) (3-leaf barnyardgrass (BYG)), mid postemergence (MPOST) (4- to 5-leaf BYG), or late postemergence (4- to 5-leaf BYG) timing at rates of either 10 or 15.5 oz/ac. Additionally, herbicide programs were applied with a 1% v/v ratio of crop oil concentrate. Herbicide programs were applied with a compressed air-pressurized Bowman MudMaster-mounted sprayer calibrated to deliver 15 GPA using Teejet® AIXR 11002 nozzles traveling 3.5 mph. Visual herbicide efficacy data were subjected to an analysis of variance, and means were separated by Fisher's protected least significant difference test with a *P*-value of 0.05.

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Results and Discussion

Overall, greater control of barnyardgrass was observed throughout the season, with Provisia® at 15.5 oz/ac followed by Provisia® at 15.5 oz/ac (Table 1). Initially, at 7 days after the EPOST application, Provisia® at 15.5 oz/ac provided 81% control of barnyardgrass, whereas all remaining treatments failed to provide greater than 74% control. Following the LPOST application, comparable control of barnyardgrass greater than 85% was observed from all programs except for the program containing three subsequent applications of Highcard® at 10 oz/ac (Table 1). A decrease in control (71%) was observed from Highcard® at 15.5 oz/ac followed by Highcard® at 15.5 oz/ac by 20 days after the LPOST application, while Provisia® applied at the same rate and timing provided 95% control of barnyardgrass. Generally, Amazon sprangletop control was higher in programs containing Provisia® than those treatments containing Highcard® at 7 days after the EPOST application (Table 2). Regardless of the herbicide applied, a gradual increase in Amazon sprangletop control was observed as subsequent applications of quizalofop at the lower rate were applied. By 20 days after the LPOST application, all herbicide programs provided 99% control of Amazon sprangletop (Table 2).

Practical Applications

These findings suggest that Provisia®, when incorporated into an herbicide program, can provide effective control of herbicide-resistant barnyardgrass in Arkansas rice. Although Highcard® and Provisia® have the same active ingredient, Highcard® failed to provide sufficient control of these problematic grass species throughout the season, regardless of the rate used or number of applications. Due to the use of multiple applications of the same herbicide, residual herbicides such as Command, Prowl, and Bolero should be utilized in a program approach to reduce multiple flushes of troublesome grass species. Integrated weed management practices will be crucial in reducing the evolution of herbicide resistance in these grass species.

Acknowledgments

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Table 1. Visual barnyardgrass control rated at 7 days after early postemergence (EPOST), 6 days after mid postemergence (MPOST), and 3, 11, and 20 days after the late postemergence (LPOST) application in Rohwer, Ark.

Treatments[a]	Rate(s)	Application Timing	Evaluation Timings				
			7 EPOST	6 MPOST	3 LPOST	11 LPOST	20 LPOST
	fl. oz/ac		---------------	---------------	%	---------------	---------------
Nontreated control			0	0	0	0	0
Provisia® fb Provisia®	15.5 15.5	EPOST MPOST	81	88	88	97	95
Highcard® fb Highcard®	15.5 15.5	EPOST MPOST	69	80	90	86	71
Highcard® fb Highcard® fb Highcard®	10 10 10	EPOST MPOST LPOST	63	71	70	70	68
Provisia® fb Provisia® fb Provisia®	10 10 10	EPOST MPOST LPOST	74	81	86	90	88
LSD (*P* = 0.05)			9.0	8.5	12.8	8.0	15.5

[a] All postemergence applications were tank-mixed with 1% v/v ratio of crop oil concentrate. All herbicide treatments had a preemergence application of halosulfuron-methyl + prosulfuron plus saflufenacil.

Table 2. Visual Amazon sprangletop control rated at 7 days after early postemergence (EPOST), 6 days after mid postemergence (MPOST), and 3, 11, and 20 days after the late postemergence (LPOST) application in Rohwer, Ark.

Treatments[a]	Rate(s)	Application Timing	Evaluation Timings				
			7 EPOST	6 MPOST	3 LPOST	11 LPOST	20 LPOST
	fl. oz/ac		---------------	---------------	%	---------------	---------------
Nontreated control			0	0	0	0	0
Provisia® fb Provisia®	15.5 15.5	EPOST MPOST	90	94	89	99	99
Highcard® fb Highcard®	15.5 15.5	EPOST MPOST	75	89	95	99	99
Highcard® fb Highcard® fb Highcard®	10 10 10	EPOST MPOST LPOST	76	85	80	99	99
Provisia® fb Provisia® fb Provisia®	10 10 10	EPOST MPOST LPOST	84	91	90	99	99
LSD (*P* = 0.05)			13.5	7.7	13.7	1.0	1.0

[a] All postemergence applications were tank-mixed with 1% v/v ratio of crop oil concentrate. All herbicide treatments had a preemergence application of halosulfuron-methyl + prosulfuron plus saflufenacil.

Quantifying the Interference of Palmer amaranth in Furrow-Irrigated Rice

T.A. King,[1] J.K. Norsworthy,[1] T.H Avent,[1] S.L. Pritchett,[1] L.T. Barber,[2] and T.R. Butts,[2]

Abstract

Furrow-irrigated rice (*Oryza sativa* L.) (FIR) acres are increasing in Arkansas, and the lack of a continual flood creates challenges for producers to prevent weed emergence. The absence of a sustained flood allows Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] emergence throughout most of the growing season and creates a conducive environment for growth and development of the weed. Palmer amaranth escaping control in a FIR system may increase the potential for reduced rice yields and a greater need for additional in-season herbicide applications. A field trial was conducted at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., during the 2022 and 2023 growing seasons to evaluate the impact of Palmer amaranth on FIR. Cotyledon Palmer amaranth plants were marked every 7 days, beginning 1 week prior to rice emergence through 4 weeks after rice emergence. End-of-season Palmer amaranth biomass decreased exponentially every 7 days that emergence of the weed was delayed relative to rice. On average, female Palmer amaranth plants that emerged one week prior to the emergence of rice produced 463,000 seeds per plant, while Palmer amaranth plants that emerged the week after rice produced 50,000 seeds per plant. Palmer amaranth plants that emerged 1 week prior to rice reduced rough rice yield by more than 80% within 6 inches from the weed. The timing of Palmer amaranth emergence relative to rice is a crucial factor influencing rough rice yield potential and biomass and seed production of the weed.

Introduction

In Arkansas, rice (*Oryza sativa* L.) is predominantly grown in a continuous flood, but furrow-irrigated rice (FIR) acres have increased by 20-fold increase since 2015 (Hardke et al., 2022). In a FIR system, the absence of a sustained flood creates a favorable environment for weed emergence and development throughout the entire growing season (Bagavathiannan et al., 2011). In a conventional paddy rice system, Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] is the 5th most problematic weed, but it becomes the 2nd most problematic weed in a FIR system (Butts et al., 2022). Palmer amaranth can heavily infest a field quickly due to its ability to produce a large number of seeds and cross-pollinate with other *Amaranthus* species (Keeley et al., 1987; Norsworthy et al., 2014). In the United States (U.S.), Palmer amaranth is resistant to 9 different sites of action (SOA) (Heap, 2024). Previous research has documented the negative yield impacts associated with Palmer amaranth emergence in corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and cotton (*Gossypium hirsutum* L.); however, there is currently no data on the impact of Palmer amaranth on rice yields. With herbicide resistance being rampant and the ability for Palmer amaranth to compete in other crops, this weed has the potential to negatively affect FIR yields. Palmer amaranth emerging with corn has been shown to reduce yields by 91%, indicating that Palmer amaranth time of emergence is associated with crop yield loss (Massinga et al., 2001). Additionally, it has been reported that competition, in terms of crop yield loss, is diminished when weed emergence occurs after that of the crop (Swanton et al. 2015).

Procedures

A field experiment was conducted in 2022 and 2023 at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., to determine the relationship between Palmer amaranth time of emergence and Palmer amaranth seed production, biomass, and rough rice yields in a FIR system. A hybrid rice cultivar (RT 7321FP) was drill-seeded at 11 seeds/ft of row on a 7.5-in. row, and the trial was irrigated using standard FIR methods. Clomazone was applied across the experimental area preemergence (PRE) at 0.3 lb ai/ac. Ten Cotyledon stage Palmer amaranth plants were randomly marked each week, starting one week prior to rice emergence through four weeks after rice emergence. In order to help mitigate competition from adjacent weeds, all marked Palmer amaranth plants were a minimum of 16 ft apart. Additionally, marked Palmer amaranth plants were covered while the trial was oversprayed with non-residual herbicides to remove undesirable weed species while still allowing new Palmer amaranth to emerge. All Palmer amaranth heights and aboveground biomass of surviving plants were collected during rice harvest. Seed production was determined for each female Palmer amaranth plant by counting 200 seeds from three plants at each emergence timing. The average weight of 200 seeds was then used to calculate the seed production for each corresponding emergence period. At each marked plant, rough rice yield was collected using hand-held rice knives and a ladder made out of polyvinyl chloride (PVC) pipe with dimensions 1 ft wide by 1 ft long per quadrat that totaled 8 ft long. Yields were collected in each individual quadrat in two directions to assess yield as a function of

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distance from each Palmer amaranth plant. All data were analyzed using JMP Pro 17.0 (SAS Institute, Cary, N.C.). Palmer amaranth seed production by biomass was linearly regressed. A logistic 3 parameter (L3P) curve was utilized to determine the relationship between yield and distance to Palmer amaranth plants. The two different directions for each plant were pooled, and separate models were built for each week of emergence. Inverse predictions based on each model were utilized to determine Palmer amaranth's influence on rough rice yield. All other data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference using an alpha value of 0.05.

Results and Discussion

Palmer amaranth seed production and biomass were influenced by time of emergence relative to the crop. Palmer amaranth biomass decreased exponentially as its emergence was delayed from one week prior to the emergence of the crop to one week after the crop (data not shown). Likewise, as Palmer amaranth emergence was delayed, seed production was reduced by 89% when comparing plants that emerged one week prior to rice to those that emerged one week after rice (Fig. 1). There was a strong, positive relationship between Palmer amaranth biomass and Palmer amaranth seed production (Fig. 2), which is supported by previous literature finding a strong correlation between the biomass of the weed and number of seed produced in soybean production systems (Schwartz et al., 2016). Although a significant reduction in weed seed set is desirable, the quantity of seed being produced 1 week after the emergence of the rice crop still poses the potential for abundant weed seed carryover into the soil seedbank, affecting weed management strategies in subsequent years.

Additionally, there was rice yield loss as a function of distance from Palmer amaranth plants for each evaluated time of emergence. All Palmer amaranth plants that emerged within 4 weeks of rice emergence had a negative impact on the crop. Palmer amaranth that emerged 1 week prior to the emergence of the crop reduced yield by 100%, 81%, 57%, 28%, and 10% at distances of 0, 6, 12, 18, and 24 in. from the weed (Fig. 3). Similarly, at distances of 0, 6, 12, 18, and 24 in. from the plant, Palmer amaranth that emerged with the crop reduced rice yields by 100%, 81%, 57%, 30%, and 12%, respectively (Fig. 3). Yield loss was reduced when Palmer amaranth emerged 1 week after the emergence of the crop, considering the highest yield loss was 45% at 6 in. away from the weed (Fig. 3). For all emergence timings, the established rice in the immediate area (0–12 in.) surrounding the weed had yield losses greater than 21%; however, maximum yield potential, assuming a 95% yield protection, was not achieved until 30 inches from the Palmer amaranth plants, suggesting that the area of influence is 19.6 ft^2. These results lead to the conclusion that Palmer amaranth time of emergence is a critical factor influencing rough rice yields.

Practical Applications

Using a zero-tolerance approach for Palmer amaranth is critical for maximizing rough rice yields along with long-term seedbank management. Allowing even a few Palmer amaranth plants to survive until harvest can have detrimental effects, like weed seed dispersal. Producers should be cognizant of the potential negative impact on the soil seedbank and the long-term costs associated with Palmer amaranth escapes at harvest. Additionally, Palmer amaranth that emerges after the crop still negatively affects rice yields; therefore, applying residual herbicides, such as pendimethalin and saflufenacil, would prove beneficial by delaying Palmer amaranth emergence to reduce potential rice yield loss and biomass and seed production of the weed.

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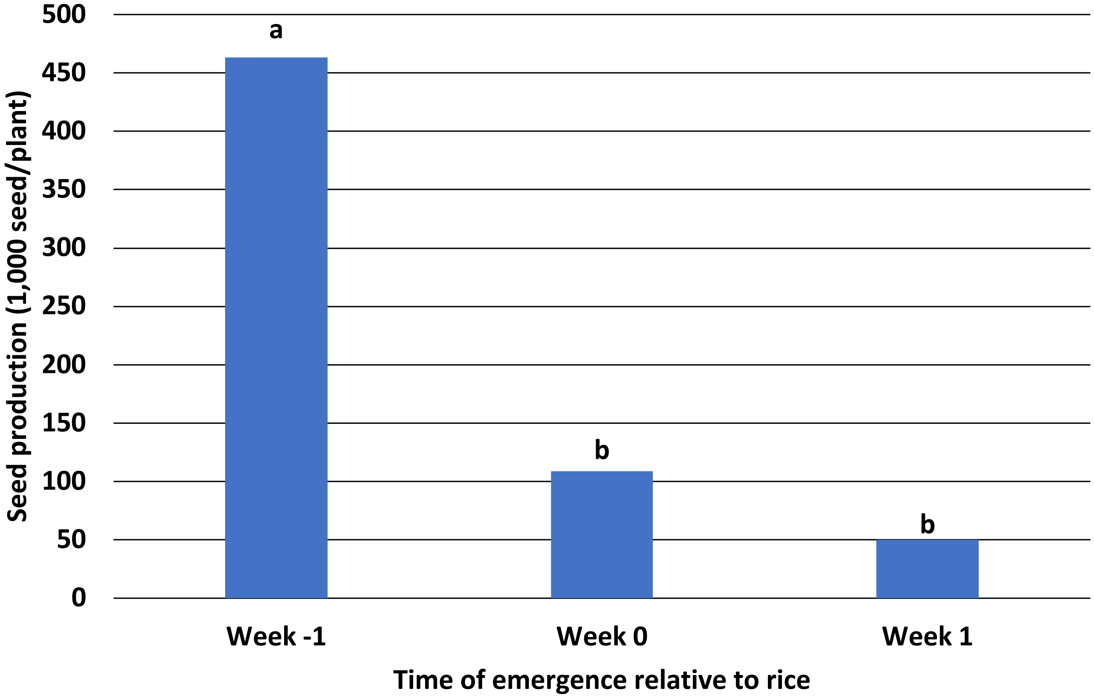

Fig. 1. Influence of Palmer amaranth emergence on seed production in Fayetteville, Arkansas, 2022 and 2023. Treatments with the same lowercase letter are not different according to Fisher's protected least significant difference at α = 0.05.

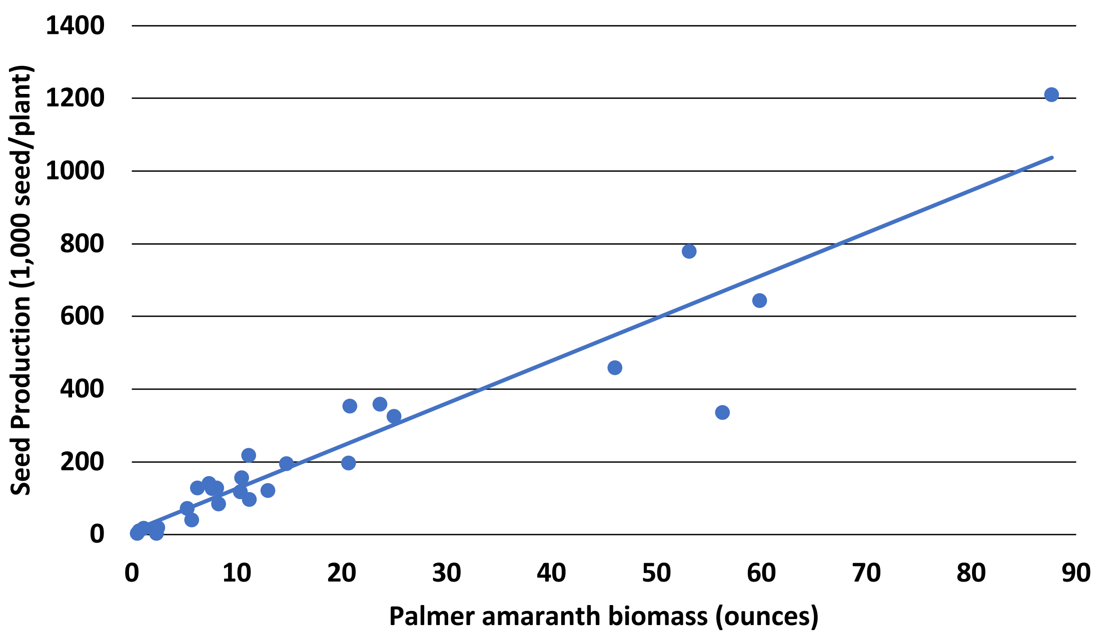

Fig. 2. Relationship between Palmer amaranth biomass and seed production in Fayetteville, Arkansas, 2022 and 2023.

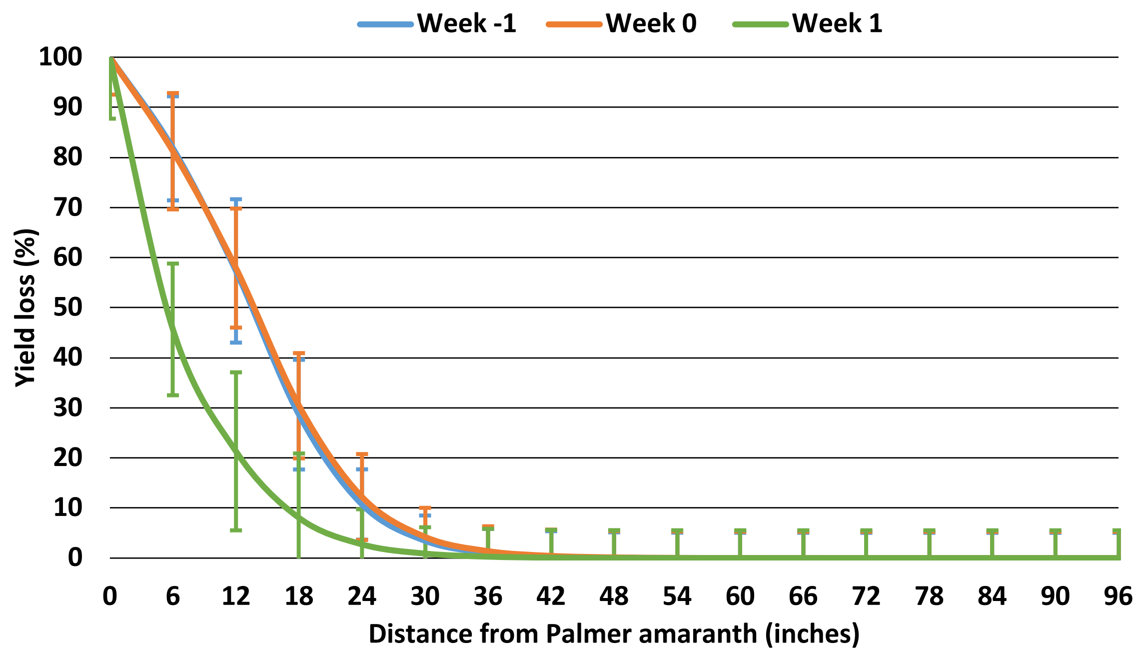

Fig. 3. Rough rice yield loss (%) as a function of distance from Palmer amaranth in Fayetteville, Arkansas, 2022 and 2023.

Rice Tolerance to Postemergence Applications of Herbicides Mixed with Fluridone

J.T. Smith,[1] J.K. Norsworthy,[1] M.C.C.R Souza,[1] T.A. King,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

The labeling of fluridone in rice (*Oryza sativa* L.) adds a new residual herbicide with both grass and broadleaf activity to the rice herbicide portfolio. Fluridone must be applied postemergence (POST) to rice but has little to no POST activity, so it is likely to be applied in conjunction with other herbicides to control weeds present at the time of application. Therefore, this study was conducted to evaluate the tolerance of rice to POST applications of herbicides mixed with fluridone. This experiment was conducted twice, once in 2022 and again in 2023, at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Arkansas. Mixtures of fluridone with fenoxaprop, quizalofop, propanil, saflufenacil, penoxsulam, bispyribac-sodium, and quinclorac were compared to applications of each of the previous herbicides applied alone. Applications were made to 3-leaf rice, and visual rice injury was rated 1, 3, and 5 weeks after treatment (WAT). Rough rice grain yield was collected at maturity. In 2022, the only differences in injury were observed 1 WAT. At this timing, mixtures of fluridone with penoxsulam, bispyribac-sodium, and quinclorac increased rice injury 20, 12, and 16 percentage points, respectively, compared to applications of the herbicides alone. In 2023, fluridone mixed with quizalofop increased injury by 6 percentage points 3 WAT compared to an application of solely quizalofop. At 5 WAT, mixtures of fluridone with fenoxaprop, quizalofop, propanil, saflufenacil, penoxsulam, and bispyribac-sodium increased injury 14, 10, 10, 8, 14, and 15 percentage points, respectively, compared to independent applications of these herbicides. Across both years of this study, mixing fluridone with other herbicides reduced yield in three instances and increased yield in one instance compared to applications of the herbicides alone. However, no treatments differed from the weed-free control according to Dunnett's procedure. While the labeling of fluridone in rice is still in its infancy, growers should be cautious when tank-mixing with fluridone.

Introduction

Fluridone is a HRAC/WSSA group 12 herbicide and has recently been labeled for use in rice under the trade name Brake® (SePRO Corporation, 11550 North Meridian Street Suite 600, Carmel, Ind.). Previously, this herbicide has been used to manage aquatic vegetation and to control a range of annual grasses and small seeded broadleaves in cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.). The labeling of fluridone in rice presents an exciting opportunity for rice growers as it adds a residual herbicide with a site of action novel to the rice weed control portfolio. This will allow growers to further diversify their weed control program, a tactic known to help combat herbicide resistance evolution (Norsworthy et al., 2012). Fluridone is known to provide effective residual control of Palmer amaranth [*Amaranthus palmeri* S. Wats] and will be especially useful in furrow-irrigated rice systems where this weed is of major concern (Braswell et al., 2016; Butts et al., 2022).

The label states that this herbicide should not be applied to rice prior to the 3-leaf stage; however, fluridone will not control weeds that have already emerged at the time of application. Therefore, it is likely to be recommended that fluridone be applied in concert with other postemergence (POST) herbicides. Research is needed to determine safe tank-mix partners that will not cause excessive injury or yield loss to rice.

Procedures

A field experiment was conducted in 2022 and then repeated in 2023 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Arkansas, to evaluate the tolerance of rice to early POST applications of fluridone alone or in a mix with other POST herbicides. Treatments included the following herbicides applied alone or mixed with fluridone to 3-leaf rice: fenoxaprop-p-ethyl, quizalofop-p-ethyl, propanil, saflufenacil, penoxsulam, bispyribac-sodium, and quinclorac (Table 1). Two additional treatments, one receiving no 3-leaf application and another receiving a 3-leaf application of fluridone alone, were also included. All applications were made at the recommended rates to Max-Ace® (RTv 7231 MA) rice drill seeded at 16 seeds/ft. In 2022, rice was planted on 12 May, and in 2023, rice was planted on 11 April. Plots were 6 ft wide by 17 ft long and received a preemergence application of clomazone and a preflood application of quizalofop for weed control. In both years, additional applications of rice POST herbicides were made as needed to keep the trial weed-free. This trial was designed as a randomized complete block with four replications. Visual crop injury was recorded 1, 3, and 5 weeks after treatment (WAT) on a scale from 0 to 100, with 0 being no injury and 100 being plant mortality (Frans et al., 1986). Rough rice grain yield was recorded at maturity. The means of each set of treatments with

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or without fluridone were compared using a two-sample *t*-test in JMP Pro 17.0 with an alpha value of 0.05. The means of each treatment were also compared to the weed-free control using Dunnett's procedure.

Results and Discussion

In 2022, rice herbicides applied alone caused injury ranging from 7% with fenoxaprop to 79% with saflufenacil 1 WAT (Table 2). In most cases, the addition of fluridone did not significantly increase injury, but injury did increase by 20, 12, and 16 percentage points when applied with penoxsulam, bispyribac-sodium, and quinclorac, respectively. At 3 and 5 WAT, there were no differences in injury when herbicides were applied alone or with fluridone. Differences in rough rice grain yield were only observed when fluridone was applied with propanil or saflufenacil (Table 3). When applied with propanil, fluridone reduced yield by 26% compared to propanil applied alone. Plots sprayed with the mixture of saflufenacil and fluridone yielded 22% higher on average than plots sprayed with saflufenacil alone. Though differences in yield were observed among the use of saflufenacil and propanil separately or in combination with fluridone, no treatment mean was different from the weed-free control according to Dunnett's procedure.

In 2023, there were no differences in injury when herbicides were applied alone or with fluridone 1 WAT (Table 2). At 3 WAT, fluridone only increased injury when applied with quizalofop, exhibiting injury 6 percentage points higher than quizalofop alone. At 5 WAT, fluridone applied alone increased injury by 13 percentage points compared to the weed-free control. Fluridone applied with fenoxaprop, quizalofop, propanil, saflufenacil, penoxsulam, or bispyribac-sodium increased injury by 14, 10, 10, 8, 14, or 15 percentage points, respectively, compared to applications of these herbicides alone 5 WAT. Despite these increases in injury, only mixes of fluridone with fenoxaprop or penoxsulam had a negative impact on rough rice grain yield, decreasing yield by 22% and 18%, respectively, compared to applications of these herbicides alone (Table 3). However, similar to the 2022 results, no treatment mean differed from the weed-free control according to Dunnett's procedure.

Practical Applications

The labeling of fluridone in rice provides a new site of action for growers to control a variety of grasses and small seeded broadleaves. Fluridone applied alone has been shown to have no negative impact on yield; however, compared to applications of the herbicides alone, yield decreases were observed when fluridone was mixed with fenoxaprop, propanil, and penoxsulam. These results lacked consistency across 2022 and 2023, so these herbicides cannot be definitively excluded as mix partners for fluridone. Nevertheless, growers need to exercise caution when tank-mixing with fluridone until more research is conducted into safe combinations.

Acknowledgments

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Table 1. List of herbicides, their trade name, and the rate applied.

Active Ingredient	Trade Name	Rate
		(oz/ac)
Clomazone[a]	Command 3ME	12.8
Fluridone	Brake	16
Fenoxaprop-p-ethyl	Ricestar HT	24
Quizalofop-p-ethyl[b]	Highcard	15.5
Propanil	Stam M4	128
Saflufenacil	Sharpen	2
Penoxsulam	Grasp SC	2.3
Bispyribac-sodium	Regiment	0.57
Quinclorac	Facet L	43

[a] The entire experiment received a preemergence application of clomazone.
[b] Quizalofop-p-ethyl was included as a 3-leaf treatment but was also applied preflood to the entire experiment.

Table 2. Visual rice injury from 3-leaf applications of herbicides alone (-) or with fluridone (+) 1, 3, and 5 weeks after treatment (WAT) from 2022 and 2023 near Colt, Arkansas.

	Crop Injury								
	1 WAT			3 WAT			5 WAT		
Herbicide	-	+		-	+		-	+	
	(%)								
2022									
-	7[a]	11		2	2		0	0	
Fenoxaprop-p-ethyl	7	16		2	1		0	0	
Quizalofop-p-ethyl	10	19		2	0		0	0	
Propanil	19	28		1	3		0	0	
Saflufenacil	79	80		18	13		6	5	
Penoxsulam	9	29	*[b]	1	3		0	0	
Bispyribac-sodium	10	22	*	2	2		0	0	
Quinclorac	9	25	*	1	1		0	0	
2023									
-	10	12		6	8		5	18	*
Fenoxaprop-p-ethyl	13	13		6	9		6	20	*
Quizalofop-p-ethyl	16	15		10	16	*	11	21	*
Propanil	12	14		7	10		8	18	*
Saflufenacil	33	36		25	26		18	26	*
Penoxsulam	11	12		7	8		11	25	*
Bispyribac-sodium	13	16		11	14		13	28	*
Quinclorac	11	14		9	9		8	8	

[a] Injury in the weed-free control was caused by the preemergence application of clomazone.
[b] Pairs of means followed by * are different at $P = 0.05$ based on a two-sample T-test.

Table 3. Rough rice grain yield after 3-leaf applications of herbicides alone (-) or with fluridone (+) in 2022 and 2023 near Colt, Arkansas.

	Rough rice grain yield					
	2022			2023		
Herbicide	-	+		-	+	
	(bu./ac)			(bu./ac)		
-	194[a]	217		214	192	
Fenoxaprop-p-ethyl	225	214		223	175	*
Quizalofop-p-ethyl	216	229		186	184	
Propanil	242	192	*[b]	225	198	
Saflufenacil	173	222	*	196	180	
Penoxsulam	207	216		228	186	*
Bispyribac-sodium	212	235		201	179	
Quinclorac	226	220		216	198	

[a] In both years, no treatment had a mean different from the weed-free control according to Dunnett's procedure.

[b] Pairs of means followed by * are different at $P = 0.05$ based on a two-sample T-test.

Effect of Fluridone Application Timing on Rice Tolerance

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Abstract

The increasing adoption of furrow-irrigated rice (*Oryza sativa* L.) has contributed to an increased occurrence of (*Amaranthus palmeri* S. Wats.) in rice fields. Furthermore, Palmer amaranth has evolved resistance to herbicides targeting nine sites of action. Fluridone (Brake®) is an effective Palmer amaranth herbicide labeled for rice use in 2023. However, additional research is needed to evaluate rice tolerance to this herbicide. This study aimed to evaluate the influence of application timing on rice tolerance to fluridone. Experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas, in 2022 and 2023. Experiments were organized as a randomized complete block design with 4 replications per treatment. Treatments included a weed-free control for comparison and 10 application timings [20 and 10 days preplant, preemergence (PRE), delayed-preemergence (DPRE), 1-leaf, 2-leaf, 3-leaf, 4-leaf, tillering, and immediately after flooding (post-flood)]. At all timings, fluridone was applied at 0.15 lb/ac (Brake® at 16 fl oz/ac). Visual injury ratings were collected weekly, and rough rice grain yield was determined at harvest. At 3 weeks after emergence (WAE), the injury did not exceed 5% in 2022. In contrast, PRE and DPRE treatments caused up to 30% injury to rice in 2023. At 10 WAE, the greatest injury levels in 2022 were displayed by rice treated PRE and DPRE, with 31%, comparable to the 1-leaf (26%) application. In 2023, a PRE application caused the greatest injury at 39%. In 2022, the yield obtained from rice treated 20 and 10 days preplant, 4-leaf, tillering, and post-flood were comparable to the weed-free control. In 2023, except for the PRE application, all other treatments resulted in rice yield comparable to the weed-free control. These results indicate that application timing influences rice tolerance to fluridone, and rice is more prone to injury from this herbicide in early applications, especially preemergence.

Introduction

The increasing occurrence of Palmer amaranth (*Amaranthus palmeri* S. Wats.) infestations poses a significant challenge in furrow-irrigated rice (*Oryza sativa* L.) fields in Arkansas. The increased adoption of the furrow-irrigated system, now constituting approximately 20% of the total rice acreage in the state (Hardke, 2022), is a primary factor contributing to the higher occurrence of Palmer amaranth as it provides favorable environmental conditions for its growth throughout the season. Moreover, Palmer amaranth has evolved resistance to herbicides targeting nine sites of action, establishing it as one of the two most troublesome weeds in furrow-irrigated rice (Butts et al., 2022; Heap, 2024).

Fluridone (Brake®), classified as a WSSA/HRAC Group 12 herbicide, was registered for use in rice in 2023, introducing a novel site of action to the rice herbicide portfolio. Previously labeled for use in cotton, fluridone exhibits high efficacy for Palmer amaranth control. Preemergence application of fluridone in cotton (*Gossypium hirsutum* L.) at varying rates ranging from 0.15 to 0.2 lb/ac (Brake® at 16-21 fl oz/ac) provided Palmer amaranth control of 86% or more up to six weeks after treatment (Grichar et al., 2020).

While fluridone has shown desirable Palmer amaranth control, it is imperative to conduct additional research to assess rice tolerance under multiple application timings. Therefore, this study aimed to evaluate the influence of application timing on rice tolerance to fluridone.

Procedures

Field experiments were conducted during the 2022 and 2023 rice growing season at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. The field was drill-seeded with a long-grain Provisia® rice variety (PVL02) at a rate of 22 seeds/row ft and a depth of 0.5 in. The plots were 6 ft wide by 17 ft long. The field trial was organized in a randomized complete block design with 10 application timings and a weed-free control as a comparison. Each treatment had 4 replications. Fluridone (Brake 1.2L, SePRO Corporation, Carmel, Ind.) was applied at 0.15 lb/ac (Brake® at 16 fl oz/ac) at the following application timings: 20 and 10 days preplant, preemergence (PRE), delayed-preemergence (DPRE), 1-leaf, 2-leaf, 3-leaf, 4-leaf, tillering, and immediately after flooding. The trial was conducted as a weed-free trial using standard herbicides labeled in rice to avoid weed interference. The herbicides were applied with a 4-nozzle backpack sprayer propelled by CO_2 using AIXR 110015 nozzles at 3 mph, delivering 15 gallons per acre (GPA). Visual crop injury was collected 3 and 10 weeks after emergence (WAE). Injury was rated on a scale of 0 to 100, with 0 being no injury and 100 being plant mortality (Frans et al., 1986).

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Rough rice grain yield was determined at crop maturity. Data were subjected to analysis of variance in JMP Pro 17 (SAS Institute, Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference (α = 0.05).

Results and Discussion

The response of rice to fluridone varied between site years. In 2022, injury to rice did not exceed 5% under any treatment at 3 WAE, and differences were not observed among treatments. In contrast, during the same evaluation period in 2023, injury levels reached up to 30% in the PRE treatment, comparable to the DPRE treatment, with 22% (Table 1). Notably, in 2022, there was a progressive increase in injury over time, with the PRE and DPRE treatments causing the greatest injury levels (31%) at 10 WAE, comparable with the 1-leaf treatment with 26% (Table 1). In 2023, the PRE treatment caused the greatest injury at 39% (Table 1). The observed increase in injury over time may be attributed to the establishment of the flood, which could have potentially reactivated the herbicide. However, in 2023, the increase in injury over time was only observed in treatment PRE.

Consistent with findings by Waldrep and Taylor (1976), this study confirms that soil-applied fluridone tends to induce greater injury than postemergence applications. This pattern was evident in the results, with early applications, especially PRE, causing the most substantial injury to rice. Additionally, the results obtained in this study are similar to research conducted by Martin et al. (2018), where the PRE application of fluridone at 0.2 lb/ac (Brake® at 21 fl oz/ac) resulted in 32% injury to rice at 1 WAE, subsequently decreasing to 25% at 6 WAE.

Rice yield was lower than the weed-free control due to the PRE, DPRE, and 1-leaf treatments in 2022 (Table 1). In 2023, except for the PRE application, all other treatments resulted in rice yields comparable to the weed-free control (Table 1). These results indicate that application timing influences rice tolerance to fluridone, and rice is more prone to injury from this herbicide in early applications, especially PRE.

Practical Applications

Late fluridone applications resulted in lower injury levels, validating the safety of rice when following the recommended application timing at the 3-leaf stage or later. However, yield loss may occur if rice injury manifests after fluridone applications. Fluridone emerges as a promising option for effectively managing Palmer amaranth in rice, particularly for furrow-irrigated systems.

Acknowledgments

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Table 1. Visible injury of Provisia® rice at 3 and 10 weeks after emergence (WAE) and rough rice grain yield as influenced by fluridone application timings.

	Visible injury											
	3 WAE				10 WAE				Grain yield			
Application timing[†]	2022		2023		2022		2023		2022		2023	
	----------------------------%------------------------								---------------bu./ac---------------			
Weed-free control	-		-		-		-		128	ab	137	abc
20 days preplant	3	a[‡]	16	bc	13	c	10	b	120	bcd	148	a
10 days preplant	5	a	7	c	15	bc	1	b	123	abc	139	abc
PRE[§]	2	a	30	a	31	a	39	a	104	de	93	d
DPRE[¶]	1	a	22	ab	31	a	10	b	101	e	138	abc
1-leaf	2	a	14	bc	26	ab	8	b	104	de	139	abc
2-leaf	2	a	15	bc	18	bc	6	b	109	cde	108	cd
3-leaf	2	a	15	bc	19	bc	4	b	109	cde	145	ab
4-leaf	0	a	11	c	13	cd	4	b	119	bcd	122	abcd
Tillering	-		-		12	cd	10	b	127	ab	123	abcd
Post-flood	-		-		4	d	0	d	139	a	112	bcd
P-values	0.0795		0.0430		<0.0001		0.0084		0.0027		0.0286	

[†] All treatments, except for the weed-free control, were sprayed with fluridone at 0.15 lb/ac (Brake® at 16 fl oz/ac).

[‡] Means followed by the same letter within a column are not different according to Fisher's protected least significant difference with α = 0.05.

[§] PRE = preemergence.

[¶] DPRE = delayed-preemergence.

Rice Response to Simulated Sprayer Contamination from a Diflufenican:Metribuzin:Flufenacet Premixture

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Abstract

Palmer amaranth [*Amaranthus palmeri* (S.) Wats] ranks as the most problematic weed across various cropping systems in Arkansas. A possible explanation for why this weed ranks as one of the most difficult to control is its evolution to nine different sites of action. Producers across Arkansas continue to search for new options to control this problematic weed. Bayer CropScience is seeking registration for Convintro™ brand herbicides, one being a three-way premixture (Convintro) that will include the active ingredient diflufenican targeted for use in soybean [*Glycine max* (L.) Merr.]. Diflufenican would add a new site of action for soybean producers across the mid-southern United States. While the targeted use of Convintro is for soybean, additional research is needed to evaluate the sensitivity of adjacently grown crops to postemergence exposure to Convintro. Therefore, an experiment was conducted at the Pine Tree Research Station near Colt, Ark., to evaluate the sensitivity of rice (*Oryza sativa* L.) to low concentrations of Convintro postemergence. Applications of Convintro were made at the 3-leaf growth stage at 0, 0.0015, 0.0062, 0.025, and 0.1 times the maximum use rate. Injury 7 days after treatment (DAT) was greatest for the highest rate of Convintro evaluated. By 28 DAT, no more than 6% injury to rice was observed for all treatments. Rough rice yields were collected at maturity, and no differences were observed. Overall, there does not appear to be a high risk for injury from postemergence exposure of rice to low rates of Convintro.

Introduction

Producers continue to struggle with the control of Palmer amaranth, ranking as the most problematic weed in soybean and cotton (*Gossypium hirsutism* L.) (Van Wychen 2022). Additionally, Palmer amaranth has jumped to the second most problematic weed in furrow-irrigated rice (Butts et al. 2022), having an impact on every major agronomic crop grown in Arkansas. With Palmer amaranth evolving resistance to nine different sites of action (Heap 2024), producers continue to search for new options to control this problematic weed. Bayer CropScience is seeking registration of Convintro brand herbicides, one being a diflufenican:metribuzin:flufenacet (Convintro) premixture targeted for use preemergence in soybean. Diflufenican is a WSSA group 12 herbicide, which would add a new site of action for soybean growers. Diflufenican was first discovered in 1979 and commercialized in the 1980s for use in Europe. In Europe, diflufenican was effective against a wide range of broadleaf weed species (Haynes and Kirkwood 1992) in cereal crops and pastures (Rouchaud et al. 1991). In Arkansas, soybean and rice are typically grown in rotation (Watkins et al. 2004); therefore, there is potential for applications of the premixture to occur near established rice fields due to the wide range of soybean planting dates. With no published data on the sensitivity of rice to low concentrations of Convintro, a field experiment was conducted to help understand rice response to various concentrations.

Procedures

A field experiment was conducted in 2023 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Arkansas, to determine rice sensitivity to postemergence applications of low concentrations of Convintro. A quizalofop-P-resistant cultivar (PVL03) was drill-seeded at 22 seeds per foot of row in 7.5-in.-wide rows into plots measuring 6 ft wide by 17 ft long. The experiment was irrigated and fertilized using standard flooded rice methods in Arkansas. A broadcast application of Facet® L at 32 fl oz/ac was applied preemergence (PRE), and standard rice herbicides were used throughout the growing season to control weeds. The trial was designed as a randomized complete block design with four replications and one factor. The Convintro rates evaluated included 0, 0.0015, 0.0062, 0.025, and 0.1 times the max use rate of 22.8 fl oz/ac. The treatments were applied when the rice reached the 3-leaf growth stage. All applications were made at 3 miles per hour with a $C0_2$-pressurized backpack sprayer calibrated to deliver 15 gallons per acre using AIXR 110015 nozzles. Visible injury ratings were collected 7, 14, 21, and 28 days after treatment (DAT). Injury was rated on a scale of 0 to 100%, with 0 being no crop injury and 100 being complete crop death. Additionally, rough rice yields were collected at maturity. Injury data were analyzed as a repeated measure using a beta distribution, and yields were analyzed as a normal distribution. Data were then subjected to an analysis of variance, and means were separated using the Sidak Method with an alpha value of 0.05.

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Results and Discussion

Injury 7 days after treatment (DAT) was less than 5% for all treatments evaluated, with the highest injury observed being for the highest rate of Convintro evaluated (Table 1). By 14 DAT, there was a slight increase in injury for the highest rate, with no other injury observed for the additional rates evaluated. By 28 DAT, injury was less than or equal to 6% for all treatments evaluated. Rough rice yields were collected once the rice reached maturity. Grain yields relative to the nontreated check (138 bu./ac) ranged from 107–124% (Table 1).

Overall, rice does not appear to be sensitive to low concentrations of Convintro. At the highest rate evaluated, injury never exceeded 10% at any evaluation timing. Additionally, rice yields were not negatively impacted, with all treated plots outyielding the nontreated check.

Practical Applications

Registration of Convintro for use preemergence in soybean should pose minimal risk to rice fields that are grown near soybean. At the highest rate of Convintro evaluated, low levels of injury and no reduction of yield were observed. In addition to simulated sprayer contamination, research is needed to determine if diflufenican has the potential to carryover and injure rice in the subsequent growing season, considering that rice and soybean are typically grown in rotation in Arkansas.

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Table 1. Influence of simulated sprayer contamination with Convintro on rice injury and relative grain yields at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Arkansas, in 2023.

Rate	Injury				Relative Yield
	7 DAT[†]	14 DAT	21 DAT	28 DAT	
	(%)				
0	-	-	-	-	-
0.0015	2 ab[‡]	0 b	0 b	0 b	124
0.0062	0 b	0 b	0 b	0 b	121
0.025	0 b	0 b	0 b	0 b	125
0.10	3 ab	8 a	7 a	6 a	107
P-value	<0.0001[§]				0.2856

[†] DAT - days after treatment.

[‡] Means within herbicide rate by injury evaluation timing not containing the same letter are different according to Sidak method (α = 0.05).

[§] *P*-values were generated using the glmmTMB procedure with repeated measures using a beta distribution.

Greenhouse Gas Emissions from Furrow-Irrigated Rice as Affected by Fertilizer-Phosphorus Source in the Greenhouse

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Abstract

Alternative fertilizer-phosphorus (P) sources, such as wastewater-recovered struvite ($MgNH_4PO_4 \cdot 6H_2O$), can provide timely released nutrients, reduce the over-exploitation of the finite phosphate-rock reserves, and potentially decrease greenhouse gas (GHG) emissions in agricultural settings, specifically in furrow-irrigated rice (*Oryza sativa* L.) production systems. The objective of this study was to evaluate the effects of fertilizer-P source [i.e., a chemically precipitated struvite (CPST), a synthetic and real-wastewater-derived electrochemically precipitated struvite ($ECST_{Syn}$ and $ECST_{Real}$, respectively), monoammonium phosphate (MAP), and an unamended control (UC)] on select plant responses, season-long GHG [i.e., methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2)] emissions, and global warming potential (GWP as $CO_2 + CH_4 + N_2O$ and GWP* as $CH_4 + N_2O$) from furrow-irrigated rice grown in a P-deficient, silt-loam soil in the greenhouse. Gas samples were collected weekly during the 2023 growing season. Season-long N_2O emissions were greatest ($P < 0.05$; 5.4 lb/ac/season) from the UC, which differed from all other fertilizer-P treatments. Season-long CO_2 emissions were greatest ($P < 0.05$) from MAP, which did not differ from $ECST_{Real}$, $ECST_{Syn}$, and CPST. Season-long CH_4 emissions were unaffected ($P > 0.05$) by fertilizer source. Total GWP was smallest ($P < 0.05$; 13,573 lb-CO_2 eq. ac/season), while GWP* was greatest ($P < 0.05$; 1448 lb-CO_2 eq. ac/season) from the UC. Results suggest that struvite materials can represent an effective alternative P-source to contribute to increasing the sustainability of furrow-irrigated rice production.

Introduction

Compared to flood-irrigated rice (*Oryza sativa*) production, furrow-irrigation could decrease water usage by up to 59.3% (Henry et al., 2021), but also can dramatically influence nutrient management, specifically phosphorus (P; Della Lunga et al., 2021). Fluctuations in soil water content and soil oxidation-reduction (redox) potential in furrow-irrigated rice fields can enhance P precipitation in occluded forms, significantly reducing plant-P uptake (Yang et al., 2011). Slow-release fertilizers, like struvite ($MgNH_4PO_4 \cdot 6H_2O$), have been suggested as an effective, multi-nutrient fertilizer source to better capture plant demand, specifically P, during the growing season (Hertzberger et al., 2020).

The use of struvite (5% N, 13% P, and 10% Mg) as a potential alternative fertilizer-P source has been studied in several agronomic crops, such as corn (*Zea mays*), soybean (*Glycine max*), wheat (*Triticum aestivum*), and rice in greenhouse settings (Ackerman et al., 2013; Barak and Stafford, 2006; Talboys et al., 2016; Ylagan et al., 2020) and under field conditions (Brye et al., 2022; Omidire et al., 2021). However, due to the relative newness and potential use in production agriculture as an alternative fertilizer-P source, possible environmental ramifications of struvite, particularly struvite's potential role in greenhouse gas (GHG) emissions, have yet to be thoroughly investigated.

The objective of this study was to evaluate the effects of fertilizer-P source [i.e., a chemically precipitated struvite (CPST), a synthetic and real-wastewater-derived electrochemically precipitated struvite ($ECST_{Syn}$ and $ECST_{Real}$, respectively), monoammonium phosphate (MAP), and an unamended control (UC)] on select plant responses, season-long GHG [i.e., methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2)] emissions, and global warming potential (GWP as CO_2+CH_4 + N_2O and GWP* as CH_4 + N_2O) from furrow-irrigated rice grown in a P-deficient, silt-loam soil in the greenhouse. It was hypothesized that measured plant properties would be similar among $ECST_{Real}$, $ECST_{Syn}$, CPST, and MAP and be lowest from the UC. It was hypothesized that CH_4 emissions would not differ among treatments, as the frequent aerobic soil conditions associated with furrow irrigation would limit methanogenic activity. It was hypothesized that N_2O emissions would be greatest from the UC due to the lack of P addition limiting plant growth, resulting in potential greater N substrate available for microbially mediate denitrification. Carbon dioxide emissions were hypothesized to be greatest from MAP and lowest from the UC, as the limited growth expected from the UC would decrease root respiration. It was hypothesized that GWP would be lowest from the UC due to lower CO_2 emissions from the UC compared to the P-fertilizer treatments. In contrast, it was hypothesized that GWP* from the UC would be greatest due to enhanced N_2O emissions in the absence of P fertilization.

Procedures

This study was conducted in the greenhouse between 1 April and 29 September 2023 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. Low soil-test-P (9-16 ppm)

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Calhoun silt-loam (fine-silty, mixed, active, thermic Typic Glossaqualfs; USDA-NRCS, 2018) soil obtained from a winter wheat field at the Pine Tree Research Station near Colt, Ark. was air-dried, sieved, and used to fill 15 soil tubs (15.4-in. wide by 21.8-in. long by 6-in. deep) with 52.9 lb of soil each (Slayden et al., 2022). Replicate initial soil subsamples were collected and analyzed for particle-size distribution (Gee and Or, 2002), Mehlich-3 extractable nutrients (i.e., P, K, Ca, Mg, and Zn), soil organic matter (SOM), total nitrogen (TN), and total carbon (TC; Nelson and Sommers, 1996; Tucker, 1992; Table 1). Plastic base collars, 11.8-in. diameter by 11.8-in. tall, were installed at the center of each tub before planting. Tubs were arranged on one greenhouse bench in a randomized complete block design with three blocks.

Five fertilizer-P treatments were randomized within each block for a total of 15 experimental units (tubs). Fertilizer-P treatments included MAP (fertilizer grade: 11-52-0), CPST as Crystal Green (fertilizer grade: 6-37-0; Ostara Nutrient Recovery Technologies Inc., Vancouver, Canada), $ECST_{Syn}$ derived from a synthetic solution (fertilizer grade: 5-37-0; Anderson et al., 2021), $ECST_{Real}$ derived from a local municipal wastewater source (fertilizer grade: 3-36-0), and an unamended control (UC) that received no fertilizer-P addition during the entire growing season.

On 16 April 2023, the hybrid rice variety 'RT 7302' (RiceTec, Alvin, Texas) was seeded manually at a rate of 11.6 seeds ft^2 in 3 rows (UADA CES, 2021. Immediately after planting, P, K, and Zn fertilizers were manually broadcast at rates of 72, 108, and 12 lb/ac, respectively, onto the soil surface (UADA CES, 2020, 2021). Recommended fertilizer rates were increased by 20% to minimize the negative effect of the shallow soil volume on nutrient availability (Slayden et al., 2022). Additional N was applied in the form of N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea (46% N) to equalize the amount of N applied to each tub due to differences in N concentrations among the fertilizer-P sources. Additionally, N was applied at 29, 36, 43, and 78 days after planting (DAP) at rates of 44.8, 60, 60, and 24 lb/ac, respectively, for a total of 204 lb/ac (UADA CES, 2020, 2023). Soil volumetric water content (VWC) was measured throughout the growing season using a soil moisture probe (SM 150, Delta-T Devices Ltd., Cambridge, UK) and maintained at ~ 50 % through weekly irrigation applications.

Gas samples were collected on a weekly basis and analyzed using gas chromatography procedures as described by Slayden et al (2022). Following previous studies (Rogers et al., 2014; Smartt et al., 2016; Rector et al., 2018a,b), gas fluxes were converted to season-long CH_4, N_2O, and CO_2 emissions on a chamber-by-chamber basis (Della Lunga et al., 2021). At the end of the growing season, grain, vegetative tissue, and roots were collected from inside each collar. Biomass was dried and weighed to determine dry matter (DM). Global warming potential as CO_2 equivalents from the combination of the three GHGs and GWP* as CO_2 equivalents from the combination of just CH_4 and N_2O emissions were calculated on a chamber-by-chamber basis using only CH_4 and N_2O, with conversion factors of 28 and 265, respectively (IPCC, 2021).

Based on a randomized complete block design, a 1-factor analysis of variance (ANOVA) was conducted using SAS (v. 9.4, SAS Institute, Inc., Cary, N.C.) with a normal distribution and alpha level of 0.05 to evaluate the effects of fertilizer-P treatment on season-long CH_4, N_2O, and CO_2 emissions, yield and vegetative, root, total aboveground, and total plant DM, GWP, and GWP*.

Results and Discussion

Initial soil property characterization confirmed a silt-loam soil texture (Table 1). Initial soil pH was slightly alkaline (pH 7.4) and above what is considered optimal (pH 5.0 to 6.75) for rice production (Havlin et al., 2014; Table 1). Soil tubs were estimated to have a bulk density of 1.17 g cm^3 and a total porosity of 57%. Initial soil P and K concentrations were categorized as low (9 to 16 ppm for P and 61 to 90 ppm for K), while Zn was optimal (>4.1 ppm) for rice grown on silt-loam soil in Arkansas (UADA CES, 2021, 2022; Table 1). Initial SOM was within the typical range for Arkansas soils (>2.0%; UADA CES, 2022; Table 1), and the C:N ratio (8.6) indicated a soil environment with rapid N mineralization potential (Brady and Weil, 2016).

Yield and vegetative DM (VDM) differed ($P < 0.05$) among treatments (Table 2). Yield was greatest from the UC (373 lb/ac) and lowest from $ECST_{Syn}$ (64.5 lb/ac), which did not differ from all other fertilizer-P treatments. Vegetative DM was greatest ($P < 0.05$) from $ECST_{Real}$ (6,446 lb/ac), which did not differ from $ECST_{Syn}$, CPST, and MAP, and was lowest from the UC (5,013 lb/ac). Root, total aboveground (TABG), and total plant DM (TDM) did not differ among fertilizer-P sources. Abnormally high nighttime temperatures in the greenhouse contributed to the low yields among all treatments, particularly in the P-fertilized treatments where a yield response to the added P was expected in the low-soil-test-P soil.

Season-long CH_4 emissions were unaffected by fertilizer-P source, while N_2O and CO_2 emissions differed ($P < 0.01$) among treatments (Table 3). Nitrous oxide emissions were greatest ($P < 0.05$) from the UC (5.40 lb/ac/season) and lowest from $ECST_{Syn}$ (1.41 lb/ac/season), which did not differ from all other fertilizer-P treatments. The increased loss of N as N_2O in the UC was most likely due to the lower plant competition for N for the constrained vegetative growth (Della Lunga et al., 2020). Season-long CO_2 emissions were greatest ($P < 0.05$) from MAP (20,813 lb/ac/season), which did not differ from $ECST_{Real}$, $ECST_{Syn}$, and CPST, and was lowest from the UC (12,126 lb/ac/season). Phosphorus-fertilized tubs had greater vegetative growth and increased plant respiration. Both GWP and GWP* differed ($P < 0.05$) among fertilizer-P sources. The GWP followed similar trends as for CO_2 emissions, while GWP* followed a similar trend as for N_2O emissions.

The significantly greater ($P < 0.05$) N_2O emissions from the UC highlight the importance of optimal macronutrient availability in furrow-irrigated rice, as the lack of P resulted in stunted plant growth and a greater loss of N (Table 2 and 3). Overall, results of this study showed that the use of ECST as an alternative fertilizer-P source in furrow-irrigated rice grown in the greenhouse performed similarly to the commercially available MAP fertilizer from an agronomic and environmental perspective (Tables 2 and 3).

Practical Applications

Both the study of furrow-irrigated rice and struvite as a fertilizer-P source have had increasing interest in recent years as the need for more sustainable agricultural practices has increased. The use of furrow-irrigation for Arkansas rice is expected to increase as water resources become increasingly stressed across eastern Arkansas; thus, a better understanding of how water management influences nutrient management and the production of GHGs, particularly N_2O, is important to both researchers and producers. Additionally, further research into struvite as an alternative fertilizer-P source was warranted, as results of this study and other studies have shown that struvite can serve as an efficient fertilizer for crop production and a potential tool to mitigate GHG emissions (Della Lunga et al., 2023a; Omidire et al., 2021).

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Table 1. Summary of means (n = 6) and standard errors (± SE) for selected initial soil chemical and physical properties for the Calhoun silt-loam soil collected from the top 15 cm of a winter wheat field at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. in 2023.

Soil Property	Mean (± SE)
Sand (%)	14 (< 0.01)
Silt (%)	72 (0.01)
Clay (%)	14 (0.01)
pH	7.4 (0.05)
Extractable soil nutrients (ppm)	
Phosphorus	10.5 (0.2)
Potassium	81 (1.6)
Calcium	1559 (26.3)
Magnesium	224 (3.2)
Zinc	7 (0.1)
Soil organic matter (%)	1.57 (0.01)
Total carbon (%)	0.51 (0.01)
Total nitrogen (%)	0.06 (< 0.01)
Carbon:nitrogen ratio	8.6 (0.12)

Table 2. Analysis of variance summary of the effect of fertilizer-phosphorus source [wastewater-recovered electrochemically precipitated struvite ($ECST_{Real}$), synthetically-produced electrochemically precipitated struvite ($ECST_{Syn}$), chemically precipitated struvite (CPST), monoammonium phosphate (MAP), and unamended control (UC)] on rice plant yield, vegetative (VDM), root, and total aboveground (TABG) and total plant dry matter (TDM) (lb/ac) during the 2023 growing season in the greenhouse.

Rice		Fertilizer-phosphorus Source					Overall
Property	*P*-value	$ECST_{Real}$	$ECST_{Syn}$	CPST	MAP	UC	Mean
Yield	0.02	99.8 b[†]	64.5 b	136.6 b	130.3 b	372.7 a	-
VDM	<0.05	6,141 a	6,446 a	5,774 ab	6,217 a	5,013 b	-
Root	0.32	6,290	3,695	4,866	4,531	2,501	4,377
TABG	0.15	6,241	6,511	5,910	6,347	5,385	6,079
TDM	0.13	12,531	10,206	10,776	10,878	7,887	10,456

[†] Values followed by different letters within a row differ at the 0.05 level.

Table 3. Analysis of variance summary of the effect of fertilizer-phosphorus source [wastewater-recovered electrochemically precipitated struvite ($ECST_{Real}$), synthetically produced electrochemically precipitated struvite ($ECST_{Syn}$), chemically precipitated struvite (CPST), monoammonium phosphate (MAP), and unamended control (UC)] on season-long methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions (lb/ac/season) and global warming potential (lb-CO_2 equivalents/ac/season) calculated including CH_4, N_2O, and CO_2 (GWP) and only CH_4 and N_2O (GWP*) during the 2023 growing season in the greenhouse.

		Fertilizer-phosphorus Source					Overall
Parameters	*P*-value	$ECST_{Real}$	$ECST_{Syn}$	CPST	MAP	UC	Mean
Emissions							
CH_4	0.28	0.58	0.23	0.79	0.42	0.60	0.52
N_2O	<0.01	1.72 b[†]	1.41 b	1.97 b	1.60 b	5.40 a	-
CO_2	0.01	20,478 a	19,655 a	19,667 a	20,813 a	12,125 b	-
GWP	0.02	20,952 a	20,034 a	20,210 a	21,248 a	13,573 b	-
GWP*	<0.01	473 b	379 b	543 b	435 b	1,448 a	-

[†] Values followed by different letters within a row differ at the 0.05 level.

Biochar Source and Rate Effects on Soil pH and Water-Soluble Phosphorus Over Time in Simulated Furrow-Irrigated Rice in the Greenhouse

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Abstract

Biochar is the byproduct of burning vegetative dry matter, which commonly occurs in biofuel production. Biochar has the potential to positively impact soil properties as a soil amendment, which has led to biochar's increased use in agroecosystems. The objective of this study was to evaluate the effects of biochar source/particle-size combination [i.e., large particle size from Douglas Fir (*Pseudotsuga menziesii*) in Colorado (CO) and smaller particle size from Southern Yellow Pine (*Pinus echinate*) in Arkansas (AR)] and rate [i.e., 0, 2232, and 4464 lb/ac (0, 2.5, and 5 Mg/ha)] on soil pH and water-soluble phosphorus (WS-P) in simulated-furrow-irrigated rice (*Oryza sativa*) on a silt loam in the greenhouse. Soil pH differed among biochar rates ($P < 0.01$) and differed over time ($P < 0.01$), while WS-P concentrations differed between biochar sources over time ($P < 0.01$). Averaged across biochar source and time, soil pH was 5.69 from the 4464 lb/ac biochar rate, which differed from a soil pH of 5.59 from the no-biochar control, and soil pH was 5.64 from the 2232 lb/ac biochar rate, which did not differ from either the 4464 lb/ac rate or the no-biochar control. Soil pH over time ranged from a minimum of 4.94 at 49 days after planting (DAP) to a maximum of 6.16 at 118 DAP. Water-soluble-P concentrations were similar between biochar sources and among measurement dates for the whole growing season, apart from 34 DAP, where WS-P was eight times greater from the AR than the CO biochar. Results of this study indicate that both biochar sources and the differing rates minimally impacted soil pH and WS-P over the course of a rice growing season under simulated furrow irrigation.

Introduction

Biochar is the product of burning vegetative dry matter in an anoxic environment through a process called pyrolysis. Biochar has potential positive effects on soil and plant growth based on biochar's physical and chemical properties, namely biochar's low density and carbon (C) and other nutrient concentrations (Bai et al., 2022). Biochar application in agroecosystems has been reported to positively impact soil properties and crop growth and yield through reduced bulk density, increased soil water retention in sandy and loamy soils (Razzaghi et al., 2020), enhanced cation exchange capacity (Kavitha et al., 2018), increased soil organic C (SOC) and soil C sequestration (Kuttippurath et al., 2023; Nguyen et al., 2014), increased crop growth (Murtaza et al., 2021), and minimally impact yield (Aller et al., 2018; Sorensen and Lamb, 2016). The reported benefits of biochar have resulted in increased use and research into biochar as a beneficial soil amendment.

Biochar is generally understood to positively impact soil and plant growth, but further investigations have led to the discovery of potential drawbacks of biochar as a soil amendment. One major drawback is that biochar sources can chemically and physically vary depending on the original feedstock and combustion temperature and duration (Masek et al., 2018). Consequently, the resulting physical and chemical property variability among biochar sources makes predicting the impact of biochar amendment on soil properties and plant growth and productivity difficult because of the limited knowledge surrounding how site-specific soil properties and plant response are impacted by different biochar sources.

Additionally, biochar's large adsorptive capacity (Zhi et al., 2023), where biochar has been shown to adsorb plant-essential nutrients like phosphate, nitrogen (N), and iron (Fe), can reduce plant nutrient availability (Kavitha et al., 2015; Xu et al., 2016). Consequently, biochar's large adsorptive capacity may represent a further complication in the already challenging management of P in rice (*Oryza sativa*) cropping systems, particularly in the furrow-irrigated rice production system, where the combination of moist and saturated soil environments can tie up different P forms (Fageria et al., 2011).

Therefore, the objective of this greenhouse study was to evaluate the effects of biochar-source/particle-size combination [i.e., large particle size from Douglas Fir (*Pseudotsuga menziesii*) in Colorado (CO) and smaller particle size from Southern Yellow Pine (*Pinus echinate*) in Arkansas (AR)] and rate [i.e., 0, 2232, and 4464 lb/ac (0, 2.5, and 5 Mg/ha)] on soil pH and water-soluble (WS) soil phosphorus (P) in simulated furrow-irrigated rice on a silt-loam soil over the course of one growing season.

Procedures

Soil Collection, Processing, and Initial Characterization

Research was conducted in the greenhouse between 16 April and 29 September 2023. Soil (fine, smectitic, thermic Typic Albaqualf) was collected from the top 4 to 6 in. (10 to 15 cm) in a field that had been cropped to furrow-irrigated rice for at least the past 6 years at the University of Arkansas System Division of

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Agriculture's Rice Research and Extension Center near Stuttgart, Ark. Soil was moist-sieved through a 0.24-in. (6 mm) screen to remove roots and air-dried.

Six subsamples of air-dried soil were collected, oven-dried for 48 hours at 158 °F (70 °C), and sieved through a 0.08-in. (2 mm) mesh screen. Sand, silt, and clay were determined using a modified 12-h hydrometer method (Gee and Or, 2002). Water-soluble (WS) soil nutrients (i.e., P, K, Mg, Ca, S, Na, Fe, Zn, and Mn) concentrations were determined by a 1:10 soil mass:water volume ratio, soil was extracted and analyzed for plant available nutrients using inductively coupled, argon-plasma spectrophotometry (Tucker, 1992; Soltanpour et al., 1996). Soil pH and electrical conductivity were determined potentiometrically using a 1:2 soil mass:water suspension volume. Soil organic matter concentration was determined by weight-loss-on-ignition at 680 °F (360 °C) for 2 h of combustion in a muffle furnace (Zhang and Wang, 2014). Total C and N were determined by high-temperature combustion (Elementar Americas Inc., Mt. Laurel, N.J.; Nelson and Sommers, 1996). Initial soil properties are summarized in Table 1.

Treatments and Experimental Design

Two biochar sources were used in this study: i) a biochar material that was sourced from Douglas Fir feedstock in CO), and ii) a biochar material sourced from Southern Yellow Pine feedstock in southeastern Ark. The CO biochar had a coarser particle size [i.e., 0.04-0.12 in. (1–3 mm) flakes] than the AR biochar, which was a powder. Biochar was applied at 3 rates equivalent to 0, 2232, and 4464 lb/ac (0, 2.5, and 5 Mg/ha). The 6 biochar source-rate treatment combinations represented a complete, full factorial design and were arranged in a randomized complete block design on a single greenhouse bench that was replicated 3 times for a total of 18 experimental units.

Soil Tub Preparation and Management

On 22 April 2023, approximately 58.2 lb (26.4 kg) of air-dried, sieved soil were placed into plastic tubs 20.1-in. wide by 26.4-in. long by 5.9-in. deep (51 cm by 67 cm by 15 cm). On 30 April 2023, each tub received N, P, and K fertilizer based on initial soil-test recommendations for furrow-irrigated rice production on a silt loam soil (UADA CES, 2020). Each tub received 0.12 ounces (3.34 g) of P at an equivalent rate of 14.7 lb/ac (14.7 kg/ha) in the form of chemically precipitated struvite (i.e., trade name Crystal Green, Ostara, Inc., Vancouver, Canada; fertilizer grade: 6-27-0; Hardke, 2020), 0.09 ounces (2.46 g) of K at an equivalent rate of 49.8 lb/ac (55.8 kg/ha) as muriate of potash. Nitrogen was added to the tubs in 3 different applications in the form of N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea (46% N) to reach an optimum 180.2 lb N/ac (202 kg N/ha). The N applications were on 21 and 28 May 2023 and 4 June 2023, and the soil was kept relatively dry right before and during applications to prevent volatilization. All recommended fertilizer application amounts were increased by 20% to account for the limited space for root growth because of the shallow depth of the tubs (Slayden et al., 2022). Weeds were manually removed as needed over the course of the study. The 18 tubs were arranged on the same greenhouse bench with stiff, wooden planks under the tubs to ensure uniform soil settling and water distribution.

Each tub was manually seeded on 29 April 2023 with a hybrid rice variety ‘RT 7302’ (RiceTec, Inc., Alvin, Texas) based on furrow-irrigation management recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service (UADA CES, 2020). Tubs were manually seeded at a depth of 0.75 in. (1.9 cm) among 3 rows with 9 seeds per row to account for a recommended seeding rate of 11.5 seeds/ft^2 (124 seeds/m^2; UADA-CES, 2021). Seeds were planted 3.1 in. (8 cm) from the short edge of the tub, 1.6 in. (4 cm) from the long edge of the tub, 2 in. (5 cm) between seeds within a row, and 6.1 in. (15 cm) between rows.

The volumetric water content of the soil was measured in the top 2.4 in. (6 cm) of each tub (model SM150, Dynamax, Inc., Houston, Texas) on a regular basis. Simulated furrow irrigation was achieved through watering each tub 2 to 3 times per week to a target volumetric water content of 56% approximately every other day.

Soil Sample Collection and Analyses

Weekly soil sampling began on 20 May and continued until 16 September 2023 for a total of 19 samples from each tub. Soil from each tub was collected by vertically inserting a copper tube with a diameter of 0.55 in. (1.4 cm) from the soil surface to the bottom of each tub. Soil samples were oven-dried for at least 48 h at 158 °F (70 °C), ground manually using mortar and pestle, and sieved through a 0.08-in. (2 mm) screen. Soil pH and WS soil P concentrations were determined using procedures previously described for initial soil characterization.

Statistical Analyses

Based on a randomized-complete-block (RCB), repeated-measure design, a linear mixed model was used to evaluate the effects of biochar source, biochar rate, time (i.e., weekly sample dates), and their interactions on soil pH and WS soil P concentrations using the ASReml package (v. 4.1.0.90; Butler, 2018) in R (v. 4.3.2, R Foundation for Statistical Computing, Vienna, Austria). Biochar source, biochar rate, time, and blocks were considered fixed effects. Biochar source and biochar rate were randomized within 3 blocks in an RCB design at the beginning of the growing season. Significance was judged and when appropriate, means were separated at the 0.05 level.

Results and Discussion

Biochar source and/or biochar rate significantly affected soil pH and/or WS-P concentrations over time (Table 2). Soil pH fluctuated over time throughout the study period and was affected by biochar rate ($P < 0.01$) and time ($P < 0.01$). Averaged across biochar source and time, soil pH ranged from a minimum of 4.9 at 49 days after planting (DAP) to a maximum of 6.2 at 118 DAP (Fig. 1). Averaged across biochar source and time, soil pH was 5.69 from the 4464 lb/ac (5 Mg/ha) rate, which differed from a soil pH of 5.6 from the no-biochar control. Soil pH was 5.6 from the 2232 lb/ac (2.5 Mg/ha) rate, which did not differ from either the 4464 lb/ac (5 Mg/ha) rate or the no-biochar control. Similar to the results of the current study, biochar has been reported to impact soil pH (Chintala et al., 2014). In an incubation study that evaluated the effects of corn (*Zea mays*) stover and switchgrass (*Panicum virgatum*) biochar and rate (i.e., 23.2, 46.4, and 69.6 T/ac [52, 104, and 156 Mg/ha)] on the chemical properties of an acidic (pH < 4.8) clay loam, Chintala et al. (2014) reported that all application rates increased soil pH. Specifically, the corn stover biochar treatment increased soil pH by 0.7, 1.0, and 1.4 units over the 165-day study period, in which the changes were numerically greater in magnitude than the values reported in the current study. The numerically greater differences in soil pH reported by Chintala et al. (2014) were likely due to the magnitude of the biochar rates that were used being at least 10 times greater than in the current study.

Soil pH also differed over time (Fig. 1). Averaged across biochar source and rate, soil pH was 5.7 at 21 DAP, after having started at a pH of 6.5 prior to any biochar addition (Table 1). Soil pH tended to decrease from 21 to 49 (pH = 4.94) DAP, at which time soil pH was numerically the smallest among all measurement dates but did not differ from the soil pH at 54 DAP (Figure 1). Soil pH then generally tended to increase until 82 DAP (pH = 6.0), which was followed by 30 days of generally lower soil pH until the season-long peak pH occurred at 118 DAP (pH = 6.2), which did not differ from the soil pH at 82 DAP (Fig. 1). From 118 DAP to the end of the study, soil pH tended to decrease again, with similar soil pHs at 21 DAP for the remainder of the study period (Figure 1). In contrast to the current study, Chintala et al. (2014) reported a spike in soil pH in the first 15 days of incubation from the corn stover and switchgrass biochars.

The decrease in soil pH during the first 30 days after measurements began may be explained by urea fertilizer being converted into ammonium and then nitrate, which tends to reduce soil pH as hydrogen ions are released in the nitrification process (Bouman et al., 1995). The relatively large increase in soil pH that occurred after the season-long minimum was achieved at 49 DAP was likely a result of the neutralization of the released hydrogen ions from nitrification of the applied urea.

In contrast to soil pH, WS-P concentrations differed between biochar sources over time ($P < 0.01$; Table 2). Water-soluble P concentrations were the same between biochar sources and among measurement dates and generally followed the same temporal pattern for the whole growing season, except for 34 DAP. At 34 DAP, the WS-P concentration was 8 times greater from the AR biochar source (16.9 ppm) than from the CO biochar source (2.0 ppm; Fig. 2). The spike in WS-P for the AR biochar source was likely due to sampling a random, undissolved fertilizer pellet. Aside from 34 DAP, WS-P concentrations ranged from 1.4 ppm at 49 DAP from the CO biochar to 6.2 ppm at 106 DAP from the AR biochar (Fig. 2). Water-soluble P at 34 DAP was at least 2.6 times greater than the next lowest measured WS-P concentration at 106 DAP (Fig. 2).

Studies have reported mixed results when evaluating biochar effect on soil-P availability (Glaser and Lehr, 2019). A meta-analysis study on biochar effects on P availability in agricultural soils reported that biochar application typically increased plant-available P, but biochar rates above 4.46 T/ac (10 Mg/ha) were generally needed to affect soil-P availability (Glaser and Lehr, 2019). Thus, in the current study, WS-P concentration was likely unaffected by biochar rate because not enough biochar was added to impact WS-P concentration.

In addition to effects on soil pH and WS-P concentrations, though presently formal analyses are incomplete, preliminary results suggest that biochar source and/or rate may also affect season-long greenhouse gas (GHG) emissions [i.e., methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O)] in furrow-irrigated rice. Measured approximately weekly throughout the growing season and in the same tubs as soil samples were collected for assessing soil pH and WS-P concentrations, GHG fluxes were measured and emissions were summed for the rice growing season following recent procedures (Slayden et al., 2022). Season-long CH_4 emissions were 7.6, 4.7, and 7.7 lb CH_4/ac/season (8.5, 5.3, and 8.6 kg CH_4/ha/season) from the AR biochar and were 7.3, 4.7, and 2.9 lb CH_4/ac/season (8.2, 5.3, and 3.2 kg CH_4/ha/season) from the CO biochar source and the 0, 2232, and 4464 lb/ac (0, 2.5, and 5 Mg/ha) biochar rates, respectively. Season-long CO_2 emissions were 13.4, 14.5, and 17.2 tons CO_2/ac/season (30.1, 32.5, and 38.5 Mg CO_2/ha/season) from the AR biochar source and were 13.4, 16.1, and 16.7 tons CO_2/ac/season (30.0, 36.2, and 37.4 Mg CO_2/ha/season) from the CO biochar source and the 0, 2232, and 4464 lb/ac (0, 2.5, and 5 Mg/ha) biochar rates, respectively. Season-long N_2O emissions were 33.3, 27.0, and 26.9 lb N_2O/ac/season (37.3, 30.3, and 30.1 kg N_2O/ha/season) from the AR biochar source and were 37.2, 15.3, and 4.4 lb N_2O/ac/season (41.7, 17.1, and 4.9 kg N_2O/ha/season) from the 0, 2232, and 4464 lb/ac (0, 2.5, and 5 Mg/ha) biochar rates, respectively. Through effects on soil pH and soluble nutrients, the use of biochar may represent a potential GHG mitigation strategy, but continued research will be needed to confirm any effects of biochar source and/or rate on season-long GHG emissions.

Practical Applications

Though the soil pH experienced increases and decreases throughout the growing season under simulated furrow-irrigation, by the end of the growing season, soil pH reverted back to a similar soil pH from 21 DAP (Fig. 1), highlighting the relevant role of the soil in buffering chemical changes. However, the initial soil pH (6.5; Table 1) prior to any biochar addition and rice growth and management (i.e., irrigation applications) clearly indicates that soil pH was impacted by some combination of biochar addition, rice cropping, and/or furrow-irrigation. Furthermore, despite a major difference on a single measurement date, for which a logical explanation exists, it appears that the use of biochar, from two different woody feedstock sources or among different application rates, has little effect on WS-P concentration over time in a simulated furrow-irrigated rice system throughout one growing season. Consequently, from this preliminary work, it appears that the potential effect of biochar's large adsorptive capacity reducing soil-P availability may be less of a concern than hypothesized. However, long-term studies are necessary to determine the biochar capacity to alter soil chemical properties.

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Table 1. Summary of initial soil physical and chemical property means (n = 6) and standard errors (SE) for the soil used in this greenhouse experiment.

Soil Property	Mean (± SE)
Sand (%)	15.0 (0.6)
Silt (%)	73.9 (0.5)
Clay (%)	11.1 (0.7)
pH	6.5 (0.1)
Electrical conductivity (µmhos/cm)	89.8 (6.6)
Water-soluble soil nutrients (ppm)	
P	2.7 (0.06)
K	27.7 (3.1)
Ca	20.3 (0.4)
Mg	3.1 (0.25)
S	11.6 (0.15)
Na	60.1 (0.45)
Fe	11.2 (2.0)
Zn	0.6 (0.04)
Mn	1.1 (0.07)
Soil organic matter (%)	2.53 (0.01)
Total C (%)	1.25 (< 0.01)
Total N (%)	0.12 (< 0.01)

Table 2. Analysis of variance summary of the effects of biochar source, biochar rate, time, and their interactions on soil pH and water-soluble (WS) soil phosphorus (P) over the 2023 growing season under simulated-furrow-irrigation on a silt-loam soil in the greenhouse.

Source of Variation	pH	WS-P
	------------------------------*P*------------------------------	
Source	0.13	0.04
Rate	< 0.01	0.87
Time	< 0.01	< 0.01
Source x rate	0.25	0.60
Source x time	0.99	< 0.01
Rate x time	0.81	0.98
Source x rate x time	0.99	0.99

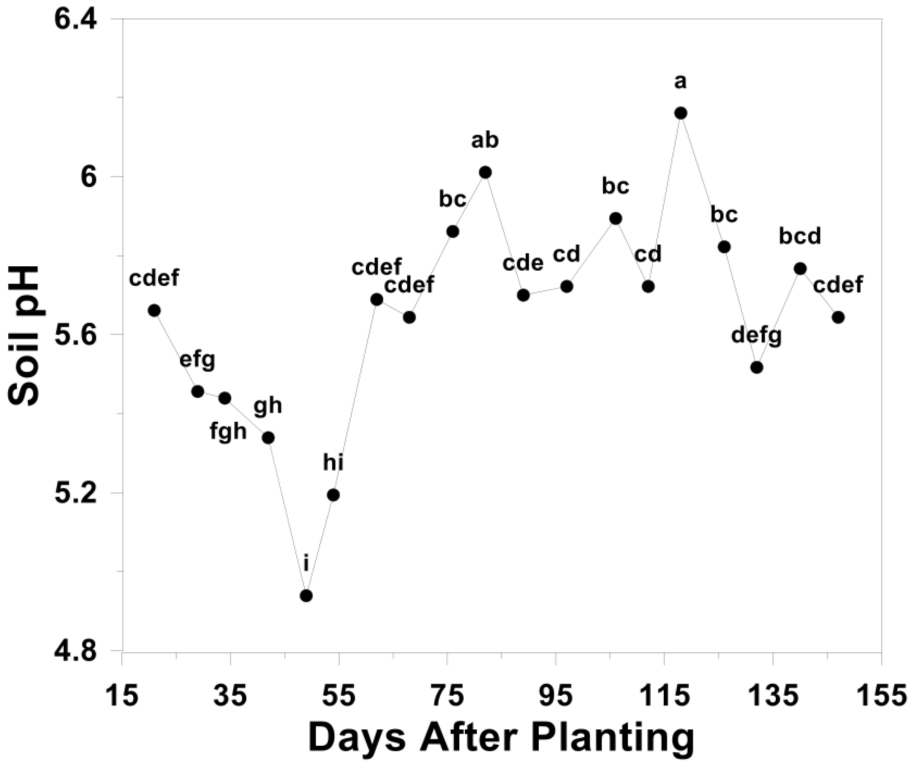

Fig. 1. Soil pH over time, averaged between biochar source [i.e., Arkansas (AR) and Colorado (CO)] and rate (i.e., 0, 2232, and 4464 lb/ac [0, 2.5, and 5 Mg/ha]), throughout the 2023 growing season from simulated furrow-irrigated rice on a silt-loam soil in the greenhouse. Lines connecting data points are for visual representation of the data only. Data points with different lowercase letters are significantly different at *P* < 0.05.

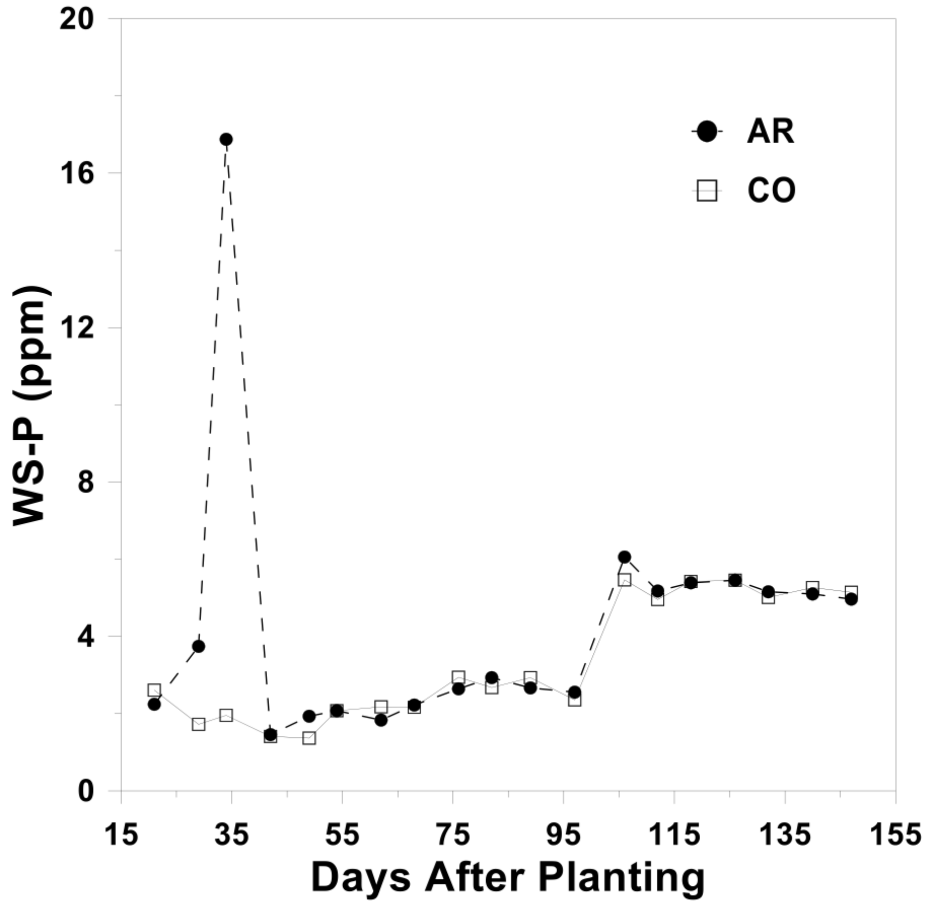

Fig. 2. Water-soluble phosphorus (WS-P) from each biochar source [i.e., Arkansas (AR) and Colorado (CO)] over time during the 2023 growing season from simulated furrow-irrigated rice on a silt-loam soil in the greenhouse. Data points with different lowercase letters are significantly different at *P* < 0.05. Lines connecting data points are for visual representation of the data only.

Grain Yield Response of Eight New Rice Cultivars to Nitrogen Fertilization

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Abstract

The purpose of the cultivar x nitrogen (N) studies is to observe and analyze the response of new rice (*Oryza sativa* L.) cultivars to N fertilization to determine the optimal N fertilizer rates across an array of soils and environments in which rice is grown in Arkansas. Eight cultivars were studied in 2023 and included ARoma 22, CLL18, CLL19, CLM04, Diamond, Ozark, PVL03, RTv7231 MA, and Taurus at 3 locations: the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), the Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC). Seed treatment and seeding rates followed current recommendations and production practices. The grain yields were fair to good for most cultivars studied at the 3 locations in 2023, with lodging ranging from mild to none. The 2023 season was the first year the cultivars ARoma 22 and RTv7231 MA were included and the second year for CLL18, Ozark, and Taurus; therefore, there is insufficient data to make a N rate recommendation for these cultivars at this time, and hence the response to N reported here may serve as a guide only while more data is collected in subsequent years. Multiple years of results for PVL03 provide evidence that this cultivar should have good yields with minimal to no lodging if 150 lb N/ac is applied in a 2-way split of 105 lb N/ac at the preflood timing followed by 45 lb N/ac at midseason when grown on silt loam soils and 180 lb N/ac in a 2-way split of 135 lb N/ac at the preflood timing followed by 45 lb N/ac applied at midseason when grown on clay soils. Above this level of fertilization, there is not a statistical difference in yield gains.

Introduction

The objectives of the cultivar × nitrogen (N) fertilizer rate trials are to record and analyze the grain yield response of new rice cultivars over a range of fertilizer rates on a representative clay and two silt loam soils as well as diverse growing environments existing in Arkansas. The goal is to determine the N fertilizer rates conducive to maximizing grain yields, maximizing returns per unit of fertilizer, and providing sound research-based baseline N management data for Arkansas rice producers. Selections of promising new cultivars from breeding programs in Arkansas, Louisiana, Mississippi, and Texas, as well as from private industry are evaluated in these trials. Eight cultivars were included in 2023 at 3 locations.

Procedures

The cultivar × N fertilizer rate studies were conducted at the following University of Arkansas System Division of Agriculture (UADA) research locations: the Northeast Research and Extension Center (NEREC) near Keiser, Ark., on a Sharkey clay (Vertic Haplaquepts) soil; the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs) soil; and the Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a Dewitt silt loam (Typic Albaqualfs) soil. The cultivars studied were ARoma 22, CLL18, CLL19, Diamond, Ozark, PVL03, RTv7231 MA and Taurus. The method employed for data analysis for all locations and each cultivar is a randomized complete block design with 4 replications. All seeds of each cultivar were treated with fungicides and insecticides following current recommendations and practices in addition to an application of a zinc (Zn) seed treatment. All experimental plots were direct-seeded in 8 rows at 7.5-in. spacing and 18 ft in length at a rate of 33 seed/ft^2 for conventional cultivars. RTv7231 MA was seeding at 45 lb/ac.

In 2008, a single preflood N application (SPF) was adopted in all cultivar × N studies in response to the rising cost of N fertilizer and the preference of medium to short stature, semi-dwarf, and stiff straw plant type currently grown. These cultivars typically reach maximal yield potential when less N is applied in a single preflood application in comparison with the traditional 2-way split application. Typically, cultivars receiving a single preflood application require 20 to 30 lb N/ac less than when N is applied in a 2-way split application where the second application is made between beginning internode elongation and the 0.5-in. internode elongation growth stages. Hence, if 150 lb N/ac is recommended for a 2-way application, then 120 to 130 lb N/ac should maximize yield potential using a single preflood application only if certain critical conditions are met. These conditions include: 1) that the field can be flooded timely, 2) the urea has been treated with the urease inhibitor NBPT or ammonium sulfate is used instead as a source of N, unless the field can be flooded in 2 days

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or less for silt loam soils and 7 days or less for clay soils, and 3) a flood of 2 to 4 in. is maintained for at least 3 weeks after flood establishment (Norman et al., 2003; Roberts et al., 2018). In consequence, a single preflood N fertilizer application (SPF) was employed for all cultivars across all locations as urea treated with a urease inhibitor (NBPT) onto a dry soil surface at the 4- to 5-leaf growth stage. The SPF N rates were 0, 60, 90, 120, 150, 180, and 210 lb N/ac. The locations with silt loam soils (PTRS and RREC) received the 0 to 180 lb N/ac rate structure and the study on the clay soil (NEREC) implemented the 0 to 210 lb N/ac rate structure with the omission of the 60 lb N/ac rate. Pertinent agronomic dates and practices for each location are reported in Table 1. The permanent flood was established within 24–48 h of the preflood N application and maintained until maturity of the rice crop. At maturity, the flood was released, and approximately 2 weeks later, the 4 center rows of each plot were harvested, and grain moisture content, yield and lodging were recorded. Yields were calculated as bushels per acre (bu./ac) and adjusted to 12% moisture, with a bushel of rice base weight of 45 lb. Statistical analysis was conducted using PROC GLIMMIX, SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) with means separation using T grouping for least-square means at an $\alpha = 0.1$.

Results and Discussion

Overall, the yields for the 2023 cultivar × N rate trials were fair to good for most of the 8 cultivars included. Maximal yields ranged from 174 to 195 bu./ac for the NEREC location, 165 to 225 bu./ac at the PTRS location, and 126–194 bu./ac for the RREC location. There were minimal lodging scores reported. In 2023, planting dates in mid-April to early May yielded higher compared to earlier or later planted rice at RREC, while rice planted in late-April to early May yielded best at NEREC compared to other planting dates (Clayton et al. 2024). The effect of planting date on rice yields has been observed previously by Clayton et al. (2022, 2023). This may explain the lower yields for the RREC location compared to the other 2 locations (Tables 1 to 9). Differences in yield for RREC for Diamond (control cultivar) ranged from 7 to 33 bu./ac at the lower end of acceptable yields to 16 to 32 bu./ac at the highest yields across locations in comparison to last year's data (Castaneda-Gonzalez et al. 2023), a trend reflected in other cultivars. In addition to planting date, a wet and cool spring may have had an influence on these yield reductions, in addition to a bloom of brown spot at midseason to early booting. Two different responses to increasing rates of N fertilizer are observed in the cultivar × N trials: a simple linear trend where yields continued to increase as the N rate increased or quadratic where the grain yield reached a vertex or a plateau, followed by decreasing yields. The results indicate that either response is independent of cultivar and greatly influenced by biotic and abiotic factors (environment).

The cultivar ARoma 22 achieved a maximal yield of 174 bu./ac at the NEREC location followed by 165 bu./ac at PTRS and 126 bu./ac at the RREC where N rates of 180, 180, and 120 lb N/ac were applied, respectively (Table 2). The data suggests that this cultivar's yields tend to plateau between 150 lb N/ac for clay soils and 120 lb N/ac for silt loam soils. The lowest preflood N rate that produced a statistically similar yield to the maximal yield for a given location was identified as 120 lb N/ac for the clay soil and 120 to 150 lb N/ac in a single SPF for the 2 silt loam soils, the response of this cultivar to N fertilization appears to be linear for PTRS, but the response was quadratic for NEREC and RREC where N rates of above 120 lb N/ac resulted in a plateau or decreasing yields. Being a specialty rice (aromatic), comparison to our check cultivar (Diamond) is complicated, and the targeted consumer needs to be taken into consideration by the grower or consultant. These results are preliminary at best since this is the first year of inclusion in the cultivar × N test.

The rice cultivar CLL18 showed a significant increase in yield for the PTRS and NEREC locations and a considerable reduction at the RREC location in comparison with last year's results (Castaneda-Gonzalez et al., 2023). In previous tests, CLL18 has shown the potential to yield over 200 bu./ac (Moldenhauer et al. 2022). In 2023, a peak yield of 201 bu./ac and 195 bu./ac was recorded in our test when 180 lb N/ac was applied at the PTRS and NEREC locations, respectively (Table 3). The peak yield at RREC was 175 bu./ac at 120 lb N/ac, a 24 lb/ac yield reduction from last year's results at the same N fertilization level. The lowest yield-maximizing N rate was 90 (179 bu./ac), 150 (197 bu./ac), and 120 (175 bu./ac) lb N/ac for the NEREC, PTRS, and RREC locations, respectively, differing from the previous year of study (Castaneda-Gonzalez et al. 2023). Yield response for this cultivar was quadratic at the NEREC and PTRS locations, meaning that once the maximal yield is achieved with a particular N treatment, any additional N has no statistically significant effect or the response is negative, i.e., yield decreases. The response at PTRS was linear with increasing yield gains as N rates increased. The evidence shown in the 2-year research indicates that the level at which increased N fertilization no longer has a statistically significant effect is at the 120 lb N/ac level of fertilization using an SPF application.

The year 2023 was the first that the cultivar CLL19 entered the cultivar × N trials. The response obtained from this cultivar is quadratic at the NEREC location and linear for PTRS and RREC, with maximal yields of 165 bu./ac (120 lb N/ac), 203 bu./ac (180 lb N/ac) and 185 bu./ac (180 lb N/ac). The lowest N fertilization rates to obtain a not statistically different yield from the maximal yield were 90 lb N/ac (179 bu./ac), 90 lb N/ac (186 bu./ac) and 120 lb N/ac (175 bu./ac) for NEREC, PTRS, and RREC, respectively (Table 4). CLL19 may have a yield potential of over 200 bu./ac and compared well to Diamond. More years of field-based research are required to make a better assessment.

The cultivar Diamond included in our trials is a check variety due to its reliable performance across soil types, environment, and multi-year results. It serves as a baseline for understanding the performance of newer varieties included in the cultivar × N studies. In 2023, maximal yields for Diamond were 193 bu./ac (150 lb N/ac), 214 bu./ac (180 lb N/ac), and 167 bu./ac (120 lb N/ac) for NEREC, PTRS, and RREC, respectively. The yield response to N rate was linear for PTRS, and quadratic for NEREC and RREC with minimum N rates to achieve maximal yield not significantly different to the peak yield being 120 lb N/ac (181 bu./ac) at NEREC, 150 lb N/ac (202 bu./ac) at PTRS, and 120 lb N/ac (167 bu./ac) at RREC (Table 5). Diamond performance is similar across sites, N rates, and years. It is against this variety that the results gathered in the 2023 test must be compared to make assessments.

The cultivar Ozark was included for the second time in the 2023 cultivar × N trials. The maximal yields obtained were 181 bu./ac (150 lb N/ac) at NEREC, 218 bu./ac (180 lb N/ac) at PTRS, and 186 bu./ac (180 lb N/ac) at RREC. The response to N fertilization was linear for PTRS and RREC (silt loam soils) and quadratic for NEREC (clay soil), in agreement with results obtained in 2022 (Castaneda-Gonzalez et al. 2023). We have obtained evidence of potential yields of 200 bu./ac or more for Ozark in these 2 years of research. The lowest level of fertilization to achieve yields not statistically different from the maximal yield were 90 lb N/ac (169 bu./ac), 150 lb N/ac (213 bu./ac), and 120 lb N/ac (182 bu./ac) at NEREC, PTRS, and RREC, respectively. This agrees with previous results indicating that Ozark is a solid performer across all growing conditions equal to or better than Diamond. More research is needed to make a proper assessment, but evidence indicates that a more than acceptable yield performance could be obtained at levels of fertilization of 120 lb N/ac in an SPF application for silt loam soils and 150 lb N/ac in an SPF application for clay soils.

The cultivar PVL03 was assessed in the cultivar × N trials for the third time. Yields for this cultivar ranged from moderate to fair at the 3 locations, with the overall highest yields reported at the PTRS location. Peak yields for PVL03 were 166 bu./ac (120 lb N/ac), 187 bu./ac (180 lb N/ac), and 132 bu./ac (120 lb N/ac) at the NEREC, PTRS and RREC locations, respectively (Table 7), making the yield response to N fertilization rates quadratic at NEREC and RREC and linear at PTRS in agreement to the results obtained in the previous 2 years where at least 1 of the silt loam sites had a linear response (Castaneda-Gonzalez et al. 2022, 2023). The lowest N rate resulting in yields not statistically different from the peak yields were 120 lb N/ac (166 bu./ac), 120 lb N/ac (176 bu./ac), and 120 lb N/ac (132 bu./ac) for NEREC, PTRS, and RREC, respectively. There is enough evidence to recommend a fertilization rate of 120 lb N/ac in a single SPF or a 150 lb N/ac in a 2-way application for silt loam soils and a 150 lb N/ac SPF or a 180 lb N/ac in a 2-way application for PVL03 to achieve a yield potential similar to Diamond with a plus considering the addition of the herbicide-tolerant technology embedded in this cultivar.

The hybrid RTv7231 MA was evaluated in our 2023 cultivar × N trial for the first time. Peak yields were 191 bu./ac (180 lb N/ac) at NEREC, 220 bu./ac (180 lb N/ac) at PTRS, and 186 bu./ac (150 lb N /ac) at RREC. Making the response to N fertilization quadratic for NEREC and RREC and linear for PTRS. There is an indication that this cultivar could achieve yields of 200 bu./ac or more. The lowest fertilizer rate to achieve yields not statistically different than maximal yields was 120 lb N/ac with 175 bu./ac, 209 bu./ac, and 176 bu./ac for NEREC, PTRS, and RREC, respectively. More research will be necessary to characterize this cultivar; all we can affirm at this point is that it is a promising long-grain hybrid cultivar with embedded herbicide tolerance technology.

It is the first year of inclusion for the medium-grain cultivar Taurus in the cultivar × N trials. Taurus is shown to be a promising addition, with a potential yield of 200 bu./ac or better and a consistent yielder across locations. The maximal yields recorded were 193 bu./ac (120 lb N/ ac), 225 bu./ac (180 lb N/ac), and 194 bu./ac (150 lb N/ac) for NEREC, PTRS, and RREC, respectively, with a quadratic response obtained at NEREC and RREC, and a linear response at PTRS. The lowest fertilizer rates resulting in yields not statistically different from the maximal yield were 90 lb N/ac (182 bu./ac) for NEREC (clay soil), 150 lb N/ac (218 bu./ac) for PTRS, and 120 lb N/ac (183 bu./ac) for RREC. This is a promising medium-grain cultivar; more research is necessary to make a final N-rate assessment.

Practical Applications

The cultivar × N fertilizer rate trials are a key component of assessing new rice cultivars and developing baseline preflood N and season total N fertilizer requirements to maximize grain yield and productivity. The primary objective is to record and analyze the grain yield performance of new rice cultivars over a range of fertilizer rates on representative soils as well as diverse growing environments in the Arkansas rice growing region. Therefore, growers and consultants can utilize the results of these trials to provide the proper N fertilizer rates to achieve maximal grain yields and best returns as per lb of N applied when grown commercially in the Arkansas rice growing region. Within the cultivar × N trials, we intend to restrict effects other than N fertilizer rate; the effects of variables not subject to manipulation, like the weather and accidental damage not caused by our management, underline the need of multi-year testing. The 2023 growing season was a year of opportunity to evaluate the sustainability of yields under unusual environmental conditions. The rice cultivars included in 2023 were ARoma 22, CLL18, CLL19, Diamond, Ozark, PVL03, RTv7231 MA, and Taurus. Most cultivars included in the 2023 cultivar × N trial are in the first or second year of assessment, and results were confounded with the effects of weather phenomena. Therefore, more data collection is required to make the best possible recommendations on N fertilizer management.

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Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Pine Tree Research Station (PTRS), and the Rice Research and Extension Center (RREC) during 2023.

Practices	NEREC	PTRS	RREC
Planting Dates	4 May 2023	3 May 2023	10 April 2023
Herbicide Spray Dates and Spray Procedures	5/4 2 qt Glyphosate + 32 oz Command + 4 oz Sharpen + 1 oz Parmit Plus + 1% COC† Broadcast	5/14 4 oz League + 24 oz Facet L + 8 oz Command. Broadcast	4/11 4 oz League + 10 oz Command Broadcast
Emergence Dates	12 May 2023	10 May 2023	23 April 2023
Herbicide Spray Dates and Spray Procedures	5/17 24 oz Ricestar + 0.8 oz Ultrablazer. Broadcast	5/7 3 qt Propanil + 0.75 Permit Plus + 2 pt Stealth. Broadcast	5/15 15 oz Clincher + 1% COC Broadcast
Herbicide Spray Dates and Spray Procedures	6/30 15 oz Clincher + 1% COC Broadcast	6/2 3 qt RiceBeaux Broadcast	5/24 3 qt Stam 4 +22 oz Facet + 1 oz Gambit. Broadcast
Preflood N Dates	22 June 2023	1 June 2023	25 May 2023
Flood Dates	23 June 2023	2 June 2023	26 May 2023
Insecticide Spray Dates and Spray Procedures	None	None	None
Drain Dates	23 August 2023	30 August 2023	17 August 2023
Harvest Dates	27 September 2023	14 September 2023	1 August 2023

† COC = crop oil concentrate.

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of ARoma 22 rice at 3 locations during 2023.

	Rice Grain Yield		
N Fertilizer Rate	NEREC†	PTRS	RREC
(lb N/ac)	--------(bu./ac)--------		
0	83 c‡	76 e	79 d
60§	-----	124 d	106 c
90	152 b	141 c	118 b
120	169 ab	152 bc	126 a
150	172 a	162 ab	126 a
180	174 a	165 a	126 a
210§	170 a	-----	-----

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

‡ Means within a column followed by the same letter are not significantly different ($P < 0.1$).

§ The 60 lb/ac rate is omitted in clay soils and the 210 lb/ac rate is omitted for the silt loam soils.

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL18 rice at 3 locations during 2023.

	Rice Grain Yield		
N Fertilizer Rate	NEREC†	PTRS	RREC
(lb N/ac)	--------(bu./ac)--------		
0	90 b‡	80 d	112 d
60§	----	131 c	155 c
90	179 a	165 b	166 b
120	184 a	177 b	175 a
150	180 a	197 a	175 a
180	195 a	201 a	167 ab
210§	192 a	----	----

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

‡ Means within a column followed by the same letter are not significantly different ($P < 0.1$).

§ The 60 lb/ac rate is omitted in clay soils and the 210 lb/ac rate is omitted for the silt loam soils.

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL19 rice at 3 locations during 2023.

	Rice Grain Yield		
N Fertilizer Rate	NEREC†	PTRS	RREC
(lb N/ac)	--------(bu./ac)--------		
0	109 b‡	92 c	98 d
60§	----	157 b	141 c
90	159 a	186 a	156 b
120	165 a	195 a	175 a
150	156 a	199 a	182 a
180	157 a	203 a	185 a
210§	155 a	----	----

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

‡ Means within a column followed by the same letter are not significantly different ($P < 0.1$).

§ The 60 lb/ac rate is omitted in clay soils and the 210 lb/ac rate is omitted for the silt loam soils.

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of Diamond rice at 3 locations during 2023.

	Rice Grain Yield		
N Fertilizer Rate	NEREC†	PTRS	RREC
(lb N/ac)	---(bu./ac)---		
0	81 d‡	105 d	99 d
60§	----	152 c	146 c
90	158 c	178 b	157 b
120	181 ab	185 b	167 a
150	193 a	202 a	159 ab
180	176 b	214 a	159 ab
210§	175 b	----	----

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
‡ Means within a column followed by the same letter are not significantly different (P < 0.1).
§ The 60 lb/ac rate is omitted in clay soils and the 210 lb/ac rate is omitted for the silt loam soils.

Table 6. Influence of nitrogen (N) fertilizer rate on the grain yield of Ozark rice at 3 locations during 2023.

	Rice Grain Yield		
N Fertilizer Rate	NEREC†	PTRS	RREC
(lb N/ac)	---(bu./ac)---		
0	90 c‡	90 e	95 d
60§	----	144 d	151 c
90	169 ab	172 c	170 b
120	176 a	191 b	182 a
150	181 a	213 a	180 a
180	171 ab	218 a	186 a
210§	158 b	----	----

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
‡ Means within a column followed by the same letter are not significantly different (P < 0.1).
§ The 60 lb/ac rate is omitted in clay soils and the 210 lb/ac rate is omitted for the silt loam soils.

Table 7. Influence of nitrogen (N) fertilizer rate on the grain yield of PVL03 rice at 3 locations during 2023.

	Rice Grain Yield		
N Fertilizer Rate	NEREC†	PTRS	RREC
(lb N/ac)	---(bu./ac)---		
0	86 c‡	108 d	87 d
60§	----	141 c	105 c
90	154 ab	165 b	117 b
120	166 a	176 ab	132 a
150	164 ab	182 ab	135 a
180	146 b	187 a	133 a
210§	146 b	----	----

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.
‡ Means within a column followed by the same letter are not significantly different (P < 0.1).
§ The 60 lb/ac rate is omitted in clay soils and the 210 lb/ac rate is omitted for the silt loam soils.

Table 8. Influence of nitrogen (N) fertilizer rate on the grain yield of RTv7231MA rice at 3 locations during 2023.

	Rice Grain Yield		
N Fertilizer Rate	**NEREC†**	**PTRS**	**RREC**
(lb N/ac)	--(bu./ac)--		
0	88 c‡	94 d	102 e
60§	----	161 c	155 d
90	154 b	187 b	166 c
120	175 a	209 a	176 ab
150	180 a	217 a	186 a
180	191 a	220 a	173 bc
210§	186 a	----	----

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

‡ Means within a column followed by the same letter are not significantly different ($P < 0.1$).

§ The 60 lb/ac rate is omitted in clay soils and the 210 lb/ac rate is omitted for the silt loam soils

Table 9. Influence of nitrogen (N) fertilizer rate on the grain yield of Taurus rice at 3 locations during 2023.

	Rice Grain Yield		
N Fertilizer Rate	**NEREC†**	**PTRS**	**RREC**
(lb N/ac)	--(bu./ac)--		
0	121 c‡	99 e	89 d
60§	----	143 d	151 c
90	182 ab	168 c	166 bc
120	193 a	201 b	183 ab
150	176 ab	218 a	194 a
180	166 b	225 a	190 a
210§	126 c	----	----

† NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

‡ Means within a column followed by the same letter are not significantly different ($P < 0.1$).

§ The 60 lb/ac rate is omitted in clay soils and the 210 lb/ac rate is omitted for the silt loam soils.

2023 Degree-Day 50 (DD50) Thermal Unit Thresholds for New Rice Cultivars and Seeding Date Studies

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Abstract

The Degree-Day 50 (DD50) computer program is one of the most successful management aids developed by the University of Arkansas System Division of Agriculture. This program predicts critical growth stages that assist in increasing the effectiveness of crop management operations. In order to maintain its relevance, the computer program must be updated continually as new rice cultivars become available to growers. To accomplish this goal, studies are conducted in a controlled research environment where developmental data and DD50 thermal unit thresholds for current and new cultivars are determined. Throughout the 2023 season, DD50 thermal unit accumulation, developmental data, and the effect of seeding date (SD) on grain and milling yield potential for 21 cultivars were evaluated over 6 SDs under a dry-seeded, delayed-flood management system commonly used in southern U.S. rice production. Significant differences in grain yield were observed for all 21 cultivars at each location.

Introduction

The Degree-Day 50 (DD50) is an outgrowth of the growing degree-day concept where daily high and low air temperatures are used to determine a day's thermal quality for plant growth. Conceived in the 1970s as a tool to time midseason nitrogen (N) applications, the DD50 computer program has grown into a management aid that provides predicted dates for timing 26 key management decisions, including fertilization, pesticide applications, permanent flood establishment, times for scouting insect and disease, predicted draining date and suggested harvest time (Hardke et al., 2018).

Beginning at emergence, the DD50 (days with a minimum average temperature of at least one degree above 50 °F) generates a predicted, cultivar-specific rice plant development file based on the accumulation of DD50 units calculated using the formula: DD50 = (Daily Maximum + Daily Minimum/2)-50, considering that Maximum temperature = 94 °F if maximum temperature is >94 °F, and Minimum temperature = 70 °F if minimum temperature is >70 °F. The growth stages predicted are: beginning optimum tillering, beginning internode (BIE), half-inch internode elongation (1/2 inch IE), 50% heading, drain date, and 20% grain moisture (Hardke et al., 2018). The initial file is created by calculating thermal unit accumulation using a 30-year average weather data set collected by the National Weather Service weather station closest to the rice producer's location in Arkansas. As the season progresses, the program is updated with the current year's weather data on a daily basis, which improves accuracy.

The data used to predict plant development for a specific cultivar are generated in yearly studies where promising experimental lines and newly released conventional and hybrid rice cultivars are evaluated in 4 to 6 seeding dates (SDs) per season within the recommended range of rice SDs for Arkansas. Once a new cultivar is released, the information obtained in these studies is utilized to provide threshold DD50 thermal units to the DD50 computer program that enables the prediction of dates of plant developmental stage occurrences and predictions of suggested dates when particular management practices could be performed. Therefore, the objectives of this study were to develop a DD50 thermal accumulation database for promising new cultivars, verification and refinement of the existing database of current cultivars, and an assessment of the effect of SD on DD50 thermal unit accumulation, and also the effects of SD on grain and milling yields of a particular cultivar for the identification of optimal SDs.

Procedures

The 2023 DD50 study was conducted at the University of Arkansas System Division of Agriculture's (UADA) Rice Research and Extension Center (RREC) near Stuttgart, Ark., on a DeWitt silt loam soil and the Northeast Rice Research and Extension Center (NERREC) near Harrisburg, Ark., on a Calloway silt loam soil. Entries included 10 pure-line cultivars, including ARoma 22, CLL16, CLL18, CLL19, CLM04, Diamond, Ozark, PVL03, Taurus, and Titan were dry-seeded at a rate of 33 seed/ft^2, 2 additional pure-line cultivars including DG263L and RTv7231 MA were dry-seeded at a rate of 45 lb/ac (~20 seed/ft^2), and 9 hybrids including RTXP753, RT 3202, RT 7302, RT 7401, RT 7321 FP, RT 7421 FP, RT 7521 FP, RT 7331 MA, and RT 7431 MA were dry-seeded at a rate of 11 seed/ft^2. Plot dimensions were 8 rows

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wide (7.5-in. spacing) and 17.5 ft long. The SDs for 2023 were 22 March, 10 April, 24 April, 8 May, 23 May, and 6 June for the RREC, and 29 March, 11 April, 24 April, 8 May, 23 May, and 6 June for the NERREC. Standard cultural practices were followed according to UADA recommendations. A single preflood nitrogen (N) application of 130 lb N/ac was applied to all plots at RREC and NERREC at the 4- to 5-leaf growth stage and flooded within 2 days of application. Data collected includes maximum and minimum temperatures, date of seedling emergence, and the number of days and DD50 units required to reach 50% heading. The number of days and DD50 thermal units required to reach 0.5-in. internode elongation (IE) was also collected for 10 April and 8 May at the RREC location. At maturity, the 4 center rows in each plot were harvested, weight of grain and moisture content were recorded, and a subsample of harvested grain was taken for milling purposes on all SDs. The grain yield was adjusted to 12% moisture and reported on a bushel per acre (bu./ac) basis. The dry rice was milled to obtain data on the percent of head rice and percent of total white rice (%HR/%TR). The study design was a randomized complete block with four replications for each SD. Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc. Cary, N.C.) with means separation using Fisher's least significant difference test (P = 0.05).

Results and Discussion

The amount of time between seeding and emergence ranged from 7–18 days at the NERREC and 7–15 days at the RREC, directly affecting the required days from seeding to flooding (Tables 1 and 2). In general, SD studies report a decrease in days between seeding and emergence as the SD is delayed. The 2023 study followed this general trend of decreasing days from seeding to emergence as SD was delayed from late March to late May. The time from seeding to establishment of permanent flood followed the same trend as the SD was delayed, ranging from 51 days for the 29 March to 29 for the 8 May SDs at NERREC and 62 days for the 22 March to 29 for the 8 May SDs at RREC. The times from emergence to flooding also follow the general trend of decreasing days with later SDs.

A decreasing trend in days and thermal units was observed to reach 0.5-in. IE from emergence as SD was delayed at RREC (Table 3). The cultivars CLL19, RT 7302, RT 7331 MA, and RT 7421 FP required the fewest days and DD50 units to reach 0.5-in. IE with 46 days, and 1255, 1247, 1240, and 1247 DD50 units, respectively. CLL18, Diamond, Ozark, and Taurus required the most days and DD50 units to reach 0.5-in. IE with 62, 62, 62, and 64 days, respectively, and 1404, 1404, 1427, and 1472 DD50 units, respectively. The average days to 0.5-in IE across planting dates was 54, and the average DD50 units across planting dates was 1339.

The average days needed to reach the developmental stage, known as 50% heading from the time of emergence across SDs and cultivars, was 83 days at the RREC and the NERREC (Tables 4 and 5). The average time for cultivars to reach 50% heading ranged from 77 to 87 days at the RREC and from 80 to 87 days at the NERREC across SDs. For individual cultivars, the time required to reach 50% heading ranged from 105 days for PVL03 to 68 days for RT 3202 and RTv7231 MA at the RREC. For the NERREC, the days to 50% heading ranged from 94 days for CLL16 to 72 days for RT 3202. For 2023, the thermal unit accumulation from emergence to 50% heading averaged 2214 DD50 units at the RREC and 2171 DD50 units at the NERREC. The individual cultivar thermal unit accumulation from emergence to 50% heading ranged from 1995 DD50 units for RTv7231 MA to 2579 DD50 units for CLL16 at the RREC. For the NERREC, thermal unit accumulation from emergence to 50% heading ranged from 1970 DD50 units for RT 3202 to 2431 DD50 units for CLL16. The lowest average thermal unit accumulation was the 10 April planting at the RREC and 5 April at the NERREC.

The average grain yield for 2023 at the RREC was 187 bu./ac and 177 bu./ac at the NERREC across SDs (Tables 6 and 7). The highest average grain yield across all cultivars was the 20 April SD at the NERREC and the 10 April SD at the RREC. On average, DG263L was the highest-yielding variety, and the hybrid RT 7302 yielded the highest at the RREC and the NERREC.

The milling yields for 2023, averaged across SDs and cultivars, were 56/70 (%HR/%TR) at the RREC and 59/70 at the NERREC (Tables 8 and 9). The milling yields were similar for each location and SD except for the 23 May SD at the RREC. This date was lower than all other SDs.

Practical Applications

The data obtained during 2023 will be used to improve the DD50 thermal unit threshold for new cultivars and hybrids being grown. The grain and milling yield data contribute to the database of information used by University personnel to help producers make decisions in regard to rice cultivar selection, in particular for early- and late-seeding situations.

Acknowledgments

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Table 1. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2023 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark.

	Seeding Date					
	22 March	**10 April**	**24 April**	**8 May**	**23 May**	**6 June**
Emergence date	6 April	23 April	1 May	15 May	30 May	12 June
Flood date	23 May	23 May	6 June	6 June	22 June	6 July
Days from seeding to emergence	15	13	7	7	7	6
Days from seeding to flooding	62	43	43	29	30	30
Days from emergence to flooding	47	30	36	22	23	24

Table 2. General seeding, seedling emergence, and flooding date information for the DD50 seeding date study in 2023 at the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center near Harrisburg, Ark.

	Seeding Date					
	29 March	**11 April**	**24 April**	**8 May**	**23 May**	**6 June**
Emergence date	17 April	24 April	3 May	15 May	29 May	10 June
Flood date	19 May	19 May	6 June	6 June	23 June	8 July
Days from seeding to emergence	19	13	9	7	6	4
Days from seeding to flooding	51	38	43	29	31	32
Days from emergence to flooding	32	25	34	22	25	28

Table 3. Influence of seeding date on DD50 accumulations and days from emergence to 0.5-in. internode elongation of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. during 2023.

	Seeding Date					
	10 April		**May 8**		**Average**	
Cultivar	**days**	**DD50 units**	**Days**	**DD50 units**	**days**	**DD50 units**
ARoma 22	60	1,347	47	1,279	53	1,313
CLL18	62	1,404	53	1,451	57	1,428
CLL19	58	1,289	46	1,255	52	1,272
Diamond	62	1,404	52	1,420	57	1,412
Ozark	62	1,427	51	1,397	57	1,412
RT 3202	60	1,354	47	1,271	53	1,313
RT 7302	59	1,326	46	1,247	52	1,286
RT 7331 MA	59	1,333	46	1,240	52	1,286
RT 7401	58	1,311	47	1,287	53	1,299
RT 7421 FP	58	1,297	46	1,247	52	1,272
RT 7431 MA	59	1,326	48	1,311	53	1,318
Taurus	64	1,472	53	1,451	58	1,461
Mean	60	1,357	48	1,321	54	1,339
$LSD_{(\alpha=0.05)}$[a]	1.4	41.201	1.0107	34.006	NS[b]	38.298

[a] LSD = least significant difference.

[b] NS = not significant.

Table 4. Influence of seeding date on DD50 accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. during 2023.

	Seeding Date													
	22 March		10 April		24 April		8 May		23 May		6 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 Units	days	DD50 units	days	DD50 units	days	DD50 units
ARoma 22	101	2,289	86	2,139	90	2,421	76	2,157	76	2,234	75	2,236	84	2,246
CLL16	102	2,329	90	2,239	95	2,579	81	2,316	77	2,280	80	2,361	87	2,350
CLL18	103	2,347	88	2,193	94	2,571	81	2,292	76	2,249	77	2,289	86	2,324
CLL19	99	2,239	85	2,087	90	2,437	77	2,165	75	2,203	75	2,196	83	2,221
CLM04	99	2,240	91	2,278	93	2,532	81	2,308	78	2,297	78	2,280	87	2,322
DG236L	98	2,198	84	2,080	89	2,405	75	2,101	71	2,102	74	2,241	82	2,188
Diamond	101	2,295	88	2,178	90	2,437	78	2,221	77	2,265	76	2,266	85	2,277
Ozark	101	2,295	87	2,170	90	2,437	76	2,157	77	2,281	75	2,244	84	2,264
PVL03	105	2,393	89	2,209	91	2,469	80	2,260	78	2,304	77	2,226	86	2,310
RT 3202	94	2,103	79	1,922	83	2,218	73	2,053	68	1,995	68	2,076	77	2,061
RT 7302	98	2,205	85	2,087	90	2,437	76	2,149	71	2,110	73	2,180	82	2,194
RT 7321 FP	95	2,131	81	1,989	88	2,365	75	2,101	69	2,050	71	2,147	80	2,130
RT 7331 MA	96	2,157	82	2,010	88	2,381	75	2,109	69	2,050	71	2,156	80	2,144
RT 7401	97	2,184	84	2,080	89	2,405	76	2,141	72	2,136	75	2,188	82	2,189
RT 7421 FP	99	2,219	84	2,080	90	2,437	77	2,173	75	2,202	77	2,290	84	2,233
RT 7431 MA	97	2,171	85	2,095	89	2,413	75	2,101	70	2,080	75	2,251	82	2,185
RT 7521 FP	100	2,260	87	2,162	90	2,437	78	2,220	76	2,242	78	2,281	85	2,267
RT XP753	97	2,171	84	2,073	90	2,429	76	2,133	70	2,058	72	2,164	81	2,171
RTv7231 MA	93	2,074	78	1,909	84	2,248	73	2,053	68	1,995	69	2,060	77	2,056
Taurus	97	2,171	86	2,117	88	2,357	76	2,149	73	2,160	72	2,124	82	2,179
Titan	96	2,158	83	2,052	87	2,341	76	2,133	72	2,136	74	2,235	81	2,176
Mean	99	2,220	85	2,102	89	2,417	77	2,166	73	2,163	74	2,214	83	2,214
$LSD_{(\alpha=0.05)}$[a]	2.86	2.86	1.53	44.69	0.98	31.35	1.73	55.12	2.18	65.76	1.63	110.54	5.38	65.15

[a] LSD = least significant difference.

Table 5. Influence of seeding date on DD50 accumulations and days from emergence to 50% heading of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center near Harrisburg, Ark. during 2023.

	Seeding Date													
	29 March		11 April		24 April		8 May		23 May		6 June		Average	
Cultivar	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units	days	DD50 units
ARoma 22	91	2,136	85	2,000	89	2,130	81	2,179	77	2,188	79	2,262	83	2,149
CLL16	94	2,211	87	2,082	90	2,176	83	2,288	81	2,311	84	2,431	87	2,250
CLL18	93	2,173	84	1,985	90	2,238	82	2,248	81	2,236	83	2,391	86	2,212
CLL19	91	2,128	84	1,977	90	2,231	80	2,203	77	2,195	80	2,297	84	2,172
CLM04	92	2,165	88	2,158	92	2,280	83	2,289	82	2,359	81	2,390	86	2,273
DG236L	88	2,085	83	2,000	81	2,054	75	2,111	75	2,165	75	2,246	80	2,110
Diamond	92	2,166	86	2,015	91	2,269	81	2,248	80	2,253	80	2,320	85	2,212
Ozark	92	2,173	85	2,015	91	2,283	81	2,233	80	2,278	82	2,378	85	2,227
PVL03	92	2,136	87	2,037	88	2,238	83	2,272	80	2,234	82	2,337	85	2,209
RT 3202	85	1,994	83	1,970	81	2,039	74	2,071	72	2,087	75	2,198	78	2,060
RT 7302	92	2,143	86	2,065	84	2,094	79	2,172	78	2,225	78	2,286	83	2,164
RT 7321 FP	90	2,113	84	2,000	85	2,114	77	2,134	74	2,138	77	2,262	81	2,104
RT 7331 MA	90	2,135	84	2,007	86	2,091	80	2,196	75	2,132	76	2,207	82	2,128
RT 7401	91	2,121	84	2,007	89	2,208	80	2,196	79	2,242	80	2,318	84	2,182
RT 7421 FP	93	2,166	85	2,022	90	2,217	81	2,233	80	2,264	81	2,295	85	2,199
RT 7431 MA	92	2,171	85	2,022	87	2,201	78	2,157	74	2,154	77	2,325	82	2,172
RT 7521 FP	92	2,128	85	1,985	90	2,233	80	2,195	80	2,258	80	2,320	84	2,186
RT XP753	91	2,158	84	2,000	87	2,138	79	2,165	77	2,189	77	2,247	82	2,149
RTv7231 MA	90	2,121	84	1,977	85	2,067	79	2,127	73	2,080	75	2,191	81	2,195
Taurus	90	2,084	86	2,015	87	2,085	80	2,179	78	2,195	77	2,231	83	2,131
Titan	90	2,106	84	2,007	88	2,208	79	2,226	77	2,231	77	2,271	82	2,175
Mean	91	2,134	85	2,016	88	2,171	80	2,196	78	2,210	79	2,295	83	2,171
$LSD_{(\alpha=0.05)}$[a]	1.81	70.14	1.84	69.08	3.15	133.6	2.31	100.27	96.6	96.62	2.45	96.02	3.06	62.8

[a] LSD = least significant difference.

Table 6. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. during 2023.

	Grain Yield by Seeding Date						
Cultivar	22 March	10 April	24 April	8 May	23 May	6 June	Average
	(bu./ac)						
ARoma 22	148	143	147	150	126	135	142
CLL16	178	183	180	178	162	153	173
CLL18	187	198	183	192	161	174	183
CLL19	193	193	179	160	134	158	170
CLM04	178	168	151	167	133	155	159
DG236L	197	200	208	222	183	181	198
Diamond	183	185	173	185	157	162	175
Ozark	191	198	182	191	148	186	184
PVL03	168	167	144	126	119	144	145
RT 3202	216	210	220	228	179	189	206
RT 7302	215	214	211	233	195	196	211
RT 7321 FP	216	217	202	219	180	174	201
RT 7331 MA	210	230	231	236	202	183	215
RT 7401	210	221	210	228	211	190	212
RT 7421 FP	212	209	209	233	193	185	207
RT 7431 MA	219	219	209	217	204	191	209
RT 7521 FP	223	217	200	225	180	184	205
RT XP753	212	219	222	235	185	186	210
RTv7231 MA	186	208	214	211	158	158	189
Taurus	196	199	190	177	147	183	182
Titan	173	164	144	150	121	158	152
Mean	196	199	191	198	166	173	187
$LSD_{(\alpha=0.05)}$[a]	15.92	16.29	16.05	19.78	21.57	16.33	7.71

[a] LSD = least significant difference.

Table 7. Influence of seeding date on grain yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center near Harrisburg, Ark. during 2023.

	Grain Yield by Seeding Date						
Cultivar	**29 March**	**11 April**	**24 April**	**8 May**	**23 May**	**6 June**	**Average**
	(bu./ac)						
ARoma 22	152	159	158	136	112	117	140
CLL16	184	178	176	147	141	134	161
CLL18	178	189	195	157	125	128	163
CLL19	184	177	176	171	129	153	166
CLM04	156	160	184	148	126	126	151
DG236L	194	193	213	207	147	143	184
Diamond	178	184	164	153	136	106	146
Ozark	176	180	184	162	134	118	158
PVL03	175	165	162	155	107	105	146
RT 3202	238	228	223	203	156	154	202
RT 7302	210	227	232	214	168	161	204
RT 7321 FP	207	212	229	206	141	160	195
RT 7331 MA	209	215	229	210	150	167	199
RT 7401	210	222	229	212	188	143	201
RT 7421 FP	205	222	230	208	171	165	201
RT 7431 MA	206	222	233	213	163	151	199
RT 7521 FP	187	212	212	185	166	135	184
RT XP753	210	216	234	209	153	164	199
RTv7231 MA	173	173	205	176	141	132	168
Taurus	194	199	215	187	141	129	179
Titan	175	176	194	185	134	120	165
Mean	191	195	204	183	144	139	177
$LSD_{(\alpha=0.05)}$[a]	18.93	28.96	22.87	13.03	15.43	22.56	7.94

[a] LSD = least significant difference.

Table 8. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. during 2023.

	Milling Yield by Seeding Date						
Cultivar	**22 March**	**10 April**	**24 April**	**8 May**	**23 May**	**6 June**	**Average**
	------------(%HR/%TR)[a]------------						
ARoma 22	59/70	60/70	63/70	57/68	47/69	65/71	59/70
CLL16	53/68	53/68	58/68	52/67	47/70	64/72	55/69
CLL18	51/68	52/69	57/68	52/68	44/70	63/71	53/69
CLL19	60/70	61/70	65/70	56/69	47/69	66/73	59/70
CLM04	62/70	63/68	65/69	64/69	46/70	68/72	61/70
DG236L	60/69	59/68	60/69	53/68	41/68	64/71	56/69
Diamond	51/70	55/70	60/70	52/69	42/70	66/73	54/70
Ozark	52/70	54/69	60/70	54/70	42/70	67/73	55/70
PVL03	55/71	59/72	64/72	55/69	42/70	67/74	57/71
RT 3202	58/70	61/71	65/71	55/69	42/70	64/72	57/71
RT 7302	55/71	58/71	60/71	55/70	41/70	65/74	56/71
RT 7321 FP	50/71	56/71	54/70	44/70	35/70	61/73	50/71
RT 7331 MA	57/72	61/72	60/71	48/71	47/71	66/74	57/72
RT 7401	55/70	57/70	58/71	54/70	37/71	65/73	54/71
RT 7421 FP	54/70	56/70	56/70	52/70	34/71	65/73	53/70
RT 7431 MA	53/71	60/71	60/71	51/70	42/72	65/73	55/71
RT 7521 FP	55/70	55/69	59/69	55/69	45/70	66/72	56/70
RT XP753	55/72	58/72	58/71	49/71	36/71	64/74	53/72
RTv7231 MA	52/70	56/70	57/70	49/70	36/69	60/71	51/70
Taurus	63/72	63/71	65/71	57/70	46/70	69/73	60/71
Titan	59/70	64/70	66/70	58/69	38/70	65/72	58/70
Mean	56/70	58/70	61/70	53/69	42/70	65/72	56/70
$LSD_{(\alpha=0.05)}$[b] %HR[a]	4.28	3.0	NS	2.45	NS	1.66	1.36
$LSD_{(\alpha=0.05)}$[b] %TR[a]	NS[c]	0.94	0.66	NS	0.92	NS	0.38

[a] %HR/%TR = percent head rice/percent total rice.

[b] LSD = least significant difference.

[c] NS = not significant.

Table 9. Influence of seeding date on milling yield of selected rice cultivars in studies conducted at the University of Arkansas System Division of Agriculture's Northeast Rice Research and Extension Center near Harrisburg, Ark. during 2023.

	Milling Yield by Seeding Date						
Cultivar	**29 March**	**11 April**	**24 April**	**8 May**	**23 May**	**6 June**	**Average**
	--			(%HR/%TR)[a]			--
ARoma 22	60/69	59/69	60/69	57/67	56/69	59/68	59/69
CLL16	54/68	58/69	52/66	53/67	61/71	57/68	56/68
CLL18	57/69	57/69	55/67	53/66	61/70	58/67	57/68
CLL19	58/69	58/69	58/69	56/67	57/69	60/68	58/68
CLM04	65/71	62/70	64/69	61/67	63/70	65/70	63/69
DG236L	57/68	58/69	58/69	57/68	58/68	59/67	58/68
Diamond	57/70	58/70	56/70	55/68	59/70	62/69	58/70
Ozark	59/70	58/69	58/70	56/69	59/71	61/68	59/70
PVL03	59/70	60/70	59/70	56/68	59/69	62/70	59/69
RT 3202	64/71	63/70	64/71	59/69	60/70	61/69	62/70
RT 7302	62/72	59/70	60/71	59/70	56/70	62/70	59/71
RT 7321 FP	55/71	57/70	56/71	54/70	51/69	57/70	55/70
RT 7331 MA	61/72	60/70	61/72	59/71	53/70	63/72	59/71
RT 7401	58/71	59/70	59/71	57/69	54/71	60/70	58/70
RT 7421 FP	58/70	57/70	59/71	57/69	60/72	59/69	58/70
RT 7431 MA	61/72	58/70	62/72	60/71	54/71	61/71	59/71
RT 7521 FP	57/69	57/69	57/69	54/67	63/71	61/70	58/69
RT XP753	60/72	60/71	58/72	56/71	52/72	59/71	58/71
RTv7231 MA	58/70	60/71	58/71	59/70	55/68	60/69	58/70
Taurus	64/70	63/70	64/71	61/68	56/69	59/68	61/69
Titan	63/69	61/69	64/70	60/68	56/69	58/68	60/69
Mean	59/70	59/70	59/70	57/69	57/70	60/69	59/70
$LSD_{(\alpha=0.05)}$[b] %HR[a]	2.65	NS[c]	1.86	2.67	0.03	2.49	1.18
$LSD_{(\alpha=0.05)}$[b] %TR[a]	1.01	NS	1.16	1.42	1.17	1.98	0.58

[a] %HR/%TR = percent head rice/percent total rice.

[b] LSD = least significant difference.

[c] NS = not significant.

Arkansas Rice Performance Trials, 2023

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Abstract

The use of on-farm commercial fields and research stations provides the opportunity to evaluate cultivar performance across a wide range of environmental conditions and management situations. The Arkansas Rice Performance Trials (ARPT) utilize experiment stations and commercial fields throughout the rice-producing regions of Arkansas to evaluate the performance of commercial rice cultivars. These trials provide information on agronomic factors of cultivars such as disease resistance, lodging, plant stand, plant height, grain yield, and milling yield across a range of environmental conditions, growing practices, and soil types. Choosing a cultivar is a critical decision annually for producers. Studies in 2023 were in grower fields in Clay, Desha, Greene, Jackson, Lawrence, and southern Arkansas counties, and on research stations in Arkansas, Mississippi, Poinsett, and St. Francis counties. The average grain yield across all trials was 187 bu./ac, with the highest average yielding location being the on-farm location in Lawrence County at 202 bu./ac. Cultivars with the highest grain yield averaged across all locations include RT 7302, RT 3202, RT 7321 FP, RT 7421 FP, RT 7521 FP, and RT XP753. The average milling yield across all cultivars and locations was 57/71 (%HR/%TR). Averaged across locations, ProGold M3, CLM04, Jupiter, DG353M, LAX-19207, and Taurus produced the highest head rice yields, and total rice yield was similar between all cultivars during 2023.

Introduction

The University of Arkansas System Division of Agriculture (UADA) strives to provide a complete production package for growers as they choose rice cultivars. Information provided about individual cultivars can include grain and milling yield potential, disease susceptibility, fertilizer recommendations, and Degree-Day 50 (DD-50) Program thresholds. New rice cultivars are developed and evaluated annually at research station locations under controlled conditions. Large amounts of data are garnered from these trials, which include grain yield and quality, growth behavior, and disease resistance. While this information is useful, it does not consider environment and management variability, which can be provided by on-farm locations. Field research in an on-farm setting can provide growers with additional information that helps them make informed decisions when choosing a cultivar best suited for their specific needs.

The Arkansas Rice Performance Trials (ARPT) are designed to assess cultivars across various environments in Arkansas. Information collected each year for each cultivar includes percent lodging, grain moisture at harvest, grain yield, and milling yields. Ratings of disease pressure are also collected to aid in determining a cultivar's disease susceptibility. The trials are also available to provide hands-on educational opportunities to county agents, consultants, and producers.

The objectives of the ARPT include 1) comparing the potential yield of available commercial cultivars and advanced experimental lines on fields used for commercial production, 2) monitoring disease pressure across different locations in Arkansas, and 3) evaluating the performance of rice cultivars under day-to-day field management differing from that of experiment stations.

Procedures

Twenty-seven cultivars were evaluated at 4 research station sites (Arkansas, St. Francis, Mississippi, and Poinsett counties) and 6 on-farm sites (Clay, Desha, Greene, Jackson, Lawrence, and southern Arkansas counties) during 2023. Entries included the conventional (non-herbicide-tolerant) long-grain varieties DG263L, Diamond, Ozark, and experimental line LAX-19207, the Clearfield long-grain varieties CLL16, CLL18, and CLL19, the Provisia long-grain varieties PVL03 and PVL04, the MaxAce long-grain variety RTv7231 MA, the MaxAce long-grain hybrids RT 7331 MA and RT 7431 MA, the FullPage long-grain hybrids RT 7321 FP, RT 7421 FP, RT 7521 FP, and RT 7523 FP, the conventional long-grain hybrids RT 7302, RT 7401, and RT XP753, the conventional medium-grain varieties DG353M, Jupiter, ProGold M3, Taurus, and Titan, the medium-grain hybrid RT 3202, and the Clearfield medium-grain varieties CLM04 and CLM05. In addition, the long-grain aromatic variety ARoma 22 was evaluated at the 4 research station sites.

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Plots were 8 rows (7.5-in. spacing) wide and 17-ft in length, arranged in a randomized complete block design with 4 replications. Pure-line cultivars (varieties) were seeded at 33 seed/ft^2, with hybrid cultivars seeded at 11 seed/ft^2. Exceptions were DG263L and RTv7231 MA, which were seeded at 20 seed/ft^2. All entries included a seed treatment package of CruiserMaxx Rice (7 fl oz/cwt), Vibrance 500 (0.12 fl oz/cwt), Zinche ST (8 fl oz/cwt), Fortenza (3.47 fl oz/cwt) and AV-1011 (18.3 fl oz/cwt). Cultural data for each site, including trial location, soil type, seeding, emergence, and harvest dates, are given in Table 1.

ARPT locations had some cultural practice variations but, overall, were grown for highest yield. Trials planted at on-farm locations were managed as part of the grower's field. All plots were managed as non-herbicide-tolerant conventional cultivars.

At maturity, each plot was rated for the presence of diseases (data not shown) and lodging observations were made and reported as a percentage of total plot (%). Plot weight and percent harvest moisture were determined by harvesting the center 4 rows of each plot using a small-plot research combine. Grain yield was reported in bushels per acre (bu./ac) adjusted to 12% moisture dry weight. A bushel of rice weighs 45 lb. A subsample was collected from each plot during harvest to evaluate milling. The dried rice sample was milled using a Zaccharia PAZ-1/DTA Lab Rice Mill to determine the percent head rice (%HR, whole kernels) and the percent total white rice (%TR) expressed as %HR/%TR. Data were analyzed using analysis of variance, PROC GLM, SAS v. 9.4 (SAS Institute, Inc., N.C.) with means separated using Fisher's least significant difference test (P = 0.05).

Results and Discussion

Across all locations during 2023, lodging percentage was below 10% and was generally lower for the long-grain pure-line cultivars (Table 2). Average grain yield was 187 bu./ac, and the highest-yielding cultivars included RT 7302, RT 3202, RT 7321 FP, RT 7421 FP, RT 7521 FP, and RT XP753. Milling yields were also within the standard of 55/70 with few exceptions.

At Arkansas Co. near Stuttgart, Ark., the overall grain yield was 168 bu./ac averaged across all cultivars (Table 3). No lodging was noted at this location during 2023. The highest-yielding long-grain variety was DG263L. The highest-yielding long-grain hybrid was RT 7302. The highest-yielding medium-grain was the RT 3202 hybrid. The site had an average milling yield of 63/71 (%HR/%TR) with CLM04, RT 3202, ProGold M3, Jupiter, DG353M, and the experimental line LAX-19207, resulting in the highest head rice yields. Percent total rice yield was similar among all cultivars.

The St. Francis Co. location near Colt, Ark., had an average grain yield of 193 bu./ac (Table 4). No lodging was noted at this location during 2023. The highest-yielding long-grain variety was DG263L. The highest-yielding long-grain hybrid was RT 7302. The highest-yielding medium-grain was RT 3202. The grain yield of the long-grain aromatic variety Aroma 22 was the highest among the 4 research stations during 2023. The St. Francis Co. location had an average milling yield of 54/71 (%HR/%TR). Head rice yields were highest for the medium-grain varieties CLM04, ProGold M3, and Jupiter. Total rice percentages were similar between cultivars.

The trial at Mississippi Co. near Keiser, Ark., had an average grain yield of 167 bu./ac (Table 5). Lodging was noted for Taurus and Titan at this location during 2023. The highest-yielding long-grain variety was Ozark. The highest-yielding long-grain hybrid was RT 7302. The highest-yielding medium-grain was RT 3202. This location had a milling yield of 56/70 (%HR/%TR) when averaged across all cultivars. ProGold M3, followed by CLL16, were the highest milling entries for %HR during 2023. The percentage of total rice was lowest for Jupiter and CLM05 and similar among all other cultivars.

During 2023, the Poinsett Co. location near Harrisburg, Ark., had an average grain yield of 184 bu./ac (Table 6). Lodging was present in the cultivars DG263L, RTv7231 MA, RT 7331 MA, RT 7431 MA, Titan, and CLM04. The highest-yielding long-grain variety was DG263L. The highest-yielding long-grain hybrid was RT 7321 FP. The highest-yielding medium-grain was RT 3202. The average milling yield of this trial was 61/71 (%HR/%TR). Entries that provided the highest head rice milling yields were ProGold M3, CLM05, DG353M, Jupiter, and LAX-19207. Total rice milling yields were similar between all cultivars.

Grain yield at the on-farm Clay Co. trial located near McDougal, Ark., averaged 188 bu./ac during 2023 (Table 7). Lodging was noted in the variety Titan. The highest-yielding long-grain variety was DG263L. The highest-yielding long-grain hybrid was RT 7521 FP. The highest-yielding medium-grain was RT 3202. Grain yield exceeded 200 bu./ac for the Clearfield medium-grain CLM05 at this location during 2023. The average milling yield for this location was 52/69 (%HR/%TR). Cultivars with the highest head rice milling yields included CLM04, Taurus, ProGold M3, DG353M, and LAX-19207. Total rice was lowest for CLM05 and Jupiter at this location.

The on-farm location in Desha Co. near McGehee, Ark., yielded an average of 188 bu./ac (Table 8). No lodging was noted at this location during 2023. The highest-yielding long-grain variety was CLL18. The highest-yielding long-grain hybrid was RT 7521 FP. The highest-yielding medium-grain was RT 3202. This location had an average milling yield of 53/69 (%HR/%TR). Cultivars with the highest head rice included ProGold M3, CLM04, RT 3202, Taurus, and Jupiter. The percent total rice was lowest for DG353M at this location.

The on-farm location in Greene Co., located near Paragould, Ark., had an average grain yield of 196 bu./ac (Table 9). Lodging was noted in the hybrid cultivars RT 7431 MA, RT 7321 FP, RT 7521 FP, RT 7523 FP, and RT 7401. The highest-yielding long-grain varieties were DG263L and Ozark. The highest-yielding long-grain hybrid was RT 7521 FP. The highest-yielding medium-grain was the hybrid RT 3202. Greene Co. had an average milling yield of 61/72 (%HR/%TR) during 2023. Percent head rice was highest for the medium-grain varieties ProGold M3, CLM04, DG353M, and Jupiter. The percent total rice was similar among all cultivars.

The Jackson Co. on-farm location near Newport, Ark., produced an average grain yield of 186 bu./ac (Table 10). No lodging was present at this location during 2023. The highest-yielding long-grain variety was Ozark. The highest-yielding long-grain hybrid was RT 7302. The highest-yielding medium-grain was RT 3202. Averaged across all cultivars, the milling yield was 48/71 (%HR/%TR). The highest percent head rice yields were Jupiter, CLM04, ProGold M3, DG353M, LAX-19207, PVL04, and Ozark. The percent total rice was similar among all cultivars.

During 2023, the on-farm Lawrence Co. trial was located near Walnut Ridge, Ark. Average grain yield for this location was 202 bu./ac (Table 11), which was the highest for all locations during this study year. Lodging was observed in the hybrid RT 7521 FP. The highest-yielding long-grain variety was Ozark. The highest-yielding long-grain hybrid was RT 7321 FP. The highest-yielding medium-grain was the hybrid RT 3202. The milling yield average for this location was 56/70 (%HR/%TR). Percent head rice was highest for CLM04, ProGold M3, Jupiter, and Taurus. The percent total rice was generally consistent across all cultivars.

The southern Arkansas Co. on-farm location located near Gillett, Ark., in 2023 produced an average grain yield of 195 bu./ac (Table 12). No lodging was present at this location during this study year. The highest-yielding long-grain variety was CLL19. The highest-yielding long-grain hybrids were RT 7302 and RT 7521 FP followed closely by RT 7331 MA. The highest-yielding medium-grain was RT 3202. The average milling yield at this location was 64/72 (%HR/%TR). Percent head rice was highest for all medium grain cultivars, the hybrid RT 7302, and the variety CLL19. The percent total rice was consistent across all cultivars.

Practical Applications

The 2023 Arkansas Performance Rice Trials provide additional data to rice breeding and disease management programs to determine the best selections for Arkansas environments. The 2023 ARPT trials also provide additional information on the performance and disease reaction of current cultivars available for use by Arkansas growers on their farms.

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Table 1. Cultural Data Summary for the 2023 Arkansas Rice Performance Trials.

County	City	Soil Class	Planting Date	Emergence Date	Harvest Date
Arkansas	Stuttgart	Dewitt silt loam	4/10	4/23	9/11
St. Francis	Colt	Calhoun-Henry silt loam	5/3	5/10	9/15
Mississippi	Keiser	Sharkey silty clay	5/4	5/12	9/27
Poinsett	Harrisburg	Calloway-Henry silt loam	4/11	4/24	9/19
Clay	McDougal	Crowley silt loam/ Jackport silty clay	4/4	4/20	9/6
Desha	McGehee	Rilla silt loam / Portland clay	4/19	5/1	8/31
Lawrence	Walnut Ridge	Foley-Calhoun silt loam	5/10	5/18	9/21
Jackson	Newport	Amagon / Forestdale silt loam	5/11	5/28	9/29
Greene	Paragould	Jackport silty clay loam	5/11	5/17	9/21
Arkansas	Gillett	LaGrue silty clay loam	3/30	4/12	8/24

Table 2. Results of the Arkansas Performance Rice Trials (ARPT) at 10 Locations during 2023.

Cultivar	Grain Type[a]	Lodging[b]	Milling Yield[c]	Grain Yield by Location										
				ARK[d]	STF	MIS	POI	CLA	DES	GRE	JAC	LAW	SAR	Mean
		(%)	(%HR/%TR)	------(bu./ac)------										
DG263L	L	2	56/69	172	203	165	203	215	187	202	181	210	178	191
Diamond	L	0	56/71	156	182	162	174	170	164	182	166	193	175	172
Ozark	L	0	57/71	168	193	174	178	177	172	202	196	215	189	186
LAX-19207	L	0	61/72	141	169	130	158	160	185	175	147	176	183	163
CLL16	CL	0	55/70	155	178	156	165	177	184	198	172	186	188	176
CLL18	CL	0	55/70	162	189	169	184	188	190	197	186	196	201	186
CLL19	CL	0	58/71	156	189	161	162	186	187	196	163	207	207	182
PVL03	PL	0	59/72	146	167	126	161	155	176	167	151	158	200	161
PVL04	PL	0	59/71	135	178	153	162	156	151	192	144	183	175	162
RTv7231 MA	ML	2	51/71	170	189	171	170	196	191	178	180	197	175	182
RT 7331 MA	MLH	1	53/72	210	217	197	200	215	204	213	191	236	226	211
RT 7431 MA	MLH	3	55/72	200	221	190	207	201	202	200	209	201	207	204
RT 7321 FP	FLH	2	49/71	211	214	194	219	223	213	211	210	242	223	216
RT 7421 FP	FLH	0	54/71	219	235	210	217	205	203	219	215	223	199	215
RT 7521 FP	FLH	8	56/70	215	231	171	209	241	230	229	187	203	228	216
RT 7523 FP	FLH	2	52/71	207	216	190	210	195	204	188	219	234	201	206
RT 7302	LH	0	53/71	232	227	221	230	231	229	219	225	238	228	228
RT 7401	LH	1	53/71	206	223	203	214	195	201	201	211	219	213	208
RT XP753	LH	0	51/72	215	213	200	217	208	211	220	213	231	218	215
DG353M	M	0	62/71	118	164	128	151	132	163	173	184	171	149	154
Jupiter	M	0	63/69	111	149	149	150	147	159	166	175	165	146	152
ProGold M3	M	0	65/70	158	176	193	172	172	190	204	187	181	196	183
Taurus	M	2	60/71	169	184	153	178	187	198	200	186	206	207	187
Titan	M	4	58/70	130	170	132	155	171	155	173	169	195	159	162
RT 3202	MH	0	56/71	211	227	207	229	218	201	224	204	230	225	217

Table 2. Continued.

Cultivar	Grain Type[a]	Lodging[b]	Milling Yield[c]	Grain Yield by Location										
				ARK[d]	STF	MIS	POI	CLA	DES	GRE	JAC	LAW	SAR	Mean
		(%)	(%HR/%TR)	---(bu./ac)---										
CLM04	CM	2	64/70	124	173	135	163	167	177	169	181	170	165	163
CLM05	CM	0	59/69	147	177	146	179	204	175	183	168	199	201	177
Aroma 22	LA	0	58/70	113	154	131	145	-	-	-	-	-	-	136
MEAN		1	57/71	168	193	167	184	188	188	196	186	202	195	187
$LSD_{0.05}$[e]		3.1	2/0.4	18	12	20	16	16	11	14	21	25	11	6

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain; LA = long-grain aromatic.

[b] Lodging = % of plot down at harvest.

[c] Milling yield = % Head Rice/% Total Rice.

[d] ARK = Arkansas Co., Rice Research & Extension Center, Stuttgart, Ark.; STF = St. Francis Co., Pine Tree Research Station, Colt, Ark.; MIS = Mississippi Co., Northeast Research & Extension Center, Keiser, Ark.; POI = Poinsett Co., Northeast Rice Research and Extension Center, Harrisburg, Ark.; CLA = Clay Co., producer field near McDougal, Ark.; DES = Desha Co., producer field near McGehee, Ark.; LAW = Lawrence Co., producer field near Walnut Ridge, Ark.; JAC = Jackson Co., producer field near Newport, Ark.; GRE = Greene Co.; producer field near Paragould, Ark.; SAR = Arkansas Co., producer field near Gillett, Ark.

[e] LSD = least significant difference (α = 0.05).

Table 3. Results of the Arkansas County Arkansas Rice Performance Trial (ARK-ARPT) during 2023 (planted 10 April; harvested 11 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	16	172	61/70
Diamond	L	0	16	156	59/71
Ozark	L	0	16	168	63/72
LAX-19207	L	0	17	141	67/72
CLL16	CL	0	19	155	62/71
CLL18	CL	0	17	162	61/70
CLL19	CL	0	14	156	64/71
PVL03	PL	0	16	146	65/72
PVL04	PL	0	17	135	61/71
RTv7231 MA	ML	0	13	170	60/71
RT 7331 MA	MLH	0	13	210	63/72
RT 7431 MA	MLH	0	14	200	62/72
RT 7321 FP	FLH	0	13	211	56/71
RT 7421 FP	FLH	0	15	219	59/72
RT 7521 FP	FLH	0	14	215	63/71
RT 7523 FP	FLH	0	15	207	62/71
RT 7302	LH	0	14	232	63/72
RT 7401	LH	0	14	206	59/71
RT XP753	LH	0	13	215	61/72
DG353M	M	0	19	118	67/71
Jupiter	M	0	21	111	67/70
ProGold M3	M	0	18	158	67/71
Taurus	M	0	16	169	62/72
Titan	M	0	17	130	63/70
RT 3202	MH	0	14	211	67/71
CLM04	CM	0	18	124	68/71
CLM05	CM	0	15	147	64/69
ARoma 22	LA	0	15	113	63/70
Mean	-	0	16	168	63/71
$LSD_{0.05}$[e]	-	0	2	18	2/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain; LA = long-grain aromatic.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference (α = 0.05).

Table 4. Results of the St. Francis County Arkansas Rice Performance Trial (STF-ARPT) during 2023 (planted 3 May; harvested 15 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	11	203	55/69
Diamond	L	0	11	182	54/72
Ozark	L	0	11	193	54/71
LAX-19207	L	0	12	169	60/72
CLL16	CL	0	13	178	52/70
CLL18	CL	0	12	189	55/70
CLL19	CL	0	11	189	56/71
PVL03	PL	0	12	167	60/72
PVL04	PL	0	13	178	58/71
RTv7231 MA	ML	0	10	189	42/71
RT 7331 MA	MLH	0	11	217	44/71
RT 7431 MA	MLH	0	10	221	48/71
RT 7321 FP	FLH	0	11	214	40/70
RT 7421 FP	FLH	0	11	235	48/70
RT 7521 FP	FLH	0	10	231	56/69
RT 7523 FP	FLH	0	10	216	49/70
RT 7302	LH	0	11	227	49/70
RT 7401	LH	0	10	223	49/70
RT XP753	LH	0	10	213	52/71
DG353M	M	0	13	164	59/72
Jupiter	M	0	16	149	64/69
ProGold M3	M	0	14	176	65/71
Taurus	M	0	12	184	55/72
Titan	M	0	13	170	47/70
RT 3202	MH	0	10	227	52/70
CLM04	CM	0	14	173	65/71
CLM05	CM	0	13	177	60/69
ARoma 22	LA	0	11	154	52/69
Mean	-	0	12	193	54/71
$LSD_{0.05}$[e]	-	0	1	12	6/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain; LA = long-grain aromatic.
[b] Lodging = % of plot down at harvest.
[c] Moisture = Grain moisture at harvest.
[d] Milling yield = % Head Rice/% Total Rice.
[e] LSD = least significant difference (α=0.05).

Table 5. Results of the Mississippi County Arkansas Rice Performance Trial (MIS-ARPT) during 2023 (planted 4 May; harvested 27 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	13	165	56/69
Diamond	L	0	16	162	60/72
Ozark	L	0	14	174	57/71
LAX-19207	L	0	15	130	57/71
CLL16	CL	0	19	156	61/71
CLL18	CL	0	16	169	58/70
CLL19	CL	0	13	161	53/69
PVL03	PL	0	14	126	58/71
PVL04	PL	0	17	153	60/71
RTv7231 MA	ML	0	12	171	54/71
RT 7331 MA	MLH	0	12	197	54/71
RT 7431 MA	MLH	0	13	190	52/71
RT 7321 FP	FLH	0	13	194	55/71
RT 7421 FP	FLH	0	14	210	55/71
RT 7521 FP	FLH	0	13	171	52/69
RT 7523 FP	FLH	0	14	190	55/70
RT 7302	LH	0	13	221	54/71
RT 7401	LH	0	13	203	56/71
RT XP753	LH	0	13	200	51/70
DG353M	M	0	16	128	58/70
Jupiter	M	0	19	149	60/67
ProGold M3	M	0	18	193	62/69
Taurus	M	15	14	153	60/70
Titan	M	10	16	132	60/70
RT 3202	MH	0	12	207	46/70
CLM04	CM	0	16	135	58/69
CLM05	CM	0	15	146	54/67
ARoma 22	LA	0	15	131	56/70
Mean	-	1	15	167	56/70
$LSD_{0.05}$[e]	-	10	1	20	6/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain; LA = long-grain aromatic.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference (α = 0.05).

Table 6. Results of the Poinsett County Arkansas Rice Performance Trial (POI-ARPT) during 2023 (planted 11 April; harvested 19 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield [d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	23	13	203	59/70
Diamond	L	0	13	174	57/71
Ozark	L	0	13	178	61/72
LAX-19207	L	0	14	158	65/72
CLL16	CL	0	17	165	57/70
CLL18	CL	0	15	184	61/72
CLL19	CL	0	12	162	60/71
PVL03	PL	0	14	161	63/72
PVL04	PL	0	17	162	61/71
RTv7231 MA	ML	15	12	170	59/72
RT 7331 MA	MLH	10	12	200	60/72
RT 7431 MA	MLH	8	12	207	61/72
RT 7321 FP	FLH	0	12	219	55/71
RT 7421 FP	FLH	0	13	217	61/72
RT 7521 FP	FLH	0	12	209	60/71
RT 7523 FP	FLH	0	12	210	59/72
RT 7302	LH	0	12	230	58/72
RT 7401	LH	0	13	214	57/72
RT XP753	LH	0	11	217	54/72
DG353M	M	0	16	151	65/71
Jupiter	M	0	18	150	65/70
ProGold M3	M	0	17	172	67/71
Taurus	M	0	14	178	63/71
Titan	M	19	16	155	62/71
RT 3202	MH	0	12	229	61/71
CLM04	CM	25	16	163	64/69
CLM05	CM	0	14	179	65/70
ARoma 22	LA	0	13	145	61/70
Mean	-	4	14	184	61/71
$LSD_{0.05}$[e]	-	21	1	16	3/2

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain; LA = long-grain aromatic.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference ($\alpha = 0.05$).

Table 7. Results of the Clay County Arkansas Rice Performance Trial (CLA-ARPT) during 2023 (planted 4 April; harvested 6 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield [d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	12	215	49/67
Diamond	L	0	14	170	51/69
Ozark	L	0	13	177	55/70
LAX-19207	L	0	14	160	61/72
CLL16	CL	0	16	177	47/68
CLL18	CL	0	14	188	54/69
CLL19	CL	0	14	186	58/70
PVL03	PL	0	14	155	57/72
PVL04	PL	0	15	156	55/70
RTv7231 MA	ML	0	13	196	48/70
RT 7331 MA	MLH	0	13	215	44/71
RT 7431 MA	MLH	0	13	201	42/71
RT 7321 FP	FLH	0	12	223	38/70
RT 7421 FP	FLH	0	13	205	50/70
RT 7521 FP	FLH	0	13	241	52/69
RT 7523 FP	FLH	0	12	195	40/70
RT 7302	LH	0	13	231	37/69
RT 7401	LH	0	13	195	49/70
RT XP753	LH	0	13	208	42/71
DG353M	M	0	17	132	61/69
Jupiter	M	0	19	147	58/66
ProGold M3	M	0	18	172	61/67
Taurus	M	0	17	187	62/69
Titan	M	7	17	171	59/69
RT 3202	MH	0	12	218	49/70
CLM04	CM	0	18	167	63/68
CLM05	CM	0	18	204	57/66
Mean	-	0.3	14	188	52/69
$LSD_{0.05}$[e]	-	4	1	16	5/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference (α = 0.05).

Table 8. Results of the Desha County Arkansas Rice Performance Trial (DES-ARPT) during 2023 (planted 19 April; harvested 31 August).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	12	187	54/68
Diamond	L	0	14	164	50/70
Ozark	L	0	14	172	51/68
LAX-19207	L	0	13	185	56/71
CLL16	CL	0	14	184	47/68
CLL18	CL	0	13	190	44/68
CLL19	CL	0	12	187	53/69
PVL03	PL	0	12	176	48/71
PVL04	PL	0	13	151	51/69
RTv7231 MA	ML	0	11	191	52/70
RT 7331 MA	MLH	0	11	204	54/71
RT 7431 MA	MLH	0	12	202	55/70
RT 7321 FP	FLH	0	11	213	50/70
RT 7421 FP	FLH	0	12	203	51/69
RT 7521 FP	FLH	0	12	230	49/69
RT 7523 FP	FLH	0	12	204	51/70
RT 7302	LH	0	12	229	51/70
RT 7401	LH	0	12	201	50/69
RT XP753	LH	0	12	211	53/71
DG353M	M	0	15	163	54/68
Jupiter	M	0	18	159	58/66
ProGold M3	M	0	16	190	62/70
Taurus	M	0	14	198	59/70
Titan	M	0	15	155	57/69
RT 3202	MH	0	12	201	59/70
CLM04	CM	0	16	177	61/69
CLM05	CM	0	14	175	51/68
Mean	-	0	13	188	53/69
$LSD_{0.05}$[e]	-	0	1	11	5/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference (α = 0.05).

Table 9. Results of the Greene County Arkansas Rice Performance Trial (GRE-ARPT) during 2023 (planted 11 May; harvested 21 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	12	202	61/70
Diamond	L	0	13	182	58/72
Ozark	L	0	13	202	61/73
LAX-19207	L	0	12	175	61/73
CLL16	CL	0	15	198	59/71
CLL18	CL	0	13	197	59/72
CLL19	CL	0	12	196	62/72
PVL03	PL	0	13	167	63/72
PVL04	PL	0	14	192	62/72
RTv7231 MA	ML	0	11	178	55/71
RT 7331 MA	MLH	0	12	213	60/73
RT 7431 MA	MLH	20	11	200	57/73
RT 7321 FP	FLH	23	12	211	53/72
RT 7421 FP	FLH	0	12	219	59/72
RT 7521 FP	FLH	29	11	229	59/72
RT 7523 FP	FLH	21	12	188	55/71
RT 7302	LH	0	12	219	55/72
RT 7401	LH	10	12	201	53/72
RT XP753	LH	0	12	220	54/73
DG353M	M	0	16	173	68/72
Jupiter	M	0	19	166	68/71
ProGold M3	M	0	18	204	69/72
Taurus	M	0	15	200	66/73
Titan	M	0	15	173	65/72
RT 3202	MH	0	12	224	63/72
CLM04	CM	0	16	169	68/72
CLM05	CM	0	15	183	66/70
Mean	-	4	13	196	61/72
$LSD_{0.05}$[e]	-	14	1	14	4/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference (α = 0.05).

Table 10. Results of the Jackson County Arkansas Rice Performance Trial (JAC-ARPT) during 2023 (planted 11 May; harvested 29 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	11	181	49/70
Diamond	L	0	11	166	51/71
Ozark	L	0	11	196	57/72
LAX-19207	L	0	11	147	59/72
CLL16	CL	0	12	172	49/71
CLL18	CL	0	11	186	52/71
CLL19	CL	0	11	163	46/70
PVL03	PL	0	11	151	51/72
PVL04	PL	0	12	144	58/71
RTv7231 MA	ML	0	11	180	29/71
RT 7331 MA	MLH	0	11	191	38/72
RT 7431 MA	MLH	0	11	209	43/72
RT 7321 FP	FLH	0	11	210	34/72
RT 7421 FP	FLH	0	11	215	45/72
RT 7521 FP	FLH	0	10	187	49/71
RT 7523 FP	FLH	0	11	219	43/71
RT 7302	LH	0	11	225	39/72
RT 7401	LH	0	11	211	44/72
RT XP753	LH	0	11	213	34/72
DG353M	M	0	12	184	59/72
Jupiter	M	0	13	175	63/70
ProGold M3	M	0	13	187	61/71
Taurus	M	0	12	186	48/72
Titan	M	0	13	169	43/71
RT 3202	MH	0	10	204	40/71
CLM04	CM	0	13	181	61/72
CLM05	CM	0	12	168	55/70
Mean	-	0	11	186	48/71
$LSD_{0.05}$[e]	-	0	1	21	4/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference (α = 0.05).

Table 11. Results of the Lawrence County Arkansas Rice Performance Trial (LAW-ARPT) during 2023 (planted 10 May; harvested 21 September).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	14	210	53/68
Diamond	L	0	15	193	59/71
Ozark	L	0	15	215	59/71
LAX-19207	L	0	15	176	63/72
CLL16	CL	0	16	186	55/70
CLL18	CL	0	15	196	56/69
CLL19	CL	0	14	207	59/70
PVL03	PL	0	14	158	59/71
PVL04	PL	0	16	183	58/70
RTv 7231 MA	ML	0	14	197	52/72
RT 7331 MA	MLH	0	13	236	56/71
RT 7431 MA	MLH	0	13	201	57/71
RT 7321 FP	FLH	0	13	242	50/71
RT 7421 FP	FLH	0	13	223	52/71
RT 7521 FP	FLH	47	12	203	53/69
RT 7523 FP	FLH	0	13	234	46/70
RT 7302	LH	0	13	238	48/70
RT 7401	LH	0	13	219	55/71
RT XP753	LH	0	13	231	51/72
DG353M	M	0	15	171	59/70
Jupiter	M	0	18	165	61/69
ProGold M3	M	0	16	181	62/70
Taurus	M	0	16	206	61/71
Titan	M	0	16	195	58/71
RT 3202	MH	0	12	230	58/71
CLM04	CM	0	16	170	64/70
CLM05	CM	0	16	199	56/68
Mean	-	1	14	202	56/70
$LSD_{0.05}$[e]	-	12	1	25	4/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference (α = 0.05).

Table 12. Results of the Arkansas County Arkansas Rice Performance Trial (SAR-ARPT) during 2023 (planted 30 March; harvested 24 August).

Cultivar	Grain Type[a]	Lodging[b]	Moisture[c]	Grain Yield	Milling Yield[d]
		(%)	(%)	(bu./ac)	(%HR/%TR)
DG263L	L	0	15	178	64/71
Diamond	L	0	15	175	60/72
Ozark	L	0	15	189	58/72
LAX-19207	L	0	16	183	64/73
CLL16	CL	0	18	188	61/71
CLL18	CL	0	16	201	55/71
CLL19	CL	0	14	207	66/73
PVL03	PL	0	15	200	62/73
PVL04	PL	0	18	175	63/72
RTv7231 MA	ML	0	12	175	61/72
RT 7331 MA	MLH	0	13	226	64/73
RT 7431 MA	MLH	0	14	207	63/73
RT 7321 FP	FLH	0	12	223	57/72
RT 7421 FP	FLH	0	15	199	63/72
RT 7521 FP	FLH	0	15	228	64/72
RT 7523 FP	FLH	0	15	201	63/73
RT 7302	LH	0	14	228	66/73
RT 7401	LH	0	14	213	57/73
RT XP753	LH	0	13	218	62/74
DG353M	M	0	18	149	68/73
Jupiter	M	0	21	146	68/71
ProGold M3	M	0	18	196	69/72
Taurus	M	0	16	207	66/73
Titan	M	0	17	159	67/72
RT 3202	MH	0	14	225	67/72
CLM04	CM	0	17	165	69/72
CLM05	CM	0	17	201	68/71
Mean	-	0	15	195	64/72
$LSD_{0.05}$[e]	-	0	1	11	3/1

[a] Grain type: L = long-grain; CL = Clearfield long-grain; PL = Provisia long-grain; ML = MaxAce long-grain; MLH = MaxAce long-grain hybrid; FLH = FullPage long-grain hybrid; LH = long-grain hybrid; M = medium-grain; MH = medium-grain hybrid; CM = Clearfield medium-grain.

[b] Lodging = % of plot down at harvest.

[c] Moisture = Grain moisture at harvest.

[d] Milling yield = % Head Rice/% Total Rice.

[e] LSD = least significant difference (α = 0.05).

Influence of Nitrogen Strategy on Performance of Selected Hybrids in Arkansas

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Abstract

Hybrid rice (*Oryza sativa* L.) accounts for over 50% of Arkansas rice acres annually. The objective of this research is to determine the optimal nitrogen (N) fertilizer rates for new hybrids across different soils and environments in the Arkansas rice production region. The hybrids RT 7302, RT 7321 FP, and RT 7421 FP were evaluated at a range of preflood N rates. Previous studies have found that a 2-way split application (preflood and boot) increases grain and milling yields combined with reduced lodging. Therefore, a boot N application was made for all treatments. However, to reevaluate the benefits of the boot N application, 2 additional treatments were included to compare with and without boot N. The results of the 2023 season suggest that all of the hybrids evaluated achieve near-optimal yields at 90–120 lb N/ac. However, additional years of study are needed to make this recommendation, which differs from past research.

Introduction

The intent is to conduct nitrogen (N) rate studies on current hybrid rice cultivars and determine their response with preflood and with the late-boot N application in regard to grain yield, milling yield, and lodging. The effect of N has proven to be an essential nutrient for plant growth. However, it is not found readily available within crop production soils. Previous studies have found that a 2-way split application (preflood and boot) increases grain and milling yields combined with a reduction in lodging. These studies aim to build on previous research by evaluating new hybrids in their response to N rate strategy. In 2023, studies were conducted at 3 locations in Arkansas representing the different rice production regions across soil types.

Procedures

The hybrid × N fertilizer rate studies were established at the following University of Arkansas System Division of Agriculture (UADA) research locations: the Northeast Research and Extension Center (NEREC), Keiser, Ark., on a Sharkey Clay (Vertic Haplaquepts) soil; the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam (Glossaquic Fragiudalfs) soil; and the Rice Research and Extension Center (RREC), near Stuttgart, Ark., on a Dewitt silt loam (Typic Albaqualfs) soil.

The experimental design utilized for data analysis for all locations and each cultivar was a randomized complete block design with 4 replications per location. All experimental plots were direct-seeded with a plot size 17.5 ft long with 8 rows on 7.5-in. row spacing. The 3 hybrids used in this study were RT 7321 FP, RT 7302, and RT 7421 FP. All seed was treated according to UADA recommendations to include insecticide and fungicides. The experimental plots all received preflood N at rates of either 60, 90, 120, 150, or 180 lb N/ac, followed by a second N application at late boot of 30 lb N/ac. Two additional treatments were included at the 90 and 120 lb N/ac preflood N rates that received no late boot N application.

At maturity, the 4 center rows of each plot were harvested, and weight and moisture were recorded. A subsample of harvested grain was collected from selected treatments for milling purposes. Grain yield was adjusted to 12% moisture and reported on a bushel per acre (bu./ac) basis. The dry rice was milled to obtain data on the percent of head rice and the percent of total white rice (%HR/%TR). Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separation using Fisher's least significant difference test ($P = 0.1$).

Results and Discussion

The influence of N fertilizer at the tested preflood rates on RT 7302 the grain yield was observed to vary slightly between locations (Table 1). At NEREC, the 90–180 lb N/ac rates were the highest-yielding N rates. At PTRS, 120–180 lb N/ac did not differ. At RREC, 120–180 lb N/ac rates did not differ. The treatments with the highest numerical yields at each location were 150 lb N/ac, 180 lb N/ac, and 180 lb N/ac at NEREC, PTRS, and RREC, respectively.

The influence of N fertilizer preflood rates on RT 7321 FP grain yield was observed to vary slightly between locations (Table 2). At NEREC, 150–180 lb N/ac were the highest-yielding treatments, greater than 0–120 lb N/ac. For the PTRS location, yields for the 180 lb N/ac rates were greater than all rates except 150 lb N/ac rates. For the RREC, all N rates produced higher yields compared to the untreated control, while the 180 lb N/ac treatment was also higher than the 60–90 lb N/ac treatments. The treatments with the highest numerical yields at each location were 150 lb N/ac, 180 lb N/ac, and 180 lb N/ac at NEREC, PTRS, and RREC, respectively.

Table 3 shows the influence of N fertilizer preflood rates on RT 7421 FP. For the NEREC location, 90–180 lb N/ac rates had greater yields than the 0 and 60 lb N/ac rates. For the PTRS location, 150–180 lb N/ac had higher yields than 0–120 lb N/ac rates. At the RREC, 150–180 lb N/ac had higher yields than all treatments except 120 lb N/ac. The treatments with the highest numerical yields

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at each location were 150 lb N/ac, 180 lb N/ac, and 180 lb N/ac at NEREC, PTRS, and RREC, respectively.

Averaged across cultivars and locations, where 30 lb N/ac at late boot was applied, the grain yields were higher compared to those without boot N applied (Table 4). In contrast to previous work, there was no increase in head rice or total rice milling yields when boot N was applied (Table 5).

Practical Applications

The hybrid × N fertilizer trials are essential in the assessment of new hybrid rice cultivars as well as developing a N timing regimen to maximize grain yield and productivity. The objective of this study is to determine hybrid rice cultivars' response to N and late-boot N application in regard to grain yield, milling yield, and lodging. This scientific study was conducted on representative soils as well as diverse growing environments throughout the Arkansas rice-growing region. The results of these trials can be utilized to determine the optimal rate for N maximizing grain yield for the 3 hybrids in response to the soil type as well as environmental conditions. Results also show that the grain yield and milling benefited from the current preflood N application as well as the boot N application.

Acknowledgments

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Table 1. Influence of nitrogen (N) fertilizer at the preflood N rate application on grain yield (bu./ac) of RT 7302 hybrid rice by location during 2023.

	Rice Grain Yield		
N Fertilizer Rate	**NEREC[†]**	**PTRS**	**RREC**
(lb N/acre)	-----------------	(bu./ac)	-----------------
0	122.4 c[‡]	104.3 d	125.6 c
60	202.2 b	175.1 c	190.5 b
90	231.4 a	191.0 b	201.1 b
120	233.8 a	220.9 a	219.5 a
150	248.2 a	220.5 a	219.2 a
180	239.7 a	231.8 a	222.7 a
P-value	<0.0001	<0.0001	<0.0001

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[‡] Values with different lowercase letters are significantly different at $P < 0.05$.

Table 2. Influence of nitrogen (N) fertilizer at the preflood N rate application on grain yield (bu./ac) of RT 7321 FP hybrid rice by location during 2023.

	Rice Grain Yield		
N Fertilizer Rate	**NEREC[†]**	**PTRS**	**RREC**
(lb N/acre)	-----------------	(bu./ac)	-----------------
0	101.1 d[‡]	116.9 e	112.2 d
60	159.5 c	180.3 d	160.8 c
90	231.4 b	195.8 c	167.7 bc
120	233.8 b	208.5 b	180.9 ab
150	248.2 a	216.6 ab	186.8 ab
180	239.7 a	228.0 a	197.0 a
P-value	<0.0001	<0.0001	<0.0001

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[‡] Values with different lowercase letters are significantly different at $P < 0.05$.

Table 3. Influence of nitrogen (N) fertilizer at the preflood N rate application on grain yield (bu./ac) of RT 7421 FP hybrid rice by location during 2023.

	Rice Grain Yield		
N Fertilizer Rate	**NEREC**[†]	**PTRS**	**RREC**
(lb N/acre)	**------------(bu./ac)------------**		
0	110.1 c[‡]	88.3 d	127.2 d
60	190.6 b	163.6 c	163.5 c
90	223.8 a	190.5 b	172.9 bc
120	225.4 a	201.5 b	183.2 ab
150	249.4 a	215.3 a	193.1 a
180	223.8 a	223.6 a	195.3 a
P-value	<0.0001	<0.0001	<0.0001

[†] NEREC = Northeast Research and Extension Center, Keiser, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RREC = Rice Research and Extension Center, Stuttgart, Ark.

[‡] Values with different lowercase letters are significantly different at $P < 0.05$.

Table 4. Influence of nitrogen (N) fertilizer on rice grain yield (bu./ac) at the boot growth stage averaged across location[†] and cultivar[‡] in 2023.

Boot N Rate	**Rice Grain Yield**
(lb N/acre)	**(bu./ac)**
0	200.7 b[§]
30	204.5 a
P-value	0.1584

[†] Locations include the Northeast Research and Extension Center, Keiser, Ark.; Pine Tree Research Station, Colt, Ark.; Rice Research and Extension Center, Stuttgart, Ark.

[‡] Cultivars include RT 7302, RT 7321 FP, and RT 7421 FP.

[§] Values with different lowercase letters are significantly different at $P < 0.05$.

Table 5. Influence of nitrogen (N) fertilizer on rice milling yield (% head rice/% total rice) at the boot growth stage averaged across location[†] and cultivar[‡] in 2023.

Boot N Rate	**Milling Yield**	
(lb N/acre)	**(%HR)**	**(%TR)**
0	48.9 a[§]	68.4 a
30	49.9 a	68.5 a
P-value	0.1270	0.4652

[†] Locations include the Northeast Research & Extension Center, Keiser, Ark.; Pine Tree Research Station, Colt, Ark.; Rice Research & Extension Center, Stuttgart, Ark.

[‡] Cultivars include RT 7302, RT 7321 FP, and RT 7421 FP.

[§] Values with different lowercase letters are significantly different at $P < 0.05$.

Results from Six Years of the University of Arkansas System Division of Agriculture Rice Irrigation Yield Contest

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Abstract

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was conducted between 2018 and 2023. The contest was designed to promote better use of irrigation water and to record data on water use and water use efficiency. Unlike yield contests, where winners are decided by yield alone, the irrigation contest results are decided by the highest total Water Use Efficiency (WUE) achieved. Irrigation water was recorded using 6, 8, 10, and 12-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average WUE measured in the contest between 2018–2023 for rice was 5.99 bu./in. The winning WUE was 8.23 bu./in. for 2023, 7.84 bu./in. for 2022, 9.77 bu./in. for 2021, 8.72 bu./in. for 2020, 7.24 bu./in. for 2019, and 7.80 bu./in. for 2018. Adoption of irrigation water management (IWM) practices, such as computerized hole selection (CHS), surge irrigation, and soil moisture sensors, have increased since the first year of the contest. Approximately 66% have used the furrow irrigation production system between 2018 and 2023. On average, rice growers in the contest across the 6 years averaged 198.5 bu./ac, 27.8 ac-in./ac of irrigation, and a total water use of 42.2 in.

Introduction

According to data from 2015 reported by the United States Geological Survey, Arkansas ranks 3rd in the United States for irrigation water use and 2nd for groundwater use (Dieter et al., 2018). For comparison, Arkansas ranked 18th in 2017 in total crop production value (USDA-NASS, 2017). Of the groundwater used for irrigation, 96% comes from the Mississippi River Alluvial Aquifer (Kresse et al., 2014). One study of the aquifer found that 29% of the wells that were tested had dropped in water levels between 2009 and 2019 (Arkansas Department of Agriculture Natural Resource Division, 2019).

Arkansas is the largest producer of rice in the U.S., producing 45.6% of the total rice in the U.S. (Hardke, 2019). The most common method of irrigation for rice is flood irrigation (Vories et al., 2002). Producers in Arkansas using flood irrigation use approximately 24–32 ac-in./ac of water (Henry et al., 2013). This equates to rice production using roughly half of all water taken from the Mississippi River Alluvial Aquifer in Arkansas (Kresse et al., 2014).

A study was conducted from 2013 to 2017 in primarily corn and soybean fields to assess the water-saving potential of implementing 3 irrigation water management (IWM) tools: computerized hole selection (CHS), surge irrigation, and soil moisture sensors (Spencer et al., 2019). Paired fields were set up using the IWM tools and conventional irrigation methods. It was found that the implementation of all 3 IWM tools reduced water use in the soybean fields by 21% while not reducing yields. This resulted in an increase in water use efficiency (WUE) of 36%. For the cornfields, a 40% reduction in water use was observed, and WUE was 51% higher for IWM fields. For soybeans, no significant difference in net returns was found, but in corn, net returns were significantly improved by adopting IWM.

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was designed as a novel way of encouraging Arkansas producers to use water-saving methods. The competition aimed to promote water-reducing management practices by educating producers on the benefits of irrigation water management tools, providing feedback to participants on how they compared to other producers, documenting the highest achievable water use efficiency in multiple crop types under irrigated production in Arkansas, and by recognizing producers who achieved a high-water use efficiency.

Procedures

Rules for an irrigation yield contest were developed in 2018. Influence was taken from already existing yield contests (Arkansas Soybean Association, 2014; National Corn Growers Association, 2015; National Wheat Foundation, 2018; University of California Cooperative Extension, 2018). The rules were designed to be as unobtrusive as possible to normal planting and harvesting operations. Fields must be at least 30 acres in size. A yield minimum of 180 bu./ac must be achieved to qualify.

A portable propeller-style mechanical flowmeter was used to record water use. All flow meters were checked for proper installation and sealed using poly-pipe tape and serialized tamper-proof cables. Rainfall was recorded using Farmlogs™, an online software that provides rainfall data for a given location. Rainfall amounts were totaled from the date of emergence to the predicted drain date. Emergence was assumed to be 7 days after the planting date provided on the entry form. To find the predicted drain date

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for the rice field, the University of Arkansas System Division of Agriculture DD50 Rice Management Program was used (Hardke et al., 2020). Rainfall is adjusted for extreme events.

The harvest operations were observed by a third-party observer, often an Extension agent, NRCS employee, or Division of Agriculture staff. For the yield estimate, a minimum of 3 acres was harvested from the contest field.

The equation used for calculating WUE for the contest was: WUE = Y/(Pe + IRR) where WUE = water use efficiency in bushels per inch, Y = yield estimate from harvest in bushels per acre, Pe = Effective precipitation in inches, and IRR = Irrigation application in ac-inches/ac. Statistical analysis was performed using Microsoft Excel and JMP 15 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Detailed results are published on the contest website (www.uaex.uada.edu/irrigation) for each year of the contest. Over the 6 years that the competition has been conducted, 76 fields have been entered for rice. The average WUE over the 6 years was 5.25 bu./in. By year, the average WUE was 5.99 bu./in. for 2023, 5.49 bu/in for 2022 with 11 contestants, 5.46 bu./in. for 2021 with 6 contestants, 4.62 bu./in. for 2020 with 22 contestants, 4.70 bu./in. for 2019 with 6 contestants, and 5.17 bu./in. for 2018 with 11 contestants (Table 1). 2018 and 2019 both had a higher average WUE than 2020. In 2020, there were more contestants in rice than in 2018 and 2019 combined. This may partially explain the lower WUE because more variation is expected with a larger number of growers. The winning WUE was higher in 2021, 2022, and 2023 than in 2018, 2019, and 2020. The highest winning water use to date was in 2021, with 9.77 bu./in. The winning result for 2023 was 8.23 bu./in., 7.94 bu./in. in 2022, 9.77 bu./in. again in 2021, 8.72 in 2020, 7.24 bu./in. in 2019, and 7.80 bu./in. in 2018.

In 2022, subcategories were added for furrow-irrigated rice (FIR) and levee rice. Results for FIR are detailed in Table 2, and results for levee-irrigated rice are detailed in Table 3. The number of entries in FIR ranged from a high of 15 to a low of 5 per year, with the average of all years being 7.8 entrants/year. In levee rice, the number of entries ranged from a high of 7 to a low of 1, with an average of 3.8 entrants/year. FIR number of entries favored levee entries by approximately 1.6:1. The 6-year averages reveal the following: WUE of furrow irrigated was 4.80 bu./in. and levee irrigated was 5.46 bu./in.; furrow irrigation yields were 193 bu./ac and levee irrigation yields were 209 bu./ac. Total irrigation water applied for furrow irrigation was 30.0 acre-in./ac. and levee irrigation was 28.3 ac-in./ ac. Total water for furrow irrigation was 44.7 in. and 42.4 in. for levee irrigation.

In 2023, an additional category was added for zero-grade rice. Results for zero-grade are detailed in Table 4. There were 6 contestants entering zero-grade fields (30%) in 2023. Average water use efficiency was 7.1 bu./in. This was the highest water use efficiency for rice by irrigation method in 2023. Average yield was 199 bu./ac. Total irrigation water applied for zero-grade rice was 14.5 ac-in./ac, and 28.21 in. of total water.

Additional data is available based on a limited number of participants from levee-irrigated rice. The practices shown are Cascade (single inlet), multiple in rice irrigation (MIRI), and alternate wetting and drying (AWD) (Table 5). AWD had the highest average WUE of 6.65 bu./in., followed by Cascade with a WUE of 5.78 bu./in., and MIRI with a WUE of 4.45 bu./in.

In 2015, a survey was conducted across the mid-South to determine the adoption rate of various irrigation water management (IWM) tools (Henry 2019). On the entry form for the contest, a similar survey was included to assess the usage of IWM tools in the contest entrants. Mid-South and in Arkansas. In the 2015 survey, 40% reported using CHS, and 66% of the Arkansas growers reported using CHS. Twenty-four percent of respondents said they used soil moisture sensors in the region on their farm, and only 9% of Arkansas irrigators reported using soil moisture sensors.

Contestants for all crop categories are asked about their adoption of IWM tools when they enter the contest. In total, 64% of all contest participants reported using the entry form. The IWM tool that was most widely adopted was CHS. The average use among respondents was 82% across all 6 years, with 73% in 2018, 43% in 2019, 100% in 2020, 98% in 2021, 79% in 2022, and 100% in 2023. The use of FIR saw an increase in respondents from 56% and 50% in 2018 and 2019, respectively, to 73% in 2020, 80% in 2021, and 64% in 2022, and 33% in 2023, due primarily to an increase in entries for zero grade rice and levee rice. About 60% of rice contest fields used furrow irrigation in the 6-year history of the contest. Another water-saving method of rice irrigation is MIRI. Thirty-seven percent of respondents from all 6 years reported using MIRI, with 33% in 2018, 17% in 2019, 27% in 2020, 100% in 2021, 25% in 2022, and 20% in 2023. Sixty-four percent of respondents from all 6 years said that they used soil moisture sensors on their farm, with 50% in 2018, 40% in 2019, 42% in 2020, 87% in 2021, 81% in 2022, and 85% in 2023. Surge valves were the least used IWM tool, with 44% in 2018, 28% in 2019, 25% in 2020, 35% in 2021, 12% in 2022 and 7% in 2023 (Table 6). Over the 6-year period, 3 entries used MIRI for 23 rice levee entries. AWD was used by 6 fields for the 29 rice-levee and zero-grade entries for the 6-year period. Thus, these IWM practices for levee rice and zero-grade are not widely used in the rice contest. The IWM tool that was most widely adopted was CHS. The average use among respondents was 82% across all 6 years.

Practical Applications

Irrigation WUE of working farms is not a common metric available in the literature, and it is not a metric familiar to rice farmers. The data recorded from the Arkansas Irrigation Yield Contest provides direct feedback to irrigators about their irrigation performance in maintaining high yields and low irrigation water used. Such direct feedback to Arkansas rice farmers will likely provide many with a competitive advantage when water resources become more scarce. The contest provides a mechanism for rice farmers to evaluate the potential for water savings by adopting water-saving techniques or management changes. On average, rice growers in the contest across the 6 years averaged 198.5 bu./ac, 27.8 ac-in./ac of irrigation, and a total water use of 42.2 in.

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Table 1. Maximum, average, and minimum for 2018, 2019, 2020, 2021, 2022, and 2023 of various water and yield data points from the Arkansas Irrigation Yield Contest.

		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)
2023	**Maximum**	8.07	243	19.0	108.1	122.6
	Average	5.95	203	13.7	24.6	38.5
	Minimum	1.94	135	7.4	5.4	19.2
2022	**Maximum**	7.94	251	17.1	47.1	64.2
	Average	5.44	178	12.8	23.2	36.0
	Minimum	2.61	125	8.4	8.6	22.6
2021	**Maximum**	9.77	245	16.5	51.7	66.3
	Average	5.46	216	14.0	29.9	43.8
	Minimum	3.69	183	11.1	13.5	24.5
2020	**Maximum**	8.72	251	18.1	92.1	104.2
	Average	4.62	196.4	14.8	33.1	47.9
	Minimum	1.55	120.0	11.7	14.0	27.6
2019	**Maximum**	7.24	209.9	24.0	30.5	48.7
	Average	4.70	190.6	17.7	22.4	42.3
	Minimum	3.55	162.8	13.2	13.4	28.7
2018	**Maximum**	7.80	266.6	16.0	47.9	63.8
	Average	5.17	208.9	13.7	28.8	42.4
	Minimum	2.84	131.9	7.4	16.0	29.4
6 Yr.	**Average**	5.25	198.5	14.2	27.8	42.2

Table 2. Maximum, average, and minimum of furrow irrigated rice for 2018, 2019, 2020, 2021, 2022, and 2023 of various water and yield data points from the Arkansas Irrigation Yield Contest.

		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water	Entries
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)	
2023	**Maximum**	6.81	238	16.5	108.1	122.6	
	Average	5.52	197	13.5	30.4	44.0	8
	Minimum	1.94	165	9.4	11.3	20.7	
2022	**Maximum**	7.94	194	17.1	47.1	64.2	
	Average	5.45	164	13.0	20.7	33.7	7
	Minimum	2.61	125	8.4	8.6	22.6	
2021	**Maximum**	9.77	240	16.5	30.5	48.6	
	Average	5.82	210	13.9	25.5	39.4	5
	Minimum	3.77	183	11.1	13.5	24.5	
2020	**Maximum**	6.74	227	18.0	92.1	104.2	
	Average	4.35	193	14.6	35.1	49.8	15
	Minimum	1.51	123	11.7	14.0	30.1	
2019	**Maximum**	4.89	210	24.0	30.5	48.7	
	Average	4.19	187	18.6	24.2	45.0	5
	Minimum	3.55	163	12.7	18.7	38.8	
2018	**Maximum**	6.14	267	16.0	47.9	63.8	
	Average	4.7	201	13.5	30.7	44.2	7
	Minimum	2.84	132	7.4	19	31.6	
6 Yr.	**Average**	4.91	192	14.4	29.3	43.9	7.8

Table 3. Maximum, average, and minimum of levee irrigated rice for 2018, 2019, 2020, 2021, 2022, and 2023 of various water and yield data points from the Arkansas Irrigation Yield Contest.

		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water	Entries
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)	
2023	**Maximum**	7.01	250	18.0	46.2	59.8	
	Average	5.40	212	14.2	26.6	41.2	6
	Minimum	3.61	179	12.1	21.0	29.9	
2022	**Maximum**	7.66	251	14.4	37.8	50.8	
	Average	5.42	202	12.4	27.5	39.9	4
	Minimum	2.91	139	10.4	16.6	28.5	
2021	**Maximum**	3.69	245	14.6	51.7	66.3	
	Average	3.69	245	14.6	51.7	66.3	1
	Minimum	3.69	245	14.6	51.7	66.3	
2020	**Maximum**	8.72	251	18.1	66.6	83.8	
	Average	5.19	203	15.3	28.7	44.0	7
	Minimum	2.39	120	12.6	14.9	27.6	
2019	**Maximum**	7.24	208	13.2	13.4	28.7	
	Average	7.24	208	13.2	13.4	28.7	1
	Minimum	7.24	208	13.2	13.4	28.7	
2018	**Maximum**	7.8	229	15.3	39.8	53.5	
	Average	6.0	223	13.9	25.4	39.3	4
	Minimum	4.2	218	13.3	16.0	29.4	
6 Yr.	**Average**	5.46	209	14.0	28.3	42.4	3.8

Table 4. Maximum, average, and minimum of zero grade rice for 2023 of various water and yield data points from the Arkansas Irrigation Yield Contest.

		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water	Entries
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)	
2023	**Maximum**	8.23	242	19.0	23.3	34.0	
	Average	7.07	199	14.2	14.1	28.2	6
	Minimum	6.08	135	7.4	5.35	19.2	
	Average	7.07	199	14.2	14.1	28.2	6

Table 5. Levee rice technology 6-year average summary.

	Water Use Efficiency	Yield	Irrigation Water	Total Water	Entries
	(bu./in.)	(bu./ac)	(ac-in./ac)	(in.)	
Cascade	5.78	215	30.1	43.5	5
AWD	6.65	211	20.4	34.1	7
MIRI	4.45	191	32.4	47.5	8

Table 6. Technology adoption from the Arkansas Irrigation Yield Contest (% by respondents).

	Computerized Hole Selection	Furrow-Irrigated Rice	Multiple Inlet Rice Irrigation	Soil Moisture Sensors	Surge Irrigation
	---------------	---------------	(%)	---------------	---------------
2023	100	33	20	85	7
2022	79	64	25	81	12
2021	98	80	100	87	35
2020	100	73	27	42	25
2019	43	50	17	40	28
2018	73	56	33	50	44
6-year Avg.	82	59	37	64	25

Yield Responses of Pure-Line and Hybrid Rice to Potassium Fertilization

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Abstract

Potassium (K) is one of the most limiting nutrients for rice (*Oryza sativa* L.) grown in the direct-seeded, delayed-flood production system common in the U.S. mid-South, and substantial yield reductions can occur when produced on soils low in exchangeable K. The primary objective of our research was to compare yield responses of pure-line and hybrid rice cultivars to K fertilization in a trial where various K rates (0, 40, 80, 120, and 160 lb K_2O/ac) have been applied annually for over 20 years. With Very Low (<61 ppm) Mehlich-3 K in the no-fertilizer-K control plots, both cultivars responded to K fertilization. In the no-K control treatment, the pure-line (Diamond) and hybrid (RT 7421 FP) produced 79% and 56%, respectively, of the maximum yield observed with K fertilization. Diamond produced a greater yield than the hybrid when fertilizer-K was not applied, but the hybrid resulted in greater yields at all other K application rates. Within each cultivar, grain yields did not differ from application rates of 80 lb K_2O/ac or greater, which averaged 184 bu./ac for Diamond and 213 bu./ac for RT 7421 FP. Substantial lodging (48% of plot down at harvest) likely enhanced the yield reduction of the hybrid without fertilizer-K, but lodging was nearly eliminated when K was applied. Considering the influence of fertilizer-K rate on lodging, this study suggests that RT 7421 FP may be more responsive to K fertilizer than pure-line cultivars, but recent trials observed another hybrid (RT Gemini 214 CL) to be less responsive. Based on inconsistent responses of hybrid rice to K fertilization and the fact that earlier studies predominantly evaluated pure-line cultivars, it is important to continue studying the response of hybrid rice to K fertilization to build a database for proper interpretation of tissue data and potential adjustments to K fertilizer recommendations.

Introduction

Soil testing is currently the most common method for estimating soil potassium (K) availability and making fertilizer-K recommendations to ensure an adequate K supply to prevent K deficiency in rice. Based on soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing Laboratory in Marianna in 2021, DeLong et al. (2023) reported that 34% of sampled acreage following soybean [*Glycine max* (L.) Merr.] or rice, which accounted for the majority of Arkansas rice produced in 2022 (67% followed soybean and 20% followed rice; Hardke, 2023), had Low (61–90 ppm) or Very Low (<61 ppm) Mehlich-3 soil-test K concentrations. The likelihood of a positive rice yield response to K fertilizer is good when soil-test K is considered Low or Very Low, as Slaton et al. (2009) reported a positive yield response to K fertilization in 15 of 19 site-years of Arkansas rice trials where Mehlich-3 K was less than 99 ppm. Of the 31 harvested site-years in the study, 15 did not respond positively to K fertilizer, and rice receiving no K fertilizer produced an average yield of 183 bu./ac. Slaton et al. (2009) also showed that responsive sites had an average yield of 158 bu./ac without K fertilizer and 185 bu./ac in the highest-yielding treatments that received fertilizer-K. Appropriate K fertilization of K-deficient rice resulted in yield increases of 6 to 51 bu./ac (up to 48% increase relative to control), indicating the potential of proper K fertilization to substantially increase rice yields on K-deficient soils.

Tissue analysis is another tool that can indicate the nutritional status of a crop, but it is generally used to aid in the diagnosis of potential nutrient deficiencies and toxicities rather than to guide regular nutrient management of U.S. mid-South rice production systems. Recent research (Gruener et al., 2022) has examined changes in tissue-K concentration of Y-leaves from R1 (panicle differentiation) to R3 (50% heading), but previous work with rice has focused only on tissue-K concentration of whole-plant samples collected at R1 or R3, so data is limited for interpretation of K nutritional status in the 4 to 5 weeks between R1 and R3 growth stages. Research in Arkansas (Maschmann et al., 2010) has shown a positive yield response to fertilizer-K applied to rice as late as flag-leaf emergence (R2), indicating the potential to alleviate in-season K deficiency with a proper and timely interpretation of tissue-K concentrations.

The response of hybrid rice to K fertilization has been recently studied in Arkansas (Gruener et al., 2022), but most previous research in Arkansas has been focused on the response of pure-line rice to K fertilization. Dobermann and Fairhurst (2000) indicated that hybrids generally produce more biomass, resulting in greater K demand and requiring more available K than pure-line cultivars. Aboveground plant samples collected at heading from field tri-

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als in Arkansas have shown 20% greater K uptake (Slaton et al., 2010) and 17% greater N uptake (Norman et al., 2013) by hybrid rice relative to a pure-line cultivar. Gruener et al. (2022), however, observed a positive yield response to fertilizer-K in 2 of 5 site-years for pure-line rice (average increase of 34 bu./ac), while hybrid rice did not respond in any of the 5 matching site-years. The inconsistent results reported in the literature indicate that additional research investigating rice responses to K fertilization is needed. The objective of this research was to improve our understanding of the yield responses of hybrid and pure-line rice cultivars to K fertilization.

Procedures

Long-term field trials were established adjacent to each other at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS, Colt, Arkansas) in 2000 and 2002 on a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualf) and have been cropped to a 1:1 rice-soybean rotation (1 trial is rice and the other is soybean each year). Rice main plots were 16 ft long and 26 ft wide in 2023 in the trial area established in 2002, each accommodating 4 passes with a 9-row drill (7.5-in. row spacing). Composite soil samples from the 0- to 4-in. depth were collected from every main plot prior to fertilization and planting and were all analyzed for pH (1:2 soil:water mixture) and Mehlich-3 extractable nutrients. Each main plot was split into sub-plots by seeding 2 drill passes with a pure-line (Diamond) and 2 passes with a hybrid cultivar (RT 7421 FP). The seeding rates used in the study were 75 lb seed/ac and 35 lb seed/ac for the pure-line and hybrid cultivars, respectively. The trial contained 9 replicates, each consisting of K-fertilization rates of 0, 40, 80, 120, and 160 lb K_2O/ac. Fertilizer-K treatments were applied on 4 May 2023 prior to planting on the same date. To ensure adequate P and N availability for rice growth, a uniform application of triple superphosphate (60 lb P_2O_5/ac) was broadcast over all plots at the same time as K-treatment application and a uniform application of urea treated with NBPT (130 lb N/ac) was made on 7 June, prior to flooding at the 5-leaf stage. A flood was established the day after preflood-N application and was maintained until dry-down for harvest. An additional 30 lb N/ac was applied on 1 August to the hybrid at the late-boot growth stage to reduce the severity of lodging observed in this trial in recent years. Additional rice crop management closely followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations for direct-seeded, delayed-flood rice production. The middle 5 rows of each drill pass of each plot were harvested with a small-plot combine, and grain moisture was standardized to a content of 12% for final grain yield calculation and statistical analysis.

Tissue samples were collected from all fertilizer-K rate treatments at late-boot to early heading by separating 15 Y-leaf/flag leaf blades at the leaf collar from plants throughout the inside rows of each plot. Tissue samples were dried in a forced-draft oven, and tissue was ground to pass a 1-mm sieve prior to digestion by nitric acid and analysis by ICP-AES.

Soil pH and Mehlich-3 extractable K were analyzed as a randomized complete block with K rate as the only factor. The treatment structure for tissue samples and yield data was a split-plot where fertilizer-K rate was the main plot factor and rice cultivar was the subplot factor. Analysis of variance was performed using the MIXED procedure of SAS v. 9.4 (SAS Institute, Cary, N.C.), and differences were interpreted as significant when the P-value was ≤ 0.10.

Results and Discussion

Mehlich-3 extractable soil K differed based on the annual K application rate in 2023 (Table 1). Soil-test K did not differ from annual applications of 0 or 40 lb K_2O/ac, which averaged 42 ppm but increased significantly with each increase in K rate to a maximum of 80 ppm from the annual application of 160 lb K_2O/ac. The interaction of K application rate and rice cultivar significantly influenced tissue-K concentration (Table 2). The tissue-K concentration of RT 7421 FP was significantly lower than Diamond, where no fertilizer-K was applied, but within other K-rate treatments, concentrations did not differ between cultivars. Application rates of 0, 40, and 80 lb K_2O/ac for Diamond and 40 and 80 lb K_2O/ac for RT 7421 FP resulted in similar tissue-K concentrations, averaging 1.18%. Tissue-K concentrations were greater from application rates of 120 and 160 lb K_2O/ac, which averaged 1.28% and also did not differ based on cultivar. These results are generally consistent with the results of this trial in 2021 and 2022, where the cultivar did not substantially influence Y-leaf tissue-K concentrations, which increased as the fertilizer-K application rate increased (Smartt et al., 2022; 2023). Tissue-K concentrations without fertilizer-K were similar in 2021, 2022, and 2023 (1.04, 1.06, and 1.12%, respectively), but averaged 1.73, 1.45, and 1.29% in 2021, 2022, and 2023, respectively, at the highest K application rate. These results are consistent with research by Gruener et al. (2022) that found the Y-leaf K concentration of rice without added K was nearly constant from the R1 to R3 growth stages, but tissue-K declined during reproductive growth when fertilizer-K was applied. Decreasing tissue-K concentrations of the 160 lb K_2O/ac application rate treatment from 2021 to 2023 are likely due to later sample timing as samples were collected at mid-boot in 2021, late-boot in 2022, and closer to heading in 2023.

Rice grain yields in 2023 were significantly affected by K rate, cultivar, and the interaction of the 2 factors (Table 2). The lowest yielding treatment combination was RT 7421 FP without fertilizer-K, producing 123 bu./ac, followed by Diamond without fertilizer-K (149 bu./ac), which yielded greater than the hybrid at that rate but less than all other treatment combinations. Although the yield without fertilizer-K was 26 bu./ac lower from the hybrid, relative to Diamond, grain yields were significantly greater from the hybrid in all other K-rate treatments, with an average increase of 26 bu./ac, relative to Diamond, when fertilizer-K was applied (ranging from increases of 17 to 33 bu./ac with applications of 40 and 160 lb K_2O/ac, respectively). Within each cultivar, grain yields were greatest from and did not differ among application rates of 80, 120, and 160 lb K_2O/ac, averaging 184 and 213 bu./ac for Diamond and RT 7421 FP, respectively. The application of 40 lb K_2O/ac produced intermediate grain yields for both cultivars. Overall, greater average yields of RT 7421 FP, relative to Diamond, in 2023 were expected and are consistent with 2022 Arkansas Rice Performance Trials, where, averaged among 10 locations, grain yields were 188 and 170 bu./ac for RT 7421 FP and Diamond, respectively (Amos et al., 2023). This contrasts with the results of this study in 2021 and 2022, where yields of RT 7321 FP were significantly lower than Diamond (Smartt et al., 2022; 2023). The yield reduction of the hybrid in 2021 and 2022 was likely related to lodging that only occurred in RT 7321 FP. While no lodging was observed for Diamond from 2021 to 2023 in this study, among K-rate treatments, lodging of RT 7321 FP averaged 47% and 32% in 2021 and 2022, respectively, and lodging of RT 7421 FP (with a late-boot N application) averaged 11% in 2023. In 2020, grain yields did not differ between Diamond and RT 7521 FP when no lodging occurred (Smartt et al., 2022).

In 2023, grain yields of both cultivars were maximized with the application of 80 lb K_2O/ac, which is consistent with results from 2020 and 2021, where 80 to 120 lb K_2O/ac maximized yields. Similarly, grain yields of Diamond did not increase significantly with application rates above 80 lb K_2O/ac in these long-term trials in 2018 or 2019 (Gruener et al., 2019; 2020). Surprisingly, grain yields in this study were greatest when 160 lb K_2O/ac was applied in 2022, which was unexpected as K should not be a limiting factor when applied at a rate of 120 lb K_2O/ac and initial soil-test K of 70 ppm (Smartt et al., 2023). A hybrid cultivar was not evaluated in the long-term trials in 2018 and 2019, but Gruener et al. (2019; 2020) observed lower yield responses from a hybrid (Gemini) than from Diamond in matching short-term site-years. Interestingly, in this trial, the hybrids were more responsive to fertilizer-K in 2020, 2021, 2022, and 2023 than Diamond (average maximum increase of 49 bu./ac for Diamond and 83 bu./ac for the hybrid over those years). Those differences may have been enhanced by lodging in 2021 and 2022, but the hybrid was also more responsive than Diamond when lodging did not occur in 2020 (relative to the control, fertilizer-K increased yields by 33% and 56% for the pure-line and hybrid, respectively). These results are consistent with the generalization by Dobermann and Fairhurst (2000) that hybrids tend to produce more biomass and require more available K than pure-line cultivars.

Based on 8 site years in 2018 and 2019, Gruener et al. (2022) predicted a critical Y-leaf concentration (to achieve 95% relative yield) of 1.60% for pure-line rice between the R1 and R2 growth stages and 1.30% from R2 to R3. Results of this study have shown the dynamic nature of tissue-K concentrations between R1 and R3, the importance of timing for tissue sampling, and the need to refine the changes in critical Y-leaf K concentration within those growth stages. In 2021, Y-leaf samples collected before R2 (when 50% of flag-leaf collars are visible) accurately predicted yield responses, except for Diamond with 80 lb K_2O/ac, which produced 96% relative grain yield when tissue-K was 1.46% (Smartt et al., 2022). In 2022, with samples collected a couple of days past R2, all treatments would be interpreted as deficient based on the critical concentration of 1.6% and, besides the non-K-fertilized controls, sufficient based on the 1.3% critical concentration. The data in 2022, with samples collected near the transition between 1.6% and 1.3% critical concentrations, indicates a critical concentration closer to the midpoint of those values would be more appropriate as 1.42% tissue-K resulted in 94% relative grain yield (Smartt et al., 2023). In 2023, with samples collected just before R3, it is evident that the window of time for useful leaf-tissue K data interpretation is nearly closed by R3. The range of tissue-K concentrations was 0.17% in 2023, compared to 0.39% and 0.70% in 2022 and 2021, respectively, and tissue-K concentrations of 1.18% and 1.19% producing relative grain yields of 87% and 96%, respectively, in 2023 exemplifies that issue. Since research indicates a decrease in critical Y-leaf concentration at R2, tissue samples should be collected prior to that growth stage to accurately assess the K nutrition status of rice as well as to provide time for corrective actions to be taken, if necessary.

Practical Applications

Four years of data in the long-term K response trials at the Pine Tree Research Station suggest that there are differing responses of pure-line and hybrid rice cultivars to exchangeable soil K and K-fertilizer applications. While these results are consistent with the idea of a greater expected K demand for hybrid rice, recent research has shown Gemini, another hybrid, to be less responsive to K than Diamond. The results of this work are somewhat inconclusive but indicate that more research is needed to identify if the tissue-K concentrations proposed by Gruener et al. (2022) are applicable to both pure-line and hybrid rice cultivars. Additionally, the ability to use this data to further refine changes in critical tissue-K concentrations between the R1 and R3 growth stages, as opposed to the abrupt change from 1.6% to 1.3% at R2, would be beneficial. The results of this work, coupled with future experiments, will aid researchers and producers in identifying the best way to manage fertilizer-K for pure-line and hybrid rice cultivars.

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Table 1. Soil pH (measured in a 1:2 soil:water mixture) and Mehlich-3 extractable soil K means (0–4 inch depth, *n* = 9) as affected by annual fertilizer-K rate in long-term trials at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, in 2023.

Fertilizer-K rate	Soil pH	Soil-test K
(lb K_2O/ac/yr)		(ppm)
0	7.9	40 d†
40	7.9	44 d
80	7.9	57 c
120	7.8	68 b
160	7.9	80 a
mean	7.9	58
C.V. (%)	0.7	14.2
P-value	0.4667	<0.0001

† Means in the same column followed by different letters are significantly different ($P \leq 0.10$).

Table 2. Y-leaf tissue-K concentration (%) of rice plants sampled prior to the heading growth stage and grain yield (*n* = 9) as affected by annual fertilizer-K rate, rice cultivar, and their interaction in a long-term trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Arkansas, in 2023.

Fertilizer-K rate	Tissue K			Grain yield			Lodging[†]
	Diamond	RT 7421 FP	K rate mean	Diamond	RT 7421 FP	K rate mean	RT 7421 FP
(lb K_2O/ac/yr)	-----------------(%)-----------------			------------(bu./ac)------------			(%)
0	1.17 b[‡]	1.06 c	1.12	149 d	123 e	136	48 A[§]
40	1.18 b	1.17 b	1.18	168 c	185 b	176	6 B
80	1.18 b	1.20 b	1.19	180 bc	208 a	194	0 B
120	1.29 a	1.26 a	1.27	188 b	212 a	200	0 B
160	1.28 a	1.30 a	1.29	185 b	218 a	202	0 B
Cultivar mean	1.22	1.20	--	174	189	--	--
K rate	----------<0.0001-----------			---------<0.0001----------			<0.0001
Cultivar	------------0.4631-----------			-----------0.0004----------			--
Interaction	------------0.0601-----------			---------<0.0001----------			--
C.V. (%)	--------------5.2--------------			-------------9.1-------------			71.4

[†] Lodging estimates at harvest; no lodging was observed for Diamond.

[‡] Different lowercase letters next to means indicate significant differences within cultivar and K-rate treatment combinations ($P \leq 0.10$).

[§] Different uppercase letters next to means indicate significant differences for that variable ($P \leq 0.10$).

Grain Yield Response of Rice Cultivars to Nitrogen Fertilization at Two Locations in Arkansas

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Abstract

The purpose of these nitrogen (N) studies was to evaluate the growth and response of various rice (*Oryza sativa* L.) cultivars to N fertilization across a range of soils and environments. Rice cultivars evaluated in 2023 included CLL16, Diamond, RT 7302, and RT 7521 FP at 2 locations: the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and the Rohwer Research Station (RRS). Standard seed treatments and seeding rates were utilized based on current Arkansas production practices. Preflood N application rates of 0, 45, 90, 135, 180, and 225 lb N/ac were evaluated. Lodging was minimal in both testing locations for all cultivars evaluated. Maximum yields of 276 bu./ac and 256 bu./ac were observed with RT 7302 at PTRS and RRS, respectively. Yield maximizing N rates ranged from 135 to 225 lb N/ac across the cultivars and locations. Overall, the data from these studies provides insight as to how new rice cultivars respond to N applications on typical rice soils within the primary rice-producing regions of eastern Arkansas.

Introduction

The objective of the cultivar by nitrogen (N) studies was to evaluate the performance of various cultivars with preflood N fertilization rates in differing soil types, including a silt loam and a mixed type soil in Arkansas rice production areas. The goal was to identify the optimum N fertilization rates for rice producers in Arkansas. Four cultivars were evaluated in 2023 at 2 locations.

Procedures

The cultivar × N fertilizer rate studies were conducted on a Calhoun silt loam at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., and on Sharkey and Desha clays at the Rowher Research Station (RRS) near Rowher, Ark. The cultivars studied were CLL16, Diamond, RT 7302, and RT 7521 FP. Experiments were arranged in a randomized complete block design with 4 replications at each location. Seeds were treated with fungicide and insecticide following current recommendations. Experimental plots were direct-seeded into tilled ground on 7.5-in. row spacing and 18 ft in length at a rate of 33 seeds/ft^2 for non-hybrid cultivars and 11 seeds/ft^2 for hybrid cultivars. The preflood N rates were 0, 45, 90, 135, 180, and 225 lb N/ac. Urea was treated with a urease inhibitor, NBPT, prior to application onto a dry soil surface in a single preflood timing at the 4- to 5-leaf growth stage. A permanent flood was established after urea application and maintained until maturity. Plots were drained at maturity, and rice was harvested with a small plot research combine approximately 2 weeks later (Table 1). Yields were calculated as bushels per acre (bu./ac) and adjusted to 12% moisture, based on 45 lb rough rice/bu. Statistical analyses were performed utilizing JMP Pro 17 (JMP Statistical Discovery, LLC, Cary, N.C.) with means separation using Student's T grouping for least-square means at an $\alpha = 0.05$.

Results and Discussion

In general, rice yields in 2023 were good, with maximum yields of 276 bu./ac at PTRS and 255 bu./ac at RRS. Planting was 18 days earlier at PTRS than at the RRS location, which may have a potential influence on the higher yields found at PTRS in general (Table 1).

The rice cultivar CLL16 (Table 2) had maximum yields of 222 bu./ac with 180 lb N/ac at PTRS and 191 bu./ac with 225 lb N/ac at RRS. Yield response was quadratic for PTRS and linear for RRS. The lowest fertilizer rate that was statistically similar to the maximum yield was 135 lb N/ac at PTRS with 218 bu./ac and 180 lb N/ac at RRS with 189 bu./ac. These results coincide with the current recommended N rates for this cultivar.

The rice cultivar Diamond (Table 3) had maximum yields of 221 bu./ac at PTRS and 200 bu./ac at RRS, both at the 225 lb N/ac application rate. Yield response was quadratic at both locations. The lowest fertilizer rate that was statistically similar to the maximum yield was 135 lb N/ac at PTRS with 216 bu./ac. This was a higher yielding year for Diamond at PTRS than observed in 2017 with 150 lb N/ac (Norman et al., 2017). However, the 225 lb N/ac application rate yielded significantly more than any other treatment at RRS. Yields for the rice cultivar Diamond were 30

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bu./ac higher in general in 2023 than in similar cultivar × N trials in 2022 at PTRS (Castaneda-Gonzalez et al., 2023).

The rice cultivar RT 7302 (Table 4) had maximum yields of 276 bu./ac with 225 lb N/ac at PTRS and 256 bu./ac at 180 lb N/ac at RRS. The lowest fertilizer rate that was statistically similar to the maximum yield was 180 lb N/A at PTRS with 273 bu./ac. This fertilizer rate was the maximizing rate for RRS. The yield response was quadratic at both locations.

The rice cultivar RT 7521 FP (Table 5) had maximum yields of 231 bu./ac at PTRS and 232 bu./ac at RRS, both at the 135 lb N/ac fertilization rate. Yield response was quadratic at both locations with high similarity between locations. The lowest fertilizer rate that was statistically similar to the maximum yield was 135 lb N/ac with 236 bu./ac at PTRS and 90 lb N/ac with 222 bu./ac at RRS.

Practical Applications

The continued evaluation of rice cultivar by N fertilization rates is key to providing locally sound data for producers to determine fertilization practices for the upcoming production cycle. The inclusion of baseline cultivars, like Diamond, is critical to assessing the growing season experienced in that given year, as noted for the differences in overall yield in 2023 compared to 2022 with similar planting and harvest dates (Castaneda-Gonzalez et al., 2023). This research allows growers access to unbiased cultivar response to N fertilization at two different rice production growing regions in Arkansas.

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Table 1. Pertinent agronomic information for the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS) during 2023.

Practices	PTRS	RRS
Planting Dates	5 May	23 May
Herbicide Spray Dates and Spray Procedures	----	25 May 10 oz Caravel (Clomazone) + 6.4 oz League + 32 oz Glyphosate 53.8% + 32 oz Paraquat Broadcast
Emergence Dates	12 May	30 May
Flush Dates	----	3 June
Herbicide Spray Dates and Spray Procedures	15 May 3 qt Stam + 1 qt Prowl + 22 oz Facet L Broadcast	----
Herbicide Spray Dates and Spray Procedures	25 May 3 qt Stam + 0.75 oz Permit Plus Broadcast	----
Herbicide Spray Dates and Spray Procedures	8 June 4 qt Rice Beaux Broadcast	23 June 8.5 oz Caravel Broadcast
Preflood N Dates	7 June	20 June
Flood Dates	9 June	28 June
Insecticide Spray Dates and Spray Procedures	None	2.56 oz Lambda-Cy Aerial Broadcast
Drain Dates	1 September	Unrecorded
Harvest Dates	21 September	27 September

Table 2. Influence of nitrogen (N) fertilizer rate on the grain yield of CLL16 rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS) during 2023.

	Grain Yield	
N Fertilizer Rate	PTRS†	RRS
(lb N/ac)	---(bu./ac)---	
0	105 d‡	102 e
45	155 c	124 d
90	196 b	148 c
135	218 a	169 b
180	222 a	189 a
225	216 a	191 a

† PTRS = Pine Tree Research Station, Colt, Ark.; RRS = Rohwer Research Station, Rohwer, Ark.
‡ Means within a column followed by the same letter are not significantly different ($P < 0.0001$).

Table 3. Influence of nitrogen (N) fertilizer rate on the grain yield of Diamond rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS) during 2023.

	Grain Yield	
N Fertilizer Rate	PTRS†	RRS
(lb N/ac)	---(bu./ac)---	
0	109 d‡	105 e
45	157 c	130 d
90	191 b	160 c
135	216 a	168 c
180	219 a	182 b
225	221 a	200 a

† PTRS = Pine Tree Research Station, Colt, Ark.; RRS = Rohwer Research Station, Rohwer, Ark.
‡ Means within a column followed by the same letter are not significantly different ($P < 0.0001$).

Table 4. Influence of nitrogen (N) fertilizer rate on the grain yield of RT 7302 rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS) during 2023.

	Grain Yield	
N Fertilizer Rate	PTRS†	RRS
(lb N/ac)	--- (bu./ac) ---	
0	135 e‡	160 e
45	179 d	199 d
90	215 c	213 c
135	232 b	242 b
180	273 a	256 a
225	276 a	255 a

† PTRS = Pine Tree Research Station, Colt, Ark.; RRS = Rohwer Research Station, Rohwer, Ark.
‡ Means within a column followed by the same letter are not significantly different ($P < 0.0001$).

Table 5. Influence of nitrogen (N) fertilizer rate on the grain yield of RT 7521 FP rice at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS) during 2023.

	Grain Yield	
N Fertilizer Rate	**PTRS**[†]	**RRS**
(lb N/ac)	--(bu./ac)--------------------------------------	
0	135 d[‡]	136 c
45	191 c	201 b
90	224 b	222 a
135	236 a	232 a
180	225 b	230 a
225	231 ab	230 a

[†] PTRS = Pine Tree Research Station, Colt, Ark.; RRS = Rohwer Research Station, Rohwer, Ark.

[‡] Means within a column followed by the same letter are not significantly different ($P < 0.0001$).

Summary of N-STaR Nitrogen Recommendations in Arkansas During 2023

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Abstract

Seeking to fine-tune nitrogen (N) application, increase economic returns, and decrease environmental N loss, some Arkansas rice (Oryza sativa L.) producers are moving from blanket N recommendations based on soil texture and cultivar and using N-STaR (Nitrogen Soil Test for Rice) to determine their field-specific N rates. In 2010, Roberts et al. correlated years of direct steam distillation (DSD) results from both 0-12 and 0 to 18-inch soil samples to plot-scale N response trials across the state to develop a field-specific, soil-based N test for Arkansas rice. Following small-plot and field-scale validations, N-STaR is available to Arkansas farmers for silt loam and clay soils. Samples submitted to the N-STaR Lab in 2023 were summarized by county and soil texture, totaled 14 fields across 10 counties, and were from 4 clay and 10 silt loam fields. The N-STaR N-rate recommendations were compared to the producer's estimated N rate, the 2023 Nitrogen Rates and Distribution for Rice Cultivars, and the standard Arkansas N-rate recommendation of 150 and 180 lb N/ac for silt loam and clay soils, respectively. Each comparison was divided into 3 categories based on a decrease or increase in N recommendation or no change in recommended N rate. The downward trend of sample submissions continued—resulting in the lowest number of samples, only 4.6 % of those submitted in 2013, at the inception of the N-STaR program. Reduced submissions resulted in neither soil texture, county, or cultivar being a significant factor in any of the comparisons for 2023. By not utilizing N-STaR, producers can be missing potential N cost savings opportunities that were recommended in 71%, 82%, and 69% of fields in the standard, estimated, and cultivar comparisons, respectively. As Arkansas producers face shrinking profit margins and increasing environmental pressures, N-STaR remains a valuable, yet underutilized, tool in their toolbox.

Introduction

Nitrogen (N) recommendations for rice in Arkansas were conventionally based on soil texture, cultivar selection, and the previous crop, often resulting in over-fertilization, which can decrease possible economic returns and increase environmental N loss (Khan et al., 2001). Searching for a field-based factor to drive N recommendations, scientists obtained several years of 0 to 18-inch soil samples, equivalent to rice rooting depth on a silt loam soil (Roberts et al., 2009), conducted direct steam distillation (DSD) analysis as an estimator of plant available N, correlated to plot-scale N response trials across the state, and developed a site-specific, soil-based N test for Arkansas rice (Roberts et al., 2011). Direct-seeded, delayed-flood rice production, with proper flood management and the use of ammonium-based fertilizers and best management practices, has a consistent N mineralization rate and one of the highest N use efficiencies of any cropping system; therefore, it lends itself to a high correlation of mineralizable-N to yield response (Roberts et al., 2011). After extensive field testing and validation, N-STaR became available to the public for silt loam soils in 2012 with the initiation of the University of Arkansas N-STaR Soil Testing Lab in Fayetteville, Arkansas. Later, researchers correlated direct steam distillation results from 0 to 12-inch soil samples to N response trials on clay soils (Fulford et al., 2019), and N-STaR rate recommendations became available for clay soils in 2013. Some Arkansas farmers are benefiting from this research by using N-STaR's field-specific N rates, but many continue to depend on soil texture, cultivar, or routine management habits to guide N-rate decisions, which may not always be the most profitable or environmentally sound practice.

Procedures

Samples, categorized by county and soil texture, were submitted to the N-STaR Soil Testing Lab for the 2023 growing season to evaluate the effect of the N-STaR program in Arkansas. The N-STaR rate recommendations for these samples were then compared to the producer's estimated N rate supplied on the N-STaR Soil Test Laboratory Soil Sample Information Sheet, the 2023 Nitrogen Rates and Distribution for Rice Cultivars found in the 2023 Rice Management Guide (Hardke et al., 2023), and to the standard Arkansas N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils. Results were then divided into 3 categories—those with a decrease in the N-fertilizer rate recommendation, no change in the recommended N rate, or an increase in the N rate recommendation. The resulting data was analyzed using JMP Pro 17 (SAS Institute, Inc., Cary, N.C.) with means separated using Fisher's least significant difference test (P = 0.05).

Results and Discussion

Samples were submitted from 14 producer fields across 10 Arkansas counties (Fig. 1) during the 2023 production year, which is only 4.6% of the 304 fields sampled in 2013 when the program was initiated, and analysis costs were partially subsidized. Samples were submitted by 10 different producers or consultants, and the average

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number of fields submitted by clients was 1.3. The highest number of samples submitted were from one producer in Lawrence County, ranked 3rd in Arkansas rice production acres (USDA-FSA, 2023), while 7 of the 14 fields submitted were part of the Rice Research and Verification Program. All 2023 samples were received after rice had been planted during the typically wetter spring months when soil sampling at proper moisture is more problematic, as opposed to sampling after harvest of the previous crop.

When N-STaR recommendations were compared to Arkansas' standard N-rate recommendation of 150 lb N/ac for silt loam soils and 180 lb N/ac for clay soils, soil texture nor county proved to be a significant factor as opposed to years past when a larger sample size suggested some counties had increased residual N stores and would therefore require lower N fertilizer application rates. There were no increases in N-rate recommendations among the 4 clay-textured soils submitted (Table 1). It should be noted that the validation of N-STaR on clay soils found no increased yield response to fertilizer rates above the standard N recommendation; therefore, N-STaR does not recommend N rates greater than 180 lb N/ac (Davidson et al., 2016). Of the 14 fields in this comparison, there was a decrease in N recommendation for 10 fields (71.4% of submitted fields), with an average decrease of 31 lb N/ac and an increase in recommendation for 2 fields (14.3% of those submitted and all on silt loam soils), with an average increase of 8 lb N/ac. N-STaR recommendations continue to be largely dependent on proper sampling depth for the respective soil texture and the correct soil textural classification of the field.

Three of the submitted fields had no estimated N rate specified on the N-STaR Sample Submission Sheet and were excluded from the comparison of the N-STaR recommendation to the producer's estimated N rate. Of the 11 fields that were compared, N-STaR recommended a decrease in N rate for 81.8% of fields with an average decrease of 25 lb N/ac and an increase in recommendation in 18.2% of fields with an average increase of 10 lb N/ac (Table 2). Neither county nor soil texture was a significant factor in this comparison.

When the N-STaR recommendation was compared to the 2023 Nitrogen Rates and Distribution for Rice Cultivars, cultivar recommendations were adjusted for soil texture as recommended by adding 30 lb N/ac for rice grown on clay soils and then compared to the N rates determined by N-STaR. One field failed to include cultivar on the N-STaR Sample Submission Sheet and was therefore excluded from this comparison. There was a decrease in the N recommendation for 9 fields (69.2% of the 13 fields), with an average decrease of 29 lb N/ac (Table 3). Three silt loam fields (23.1% of compared fields) had an average increase in N recommendation of 10 lb N/ac. While neither soil texture nor county demonstrated significance in this comparison, recommended decreases were 3 times higher than possible increases, reiterating the possible N savings potential with N-STaR sampling.

In all 3 comparisons, N-STaR proposed decreases as high as 60 lb N/ac. Decreases of 15 lb N/ac or greater were proposed in 42.8%, 63.6%, and 46.2% of fields evaluated in the standard, estimated, and cultivar rate comparisons, respectively. Alternatively, the greatest N-STaR recommended-N rate increase was only 15 lb N/ac observed in one field in both the producer's estimate and cultivar comparison.

Practical Applications

Despite low sample submission numbers, these results continue to show the value of the N-STaR program to Arkansas producers and can help target areas of the state that would most likely benefit from its incorporation. Standard recommendations and cultivar recommendations will continue to be good starting points for N recommendations, but field-specific N rates continue to offer the best estimate of needed N, regardless of soil texture or cultivar selection. By using a field-specific N rate, farmers could see sizable fertilizer cost savings as future fertilizer-N costs rise while simultaneously decreasing possible negative environmental impacts as concerns intensify to protect the sensitive Mississippi watershed. Discussions with producers have suggested that they are using samples submitted from a single field to make management decisions for anywhere from 100-500 acres. Additionally, farmers have suggested that they are using N-STaR rate recommendations for 5-10 years. These 2 observations indicate that the true impact of the N-STaR program is hard to measure based on annual sample submissions. Farmers are encouraged to consider taking N-STaR samples at the harvest of the previous crop when fields are typically in optimal conditions for soil sampling and time for sampling is more likely. Sample submissions are expected to increase as fertilizer costs continue to cycle upward, and farmers are aware of the potential cost savings possible with N-STaR sampling.

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Table 1. Distribution and change in nitrogen (N) fertilizer rate compared to the standard recommendation, producer's estimated N rate, and the 2023 Nitrogen Rates and Distribution for Rice Cultivars based on soil texture.[a]

		Decreased N-STaR Recommendation		Increased N-STaR Recommendation		
Soil Texture	**Number of Fields Submitted**	**Number of Fields**	**Mean N Decrease**	**Number of Fields**	**Mean N Increase**	**No Change in Recommendation**
			(lb N/ac)		**(lb N/ac)**	
Standard Soil Texture						
Clay	4	4	44	–	–	–
Silt Loam	10	6	22	2	8	2
Total	14	10	31	2	8	2
Producer Estimate						
Clay	3	3	25	–	–	–
Silt Loam	8	6	25	2	10	–
Total	11	9	25	2	10	–
Cultivar						
Clay	4	4	40	–	–	–
Silt Loam	9	5	21	3	10	1
Total	13	9	29	3	10	1

[a] Failure to include a producer's estimated N rate excluded 3 fields from the producer's estimate comparison. In the cultivar comparison, failure to list cultivar excluded 1 field.

Table 2. Distribution and change in nitrogen (N) rate compared to the producer's estimated N rate by county.[a]

County	Number of Fields Submitted	Decreased N-STaR Recommendation		Increased N-STaR Recommendation		No Change in Recommendation
		Number of Fields	Mean N Decrease	Number of Fields	Mean N Increase	
			(lb N/ac)		(lb N/ac)	
Clark	1	1	25	–	–	–
Cross	1	1	20	–	–	–
Drew	1	1	5	–	–	–
Jefferson	1	1	45	–	–	–
Lawrence	3	3	38	–	–	–
Phillips	1	1	5	–	–	–
White	2	1	9	1	5	–
Woodruff	1	–	–	1	15	–
Total	11	9	25	2	10	–

[a] Three fields were excluded from this analysis because no estimated N rate was listed on the N-STaR sample submission sheet.

Table 3. Distribution and change in nitrogen (N) rate compared to the 2023 Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas by cultivar.[a]

Cultivar	Number of Fields Submitted	Decreased N-STaR Recommendation		Increased N-STaR Recommendation		No Change in Recommendation
		Number of Fields	Mean N Decrease	Number of Fields	Mean N Increase	
			(lb N/ac)		(lb N/ac)	
DG 263L	2	1	45	1	15	–
Diamond	3	2	5	1	10	–
Jewel	3	3	48	–	–	–
Jupiter	1	1	5	–	–	–
RT 7321 FP	2	–	–	1	5	1
RT 7521 FP	2	2	30	–	–	–
Total	13	9	29	3	10	1

[a] One field did not list a cultivar on the N-STaR sample submission sheet, so it was excluded from the analysis.

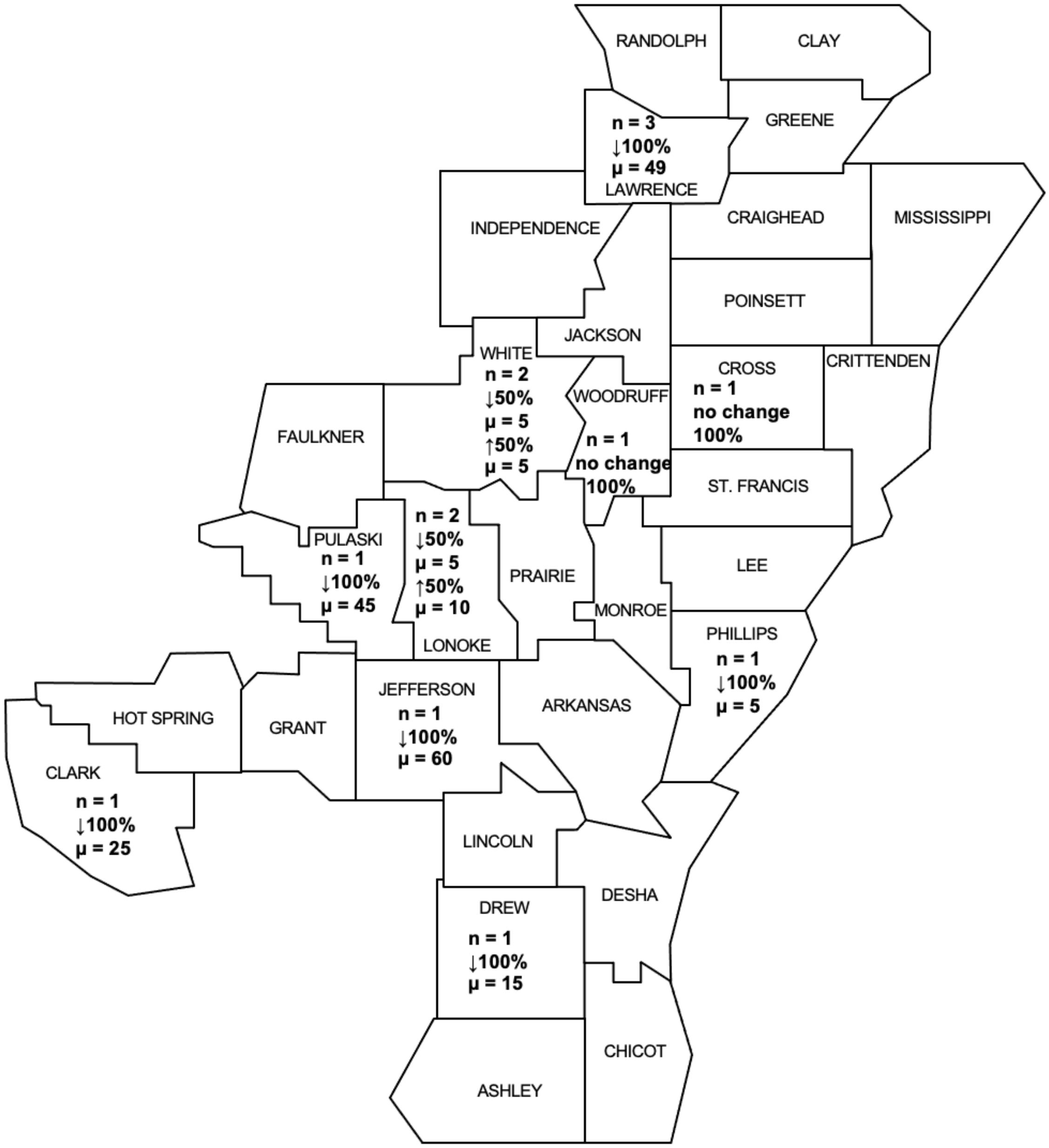

Fig. 1. Number of fields submitted, percent, and mean decrease and increase in N-STaR nitrogen (N) recommendation (lb N/ac) by county compared to the standard recommendation.

Impact of Biochar on Rice Grain Yield and Nutrient Uptake

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Abstract

Wood biochar, a carbon (C)-rich byproduct of timber waste pyrolysis is increasing in popularity in Arkansas agriculture to possibly improve soil organic matter and other soil health parameters. Little work has been done using biochar in rice (*Oryza sativa*) production in Arkansas. Biochar was applied and incorporated prior to planting at rates of 0, 500, 1000, 1500, 2000, and 2500 lb of product per acre in a randomized complete block design with 4 replications in a small plot study at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS). Plant samples were collected at the 50% heading growth stage to evaluate rice nutrient uptake. Grain yield was compared at harvest, and no significant differences were observed. Biochar application had a significant inverse relationship with nitrogen (N, $P < 0.0124$), phosphorus (P, $P < 0.0364$), sulfur (S, $P < 0.0032$), magnesium (Mg $P < 0.0068$), and zinc (Zn, $P < 0.0370$) rice aboveground nutrient uptake. Although there were no significant differences in yield, the reductions in aboveground nutrient uptake for plant essential elements that are often limiting in Arkansas production systems need further investigation.

Introduction

Biochar, a promising carbon (C)-rich renewable resource derived from heating timber waste in a low oxygen environment through a process called pyrolysis, may offer improvements in soil chemical and physical properties for Arkansas rice farmers. Biochar has been shown to improve soil porosity, increase water-holding and cation exchange capacity, decrease bulk density, bolster microbial diversity, and enhance soil fertility (Noguera et al., 2010). However, biochar may vary greatly in terms of possible benefits depending on the type of feedstock and pyrolysis temperatures used for production (Ding et al., 2016). Biochars produced at higher temperatures generally have a higher non-degradable C fraction than those produced at lower temperatures (Navair et al., 2023). Proprietary pyrolysis details of available biochar amendments are not always disclosed to the end user, so heavy reliance on general feedstock properties allows farmers to make the best guess on the advantages possible in their agricultural system (Mukome et al., 2013). Navair et al. (2023) identified the most important characteristic readily available to indicate possible biochar amendment benefits to be the biochar's C:Nitrogen (N) ratio, with wood biochar having higher C:N ratios, lower ash content, and higher pH when compared to crop residue or manure derived biochar. Biochar effects on phosphorus (P), potassium (K), and other nutrient uptakes also vary greatly depending on feedstock (Navair et al, 2023). Variation in physicochemical properties of the soil and ecosystem that biochar is applied to can also affect the benefits observed (Ding et al 2016). Given the wide range of biochar properties and soil characteristics, it is wise to evaluate individual biochar sources to determine possible advantages in an agricultural system. The goal of this study was to examine the effects of preplant application of wood biochar readily available in southeast Arkansas on rice yield and nutrient uptake in the direct-seeded, delayed-flood, silt loam rice production system.

Procedures

In 2023, pure-line (Diamond) rice was dry-seeded at the rate of 75 lb/ac to establish a 24-plot study at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark., on a Calloway silt loam soil. Plots were 6 ft wide (7.5-in. row spacing) and 16 ft in length and were uniformly fertilized to ensure adequate P and K fertility. Treatments were arranged as a randomized complete block with 4 replicates. Prior to rice establishment, biochar residue derived from timber waste pyrolysis was obtained from enviraPAC Monticello LLC and was hand applied and mechanically incorporated to a depth of 4 in. at the rates of 0, 500, 1000, 1500, 2000, and 2500 lb of product per acre. All plots received 150 lb N/ac prior to flood establishment at the 5-leaf growth stage. Aboveground whole plant samples were collected in each plot from a 3-ft section of a bordered row when 50% of panicles emerged from the stem. Biomass samples were dried in a forced-air oven and ground to pass a 1 mm sieve prior to nitric acid digestion and analyzed by ICP-AES for nutrient content. Samples were also analyzed by combustion for C and N. Interior rows of each plot were harvested with a small plot combine, and grain yields were standardized to 12% moisture prior to linear regression analysis using JMP Pro 17 (SAS Institute, Inc., Cary, N.C.) using an α value of 0.05 to indicate the significance of yield and nutrient uptake to the rate of the product.

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Results and Discussion

No significant difference was observed in rice grain yield with biochar addition (Table 1), which follows the inconsistencies in yield effects summarized by the recent review of biochar application in the rice paddy system (Navair et al., 2023). Rice N uptake at 50% heading did significantly ($P < 0.0124$) decrease from 249.7 lb N/ac observed in the control to 180.6 mean lb N/ac with the highest biochar addition. Mekome et al. (2013) suggested the addition of the wood-derived biochar would result in a net N immobilization in the soil due to higher C:N ratios present in biochar produced at higher pyrolysis temperatures, which could explain the results observed in this study. While the decrease in total N uptake did not reduce rice grain yield, high application rates of biochar that reduce N uptake could reduce rice grain yield if N is inadequate or N loss occurs. While biochar rates used in this study would not greatly alter the total soil C:N ratio, the C:N ratio in the labile soil solution could be influencing soil microbial N absorption. A more plausible explanation is the reduction in the amount of N available to urea-fertilized rice by increasing adsorption of available ammonium ions to biochar, rendering them less available for rice uptake (Navair et al., 2023).

Another nutrient heavily influenced by feedstock choice, pyrolysis temperature, and ratio to C is sulfur (S). Ippolito et al. (2020) state that higher pyrolysis temperature biochar has higher C:S ratios, and any S present is likely bound to recalcitrant C and not available to plants. Wood biochar application in this study had a significant ($P < 0.0032$) negative effect on S uptake by rice at 50% heading. Means of the control and the highest biochar rate (2500 lb/ac) differed by 6.0 lb S/ac. This effect could be due to biochar application increasing the C:S ratio present in the soil, increasing S immobilization by the soil organic matter or microbial population, and therefore decreasing the amount of S available for plant uptake.

Biochar application had an inverse effect ($P < 0.0364$) on P uptake by rice at 50% heading in this study—48 lb P/ac in control, decreasing to 38.7 lb P/ac in the highest biochar treatment (Table 1). Biochar application effects on P availability are generally inconsistent and were highly influenced by soil acidity and biochar application changing P sorption and desorption capacity of the soil (Xu et al., 2014). There was also a significant inverse relationship effect of biochar application on Mg ($P < 0.0068$) and Zn ($P < 0.0370$) rice uptake at 50% heading (Table 1). The reduction in all rice nutrient uptake values observed in this study for S, P, Mg, and Zn, is most likely an effect of decreased ammonium ions available for rice uptake and subsequent dry matter production, immobilization of nutrients by microbes or other complex exchange mechanisms on the surface of the biochar. Dry matter production was strongly correlated with N ($P < 0.0001$), S ($P < 0.0001$), P ($P < 0.0001$), Mg ($P < 0.0001$), and Zn ($P < 0.0001$) plant uptake. Wood biochar has a high adsorption capacity for ammonium ions, but over time can act as a slow-release fertilizer as the biochar releases bonds to the ammonium ions increasing plant available N (Aghoghovwia et al., 2022).

Practical Applications

While some biochar can offer agricultural benefits, not all biochar is created equal and varies greatly in its effect on soil cation exchange capacity, C to nutrient ratios, and subsequent plant nutrient availability depending on feedstock and production temperature. The use of biochar in the flooded Arkansas rice production system with urea fertilization may not be the best combination for maximum crop production for the season of biochar application, but it can build up soil N and C over time. Additional work needs to be done to evaluate the long-term effects of biochar applications and how that may impact available nutrients that may limit rice production.

Acknowledgments

This research was funded by Arkansas Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board and the University of Arkansas System Division of Agriculture. Sincere gratitude is extended to the employees of the University of Arkansas N-STaR Soil Testing Lab for the many hours of analysis and to the hourly personnel who spent many hours grinding plant samples.

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Table 1. Mean rice grain yield and nutrient uptake response to biochar application.

Biochar application rate	Grain yield	DM uptake	N uptake	P uptake	K uptake	Ca uptake	Mg uptake	S uptake	Zn uptake
(lb/ac)	(bu./ac)	--------------------	--------------------	--------------------	--------(lb /ac)--------	--------------------	--------------------	--------------------	--------------------
0	198.3	335.1	249.7	48.4	339.7	32.4	36.2	20.2	0.75
500	195.4	289.4	198.1	41.4	273.1	25.8	30.0	16.3	0.67
1000	195.6	315.0	190.4	46.2	305.6	25.7	30.1	16.6	0.67
1500	194.9	277.8	205.3	41.6	301.1	24.9	28.2	16.2	0.69
2000	194.9	277.8	191.3	39.5	285.3	28.8	26.7	15.0	0.59
2500	190.5	283.7	180.6	38.7	270.4	24.6	26.3	14.2	0.60
P-value	*0.3232*	*0.0570*	*0.0124*	*0.0364*	*0.0778*	*0.1149*	*0.0068*	*0.0032*	*0.0370*
LSD *P* = 0.05	*16.73*	*60.41*	*48.66*	*10.21*	*66.18*	*6.81*	*7.91*	*3.95*	*0.161*

Rice Grower Research and Demonstration Experiment Program

A. Wright[1] and J.T. Hardke[1]

Abstract

Throughout 2023, the Rice Grower Research and Demonstration Experiment (GRADE) Program was located in Poinsett County, Lawrence County, Jackson County, and Clay County. These demonstration trials consisted of replicated large-block demonstrations evaluating the rice varieties Diamond, Ozark, CLL16, and CLL18. The University of Arkansas System Division of Agriculture and the Arkansas Rice Research and Promotion Board first initiated the program in 2017 to conduct replicated large block field trials approximately ½ acre or larger on growers' farms to bridge information between small plot research and developing growers' field experiences.

Introduction

The goal of the Rice Grower Research and Demonstration (GRADE) Program is to first execute larger-scale trials on commercial rice farms throughout Arkansas and to also arrange hands-on training of county agents, consultants, and rice growers throughout the state. The program also gives exclusive data to support the development of rice budgets, computer-assisted management programs, agronomic practices, resource utilization, and statewide rice extension programs.

Demonstration of the large block trials allows more hands-on participation by county agents, consultants, and others while providing multiple sites for educational field events. Additional benefits from these larger style trials include providing supplemental information to the verification program as well as allowing more opportunities for rice growers to evaluate and provide input on practices at a larger scale than small-plot research in multiple counties scattered across the state. The large-scale demonstration program has the overall objective of increasing the confidence and visibility of research as well as bridging the gap between small-plot research trials and whole-field verification program demonstrations. The main benefit of the long-term spectrum is the result of allowing the adoption of lower-risk recommended practices and increasing the revenue across the entire grower's farm.

Procedures

Before planting, these fields are selected for involvement in the Rice GRADE Program for the 2023 season. These variety demonstration trials in 2023 were in Jackson, Lawrence, Clay, and Poinsett Counties and included the cultivars CLL16, CLL18, Diamond, and Ozark. Each of these locations was seeded with a John Deere 6120E tractor and an 8-ft Great Plains no-till box drill (7.5-in. row spacing). Based on the harvest equipment sizes and field layout, each of the variety demonstration plots was arranged in a randomized complete block design with 3–4 replications of these varieties with plot sizes 32 ft wide and 300–500 ft in length.

Results and Discussion

The Clay County and Poinsett County locations are not reported due to planting and harvest issues at each location, respectively.

At the Lawrence County location, CLL18 and CLL16 were the highest yield cultivars at 223 and 218 bu./ac, respectively (Table 1). Due to variability, there were no differences in head rice or total rice among cultivars evaluated.

At the Jackson County location, while CLL18 had the highest yield at 199 bu./ac, there were no statistical differences among cultivars (Table 2). Diamond and Ozark had the highest head rice and total milled rice compared to CLL16 and CLL18.

Results of these large block demonstrations help to illustrate the yield potential of the selected cultivars. However, when comparing generally to expected outcomes based on small-plot studies, these results differ somewhat. Ozark and CLL18 are typically higher-yielding small-plot trials, while in these large demonstrations, CLL16 and Diamond are much more competitive. These results suggest that earlier evaluation of potential new cultivar releases in large block trials may be beneficial.

Practical Applications

The data collected from the 2023 Rice GRADE Program provides support for data produced from small plot research. However, the information can also be used to aid in cultivar selections for any of the Arkansas rice producers across the state.

Acknowledgments

The authors especially appreciate the cooperation of all participating rice producers who made this work possible. Funding for this project was provided through Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board. We also appreciate the support from the University of Arkansas System Division of Agriculture for making this research possible.

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Table 1. Rice Grower Research and Demonstration Experiment (GRADE) Program Lawrence County variety demonstration results.

Cultivar	Harvest Moisture	Grain Yield	Head Rice	Total Rice
	(%)	(bu./ac)	(%)	(%)
Diamond	12.9	210.6 b†	56.1	69.0
Ozark	13.1	206.4 b	57.5	68.7
CLL16	13.8	217.8 a	50.6	66.2
CLL18	12.8	223.4 a	56.3	66.5
P-value	--	0.0043	0.1977	0.1567

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).

Table 2. Rice Grower Research and Demonstration Experiment (GRADE) Program Jackson County variety demonstration results.

Cultivar	Harvest Moisture	Grain Yield	Head Rice	Total Rice
	(%)	(bu./ac)	(%)	(%)
Diamond	17.5	190.2	53.6 a†	66.0 a
Ozark	14.5	192.1	52.2 a	63.6 a
CLL16	17.2	190.6	35.9 c	55.8 c
CLL18	16.6	198.5	43.9 b	59.6 b
P-value	0.2587	0.8095	0.0008	0.0016

† Means within a column followed by the same letter are not significantly different ($P > 0.1$).

Influence of Seeding Rate on Performance of New Rice Cultivars

A. Wright,[1] J.T. Hardke,[1] H. Hartley,[1] D.L. Frizzell,[1] T.L. Clayton,[1] E. Castaneda-Gonzalez,[1] and L.R. Amos[1]

Abstract

The objective of the rice cultivar by seeding rate study is to evaluate the response of new cultivars to selected seeding rates to determine the most effective seeding rate throughout the diversity of rice-growing environmental conditions in Arkansas. Seeding rate studies were conducted at 3 locations: the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (Stuttgart; silt loam soil), the Pine Tree Research Station (Colt; silt loam soil), and the Northeast Research and Extension Center (Keiser, clay soil). The 5 pure-line varieties evaluated during the 2023 season were Ozark, Taurus, PVL03, CLL18, and RTv7231 MA seeded at 5, 10, 20, 30, and 40 seed/ft^2; and the 4 hybrids evaluated were RT 7321 FP, RT 7331 MA, RT 7421 FP, and RT 7302 seeded at 4, 6, 8, 10, and 12 seed/ft^2. Results suggest that seeding rates lower than currently recommended are capable of producing optimal yields for the cultivars evaluated.

Introduction

The intention of this study is to correlate an efficient seeding rate for these newly released rice cultivars to maximize potential throughout the different locations in Arkansas. There are a range of additional factors, such as planting date, seeding method, and seedbed preparation, that could possibly increase the seeding rate recommendations from those recommended. The findings from this study will be used to refine seeding rate recommendations for Arkansas.

Procedures

Throughout the 2023 season, the pure-line varieties that were evaluated were Ozark, Taurus, PVL03, CLL18, and RTv7231 MA seeded at 5 different rates: 5, 10, 20, 30 and 40 seed/ft^2. The hybrids evaluated were RT 7321 FP, RT 7331 MA, RT 7421 FP, and RT 7302, seeded at 5 different rates: 4, 6, 8, 10, and 12 seed/ft^2. Each of these cultivars was tested across different soil types and conditions, including the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC; Stuttgart; silt loam soil), the Pine Tree Research Station (PTRS; Colt; silt loam soil); and the Northeast Research and Extension Center (NEREC; Keiser; clay soil). Plots seeded were 8 rows (7.5-in. spacing) wide and 17.5-ft in length. The stand density of these rice cultivars was determined at approximately the 2- to 3-leaf growth stage as the number of emerged seedlings per 10 row ft within each plot. At harvest, the center 4 rows of each plot were harvested, and the moisture and grain yields were determined. Grain yield was adjusted to 12% grain moisture and reported in bushels per acre (bu./ac). Recommended practices for maximum yield were followed. The experimental design for all trials was a randomized complete block design with 5 replications. Statistical analysis was conducted using PROC GLM, SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with means separation using Fisher's least significant difference test ($P = 0.1$).

Results and Discussion

Varieties

At the RREC, all varieties displayed a significant response to seeding rate for stand density (Table 1). A seeding rate of 20 seed/ft^2 resulted in a stand density greater than 10 plants/ft^2 for all varieties. All varieties displayed a grain yield response to seeding rate at this location. CLL18 seeding rates of 40 and 30 seed/ft^2 produced the highest grain yields, which were greater than the 5 and 10 seed/ft^2 rates, though not greater than the 20 seed/ft^2 rate. For Ozark, the 10-40 seed/ft^2 rates produced greater yields than the 5 seed/ft^2 rate. PVL03 seeding rates of 20–40 seed/ft^2 were greater than the 5–10 seed/ft^2 rates. RTv7231 MA produced the highest grain yields at 20 seed/ft^2, which was greater than the 5 and 30 seed/ft^2 rates but not greater than the 10 and 40 seed/ft^2 rates. Taurus produced similar yields across the 10–40 seed/ft^2 rates, which were all greater than the 5 seed/ft^2 rate.

At the PTRS, all varieties displayed a significant response to seeding rate for stand density (Table 2). Ozark, PVL03, RTv7231 MA, and Taurus had significant responses for grain yield, while CLL18 did not. For Ozark, the 10–40 seed/ft^2 rates produced greater yields compared to the 5 seed/ft^2 rate. PVL03 at 40 seed/ft^2 produced higher yields compared to the 5–20 seed/ft^2 rates but similar to the 30 seed/ft^2 rate. For RTv7231 MA, the 10-40 seed/ft^2 rates had higher yields than the 5 seed/ft^2 rate. Taurus at 40 seed/ft^2 had the highest yields, which were similar to the 20 and 30 seed/ft^2 rates but greater than the 5 and 10 seed/ft^2 rates.

At the NEREC, a significant stand density response to seeding rate was observed for all varieties (Table 3). CLL18, Ozark, and Taurus did not have a significant yield response to seeding rate. For

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PVL03, the highest grain yields were achieved at the 5–20 seed/ft^2 rates which were greater than the 40 seed/ft^2 rate. RTv7231 MA at 30 seed/ft^2 produced the highest grain yields, which were similar to the 10 and 20 seed/ft^2 rates and greater than the 5 and 40 seed/ft^2 rates.

Hybrids

At the RREC, all hybrids displayed a significant response to seeding rate for stand density (Table 4). Only RT 7302 had a significant grain yield response, with the 8–12 seed/ft^2 rates producing greater yields compared to the 4 seed/ft^2 rate.

At the PTRS, all hybrids displayed a significant response to seeding rate for stand density (Table 5). RT 7421 FP and RT 7302 had a significant grain yield response to stand density. For RT 7421 FP, 12 seed/ft^2 produced higher grain yields compared to the 4 and 6 seed/ft^2 rates. For RT 7302, the 12 seed/ft^2 rate had higher yields than the 4 and 6 seed/ft^2 rates.

At the NEREC, all hybrids once again displayed a significant response to seeding rate for stand density (Table 6). No hybrids had a significant grain yield response to seeding rate at this location.

Results for varieties suggest that seeding rates lower than currently recommended are capable of producing optimal grain yields. However, caution should be used when attempting to use lower than recommended seeding rates, as field variability at the production level will have a greater influence on stand density than that in research trials.

Results for hybrids continue to suggest that under optimal conditions, hybrids are capable of producing optimal grain yields at very low seeding rates. Again, the same caution should be exercised that the pursuit of extremely low seeding rates can lead to excessive stand variability and yield response under suboptimal conditions.

Practical Applications

For all cultivars, stand density increased significantly as the seeding rate increased. For varieties, the 20 seed/ft^2 rate was needed to achieve minimum recommended stand densities, which is lower than the current recommended seeding rate. Similarly for hybrids, the 8 seed/ft^2 rate was needed to achieve minimum recommended stand densities, which is lower than the current recommended seeding rate. Grain yield response to seeding rate was variable and cultivar-specific. Multiple years of data are typically used to refine grain yield response to seeding rate due to variability in stand density, particularly at lower seeding rates.

The findings from this study will be used to refine seeding rate recommendations for Arkansas. The research results indicate that currently recommended hybrid seeding rates can produce adequate stands to achieve optimal yields. However, results for varieties indicate that some varieties may achieve optimal yields at lower than currently recommended seeding rates to be efficient. The findings from this study are based on results from silt loam soils and currently recommended seeding rate adjustments based on soil type and seeding date.

Acknowledgments

The authors especially appreciate the cooperation of all participating rice producers who made this work possible. Funding for this project was provided through the Rice Check-Off funds administered by the Arkansas Rice Research and Promotion Board. We also appreciate the support from the University of Arkansas System Division of Agriculture for making this research possible.

Table 1. Influence of seeding rate on stand density and grain yield of selected varieties at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center.†

Seeding Rate	Stand Density					Grain Yield				
	CLL18	Ozark	PVL03	RTv7231 MA	Taurus	CLL18	Ozark	PVL03	RTv7231 MA	Taurus
(seed/ft^2)	---------(plants/ft^2)---------					---------(bu./ac)---------				
5	3.6 d‡	3.4 d	3.8 e	2.5 e	3.6 d	150 b	129 b	117 b	142 c	130 b
10	8.2 c	7.1 c	7.0 d	6.8 d	5.8 c	148 b	169 a	113 b	169 ab	162 a
20	13.2 b	12.5 b	15.2 c	10.6 c	12.7 b	159 ab	166 a	130 a	185 a	169 a
30	18.6 a	20.8 a	19.0 b	16.3 b	20.0 a	176 a	172 a	132 a	164 b	175 a
40	20.4 a	22.1 a	25.1 a	20.4 a	22.1 a	172 a	168 a	130 a	179 ab	186 a
$LSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0991	0.0037	0.0364	0.0012	0.0038

† Research station field near Stuttgart on a silt loam soil.

‡ Means within a column followed by the same letter are not significantly different ($P > 0.1$).

Table 2. Influence of seeding rate on stand density and grain yield of selected varieties at the University of Arkansas System Division of Agriculture's Pine Tree Research Station.†

Seeding Rate	Stand Density CLL18	Ozark	PVL03	RTv7231 MA	Taurus	Grain Yield CLL18	Ozark	PVL03	RTv7231 MA	Taurus
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
5	3.7 d‡	4.2 d	3.5 e	3.5 e	3.6 e	184	176 b	127 d	175 b	189 c
10	7.5 c	6.6 c	6.7 d	5.8 d	7.3 d	199	197 a	145 c	199 a	207 b
20	14.5 b	14.4 b	12.4 c	11.1 c	13.1 c	197	201 a	161 b	203 a	214 ab
30	20.8 a	20.8 a	18.2 b	17.1 b	17.9 b	203	208 a	169 ab	218 a	216 ab
40	24.0 a	24.1 a	26.4 a	24.4 a	25.9 a	197	207 a	179 a	202 a	225 a
$LSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS¶	0.0205	0.0001	0.0215	0.0130

† Research station field near Colt on a silt loam soil.
‡ Means within a column followed by the same letter are not significantly different ($P > 0.1$).
¶ NS = not significant.

Table 3. Influence of seeding rate on stand density and grain yield of selected varieties at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center.†

Seed Rate	Stand Density CLL18	Ozark	PVL03	RTv7231 MA	Taurus	Grain Yield CLL18	Ozark	PVL03	RTv7231 MA	Taurus
(seed/ft^2)	(plants/ft^2)					(bu./ac)				
5	3.3 e‡	4.5 d	3.5 d	2.6 e	3.8 e	183	189	158 a	173 c	197
10	9.6 d	6.8 c	7.9 c	8.0 d	6.8 d	190	195	161 a	191 ab	193
20	14.2 c	13.4 b	15.5 b	13.8 c	12.6 c	188	191	156 a	189 ab	197
30	19.9 b	18.1 ab	20.7 a	18.1 b	17.4 b	197	189	153 ab	202 a	206
40	22.8 a	25.1 a	25.9 a	22.6 a	23.9 a	183	196	145 b	182 bc	196
$LSD_{0.05}$	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS¶	NS	0.0310	0.0235	NS

† Research station field near Keiser on a clay soil.
‡ Means within a column followed by the same letter are not significantly different ($P > 0.1$).
¶ NS = not significant.

Table 4. Influence of seeding rate on stand density and grain yield of selected hybrids at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center.†

Seed Rate	Stand Density RT 7321 FP	RT 7421 FP	RT 7331 MA	RT 7302	Grain Yield RT 7321 FP	RT 7421 FP	RT 7331 MA	RT 7302
(seed/ft^2)	(plants/ft^2)				(bu./ac)			
4	3.8 b‡	3.3 c	4.5 c	3.8 c	161	178	174	172 b
6	3.5 b	3.6 bc	4.8 bc	4.0 bc	160	176	188	188 ab
8	5.5 a	5.4 a	6.4 ab	6.6 a	169	171	182	193 a
10	5.8 a	4.7 ab	6.8 a	5.8 ab	169	176	183	203 a
12	5.2 a	5.4 a	6.9 a	5.8 ab	158	176	182	200 a
$LSD_{0.05}$	0.0265	0.0708	0.0730	0.0990	NS¶	NS	NS	0.1027

† Research station field near Stuttgart on silt loam soil.
‡ Means within a column followed by the same letter are not significantly different ($P > 0.1$).
¶ NS = not significant.

Table 5. Influence of seeding rate on stand density and grain yield of selected hybrids at the University of Arkansas System Division of Agriculture's Pine Tree Research Station.†

	Stand Density				Grain Yield			
Seed Rate	RT 7321 FP	RT 7421 FP	RT 7331 MA	RT 7302	RT 7321 FP	RT 7421 FP	RT 7331 MA	RT 7302
($seed/ft^2$)	($plants/ft^2$)				(bu./ac)			
4	2.7 c‡	2.8 d	3.2 c	3.1 d	204	211 bc	212	208 c
6	3.6 b	3.7 c	4.4 b	4.8 c	207	199 c	221	218 bc
8	5.5 a	5.3 b	5.5 b	6.1 b	225	215 ab	223	229 ab
10	6.6 a	6.6 ab	7.4 a	6.5 b	210	218 ab	225	231 ab
12	6.8 a	8.1 a	9.4 a	8.5 a	208	227 a	221	243 a
$LSD_{0.05}$	0.0001	<0.0001	<0.0001	<0.0001	NS¶	0.0275	NS	0.0046

† Research station field near Colt on a silt loam soil.
‡ Means within a column followed by the same letter are not significantly different ($P > 0.1$).
¶ NS = not significant.

Table 6. Influence of seeding rate on stand density and grain yield of selected hybrids at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center.†

	Stand density				Grain Yield			
Seed Rate	RT 7321 FP	RT 7421 FP	RT 7331 MA	RT 7302	RT 7321 FP	RT 7421 FP	RT 7331 MA	RT 7302
($seed/ft^2$)	($plants/ft^2$)				(bu./ac)			
4	3.0 c‡	2.2 d	3.5 c	3.9 c	218	217	207	208
6	6.0 ab	3.1 c	3.6 c	3.9 c	209	231	208	218
8	4.7 b	3.6 c	5.6 b	4.2 bc	203	217	209	213
10	6.6 a	4.6 ab	5.8 b	5.4 b	209	224	205	224
12	6.4 a	5.3 a	7.9 a	7.9 a	209	223	211	209
LSD 0.05	0.0011	0.0006	0.0005	0.0035	NS¶	NS	NS	NS

† Research station field near Keiser on a clay soil.
‡ Means within a column followed by the same letter are not significantly different ($P > 0.1$).
¶ NS = not significant.

The Influence of Soil Nitrogen Application on the Glass Transition Temperatures of Rice Kernels

E. Ameyaw Owusu,[1] K. Luthra,[1] and G.G. Atungulu[1]

Abstract

Improper drying of rice can cause defects in the kernel, such as fissuring, which leads to reduced head rice yield and significant economic losses for growers. The University of Arkansas System Division of Agriculture's Rice Processing Program has developed material state diagrams for rice as a tool to help predict the appropriate drying and tempering temperatures to employ. These diagrams consist of the glass transition temperature (T_g) of rice kernels at various moisture content (MC) levels. Agronomic practices such as soil nitrogen fertilizer application are extensively used by farmers to increase rice crop yields. These applications affect the synthesis of amylose, amylopectin, and their chain length in rice starch compositions. The T_g of rice starches is, however, stipulated to increase with increasing amylose content in rice. Due to these substantial changes from nitrogen application (amylose increase), rice kernels' T_g may be affected during active drying, which is critical for predicting their fissuring potential. Therefore, this study aimed to determine the impact of soil nitrogen application on the T_g of a selected rice cultivar. The study involved treating a long-grain pure-line cultivar (Diamond) with 6 different nitrogen rates (pounds/acre) at the pre-flood stage to obtain rice samples from fields given an application rate of 0, 90, 120, 150, 180, and 210 lb/ac. A differential scanning calorimeter was used to determine the T_g of the rice samples at various moisture levels (20%, 18%, 16%, 14%, and 12%). From the study, the application of soil nitrogen significantly increased the T_g of rice samples treated at 90 and 150 lb/ac, with the sample treated at 0 lb/ac having the lowest mean T_g. This newly generated information will aid in better controlling the drying and tempering of rice kernels.

Introduction

Rice kernels with internal fractures within the endosperm are commonly referred to as fissured kernels. These fissures tend to break during milling, and this leads to significant reductions in milling yields. The functional properties of fissured rice kernels are also immensely affected after their milling, which causes significant financial losses to the end-use processors (Siebenmorgen et al., 2009). It is, therefore, imperative to minimize kernel fissuring by understanding how these fissures tend to occur during the active drying of rice.

The glass transition temperature (T_g) is an important parameter that represents the temperature range where rice starch changes from a hard glassy phase to a soft rubbery phase. This concept has been applied to identify the role of intra-kernel material state differences that cause fissures to form in rice kernels. According to Cnossen and Siebenmorgen (2000), fissuring of a rice kernel may be attributed to the differential stress within the kernel exceeding the kernel material strength. Per the literature, these differential stresses are developed when sufficient portions of the kernel periphery transition to a glassy state while the kernel core remains in a rubbery state during drying. It is hypothesized that when the tempering temperature is below the T_g of the rice, the kernel will undergo a further glass transition into the glassy state as the kernel temperature decreases, and this causes fissuring to occur (Cnossen and Siebenmorgen, 2000). Using the T_g of rice, material state diagrams can be developed to predict the material states (glassy/rubbery) of rice kernels or portions of kernels at various moisture contents. The data from these material state diagrams, therefore, informs the rice industry on the appropriate drying and tempering temperatures to employ for drying rice kernels after their harvest.

The application of nitrogen fertilizer on contemporary rice cultivars has become a common practice. This is because nitrogen is the most important element for plant growth, development, and quality, among all other nutrients. It is used extensively to increase rice crop yield by farmers as it improves crop performance, promotes plant leaf area, plant biomass, and finally, crop yield (Sinclair, 1989). According to Zhou et al. (2020), nitrogen application affects the structure of rice starches and, as a result, changes the functional properties and the final quality of rice cultivars. The rice grain quality in terms of starch particle size, crystal structure, chain length distribution, and pasting properties are also immensely affected by nitrogen application on rice plants (Singh et al., 2011; Gu et al., 2015; Zhu et al., 2017; Zhang et al., 2019).

The impact of nitrogen fertilizer on rice grain quality is a result of its effects on carbohydrate biosynthetic enzyme activity. The biosynthesis of amylose is usually controlled by ADP glucose pyrophosphorylase (AGPase) and granule-bound starch synthase (GBSS). Biosynthesis of amylopectin, on the other hand, requires a coordinated series of enzymatic reactions that involve AGPase, soluble starch synthase (SS), starch branching

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enzyme (BE), and starch debranching enzyme (DBE), making it more complex. These syntheses of amylose, amylopectin, and the distribution of amylopectin chain-length (CLDs) tend to influence the physicochemical properties of rice. One of these properties includes the effect on the glass transition temperatures (T_g) of rice kernels during active drying, and this change is crucial in predicting the fissuring potential of rice kernels. A report by Liu et al. (2010) indicates that T_g increases with increasing amylose content; however, the influence of nitrogen application on the T_g of rice is unknown.

The objective of this study was, therefore, to determine the role of soil nitrogen application on glass transition temperatures (T_g) of a selected newer Arkansas long-grain rice cultivar.

Procedures

Sample Procurement and Preparation

A long-grain pure-line cultivar (Diamond) treated at 6 different nitrogen rates was obtained from the University of Arkansas System Division of Agriculture's Rice Research and Extension Center in Stuttgart, Arkansas. The nitrogen rates were applied at the pre-flood stage to obtain samples of 0, 90, 120, 150, 180, and 210 lb/ac. The rough rice samples were cleaned using a dockage tester (XT4, Carter-Day, Minn.). A precision sizer (ABF2, Carter-Day Company, Minn.) was used to grade the thickness of the rough rice samples to achieve uniformity in kernels and reduce variation in samples used during the experiment. The cleaned and size fractioned rough rice samples were conditioned to 12% moisture content (wet basis) using gentle natural air drying (75 °F air temperature, 56% air relative humidity). During the drying process, the moisture contents (MC) of the rough rice samples were measured to obtain samples at 20%, 18%, 16%, 14%, and 12% (wet basis). This was achieved by measuring the rice samples in triplicates using the moisture content meter (AM 5200–A, PerkinElmer, Hagersten, Sweden). Brown rice samples were obtained by hand dehulling the hulls from the rough rice samples. The samples of brown rice obtained at various MC levels were then kept in sealed plastic tubes and stored at 39 °F before further analysis.

Differential Scanning Calorimetry (DSC) Analysis

The glass transition temperatures of samples at various MC levels were determined using a differential scanning calorimeter (Diamond DSC, Perkin Elmer, Shelton, Conn.). In the DSC analysis, sections of the individual brown rice kernels were used. Each kernel was cross-sectioned into two parts using a razor blade. The sectioned kernels were placed inside the equipment's high-pressure stainless-steel pan and carefully sealed with a pan cover for each analysis. The DSC system was then set to equilibrate the sectioned brown rice samples to –86 °F and then heated from –86 to 482 °F at a rate of 41 °F/min. The T_g from each thermogram was then determined by identifying the transition corresponding to a slope change in the heat capacity of the sample.

Statistical Analysis

The study was conducted using a completely randomized design. An analysis of variance test was conducted from the experimental data using JMP Pro 17 statistical software (JMP Pro 17, SAS Institute, Cary, N.C.). Tukey's honestly significant difference test was employed to compare the means, and the level of significance was set at a 95% confidence level.

Results and Discussion

The glass transition temperatures of the various nitrogen-treated samples were analyzed and presented in Table 1. The statistical impact the diverse nitrogen-treated samples, as well as the varying MC levels, had on the glass transition temperatures, was also outlined in Table 2. The results (Table 1) indicated that, for each nitrogen sample, a strong negatively correlated linear relationship existed between the MC and the T_g. The T_g of the rice kernels increased with decreasing moisture content, which was similar to trends observed in previous studies by Perdon et al. (2000) and Sun et al. (2002). The account for this relationship indicates that water (moisture content) had a significant effect on the T_g. of rice kernels (Table 2). A factor that accounts for this observation could be that the amount of moisture in the starches, such as oligosaccharides present in high moisture kernels, can act as plasticizers (Slade and Levine, 1995). These plasticizers tend to reduce the crystallinity and intermolecular forces between polymer chains of the rice starches, allowing them to move more freely. This increased molecular mobility results in a lower T_g as the rice starch transitions from a glassy to a rubbery state.

The results also indicated that the different nitrogen treatments had significant effects ($\alpha = 0.05$) on the glass transition temperatures (Table 2). Figure 1 shows the effects that the various nitrogen-treated samples had on the glass transition temperatures. From the figure, the sample with no nitrogen treatment (0 lb/ac) had the lowest mean T_g compared to the samples with nitrogen treatment. Treated samples at 90 and 150 lb/ac were, however, significantly higher compared to the control sample (0 lb/ac). The observation from the results could be a result of the synthesis of amylose, amylopectin, and their chain length in rice starches as caused by the application of soil nitrogen fertilizer. This could also be in support of the theory that T_g rises with increasing amylose content, suggesting that the nitrogen application may have elevated amylose levels in the rice samples (Liu et al., 2010). Ultimately, the increase in these amylose levels can induce structural changes in the starch molecules. This may include the alteration in the crystallinity or amylose-amylopectin ratios. These structural changes have the potential to alter the movement of starch molecules, thereby affecting the glass transition temperature. A higher temperature would then be necessary to induce a transition in a starch structure that is more crystalline in nature.

Practical Applications

This data can be valuable in assessing how different soil nitrogen application rates can affect the glass transition temperature (T_g) of rice. The T_g is crucial in predicting the transition states (glassy/rubbery) of rice kernels at given moisture levels. This understanding is crucial for rice farmers, as it ensures that drying and tempering processes are carried out at the right temperatures and durations to avoid problems such as rice kernel fissures.

Acknowledgments

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Table 1. Glass transition temperatures of nitrogen-treated rice samples at various moisture content levels.

Nitrogen-Treated Samples (lb/ac)	Moisture Content	Glass Transition Temperature
(lb/ac)	**(wet basis)**	**(°F)**
0	16	108.65 ± 0.83
	14	110.82 ± 1.32
	12	127.19 ± 4.62
90	18	109.69 ± 1.34
	16	111.11 ± 0.33
	14	112.62 ± 1.22
	12	122.68 ± 1.26
120	20	105.45 ± 0.44
	18	105.94 ± 0.85
	16	105.40 ± 1.12
	14	109.54 ± 0.20
	12	117.84 ± 1.53
150	20	104.67 ± 2.65
	18	107.23 ± 1.05
	16	111.12 ± 4.00
	14	117.81 ± 0.43
	12	125.50 ± 0.01
180	20	100.86 ± 0.83
	18	107.29 ± 0.60
	16	109.72 ± 0.36
	14	110.53 ± 3.16
	12	121.66 ± 1.93
210	20	104.86 ± 0.05
	18	106.66 ± 1.68
	16	109.55 ± 1.34
	14	111.95 ± 0.65
	12	122.04 ± 1.83

Table 2. Statistical analysis of the effects of sample and moisture content on the glass transition temperatures of nitrogen-treated rice samples.

Source	*P*-value
Sample	0.0066*
Moisture Content	<0.001*

* indicates statistical significance at $\alpha = 0.05$.

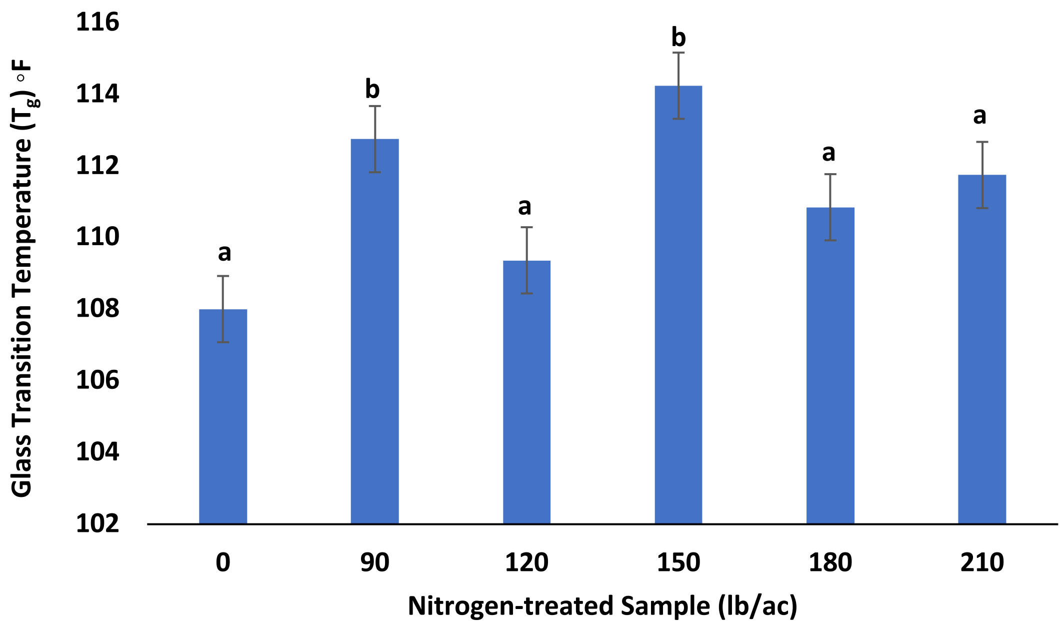

Fig. 1. Mean T_g of various Nitrogen-treated samples. Different letters indicate significant differences at α = 0.05.

Quality of Parboiled Instant White Rice Produced Using Novel Cooked Rice Drying Method vis-à-vis Traditional Approach

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Abstract

Traditional methods for producing parboiled instant rice are laborious and consume significant time and energy, particularly during the drying phase for the pre-cooked rice. This study investigated the application of 915 MHz microwave technology for drying parboiled cooked white rice. The research seeks to optimize microwave drying and assess its effects on various quality attributes of parboiled instant white rice, including color, rehydration ratio, volume increase ratio, bulk density, water activity, and texture. The experimental design involved using freshly harvested samples of long-grain rice cultivar CLL15, subjected to parboiling through hot water soaking and steaming, followed by cooking and drying treatments using microwave, step-wise hot air drying, and a combination of both referred to as microwave-assisted hot air. Microwave treatments were applied at a power level of 3 kW for 10 minutes, while stepwise hot air treatment employs air temperatures ranging from 446 to 392 °F at a fixed relative humidity of 20%. The product was conditioned to 12.5% moisture content (MC) post-treatment in a chamber set at 77 °F and 56% relative humidity. Control samples were exclusively dried to 12.5% MC at 77 °F and 56% relative humidity. Various analyses, including water activity, color change, texture, bulk density, and rehydration ratio, were conducted on the final product. Results indicated that drying methods significantly affected the percentage of moisture removed and the rehydration ratio of instantized parboiled white rice. Microwave-assisted hot air drying demonstrated the highest rehydration ratio (2.63), while microwave drying exhibited the lowest ratio (2.24). Bulk density and volume increase ratio were influenced by the type of drying method, with noticeable impacts on water activity and color attributed to drying air temperature. Both microwave and hot air-drying techniques significantly influenced textural parameters. These findings contribute to innovations with the potential to enhance the quality, processing efficiency, and sustainability of parboiled instant white rice production.

Introduction

Instant rice has emerged as a popular choice among consumers due to the convenience associated with its preparation. With its quick preparation time and perceived health benefits, including being gluten-free, it caters to the needs of busy individuals and health-conscious consumers alike (Cabral, 2024; Yadav et al., 2023). Parboiling, a hydrothermal rice processing method, involves soaking, steaming, and drying rice kernels before milling (Elbert et al., 2001, Bruce et al., 2018). While energy and labor-intensive, this pre-milling process is utilized to enhance the quality of rough rice and the nutrition of instant rice. During this process, the rough rice is soaked in excess water to a final moisture content (MC) of 25–35% (Bhattacharya, 1996). The rice is then steamed at 212–266 °F for 10 to 15 minutes and dried to approximately 12.5% MC on a wet basis. A complete parboiling process gelatinizes starch, causing the starch to expand and fill the fractures in the rice kernel, which leads to a harder kernel that resists breakage during milling (Derycke et al. 2005; Elbert et al. 2001).

In recent years, the application of 915 MHz microwave technology has shown promising results in improving rough rice drying speed and product quality. Microwave drying offers distinct advantages over conventional methods by directly targeting and heating moisture within the product, leading to more uniform drying and reduced processing durations. Short durations of microwave drying could minimize the exposure of rice to elevated temperatures, preserving its texture and nutritional content (Smith et al., 2021; Behera et al., 2018).

The quality of parboiled instant rice is affected by hydration kinetics during cooking and dehydration during drying. Traditional drying methods have often failed to produce parboiled instant rice with desirable characteristics such as proper bulk density and minimal breakage (Behera et al., 2018). Despite advancements in parboiling technology, challenges persist in achieving uniform drying, a crucial step in producing parboiled instant rice. Instantization of rice involves cooking the rice completely and then drying it back to 12.5% MC. Parboiled instant rice is cooked and then dried back to produce the parboiled instant brown or white rice. Making the parboiled instant rice ready to eat involves 6 min for rehydrating milled and 12 to 15 min for brown instant rice, respectively (Okeyo et al., 2023). It also has the advantage of producing plump kernels upon rehydration. Also, the nutritional quality of instant parboiled rice is expected to be higher than that of non-parboiled instant rice, which is consistent with the trend reported for non-instant rice (Bruce and Atungulu, 2018).

The prevailing drying methods utilized in the industry for producing parboiled instant rice include conventional stepwise

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oven drying techniques. Despite their widespread use, limited research has delved into understanding the effects of these drying techniques on the quality of parboiled instant rice and how these drying techniques could be augmented for improved process efficiency and product quality. This study aims to bridge this research gap by comprehensively analyzing the impact of microwave drying on moisture reduction in parboiled cooked rice. Additionally, the research aims to assess how this drying method influences various quality attributes of parboiled instant rice, such as color, rehydration ratio, volume increase ratio, bulk density, and texture.

Procedures

Sample Procurement

Long-grain rice cultivar CLL15 harvested at an MC of 15.2% wet basis was gathered from rice farms in Northeast Arkansas. The samples were cleaned using dockage equipment (XT4, Carter-Day, Minneapolis, Minn.), employing small-sized sieves to effectively separate shrunken, broken, scalped material, broken kernels, splits, and dust from the rice. An equilibrium MC chamber (set at 77 °F air temperature and 56% air relative humidity) was used to condition the rice. Moisture content readings were frequently taken using a moisture content meter (AM 5200, Perten Instruments, Hägersten, Sweden) to ensure the MC does not drop below the desired level. All moisture contents were reported on a wet basis. Rice was then stored in a walk-in cooler at 39 °F until the sample was used for experiments. When the rice was removed from the cooler, it was allowed to equilibrate for 24 hours in an airtight bag.

Experimental Design and Procedures

Rice samples weighing 2.20 lb each were soaked in water at 158 °F for 4 hours, then subjected to steam in an autoclave at 248 °F and 9.71 psi for 10 minutes to complete starch gelatinization. Following parboiling, the rice was dried in an equilibrium moisture content chamber set at 77 °F and 56% relative humidity until reaching 12.5% moisture content. The dried samples were dehulled using a dehuller (THU35A, Satake Engineering, Tokyo, Japan) and then milled using a laboratory mill (McGill Number 2, Rapsco, Brookshire, Texas) for 49 sec to achieve a surface lipid content of 0.4%. Head rice was separated from the broken rice using a grain sieve shaker (RX-29, RO-TAP, Mentor, Ohio). Around 0.55 lb of head white parboiled rice was cooked in excess water. Finally, the samples were independently dried. The drying methods applied to the cooked rice consisted of four treatments:

1. Control treatment: Drying the cooked rice to 12.5% moisture content (MC) at 77 °F and 56% relative humidity (RH).
2. Microwave treatment: Drying the cooked rice at a power level of 3 kW for 10 minutes, followed by conditioning with natural air drying at 77 °F and 56% RH to 12.5% MC.
3. Hot air drying: Utilizing a stepwise drying approach involving drying the cooked rice at temperatures ranging from 446 to 392 °F (20% RH) for a total duration of 10 minutes, followed by conditioning with natural air drying at 77 °F and 56% RH to 12.5% MC.
4. Hot air-assisted microwave drying: Microwave drying of the cooked rice at a power of 3 kW for 10 minutes, then transitioning to hot air drying with a stepwise approach, which included drying at temperatures ranging from 446 to 392 °F (20% RH) for 10 minutes, followed by conditioning with natural air drying at 77 °F and 56% RH to 12.5% MC.

For microwave treatment, cooked rice samples were placed in microwave-safe trays with polypropylene sides and a Teflon-coated fiberglass mesh bottom. The trays, measuring 40 cm in length, 30 cm in width, and 5 cm in height, were treated in batches for 10 minutes at a 3 kW power level. The stepwise drying consisted of drying cooked parboiled instant rice at a starting temperature of 446 ºF. After 3 minutes in the first step, the temperature gradually reduced to 428 ºF, and the rice was held for 3 minutes before the temperature reduced again (i.e., 446 ºF, 428 ºF, 410 ºF, and 392 ºF for a total of 12 min with 3 min at each temperature level). The airflow rate and air relative humidity were set at 11.2 ft/s and 20%, respectively. Samples that did not attain the required moisture content of 12.5% were further dried in the equilibrium moisture content chamber set at a temperature of 77 °F and 56% RH. Rehydration ratio, volume expansion ratio, color, bulk density, water activity, and texture were measured after parboiled rice instantization. These quality attributes were measured in three replicates following standard procedures at the University of Arkansas System Division of Agriculture's Rice Processing Program and with slight modifications where applicable: water activity (Owusu et al., 2023), rehydration ratio (Prasert and Suwannaporn, 2009), volume expansion ratio (Okeyo et al., 2017), color changes (Okeyo et al., 2017), bulk density (Onwuka, 2005, and Ohizua et al., 2017), texture profiles (Park, Kim, and Kim, 2001). The experimental factors and their settings are shown in Table 1.

Statistical Analyses

Statistical analyses were performed with JMP statistical software v. 17 pro (SAS Institute, Inc., Cary, N.C.). The statistical analyses aim to provide a comprehensive understanding of the effects of various drying treatments on the instant rice's quality parameters and textural properties. Analysis of variance (ANOVA) and descriptive statistics were used to assess the significance of differences and draw meaningful conclusions about the impact of drying methods on the final product. Assessment of variable importance was simulated. All tests were significant when $P < 0.05$.

Results and Discussion

An Analysis of Variance Approach

Table 2 shows the ANOVA table for all quality parameters due to differences in drying treatments. In the table, the "F Ratio" represents the ratio of variance between groups to variance within groups. Notably, the rehydration ratio, volume expansion ratio, bulk density, and water activity exhibited highly significant differences ($P < 0.0001$), as indicated by their extremely low P-values and notably high F ratios. This suggests that the drying treatments significantly impacted these parameters, affecting factors such as the rate of rehydration, the volume expansion upon reconstitution, the density of the dried product, and its water activity level.

Similarly, parameters like adhesiveness, cohesiveness, and gumminess also showed significant differences ($P < 0.05$), albeit to a lesser extent than hardness, springiness, chewiness, and resilience. These differences imply variations in the adhesive properties, internal cohesion, and gumminess of the parboiled instant rice due to differences in drying treatments.

Impacts of Treatments on Textural Properties of Parboiled Instant White Rice

Table 3 presents the mean and standard deviation values for various textural properties of rehydrated instant white rice resulting from different drying treatments. Notably, the "Hardness" parameter displays variations among the drying treatments, with the "Hot air" method yielding the highest hardness (36.9 lb), followed by the "Control" (34.5 lb) and "Industrial sample" (34.79 lb). The "Microwave" (30.19 lb) and "Microwave-assisted hot air" (32.58 lb) treatments produce rice with intermediate hardness values. The standard deviations indicate that the "Hot air" treatment had the least variability. In contrast, the "Adhesiveness" parameter shows significant differences, with the "Industrial sample" displaying markedly higher adhesiveness than the other treatments. The "Microwave-assisted hot air" (-7.84 lb sec) and "Control" (-2.78 lb sec) treatments exhibit relatively lower adhesiveness, while "Microwave" (-4.69 lb sec) and "Hot air" (-3.32 lb sec) methods fall in between. These findings suggest that drying methods notably impact the instant white rice hardness and adhesiveness, which are crucial textural attributes in the context of rice-based food products.

Figure 1 shows a statistical description that offers a comprehensive overview of the moisture content variations throughout each treatment's cooked rice drying process and the consistency of the different drying methods employed. The data includes initial moisture content, standard deviation (SD) values, moisture content after microwave treatment and hot air treatment, and final moisture content after conditioning in the equilibrium moisture content (EMC) chamber for the four distinct drying methods used. The initial moisture content ranges from 66.99% to 71.04% wet basis (w.b). Standard deviation values provide insights into the variability of moisture content measurements during each treatment. In the Microwave treatment, the moisture content after microwave application is 55.88% w.b., with a relatively low SD value of 0.58. The stepwise hot air treatment results in moisture content (after hot air drying) of 41.7% w.b. For the Microwave-assisted hot air treatment, the moisture content after the microwave is 55.42% w.b, then the moisture content after hot air drying is 11.58% w.b. The final moisture content after EMC varies across treatments, with the Microwave-assisted hot air method exhibiting the lowest value at 9.9% w.b.

Microwave-assisted hot air treatment is the most effective in reducing moisture, resulting in the lowest final moisture content of 9.9% w.b. with comparatively less variability. Additionally, the microwave treatment demonstrates effectiveness with a final moisture content of 12.3% w.b. and a minimal standard deviation. Conversely, the step-wise hot air treatment displays higher variability and achieves a final moisture content of 12.06% w.b. These results indicate that combining microwave and hot air techniques enhances drying performance, making it a preferable option for moisture reduction.

Figure 2 data shows the impacts of treatments on color changes, measured by Delta E values, along with the associated standard deviations. The Delta E values, indicative of color changes, are reported as 8.97, 8.70, 8.92, and 14.16 units for the control, step-wise hot air, microwave, and hot air-assisted microwave treatments, respectively. Notably, the hot air-assisted microwave method shows the highest Delta E, suggesting a more pronounced color change in the dried material. Additionally, standard deviations are provided for each treatment, indicating the variability in color changes. The control and step-wise hot air treatments exhibit relatively lower standard deviations (0.70 and 0.63, respectively), suggesting more consistent color changes. In contrast, the hot air-assisted microwave treatment shows a higher standard deviation (1.17), indicating greater variability in color alterations. This data provides insights into the effectiveness and consistency of different cooked rice drying methods in preserving the color of parboiled instant white rice.

The rehydration ratio represents the ability of the dried product to regain moisture when rehydrated. “Hot air assisted Microwave” had the highest at 2.63, followed by “Hot air” with a rehydration ratio of 2.46, while “Microwave” had the lowest rehydration ratio at 2.24 (Fig. 3). The control had a rehydration ratio of 2.27. These results suggest that a combination of hot air and microwave drying might be the most effective method for achieving higher rehydration.

The volume increase ratio measures how much the product expands when rehydrated. "Microwave treatment" resulted in the highest volume increase ratio of 1.1077, indicating that it led to the most significant expansion upon rehydration. "Hot air assisted Microwave" had a volume increase ratio of 1.0832, "Hot air" had a ratio of 1.0695, and the control had a ratio of 1.0527 (Fig. 4). These findings suggest that the "Microwave" treatment resulted in the greatest expansion, which may be desirable for applications where increased volume is important.

Bulk density measures the density of the dried product. "Hot air assisted Microwave Treatment" had the lowest bulk density at 0.032 lb/oz, making it less dense and likely lighter than the other treatments. "Hot air" had a bulk density of 0.033 lb/oz, the control had a bulk density of 0.035 lb/oz, and "Microwave" also had a bulk density of 0.035 lb/oz (Fig. 5). Lower bulk density can be advantageous when storage space is abundant or when storage costs are based on area rather than volume. Lower bulk density products are often easier to handle, which can streamline the process of loading and unloading. Lower bulk density products are less prone to compaction under their weight, which can help maintain product integrity and quality over time. Higher bulk density often requires less packaging material per unit weight, potentially saving packaging costs. Where packaging materials contribute significantly to overall expenses, the higher bulk density become advantageous.

Water activity measures the product's moisture available for microbial and chemical interactions. "Hot air-assisted Microwave" treated samples had the lowest water activity at 0.553, making it the driest. "Hot air" had a water activity of 0.558, "Microwave" had a water activity of 0.564, and the control had a water activity of 0.565 (Fig. 6). The lower water activity in "Hot air-assisted Microwave" indicates that it is drier, which can contribute to increased shelf life by reducing the likelihood of microbial growth.

Statistical analysis of quality attributes of parboiled instant white rice reveals significant differences resulting from applying different cooked rice drying approaches. The "Hot air assisted Microwave " method emerges as the most effective, demonstrating superior outcomes in moisture content reduction, favorable textural attributes, and efficient rehydration. The products processed using the "Microwave-assisted hot air" exhibited desirable textural properties such as lower hardness and adhesiveness. The "Hot air assisted Microwave " treatment demonstrated a higher rehydration ratio. The adoption of the "Hot air assisted Microwave" drying method for instant white rice production is recommended for industrial applications.

Practical Applications

This study investigated, identified, and recommended a suitable approach for drying cooked rice to produce parboiled instant white rice. The proposed approach ensures high-quality products. The innovative approaches recommended allow for the creation of unique rice products to meet diverse consumer preferences.

Acknowledgments

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Table 1. Experimental factors and settings showing drying treatments for parboiled instant white rice drying.

Factors	Levels	Total number of experiments
Drying Treatment	1. Control (77 °F, 56% RH) 2. Microwave (3 kW, 10 min) 3. Hot air (Stepwise High: 446 °F to 392 °F, 20% RH) 4. Hot air-assisted microwave (Microwave–3 kW, 10 min and Hot air–Stepwise High: 446 °F to 392 °F, 20% RH)	12
Replication	3	

Table 2. Summary of the degrees of freedom (DF), sum of squares, F ratio, and *P*-values (Prob > F) from the analysis of variance for all quality parameters due to differences in drying treatments.

Source	DF	Sum of Squares	F Ratio	Prob > F[a]
Rehydration ratio	4	0.34989333	98.4690	<0.0001*
Volume expansion ratio	4	0.23322993	721.7091	<0.0001*
Bulk Density (lb/oz)	4	0.01049807	134.7208	<0.0001*
Water activity	4	0.00236409	23.1621	0.0002*
Color	3	63.294470	50.0699	0.0001*
Hardness (lb)	4	15932204	1.0758	0.4289
Adhesiveness (lb/sec)	4	650.31117	6.0953	0.0149*
Springiness	4	12.199358	0.9945	0.4633
Cohesiveness	4	0.07549373	12.0230	0.0018*
Resilience	4	0.16759533	9.3119	0.0042*

[a] *P*-value < 0.05 depicts the statistically significant difference in drying treatments.

Table 3. Mean and standard deviation of textual properties of rehydrated instant rice as produced using different drying treatments (letters in the same row, not connected by the same letter are significantly different).

Source	Control	Microwave	Hot air	Microwave assisted hot air	Industrial sample
Hardness (lb)	34.56	30.18	36.90	32.58	34.79
	±4.95 a†	±4.64 a	±4.03 a	±1.64 a	±3.37 a
Adhesiveness (lb/sec)	-2.78	-4.69	-3.32	-7.84	-20.52
	±0.32 a	±3.19 a	±1.22 a	±1.43 a	±4.66 b
Springiness	3.05	0.71	1.12	0.67	0.82
	±3.83 a	±0.13 a	±0.67 a	±0.02 a	±0.07 a
Cohesiveness	0.79	0.65	0.70	0.64	0.58
	±0.01 a	±0.04 bc	±0.09 b	±0.03 bc	±0.04 c
Resilience	0.82	0.63	0.69	0.56	0.52
	±0.05 a	±0.06 bc	±0.12 b	±0.03 c	±0.07 c

† Means followed by the same letter in the same column are not significantly different at *P* = 0.05.

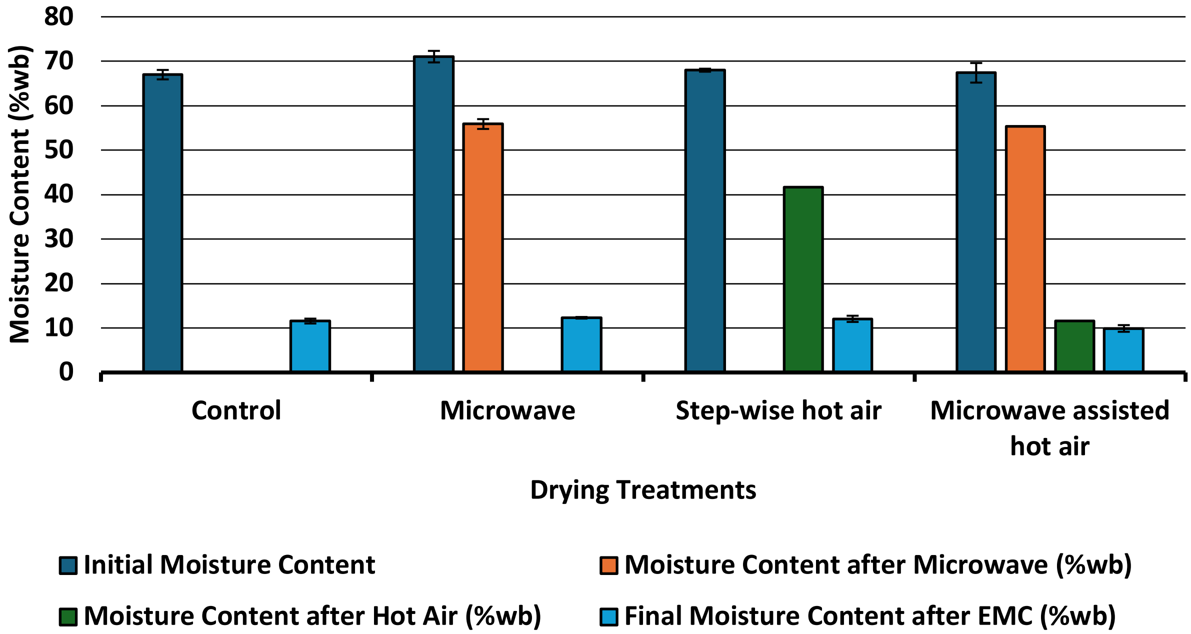

Fig. 1. Moisture content removal by using different drying treatments at different drying stages, including initial moisture content, moisture content after microwave treatment, moisture content after hot air treatment, and final moisture content after equilibrium moisture content (EMC).

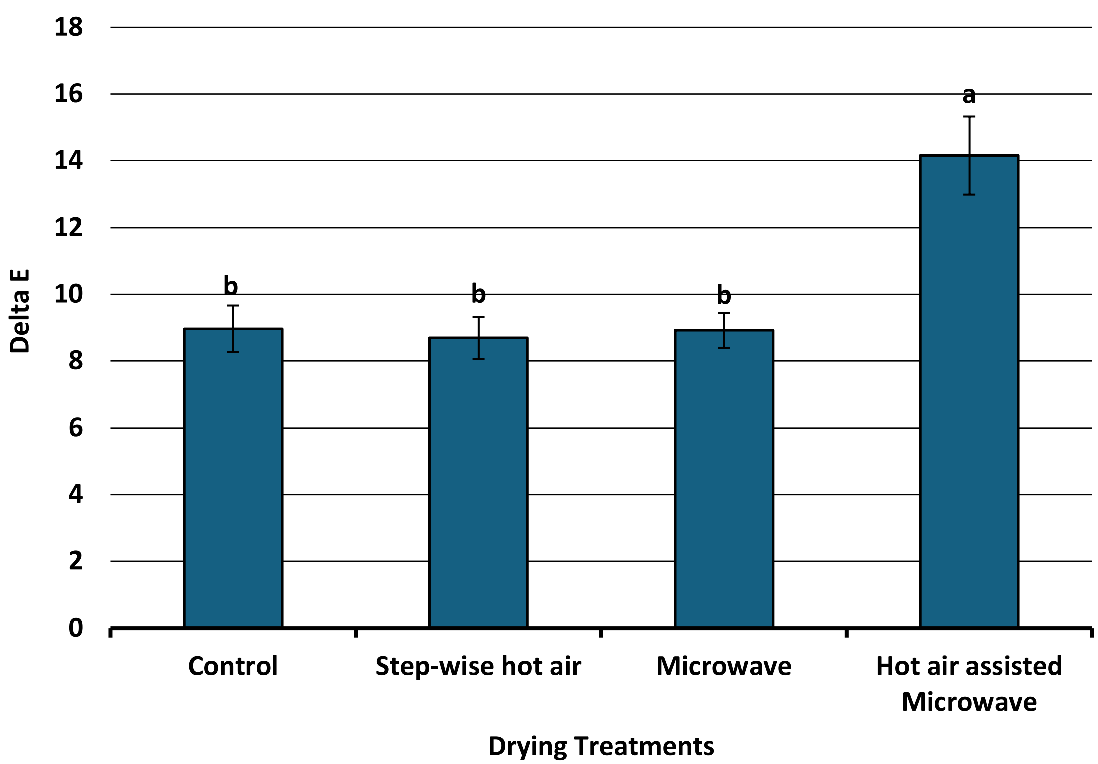

Fig. 2. Bar graphs for drying treatment on delta E (bars not connected by the same letter are significantly different).

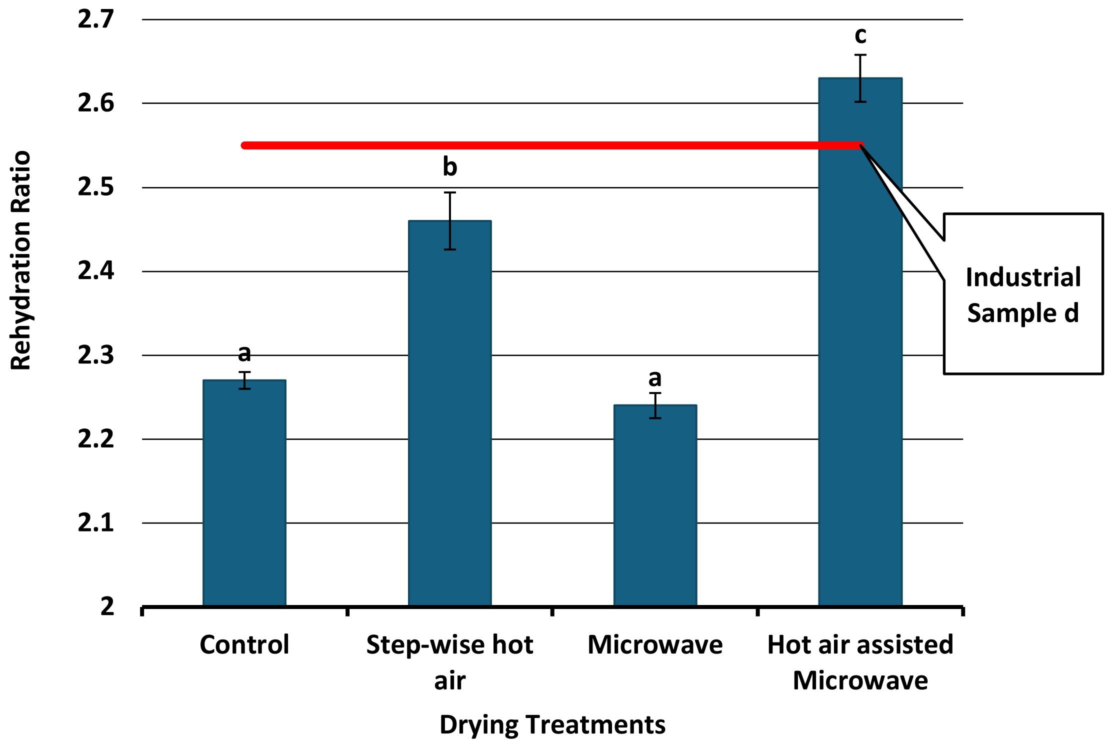

Fig. 3. Bar graphs for drying treatment on rehydration ratio (values not connected by the same letter are significantly different).

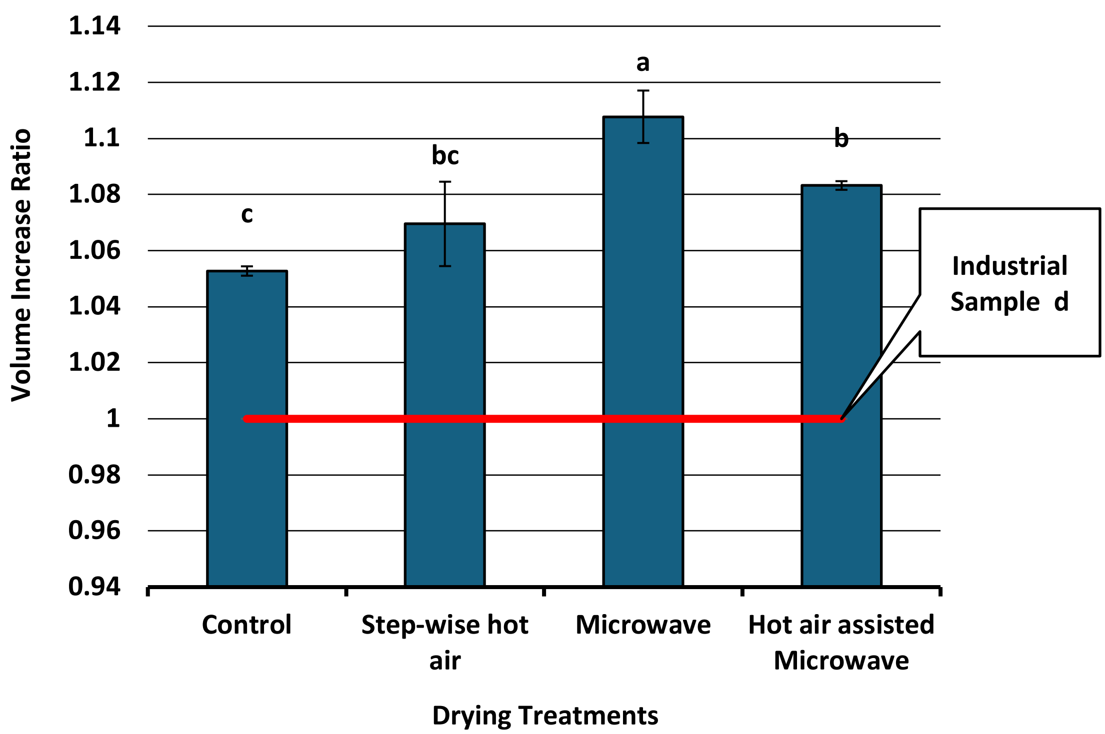

Fig. 4. Bar graphs for drying treatment on volume increase ratio (values not connected by the same letter are significantly different).

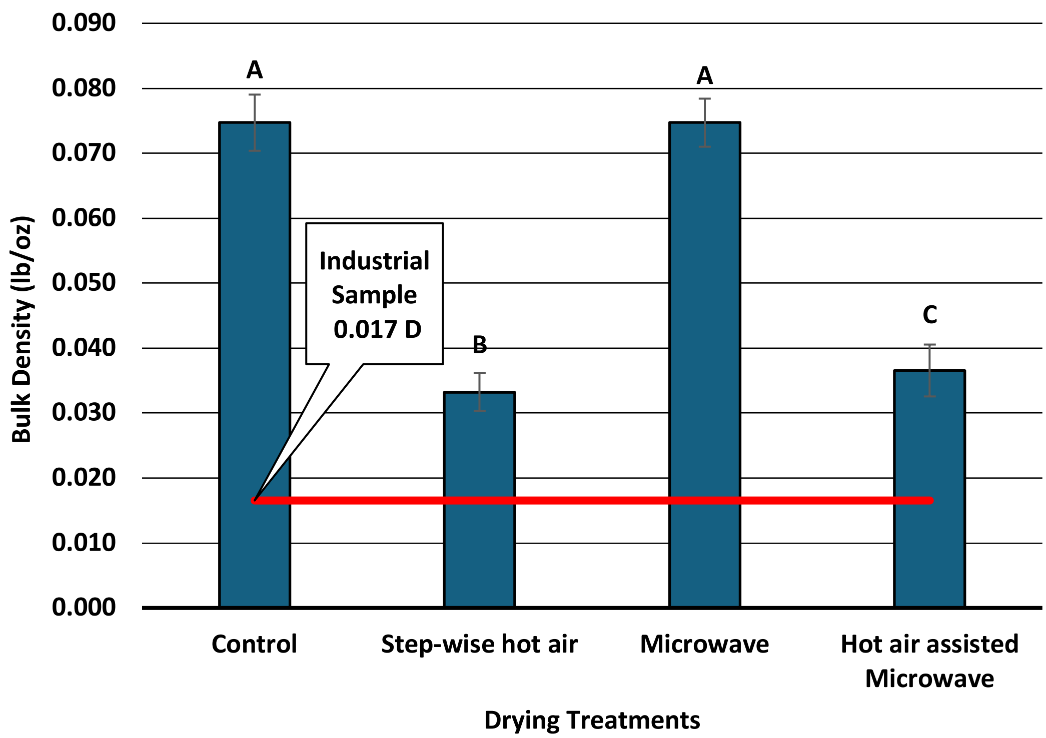

Fig. 5. Bar graphs for drying treatment on bulk density lb/oz (values not connected by the same letter are significantly different).

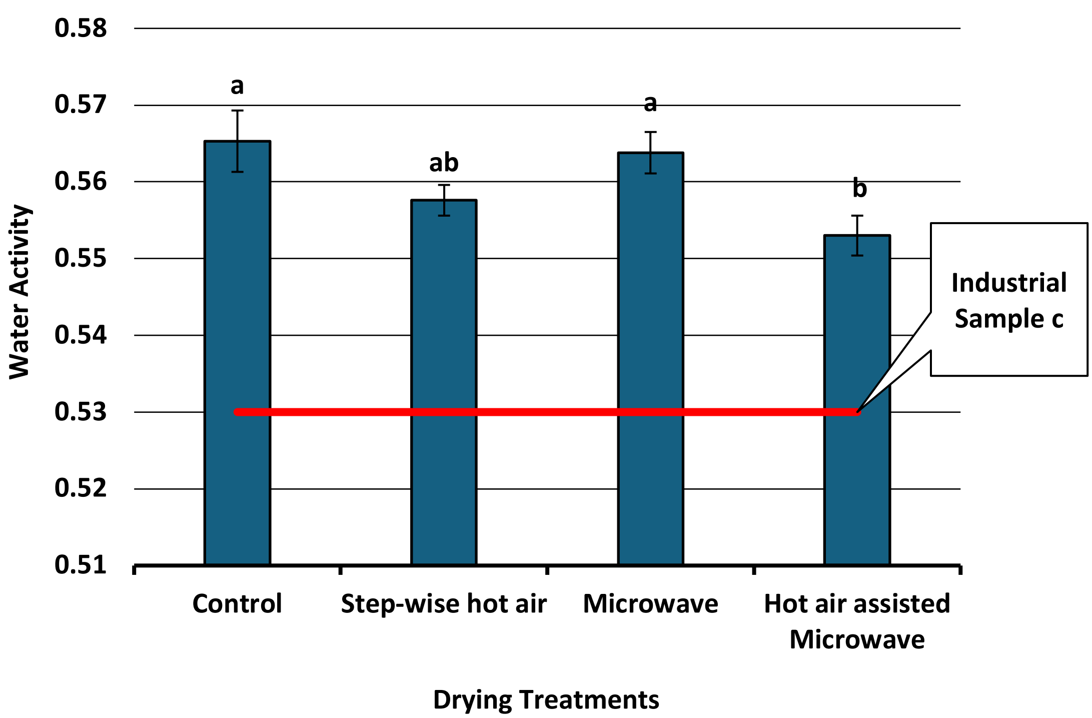

Fig. 6. Bar graphs for drying treatment on water activity (values not connected by the same letter are significantly different).

Microwave Heating's Potential to Replace Traditional Tempering in Industrial Rice Drying

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Abstract

The market value of rice heavily relies on its milling yield, particularly the head rice yield, which is greatly influenced by the drying process. In the United States, rice is typically dried post-harvest using high-temperature air drying in one or more passes. Following each pass, the rice is tempered overnight, or longer, to reduce moisture and temperature gradients developed during drying, minimizing breakage during processing. However, multiple drying passes involving transferring rice between dryer and bins pose risks of breakage and incur costs and time for processors. Microwave heating, due to its volumetric heating capacity, has shown promise in reducing moisture and temperature gradients in rice, especially after a high-temperature drying pass. This study hypothesized that microwave heating could decrease tempering duration or potentially eliminate the need for tempering altogether. A long-grain rice cultivar at 22.5% moisture content (wet basis) was dried in two passes using a parameter generation and control unit set at 113 °F (45 °C) and 20% RH for 20 minutes per pass to simulate commercial high-temperature crossflow air driers. After each pass, the rice underwent tempering using 915 MHz microwave heating for one minute at various power levels (1, 2, 3, 4, and 5 kW) with corresponding specific energy levels (120, 240, 360, 480, and 600 kJ/kg). A comparative control tempering method involved sealing the rice in a glass jar and maintaining it at 140 °F (60 °C) for four hours. Head rice yield was 50.5% and 50.2% for samples tempered using 1- and 2-kW microwave power for one minute, respectively, compared to 51.3% for the control sample. Higher power levels (3, 4, and 5 kW) resulted in significant reductions in head rice yield compared to the control. Overall, considering moisture removal and milling yields, tempering with 2 kW for one minute using microwave heating proved superior to the control method. Microwave heating has the potential to eliminate or reduce the need for traditional tempering in industrial rice drying, thereby cutting processing time. Despite not achieving complete drying after two passes to the storage moisture level of 12.5%, the advantages of microwave tempering were evident and expected to persist beyond two passes. Future studies could explore extending microwave tempering beyond two drying passes and investigate how different cultivars respond to this new tempering approach.

Introduction

In the U.S., most rice is taken after harvest to the processors, where it is dried using a high-temperature crossflow air dryer. Generally, more than one pass of drying is needed to reach the safe storage or milling moisture level of 12–13% wet basis. Each drying pass has a subsequent tempering step to reduce moisture content gradient within each rice kernel as well as in bulk. This is commonly experienced in high-temperature drying as the rice closer to the hot air inlet gets heated more and, therefore, a gradient is developed. The tempering step allows moisture to uniformly migrate in rice kernels. Reducing moisture content gradient is important to avoid rice fissuring that causes head rice yield reductions during drying.

Tempering is initiated when the rice, after the drying pass, is transferred to a tempering bin where the rice is kept for 12–24 hours and maybe more before the next drying pass. This cycle continues until rice reaches 12–13% moisture level. Typically, two drying passes are needed to bring down rice moisture content (MC) from 18–20% to 12–13%. Sometimes, a third pass is needed due to high rice harvest moisture content, excessive dockage in rice, or due to high humidity conditions. The more drying passes and handling means more processing cost and time as well as higher reduction in milling yield. Efficient tempering of rice not only reduces the overall processing time and cost but also enhances moisture removal during the following drying pass. The current tempering process utilized is too long and increases operation costs.

Tempering rice after a drying pass using microwaves is a novel approach that can save time due to its volumetric heating capacity. This volumetric heating characteristic can lead to a rapid reduction of moisture gradient in the heated rice kernels. That could eventually enable continuous drying of rice without the need to temper rice overnight in a tempering bin.

Microwave technology has been successfully tested in the laboratory for drying rough rice without significant reduction in the milling yield (Atungulu et al., 2016; Olatunde et al., 2017; Boreddy et al., 2023). The footprint required to scale up microwave technology for drying is a challenge. However, the use of microwave heating to temper rice after a drying pass can be comparatively easier to adapt for a processing plant. This study was set to prove this concept of using microwave heating to temper rice and reduce overall drying time without compromising milling yields.

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There has never been any research done to understand the impact of microwave heating to temper rice. The objective of this study was to investigate the impact of tempering rice with different microwave energy levels in a 2-pass high-temperature drying process on rice milling yield.

Procedures

Sample Procurement

Long-grain rice cultivar CLL16 (harvested at 22.5% wet basis) was gathered from a rice farm in Northeast Arkansas. The samples were cleaned using dockage equipment (XT4, Carter-Day, Minneapolis, Minn., U.S.A). Rice was then stored in a walk-in cooler at 39 °F until the sample was used for experiments. When the rice was removed, it was allowed to equilibrate in room conditions (70–75 °F) for 24 hours in an airtight bag.

Experimental Design

The study investigated five levels of microwave tempering treatment, encompassing power settings of 1 kW, 2 kW, 3 kW, 4 kW, and 5 kW, with corresponding specific energy levels of 120, 240, 360, 480, and 600 kJ/kg. Each tempering treatment at these power levels lasted for 1 minute after each of the two drying passes. As a benchmark for comparison, tempering using a hot air oven at 140 °F for 4 hours was employed as the control method. The response variables included the percentage point moisture removed (PPMR), milled rice yield (MRY), and head rice yield (HRY) of the dried rice. Two replications were conducted to ensure accuracy and minimize potential biases.

Experimental Procedures

For each experiment, samples of 500-g rough rice were used. High-temperature air drying of the rice was carried out in a controlled environment chamber (ESPEC, Hudsonville, Mich.). The process involved subjecting the rice to a two-pass drying procedure, with a temperature of 113 °F (45 °C) and a relative humidity of 20% for a duration of 20 minutes in each pass. After each drying pass, rice was treated with microwaves (kept in microwave-safe trays with a layer of 0.5 in.) for 1 min at different power levels (1, 2, 3, 4, and 5 kW). The control samples were tempered (kept in sealed glass jars) using a hot air oven set at 140 °F for 4 hours. After tempering, rice was immediately dried for a second pass and tempered again. After the second tempering, the rice subsample was allowed to cool and then taken to measure the moisture content, while the remaining rice was kept in an environmentally controlled chamber set at an air temperature of 75 °F and 56% relative humidity to allow the moisture content to reduce to 12.5% wet basis. The rice dried to 12.5% was processed to get the milling yields.

Moisture Content Determination

The MC of the initial sample and after each experiment (end of tempering period) was determined by using the AACC standard method 44-15.02. In this method, we used 15-g samples in duplicates that were kept in a convection oven at 130 °C for 24 hours, followed by cooling in a desiccator for 30 minutes. Finally, the moisture content on a wet basis was determined using the difference in the initial and final weights, as mentioned in Eq. (1) below. All reported MCs are on a wet basis. Eq. (2) was used to calculate the percentage points of moisture removed (PPMR).

$$MC\ (\%\ wet\ basis) = \frac{w_2 - w_3}{w_2 - w_1} * 100 \qquad \text{Eq. (1)}$$

$$PPMR\ (\%\ wet\ basis) = M_B - M_A \qquad \text{Eq. (2)}$$

where w_1 is the weight of the sample pan (g), w_2 is the weight of the sample pan and wet rice (g), w_3 is the weight of the sample pan and dried rice (g), M_A is the moisture content of rice after tempering for the second drying pass (% wet basis), and M_B is the moisture content of rice at the start of the first drying pass (% wet basis).

Milling Yield Determination

Rough rice samples weighing 150 g and dried to 12.5% MC were dehulled using a laboratory huller (Satake Rice Machine, Satake Engineering Co. Ltd., Tokyo, Japan) and then milled for 38 seconds using a laboratory mill (McGill #2 Rice Mill, RAPSCO, Brookshire, Texas), after which the milled samples were aspirated for 30 s using a seed blower (South Dakota Seed Blower, Seedboro, Chicago, Ill.). In a separate set of experiments, the milling duration of 38 sec was determined by regressing milling duration against rice surface lipid content of 0.4%. The broken kernels were separated from the milled rice using a double tray sizing machine (Grainman Machinery Manufacturing Corp., Miami, Fla.) to get the head rice. Milled rice yield (MRY) and head rice yield (HRY) were calculated using equation 3 and 4, respectively.

$$Milled\ rice\ yield\ (MRY, \%) = \frac{Mass\ of\ milled\ rice}{Mass\ of\ rough\ rice} \times 100 \qquad \text{Eq. (3)}$$

$$Head\ rice\ yield\ (HRY, \%) = \frac{Mass\ of\ head\ rice}{Mass\ of\ rough\ rice} \times 100 \qquad \text{Eq. (4)}$$

Statistical Analyses

Analysis of variance and Student's *t*-test test were performed using statistical software (JMP Pro 17, SAS Institute, Cary, N.C.). The statistical significance of tempering treatments on the response variables (PPMR, MRY and HRY) and differences between mean values of the responses at each level of tempering treatment were determined. The level of significance was set at 5% for mean comparison.

Results and Discussion

Effect of Drying Process Using Different Tempering Treatments on Percentage Points Moisture Removed (PPMR)

Table 1 below shows that different tempering treatments led to significant differences in the PPMR measured just after the end of the second tempering step (*P*-value of 0.0002). Looking at

Table 2, the minimum PPMR of 5.7% wet basis was observed when microwave tempering treatment of 1 kW was used for 1 min after each drying pass. The maximum PPMR value of 8.8% wet basis was observed when 5 kW microwave power was used for 1 min. The control treatment was similar to tempering treatments of 2 kW and 3 kW in 1 min. The reason for higher PPMR with an increase in microwave power level is the higher energy being transferred to the rice that causes more removal of moisture. The point to be noted is that the control tempering treatment was for 4 hours, whereas microwave tempering treatments were for only 1 minute.

Effect of Drying Process Using Different Tempering Treatments on Milling Yield of Rice

Table 1 below shows that the tempering treatments did significantly impact both MRY and HRY (*P*-value of <0.0001). The higher the microwave power level used for tempering treatment, the lower the milling yield (Table 2). MRY ranged from 49.3% to 66.7% whereas HRY ranged from 4.5% to 51.3% (Table 2). The maximum MRY (66.7%) and HRY (51.3%) were achieved when using the control tempering treatment. However, the control was not different from the tempering treatment of 2 kW for 1 minute. The MRY and HRY achieved using 2 kW and 1 min tempering treatment was 66.6% and 50.2%, respectively.

Practical Applications

Compared to the control tempering treatment, microwave heating, especially at 1 kW for 1 min and 2 kW for 1 min, was comparable in terms of moisture removed and milling yields. The main purpose of this research was to use and apply science-based knowledge to give the industry a broad understanding of how the milling yields can vary if short-duration microwave heating is used to temper rice after a drying pass instead of a regular tempering treatment. If successfully implemented, the use of microwave heating to accelerate the tempering of rice could save a significant amount of time required to dry rice. The new approach could also help achieve a continuous 2-pass high-temperature drying system. More work needs to be done to exhaustively understand changes resulting in rice quality parameters.

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Table 1. *P*-value based on the analysis of variance to depict the statistical significance of the factors across the responses (α = 0.05).

	Response variables[†]		
Factors	PPMR (% wb)	MRY (%)	HRY (%)
Tempering treatment	0.0002	<0.0001	<0.0001
Replication	0.0846	0.9183	0.8773

[†] *P*-value <0.05 depicts the statistical significance of the factor on the response variable.

Table 2. The mean value of response variables is categorized into various levels of each factor studied.

Factor	Levels	Response variables†		
		PPMR	MRY	HRY
		(% wb)	(%)	(%)
Tempering treatment	1 kW-1 min	5.7 e	66.2 a	50.5 a
	2 kW-1 min	6.3 d	66.6 a	50.2 a
	3 kW-1 min	7.0 c	61.8 b	33.2 b
	4 kW-1 min	8.2 b	57.0 c	15.6 c
	5 kW-1 min	8.8 a	49.3 d	4.5 d
	Control	6.7 cd	66.7 a	51.3 a

† Means followed by the same letter in the same column are not significantly different at $P = 0.05$.

Segregating Rice Varieties for Milling and Marketing: The Potential Impact on Producer Returns and Export Market Opportunities in Arkansas

L.L. Nalley,[1] A. Durand-Morat,[1] G. Atungulu,[2] K. Luthra,[2] and R. January[2]

Abstract

Comingling of rice has the advantage of lower production costs through a reduction of time, effort, and money, which comes with identity preservation (IP). However, given the physicochemical differences between the types of long-grain rice in Arkansas (hybrids and pure-lines) and even differences within rice types, comingling can lead to suboptimal milling results, specifically with regard to broken percentage. As Arkansas rice producers battle for export markets, rice quality is a key area of concern. The goal of this study is to conduct an economic analysis to estimate the value of various levels of rice segregation for milling quality in Arkansas. Freshly harvested rice samples were procured from farms in Northeast Arkansas and handled and processed following the procedures developed by the University of Arkansas System Division of Agriculture's Rice Processing Program (UARPP). The procured rice varieties were commingled into five samples based on Arkansas harvested acreage by variety in 2022: (1) pure-lines and hybrids, (2) purelines and hybrids except RTFP 753, (3) hybrids, (4) hybrids except RTFP 753, and (5) pure-lines. The samples were processed to estimate their respective milled rice yield (MRY) and head rice yield (HRY). The results show that sample (5) has the lowest and sample (4) has the highest broken percentage, respectively, and that there are significant differences in the broken percentage across all samples except between samples (1) and (3). Regarding differences in producer prices across samples, sample (5) yields the highest and sample (4) the lowest producer price, respectively, based on MRY and HRY. However, only sample (4) yields a significantly lower producer price than the other samples, with no significant differences between samples (1), (2), and (3). These results highlight that while commingling significantly affects HRY and broken percentage, these differences do not translate into significant differences in producer prices except for a discount for S4.

Introduction

The U.S. has lost market share in the global rice market over the last two decades. While total rice exports have almost doubled since 2000, the U.S. export share decreased from 14% of global rice exports in 2000 to 8% in 2018–2020 (USDA, 2023a). All the losses are concentrated in the long-grain segment of the market, which is the main rice type produced in Arkansas and the mid-South of the U.S. In the last two decades, U.S. long-grain rice has lost market share in Mexico, the largest market for U.S. long-grain exports, Central America, and the Caribbean (USDA, 2023b).

Rice quality is anecdotally cited as one of the reasons for the loss of export competitiveness of U.S. long-grain rice. However, there is no single definition of quality rice. Instead, the literature clearly shows that consumer preferences for rice are heterogeneous, and the value attached to specific attributes varies geographically and by the socio-cultural context in which rice consumption is embedded (Calingacion et al., 2014). There is evidence of consumers' growing awareness of rice quality, mainly from Asia and Africa (Saha et al., 2021; Cuevas et al., 2016; Diagne et al., 2017; Rutsaert, Demont, and Verbeke, 2013; Tomlins et al., 2005), but also from the Western hemisphere (Richardson et al., 2022; Phillips et al., 2024). One of the main physical attributes acknowledged in the literature is the presence of broken rice in milled rice, also known as the broken percentage. The broken percentage is the percentage of broken kernels in milled rice by weight. In the U.S., broken rice (brokens) is defined as rice kernels that are less than 75% of the length of the whole milled rice kernels (USDA, 2009).

Mixing/comingling of rice has the advantage of lowering production costs (e.g., reduction of time and effort versus identity preservation, IP). However, given the physicochemical differences between the different types of long-grain rice grown in Arkansas (e.g., hybrids and pure-lines), mixing can lead to suboptimal milling results. As Arkansas rice battles for domestic and export markets, one of the areas of concern is rice quality. The goal of this study is to estimate the impact of rice segregation on milling yield and the value of milled rice produced in Arkansas.

Procedures

Freshly harvested rice samples were procured from farms in Northeast and Southeast Arkansas and handled following the procedures developed by the University of Arkansas System Division of Agriculture's Rice Processing Program (UARPP). The samples were transported in climate-controlled conditions, cleaned thoroughly using a lab-scale rice cleaner (XT4, Carter-Day, Minneapolis, Minn.), packed in airtight containers sealed with plastic wrap, and stored at 4 °C. Before being used for experiments, the

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samples were taken from the cold room and left to adjust to room conditions in airtight containers for 24 hours. After this equilibration period, the samples were dried in a controlled environment chamber (Model No. AA-600-PF, R.S.P. Industries Inc., Brooklyn, N.Y.) set to 25 °C and 56% relative humidity until the rice moisture content reached 12.5% (±0.5%).

The rice varieties were commingled into five samples according to the share of each variety's harvested area in Arkansas in 2022 (Table 1). The five samples consist of:

1. Sample 1 (S1): A sample of rice varieties (hybrids and pure-lines) planted in Arkansas in 2022 was comingled using their harvested weighted average.
2. Sample 2 (S2): Same as S1 but removing RTFP753.
3. Sample 3 (S3): A sample of hybrid rice planted in Arkansas in 2022 comingled using their harvested weighted average.
4. Sample 4 (S4): Same as S3 but removing RTFP753.
5. Sample 5 (S5): A sample of pure-line rice varieties planted in Arkansas in 2022 comingled using their harvested weighted average.

Samples of 150 grams of rough rice at 12.5% (±0.5%) moisture content (wet basis) were dehulled using a laboratory sheller (THU 35A, Satake Engineering Co., Japan) with a clearance of 0.48 mm between the rubber rollers. Brown rice was milled (McGill No. 2. RAPSCO, Brookshire, Texas) for a set duration for each sample type. Head rice and rice fractions were separated with the help of a shaker separator (Grainman, Model: 61-117-01, Grainman Machinery Manufacturing Corp., Miami, Fla.). The rice samples were analyzed using a Vibe QM3 Rice Analyzer (Vibe Imaging Analytics, USA) to ascertain their physical characteristics, including broken and chalk percentages. For each of the five samples, we drew 35 subsamples with repetition, assessed the quality of each subsample, and estimated the distribution of each quality attribute for each sample.

Results and Discussion

Samples 1, 3, and 5 were commingled before and after drying, and the statistical analysis shows that the timing (pre or post-drying) of commingling has no impact on the broken percentage of the samples. Therefore, we focus the discussion below on the samples commingled after drying.

The percentage of broken rice in the five samples varied from a low of 18.7% for S5 to a high of 25.1% for S4 (Fig. 1). There is a significant difference at the 1% level between 6 of the 9 sample pairs (samples 1 and 2, 1 and 4, 1 and 5, 2 and 5, 3 and 5, and 4 and 5), and at the 10% level between 2 sample pairs (samples 2 and 3, and 2 and 4). The mean broken percentage between samples 1 and 3 is not significantly different from zero (Fig. 2). The results above show that commingling varieties have a significant impact on the broken percentage, one of the key attributes of rice quality.

To assess whether these broken percentages translate into differences in economic value, we estimated the producer price for each sample following the Chicago Board of Trade milling yield premium and discount fee schedule for the rough rice futures contract (CME, 2023). The 2022 loan rate was $11.08 per hundredweight (cwt) for head rice and $6.35/cwt for broken rice (USDA, 2022). The producer price varies from a high of $14.03/cwt for S5 to a low of $13.91/cwt for S4. Looking at the differences in producer prices between samples, we found that the producer price for S4 is significantly lower than that for S1, S3, and S4 at the 1% level and that of S2 at the 10% level. The producer prices of S1, S2, S3, and S5 are all statistically the same. This finding highlights that the U.S. pricing system is not sensitive to the broken percentage, as only 4 of the 9 statistically significant differences across samples (Fig. 2) result in significant differences in producer prices (Fig. 3).

Finally, Table 1 shows the mean milling quality for each of the five samples, the value of production at the farm level, and the value of sales. The production value varies from a low of $1174 million for S4 to $1180 million for S3 and S5, a 0.50% difference. The sales value varies from a low of $1361 million for S4 to a high of $1375 million for S3 and S5, a 1.03% difference.

Practical Applications

Rice quality matters and is expected to become more important as the U.S. competes for new and existing markets. We expect identity preservation (IP) to add significant value to the industry. Rice producers may already benefit if they deliver each variety in different lots. The question is whether the benefits of IP are large enough to offset the increased cost of IP.

Our preliminary results suggest that, from the point of view of broken rice, IP has little incentive as the current pricing system is not very sensitive to differences in broken percentage. Pricing is one way the industry can advance quality standards, and our results suggest that the current pricing system does not incentivize farmers to produce higher quality (lower broken percentage) rice.

This study has several limitations, among which we highlight two. First, this study focused only on broken percentage, but the economic value is also affected by many other attributes (e.g., chalk percentage, length and width, texture, aroma, stickiness) not considered in this study. Second, by assuming a producer price equal to the reference price, we ignore any endogenous effect of rice quality on the marketing year average price (MYAP). Quality issues have made exports of U.S. rice more challenging in the last several years and potentially affected (decreased) the MYAP. Ignoring this endogenous effect of quality on MYAP makes our findings about the economic impact of segregating rice varieties for milling and marketing more conservative.

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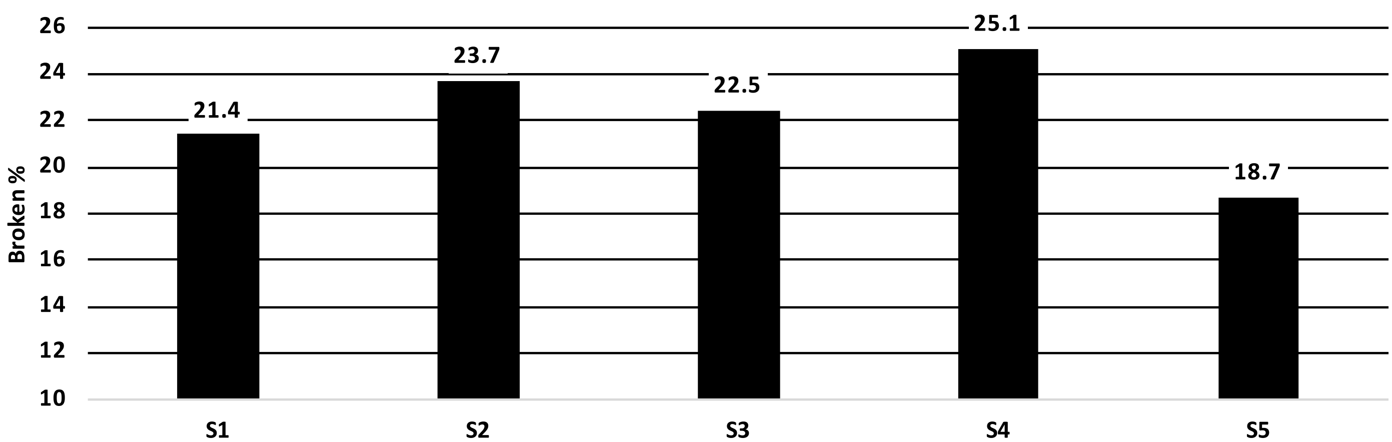

Fig. 1. Average broken percentage across the five rice samples used in this study (S1: a sample of rice varieties (both hybrids and pure-lines) planted in Arkansas in 2022 mixed using their harvested weighted average; S2: same as S1 but removing RTFP753; S3: a sample of hybrid rice planted in Arkansas in 2022 mixed using their harvested weighted average; S4: same as S3 but removing RTFP753; S5: a sample of pure-line rice varieties planted in Arkansas in 2022 mixed using their harvested weighted average).

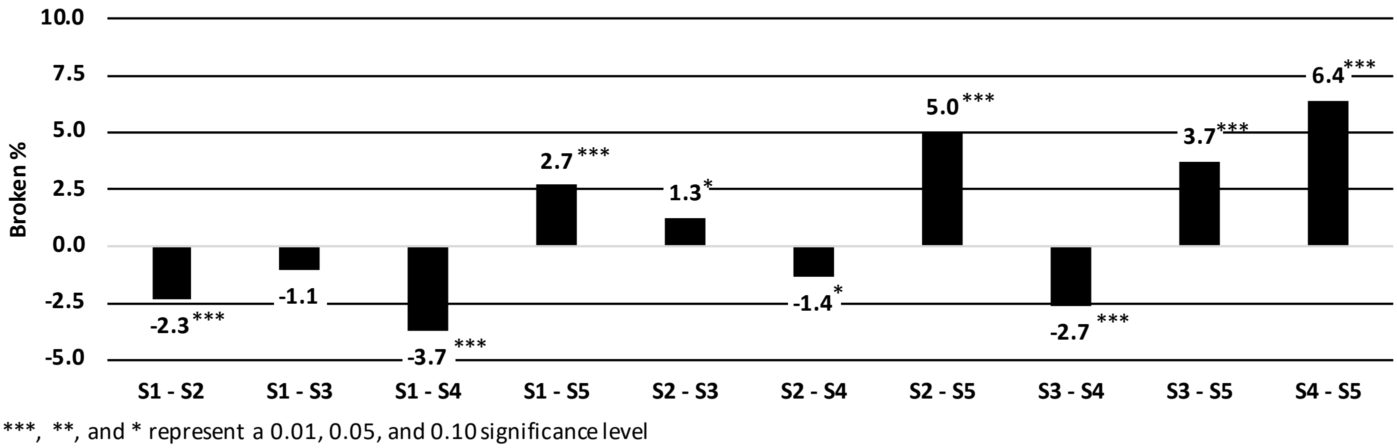

Fig. 2. Difference in mean broken percentage between the five samples used in this study (S1: a sample of rice varieties (both hybrids and pure-lines) planted in Arkansas in 2022 mixed using their harvested weighted average; S2: same as S1 but removing RTFP753; S3: a sample of hybrid rice planted in Arkansas in 2022 mixed using their harvested weighted average; S4: same as S3 but removing RTFP753; S5: a sample of pure-line rice varieties planted in Arkansas in 2022 mixed using their harvested weighted average).

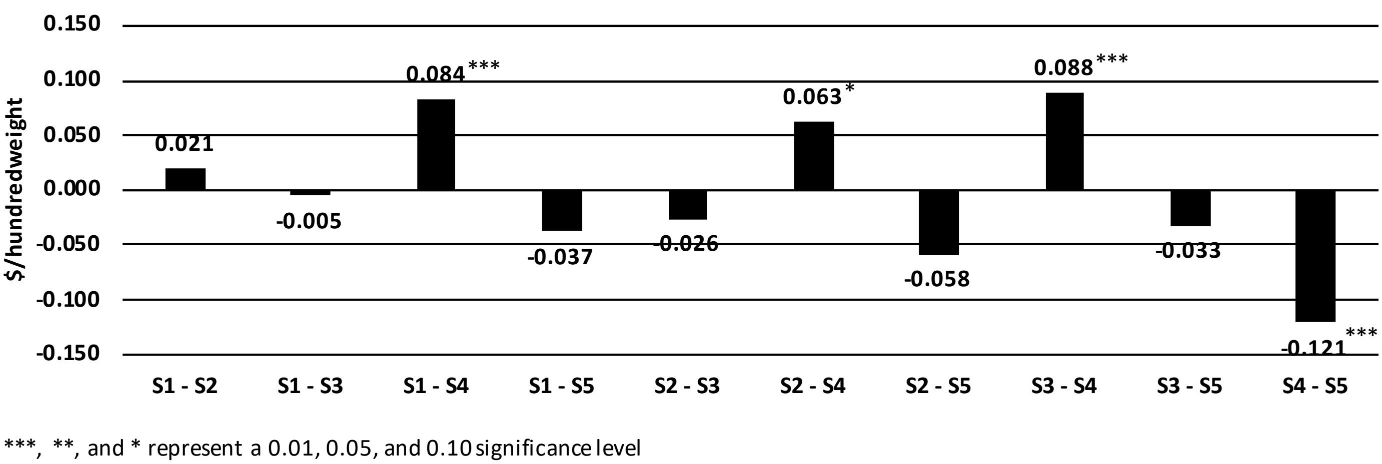

Fig. 3. Difference in producer price between the five samples used in this study (S1: a sample of rice varieties (both hybrids and pure-lines) planted in Arkansas in 2022 mixed using their harvested weighted average; S2: same as S1 but removing RTFP753; S3: a sample of hybrid rice planted in Arkansas in 2022 mixed using their harvested weighted average; S4: same as S3 but removing RTFP753; S5: a sample of pure-line rice varieties planted in Arkansas in 2022 mixed using their harvested weighted average).

Table 1. Milling quality, value of production, and value of sales for the selected rice samples.

Sample	Milling rate yield	Head rice yield	% Broken	Value Production[a]	Value of Sales[b]
				------------------($ million)------------------	
S1	69.9	54.9	21.4	1,179	1,371
S2	70.5	53.7	23.7	1,176	1,366
S3	70.3	54.5	22.5	1,180	1,375
S4	70.3	52.7	25.1	1,174	1,361
S5	69.4	56.4	18.7	1,180	1,375

[a] Estimated using Arkansas' 2022 volume of production by variety, the average milling rate and head rice yields estimated in this study, the marketing year average price of Chicago Board of Trade milling yield premium and discount fee schedule for the rough rice futures contract for 2022, and the PLC reference price of $308/metric ton ($14/hundredweight).

[b] Estimated using Arkansas' 2022 volume of production by variety, the average milling rate and head rice yields estimated in this study, assuming all rice is exported as U.S. #2/4% and the broken surplus as broken rice, taking into consideration the export price for U.S. #2/4% and broken rice from the 2023 Rice yearbook.

Optimizing Lab Methods for Consistent Rice Milling Analysis

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Abstract

The milling performance of three laboratory rice mills—McGill #2, Satake, and Zaccaria—was assessed to standardize their milling capabilities. The experiment involved two medium-grain and two long-grain rice cultivars, each comprising a pure-line and a hybrid, with moisture content levels of 13% and 15%, utilizing three sample sizes (0.31, 0.33, and 0.36 lb). The samples underwent milling until a surface lipid content (SLC) of 0.4% was achieved, after which both head rice yield (HRY) and milled rice yield (MRY) were analyzed. Moisture content, cultivar type, and mill type emerged as significant factors affecting HRY. The Satake mill exhibited the highest HRY at 15% moisture content, while the McGill #2 mill demonstrated a similar trend at 13% moisture content. MRY across all treatments fell within the 60–70% range, with the Satake mill yielding the highest MRY. No noticeable impact on HRY and MRY was observed within the explored sample size ranges. This study offers insights into the milling capabilities of the evaluated lab mills, though further research is necessary to optimize their performance effectively.

Introduction

Rice is majorly consumed as white rice, which is more popular and preferred among consumers due to its improved cooking quality, appearance, texture, and color (Gondal et al., 2021). To obtain white rice, a milling process is required, which involves the removal of husk, germ, and bran layers from the exterior of the rice kernel caryopsis (Graves et al., 2009; Ning et al., 2023). The milling process can occur in a batch, single pass, or a continuous, multi-pass process (Ning et al., 2023). The rice industry loses a lot of money due to milled rice of poor milling quality. Thus, rice milling aims to maximize head rice yield (HRY), the major quality indicator of rice (Graves et al., 2009). According to USDA-FGIS, head rice represents the portion of rice kernels that are three-fourths or more of their original length after the broken pieces have been removed. HRY is the mass percentage of rough rice remaining as head rice. Apart from HRY, the quality of milled rice is evaluated based on other parameters, such as milled rice yield (MRY), surface lipid content (SLC), total lipid content (TLC), and whiteness index (WI) (Pan et al., 2007). MRY represents the mass percentage of rough rice remaining as milled rice, i.e., head rice with brokens.

The extent to which bran layers are removed from brown rice during milling can be quantified and classified as the degree of milling (DOM), which refers to the whiteness of rice (Graves et al., 2009; Ning et al., 2023). The U.S. Department of Agriculture (USDA) developed distinct grading classes for rice in terms of the DOM into three categories, ranging from reasonably well-milled (darkest in color), well-milled (white or creamy), and hard-milled (lightest in color). This official US qualification is primarily determined based on milled rice color but lacks a quantitative approach to representing DOM. As a result, the SLC method was studied in rice processing and preferred to be a better quantifiable approach than the USDA-FGIS grading system (Siebenmorgen et al., 2006; Saleh and Meullenet, 2007). This is because most of the extractable lipids from rice kernels are located in the bran layers and endosperm. Graves et al. (2009) added that the SLC, as a measurement of DOM, has a significant impact on the physical, physicochemical, and end-use properties of rice. Also, WI and TLC are two frequently employed techniques for measuring DOM in research and commercial settings, with a higher WI number indicating whiter rice (Pan et al., 2007).

The laboratory milling system is typically employed in the rice industry, using small representative samples to estimate the milling yield, which is expected to represent the rice lots processed in the commercial milling systems (Pan et al., 2007). McGill #2 rice mill has often been used for laboratory milling evaluation of rice samples, typically starting with 0.33–0.36 lb rough rice samples dried to 12% MC, which is typically dehulled before milling (Bautista & Siebenmorgen, 2002). Andrews et al. (1992) reported that the McGill #2 mill was unsuitable for smaller rice samples (less than 0.26 lb of brown rice) as it lacks sufficient milling action for such samples. The Satake mill consists of an abrasive roller grit of different sizes depending on the rice type and requires only 0.44 lb of sample size. It contains a built-in multi-groove pulley for easy speed changes and an adjustable timer for automatic operation. The Zaccaria mill requires 0.22 lb of rough rice passed into the feeding hopper, where husking is achieved through abrasion of the rubber rolls. The husks are separated in an aspiration chamber, and whitening of the brown rice is done by friction principle through an abrasive ring and rubber brake. Based on several studies conducted on the assessment of performance and factors influencing milling using the McGill mills, it was reported that sample moisture content, milling duration, the initial temperature of the brown rice, pressure exerted on the sample inside the milling chamber, and sample mass affected the operation (Andrews et al., 1992). Further research by Graves et al. (2009) observed that MC of the rough rice sample was the most significant attribute affecting DOM, while other factors had a lesser influence.

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Limited or no information is available on quantifying the DOM of these laboratory mills beside McGill #2. Thus, it was necessary to investigate and evaluate the quality of milled rice produced using the aforementioned three mills with the aim of optimizing the laboratory methods to aid consistent rice milling. This study aimed to quantify the degree of similarity among McGill #2, Satake, and Zaccaria mills based on different MCs, rice types and cultivars, and sample sizes using HRY and MRY.

Procedures

Four rough rice samples, including one long-grain pure-line (CLL 16), one long-grain hybrid (RT 7321 FP), one medium-grain pure-line (CLM 04), and one medium-grain hybrid (RT 3202), were harvested in 2023 from rice farms in Northeast Arkansas. Immediately after harvest, samples were cleaned and gently dried to 15% and 13% MC (wet basis) in the environmentally controlled chamber (77 °F and 56% RH). Dried samples were stored in the walk-in cooler at 4 °C until needed for experiments.

Samples needed for the experiment were removed from the 39 °F cooler and allowed to equilibrate at laboratory temperature (70–75 °F) for 24 h before use. The rough rice samples in amounts of 0.31, 0.33, and 0.36 lb needed for each mill were dehulled using a laboratory huller (McGill Sheller, Houston, Texas, USA) to obtain the brown rice. These samples were passed through individual mills to obtain the surface lipid content (SLC) for each cultivar at different sizes and MCs. Milling with McGill No. 2 (McGill No. 2 RAPSCO) was performed by filling the milling chamber with brown rice, which was initially allocated to the mill, for four milling durations (15 – 60 s at 5 or 10 s intervals), depending on the cultivar. A 3.3-lb mass was positioned on the mill lever arm, 6-in. from the center of the milling chamber. Similarly, milling with the Satake (Satake TM05C, Japan) was performed by filling the milling chamber with assigned brown rice samples for four milling durations between 90–180 s at 60 s intervals. The Zaccaria mill (Zaccaria PAZ/1-DAT, Brazil) operates as a complete unit, where rough rice samples are passed through to obtain milled white rice. However, for this study, the milling compartment alone was utilized by passing brown rice into the milling chamber for four milling durations between 120–300 s at 60 s intervals, depending on the cultivar.

The SLC of the milled samples at the four different milling durations was determined using a near-infrared spectrophotometer (NIR; DA7200; Perten Instrument). These SLC values were plotted against the corresponding durations to establish the milling curve for each cultivar at different MCs across the three mills. The established milling curve generated an SLC value of 0.4% (well-milled rice), which was then used as the milling duration for the subsamples required for the experiment.

The subsamples (4 cultivars × 3 sample sizes × 2 MCs × 3 mills) were milled in duplicates at the obtained milling durations. The HRY and MRY were obtained using the following equations below:

$$Head\ rice\ yield\ (HRY,\%) = \frac{Mass\ of\ head\ rice}{Mass\ of\ rough\ rice} \times 100$$

$$Milled\ rice\ yield\ (MRY,\%) = \frac{Mass\ of\ milled\ rice}{Mass\ of\ rough\ rice} \times 100$$

Statistical Analysis

Statistical analyses were conducted using JMP Pro statistical software v. 17.0 (SAS Institute, Inc., Cary, N.C.). A comparison of the average of the HRY and MRY for each cultivar across moisture content level, mills, and sample size was explored at a significant level of 0.05.

Results and Discussion

Head Rice Yield

Table 1 provides a summary of the influence of the factors on HRY values. It was observed that cultivars, MC, mills, and their interactions had a significant effect on the HRY. From Table 2, it is evident that for all mills, HRY varies depending on MC since the results at 13% are higher than those at 15% MC. HRY increases as MC decreases with only McGill #2, which shows a slightly different result, with less than a 2 percentage point difference when compared to the 15% MC. These findings support the conclusions of Andrews et al. (1992), which showed that the MC of rice at the time of milling played a significant role in the relationship between HRY and DOM. Among the three mills, the Satake mill had the highest HRY, while McGill #2 had the lowest HRY at MC of 13%. On the other hand, McGill #2 had the highest HRY, and the Zaccaria mill had the lowest HRY at an MC of 15%. Statistical analysis revealed that sample sizes did not affect HRY. This implies that within the bound of the mass used (0.31–0.36 lb), there was no substantial impact on HRY. Lanning and Siebenmorgen (2011) reported that hybrid rice requires a shorter milling duration compared to pure-line rice to achieve the desired DOM. A shorter milling duration will result in less removal of the bran and endosperm, and less crack in the rice kernel, thereby increasing HRY. Thus, it was interesting to see that both the pure-line medium and long-grain cultivars (CLM 04 and CLL 16) demonstrated higher HRY than the hybrid cultivars (RT 3202 and RT 7321 FP). This variation may be attributed to inherent differences in properties among rice cultivars, such as shape, hardness, surface topography, and kernel size, which directly influenced the milling properties (Rohrer and Siebenmorgen, 2004).

Milled Rice Yield

Milled rice yield (MRY) represents the percentage of the total milled rice based on rough rice. Table 1 shows the factors that had the highest impact on MRY, with cultivar and mill type having significant effects. MC, within the range tested, was noticed to have no significant effect on the MRY which means that the degree of bran removal across the cultivars based on the MC levels used had little or no effect. It is worth noting that the MRY of all treatments (Cultivars × MC × Mills) was greater than 60%. At 15% MC (Table 3), Satake exhibited the highest MRY (68.7%), and the Zaccaria mill had the lowest (63.6%), while a similar pattern was also observed at 13% MC, with McGill #2 having the lowest MRY (64.9%). Across the cultivars, for the most part, the medium-grain cultivars demonstrated high MRY, particularly for the Satake mill. It is vital to point out that during the milling process with the Satake mill, some rough rice samples (as high as 0.3 oz) can be collected as part of the milled rice, depending on the sample size. MRY, just like HRY, was not substantially affected by the sample sizes explored.

Practical Applications

This study examined the milling performance of three laboratory mills and measured both HRY and MRY. The usage of McGill #2 in the industry is declining gradually, with the FGIS transitioning towards adopting the Grainman mill. Other options available for laboratory milling include Satake, Buhler, Yamamoto, and Zaccaria mills. It is essential to evaluate and standardize mills to ensure consistent reporting of MRY, HRY, and other quality attributes of milled rice. The University of Arkansas Rice Processing Program has extensively researched using McGill #2, but there's been limited investigation into the milling characteristics of other mills compared to McGill #2. This research provided baseline information and identified key factors and their effect on the HRY and MRY of the investigated mills. However, future studies may be necessary to fully understand and optimize modern laboratory mills.

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Table 1. Analysis of variance showing the effect of the factors across the responses at α = 0.05.

	P-Value	
Factors	**HRY**	**MRY**
Cultivars	<0.001*	<0.001*
Moisture content	<0.001*	0.1555
Mill type	<0.001*	<0.001*
Cultivars*Mill type	<0.001*	0.0019*
Moisture content*Mill type	<0.001*	<0.001*
Cultivar*Moisture content	0.0006*	0.0129*

* = values are significant at $P < 0.05$.

Table 2. Head rice yield of each mill across moisture content (MC) and cultivar.

Mills	MC (%)	CLM 04	RT 3202	CLL 16	RT 7321 FP
McGill #2	13	56.5 ± 0.02	42.0 ± 0.02	47.5 ± 0.01	45.0 ± 0.01
	15	58.3 ± 0.01	28.2 ± 0.03	39.1 ± 0.02	34.6 ± 0.04
Satake	13	60.4 ± 0.01	52.7 ± 0.01	53.0 ± 0.01	53.9 ± 0.00
	15	57.8 ± 0.01	52.3 ± 0.02	51.5 ± 0.01	45.0 ± 0.04
Zaccaria	13	59.3 ± 0.01	53.7 ± 0.01	55.6 ± 0.01	52.9 ± 0.01
	15	53.2 ± 0.01	38.7 ± 0.04	42.0 ± 0.02	41.7 ± 0.03

Table 3. Milled rice yield of each mill across moisture content (MC) and cultivar.

Mills	MC (%)	CLM 04	RT 3202	CLL 16	RT 7321 FP
McGill #2	13	64.9 ± 0.01	65.8 ± 0.00	65.2 ± 0.01	65.2 ± 0.01
	15	67.8 ± 0.00	64.8 ± 0.00	63.5 ± 0.00	65.6 ± 0.01
Satake	13	67.1 ± 0.00	67.1 ± 0.00	65.2 ± 0.00	66.0 ± 0.00
	15	68.7 ± 0.00	68.2 ± 0.00	65.7 ± 0.00	65.8 ± 0.00
Zaccaria	13	65.8 ± 0.01	66.2 ± 0.00	65.1 ± 0.00	65.8 ± 0.01
	15	63.6 ± 0.00	64.9 ± 0.00	63.7 ± 0.00	65.6 ± 0.00

Blend Matters: Interaction of Rice Cultivars on Milling Yield and Physicochemical Trait

B. Regonda,[1] K. Luthra,[1] R. January,[1] and G.G. Atungulu[1]

Abstract

Blending (commingling or mixing) different rice cultivars before milling is a common practice aimed at saving time and effort, yet it can lead to processing inefficiencies and inconsistent product functionality, ultimately impacting the economic value of rice. Despite its prevalence in farm or industrial settings, the extent to which this blending practice affects milling yield and the physical and chemical attributes of blended products of rice grown in Arkansas remains insufficiently studied. This study aimed to fill this gap by investigating the impact of blending different long-grain cultivars and different medium-grain cultivars, both before and after drying, on various characteristics of composite rice lots. Specifically, the study analyzed the length-to-width ratio, thickness, chalk distribution, milling yield, and color of the resulting blends. The analysis revealed significant effects of rice blending on the length-to-width ratio and thickness of the composite lots. While some cultivars benefited from blending, others experienced reductions in these attributes. For example, blending RT7321 FP with other hybrids decreased the length-to-width ratio of the composite lot by 0.13, whereas blending RT7521 FP increased it. Differences were also observed in chalk percentage among hybrid cultivars, with RT7521 FP and RT7321 FP showing the highest percentages. However, blending these cultivars reduced the overall chalk percentage of the composite lots. Regarding milling yield, pre-drying blending yielded better results compared to post-drying blending. Individual cultivars, such as RT7321 FP and RT XP753, exhibited head rice yields of 47.27% and 58.60%, respectively, while blending hybrid cultivars resulted in an overall head rice yield of around 52%. These findings offer valuable insights for rice farmers and processors, providing guidance on optimizing blending practices to enhance the overall milling yield and quality of rice.

Introduction

Rice commingling is a common practice where different rice cultivars are mixed during harvest, drying and storage operations. Combining different cultivars can have a substantial effect on physicochemical properties as well as functional qualities, particularly due to differences in chemical composition and milling properties among different rice cultivars (Siebenmorgen et al., 2006). The commingling of rice cultivars may pose sourcing challenges for industries that use rice as a key ingredient in their products. Variability in rice milling yield and physicochemical attributes can impact the consistency of the processing. This, in turn, affects the taste, texture, and overall quality of the products that reach consumers and can lead to lower sales.

Differences in milling characteristics have been observed between hybrid and pure-line rice cultivars. In studies conducted by Siebenmorgen et al. (2006), it was found that, for the same milling duration, hybrids (XL7 and XL8) exhibited lower surface lipid contents compared to pure-line cultivars (Cocodrie, Cypress, and Lemont), which was due to a thinner bran layer in hybrid cultivars. Differences in milling characteristics between two pure-line cultivars (Wells and Francis) and four hybrid cultivars (XL723, CL XL729, CL XL730, and CL XL745) were noted by Lanning and Siebenmorgen (2011).

There is still a significant knowledge gap regarding the prevalence of commingling practices, particularly concerning the contemporary Arkansas cultivars and their influence on milling yield and physicochemical attributes. This study aimed to fill this gap by investigating the effects of commingling commonly grown Arkansas rice cultivars on milling yield and physicochemical characteristics, such as length-to-width ratio, chalk percentage, and color variations, in comparison to individual cultivars.

Procedures

Sample Procurement

Freshly harvested rice cultivars (4 long-grain hybrids, 3 long-grain pure-line, 1 medium-grain hybrid, and 1 medium-grain pure-line) were procured from farms in Northeast Arkansas in 2023. They were cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, Minn., U.S.A) after harvest as soon as they were received in the laboratory. Initial moisture content was measured using an AM 5200 Grain Moisture Tester (PERTEN Instruments, Hägersten, Sweden).

Experimental Design

For long-grain cultivars, rice blends were prepared by commingling 5 cultivars, as described in Table 1. Two factors, including blends (5 levels) and pre- and post-drying (3 levels), were studied. For medium-grain cultivars, one factor, including pre- and post-drying (3 levels), was studied with a single blend made from equal portions of 2 cultivars (Table 1). Blends were made based on their production acreages in Arkansas in 2022 (Hardke, 2023). In addition, these cultivars were commingled pre- and post-drying. Rice milling yields, chalk percentage, length-to-width ratio, thickness, milled rice yield, head rice yield, and color of the samples were determined. The experiments were performed in two replicates.

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Experimental Procedures

Rice cultivars were commingled or blended both before and after the drying process. Pre-drying commingling reflects mixing that occurs either at the farm or processing plant following harvest, while post-drying commingling depicts scenarios of processors mixing after drying to meet specific rice market requirements. Pre-drying blending involved commingling samples at harvest moisture content, with weights allocated to each cultivar according to the percentages specified in Table 1 and sample sizes of 165 g (pre-drying sample) and 2500 g (pre-drying bulk sample). After commingling, samples were homogenized by mixing in a rotary rice grader (TRG, Satake, Tokyo, Japan) for 1 minute. All samples were then gently dried to 12.5 ± 0.5% moisture content (wet basis) using an equilibrium moisture content (EMC) chamber set at 77 °F air temperature and 56% relative humidity (RH). Samples of 165 g after drying were used to generate milling and physicochemical attributes data. To capture the randomness of the level of commingling, 2500 g samples were subsampled to 150 g to generate processing data.

Samples commingled post-drying were blended after conditioning each individual cultivar to 12.5 ± 0.5% moisture content (wet basis). A sample size of 150 g was prepared for all blends using the percentages for each cultivar mentioned in Table 1. After commingling, samples were homogenized by mixing in the aforementioned rotary rice grader for 1 minute.

After the commingling step, all the samples, including pre-drying and post-drying samples, were packed in airtight bags, labeled, and stored in a cooler in plastic tubs at 39 °F for at least 60 days. The physiochemical properties of rice are expected to stabilize during storage, which will enhance the milling yields (Saikrishna et al., 2018). After 60 days, samples were removed from the cooler and were allowed to equilibrate to a laboratory temperature of around 70–75 °F for 12 hours before processing to gather milling yields and physicochemical attributes.

Length-to-Width (L/W) Ratio and Thickness Determination

The samples were dehulled using a dehuller (THU-35A; Satake Engineering, Tokyo, Japan), and the dimensions of the brown rice (length, width, and thickness) were measured using the SeedCount equipment (A7050, Stadvis Pty Ltd, Australia). This equipment featured a perforated tray capable of holding 100 brown rice kernels in the perforations. Subsequently, the sample was scanned, and the software provided measurements of length, width, and thickness in millimeters. The length-to-width ratio was then calculated by dividing the mean length by the mean width of the sample.

Chalk Determination

Chalk percentage was obtained using an image analysis system (WinSeedle Pro 2005a, Regent Instruments, Inc., Sainte-Foy, Quebec, Canada). A transparent acrylic tray of 152 mm × 100 mm × 20 mm was filled with about 100 brown rice kernels from a sample; they were arranged so that no two kernels touched each other. The system counted the number of pixels that corresponded to the total kernel projected area and the area that was color-classified as chalk. The percentage of chalk was determined by multiplying these pixel numbers by 100 to get total chalk in percentage.

Milling Yield Determination

Dehulled samples were then milled for a specific milling duration using a laboratory mill (McGill #2 Rice Mill, RAPSCO, Brookshire, Texas), after which the milled samples were aspirated for 30 s using a seed blower (South Dakota Seed Blower, Seedboro, Chicago, Ill.). The sample was milled to a surface lipid content (SLC) of 0.4% for a standardized degree of milling (DOM). To attain that, each blend and control was milled for 10, 20, 30, and 40 seconds with SLC measurement at each milling duration. Millability curve was plotted between milling duration and SLC to find the milling duration corresponding to a SLC of 0.4%. After milling, head rice (75% length of the whole milled kernels) was separated from the brokens using a grain separating device (Grain Machinery Manufacturing Miami, Fla., USA). Milled rice yield (MRY) and head rice yield (HRY) were calculated using Equations 1 and 2, respectively.

$$Milled\ rice\ yield\ (MRY, \%) = \frac{Mass\ of\ milled\ rice}{Mass\ of\ rough\ rice} \times 100 \qquad \text{Eq. 1}$$

$$Head\ rice\ yield\ (HRY, \%) = \frac{Mass\ of\ head\ rice}{Mass\ of\ rough\ rice} \times 100 \qquad \text{Eq. 2}$$

Color Determination

The International Commission on Illumination (CIE) color parameters of head rice ($L^*/a^*/b^*$) were determined using a color meter (Colorflex EZ, Hunterlab, Reston, Va.). Each sample was weighed out to a maximum of 35 g and put into an opaque glass sample cup. After the first color measurement, the sample cup was rotated 90°, and a second measurement was obtained. Each sample's average of the two measurements was noted. After obtaining the color parameters L^*, a^*, and b^*, the ΔE value, which denotes the rice samples' total color shift during processing, was calculated as in Equation 3 (McKay et al., 2023). White tile served as a reference, denoted with subscript *i,* and the experimental rice samples were denoted with subscript *a*. It was preferred if ΔE had a low value.

$$\Delta E = \sqrt{(L_a^* - L_i^*)^2 + (a_a^* - a_i^*)^2 + (b_a^* - b_i^*)^2} \qquad \text{Eq. 3}$$

Statistical Analyses

Analysis of variance and Student's *t*-test were performed using the statistical software JMP Pro 17 (SAS Institute, Inc., Cary N.C.) to determine the statistical significance of each factor on the response variables and significant differences between mean values of the responses for factor levels, respectively. The level of significance was set at 5% for mean comparison.

Results and Discussion

Effect of Blending Factors and Pre-Drying and Post-Drying Scenarios on Sample Length to Width Ratio (L/W) and Thickness

Table 2 shows that commingling long-grain cultivars leads to significant differences between L/W ratio and thickness. However, pre-drying, pre-drying bulk, and post-drying scenarios did not create any statistical difference. Individual cultivar RT7521 FP had the lowest L/W ratio of 2.83, but when this cultivar was commingled with other hybrid cultivars, the overall ratio of the rice lot increased. However, the L/W ratio of RT7321 FP was reduced by 0.13 from 3.04 to 2.91 when commingled with other hybrid cultivars. A similar trend was observed when both hybrid and pure-line cultivars were commingled. Pure-line cultivars Ozark and CLL16 that had the L/W ratio of 2.93 and 3.04, respectively, when commingled, had a positive effect on the L/W ratio. But when mixed with hybrid cultivars, the overall ratio decreased (Fig. 1). Pre-drying, pre-drying bulk, and post-drying scenarios did not have much impact on the length-to-width ratio (Fig. 1). XP753 and Ozark had the highest thickness of 1.86 mm and 1.87 mm, respectively, but when commingled with other hybrid and pure-line cultivars, the overall thickness decreased (Fig. 2).

For medium-grain blend, no significant differences were found for L/W ratio and thickness due to pre-drying, pre-drying bulk, and post-drying scenarios (Table 3). However, the L/W ratio improved when Titan and RT3203 were commingled (Table 4). For rice thickness, no differences were observed due to commingling and different commingling scenarios.

Effect of Blending Factors and Pre-Drying or Post-Drying Scenarios on Chalk Percentage

Table 2 shows that commingling long-grain cultivars overall leads to statistical differences in chalk percentage. No significant differences were found due to pre-drying, pre-drying bulk, and post-drying scenarios. Among the hybrid cultivars, RT7521 FP and RT7321 FP had the highest chalk percentage of 18.51% and 12.66%, respectively. When hybrid cultivars were mixed, there was a decrease in overall chalk content. This trend was also noted when they were combined with pure-line cultivars. Ozark and CLL16 exhibited chalk values of 10.45% and 8.84%, respectively, which were lower than the overall chalk values resulting from their blending with hybrid cultivars (Fig. 3).

For medium-grain commingled blend, scenarios of commingling did not create a statistical significance on chalk percentage (Table 3). However, Titan, with the lowest chalk percentage of 5.8%, benefited from an increase in chalk percentage when commingled post-drying with RT3202 (9.8%).

Effect of Blends and Pre-Drying or Post-Drying Scenarios on Milling Yields

Long-grain cultivars commingling had a significant impact on the overall milling yield, including MRY and HRY of the samples (Table 2). Also, commingling at pre-drying, pre-drying bulk, and post-drying scenarios created changes in MRY and HRY. Post-drying commingled samples have relatively lower MRY and HRY than pre-drying commingled samples in all the blends (Fig. 4). Without blending, RT7321 FP had a HRY of 47.27%, and XP753 had a HRY of 58.60%. When all the hybrid cultivars were mixed, the overall head rice yield was around 52 %. When all the cultivars (pure-line and hybrid) were blended, excluding XP753, the overall HRY was around 51%. Alternatively, excluding RT7321 FP from the blend of all cultivars (both pure-line and hybrid) resulted in an overall HRY of around 54% (Fig. 5).

For medium-grain, no impact on MRY and HRY was observed for pre-drying, pre-drying bulk, and post-drying scenarios (Table 3). Commingling Titan and RT3202 led to a significant decrease in MRY and HRY values for Titan, but not much impact was observed in RT3202 (Table 4).

Effect of Blending Factors and Pre-Drying or Post-Drying Scenarios on Color

Table 2 shows that the commingling process and the pre-drying, pre-drying bulk, and post-drying scenarios did change the overall color of rice samples as compared to white tile reference. However, not much difference is reported as compared to the individual cultivars. Delta E values for Ozark and CLL16 were 47.32 and 46.87 units, respectively. When these two pure-line cultivars are mixed, the value of delta E was approximately the same as that of their individual cultivars (Fig. 6). For medium grain commingled blend, no significant difference was reported for color change (Table 3).

Conclusions

The results of this study provided insights into how commingling can impact the milling yield and physicochemical attributes of blended rice. Length-to-width ratio, which is an important parameter of grading of rice, was compromised for cultivars like RT7321 FP and CLL16; however, some cultivars benefitted from commingling. For other parameters like chalk percentage and milling yield, certain cultivars can benefit from commingling. However, some cultivars suffered milling yield reductions as well as chalk increase in a composite sample lot. Similarly, some of the studied individual medium-grain cultivars had overall higher milling yields and better physicochemical attributes compared to commingled sample lots. Overall, commingling of long-grain cultivars pre-drying was better than post-drying from a milling yield standpoint. No difference in medium-grain cultivars commingling was found between pre-drying and post-drying commingling. These trends observed through this research offer important information in the decision-making process of when to commingle rice, what cultivars to commingle, and the expected implications of commingling on milling yields and physicochemical attributes.

Practical Applications

This study reveals how commingling affects rice milling yield and quality attributes. While some cultivars benefit, others suffer, with compromises in parameters like L/W ratio and chalk percentage. Pre-drying commingling of long-grain cultivars is preferable for milling yield compared to post-drying commingling. Medium-grain cultivars show no difference in commingling impact based on pre- or post-drying commingling. Overall, the study findings inform decisions on when and which cultivars to commingle and the resulting effects on milling yields and quality.

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Table 1. Blends used for commingling with its cultivars and corresponding percentage included.

Blends	Cultivar percentages by weight
1. All cultivars (blend having all the long- and medium-grain cultivars)	RT7521 FP (41%), XP753 (24.5%), RT7321 FP (20.1%), Ozark (7.6%), CLL16 (6.7%)
2. Hybrid cultivars (blend having all hybrid long-grain cultivars)	RT7521 FP (47.9%), XP753 (28.6%), RT7321 FP (23.5%),
3. Pure-line cultivars (blend having all pure-line long-grain cultivars)	OZARK (52.9%), CLL16 (47.1%)
4. Excluding XP753 (blend having all long-grain cultivars excluding highest broken cultivar)	RT7521 FP (54.4%), RT7321 FP (26.6%), Ozark (10%), CLL16 (8.9%)
5. Excluding RT7321 FP (blend having all long-grain cultivars excluding highest chalk cultivar)	RT7521 FP (51.4%), XP753 (30.7%), Ozark (9.5%), CLL16 (8.4%)
6. Medium-grain (blend having all the medium-grain cultivars)	Titan (50%), RT3202 (50%)

Table 2. *P*-value based on the analysis of variance to depict the statistical significance of the factors for long-grain cultivars commingled blends across the responses (α = 0.05).

	Response variables†					
Factors	Chalk %	Length to width ratio	Thickness	Milled rice yield	Head rice yield	Color (ΔE value)
Blends	0.0041*	0.0002*	0.0119*	<0.0001*	<0.0001*	<0.0001*
Pre-drying and post-drying	0.0706	0.6353	0.8405	<0.0001*	0.0055*	0.0366*
Replication	0.3129	0.2264	0.7838	0.2089	0.7725	0.9672

† *P*-value <0.05 depicts the statistical significance of the factor on the response variable. All the variables highlighted with * had a significant impact.

Table 3. *P*-value based on the analysis of variance to depict the statistical significance of the factors for medium-grain cultivars commingled blend across the responses (α = 0.05).

	Response variables[†]					
Factors	Chalk %	Length to width ratio	Thickness	Milled rice yield	Head rice yield	Color (ΔE value)
Pre-drying and post-drying	0.5562	0.8967	0.1842	0.1246	0.6546	0.6544
Replication	0.6304	0.7238	0.1038	0.8277	0.8096	0.2269

[†] *P*-value <0.05 depicts the statistical significance of the factor on the response variable.

Table 4. The mean value of response variables categorized into various levels of drying scenario and controls for the medium-grain blend.

	Response variables[†]					
Levels	Chalk %	Length to width ratio	Thickness	Milled rice yield	Head rice yield	Color (ΔE value)
Pre-drying	9.3 ab	2.11 b	2.21 a	70.50 a	53.67 b	47.15 a
Pre-drying bulk	8.0 ab	2.12 b	2.29 a	69.27 c	52.60 b	47.07 a
Post-drying	9.8 a	2.12 b	2.25 a	69.80 abc	52.83 b	47.53 a
Titan (Control)	5.8 b	2.06 c	2.25 a	70.43 ab	57.23 a	47.20 a
RT3202 (Control)	10.6 a	2.18 a	2.26 a	69.70 bc	51.50 b	48.10 a

[†] Means followed by the same letter in the same column are not significantly different at $P = 0.05$.

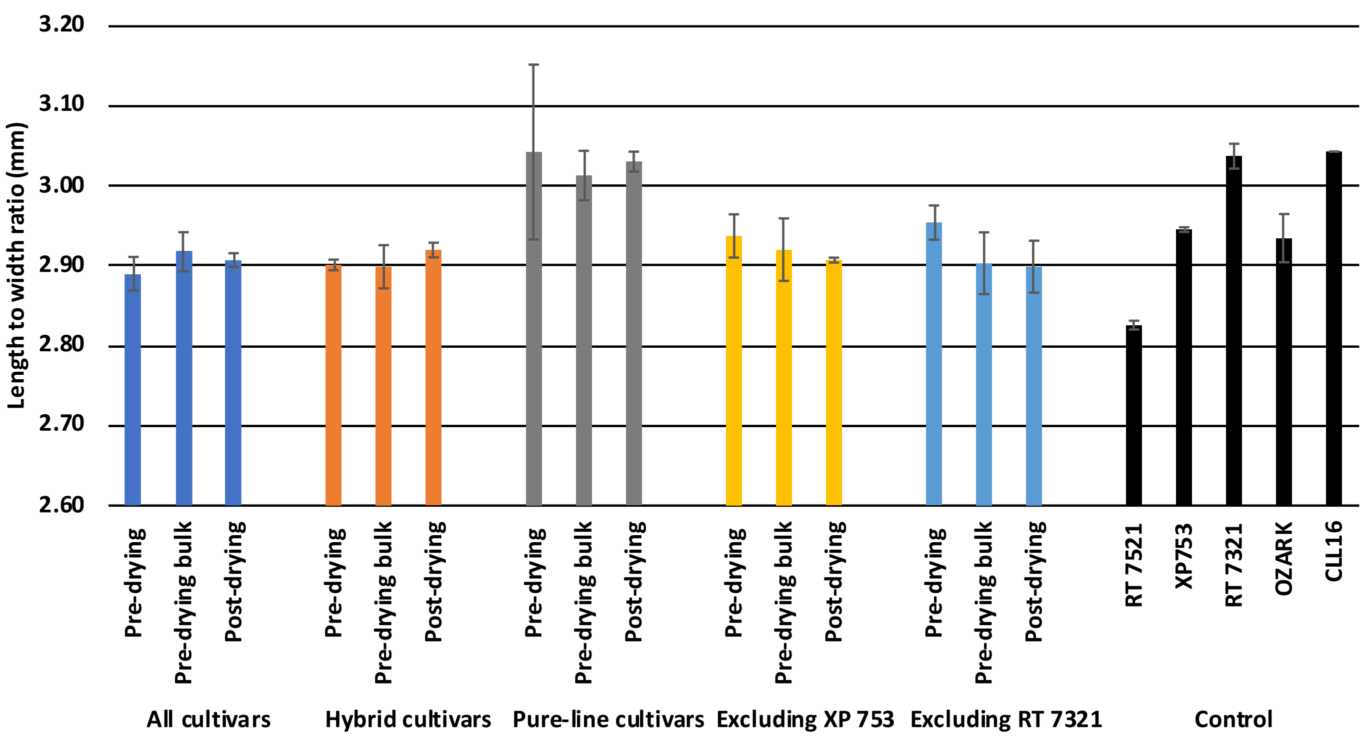

Fig. 1. The mean values of length-to-width ratio for each blend and control.

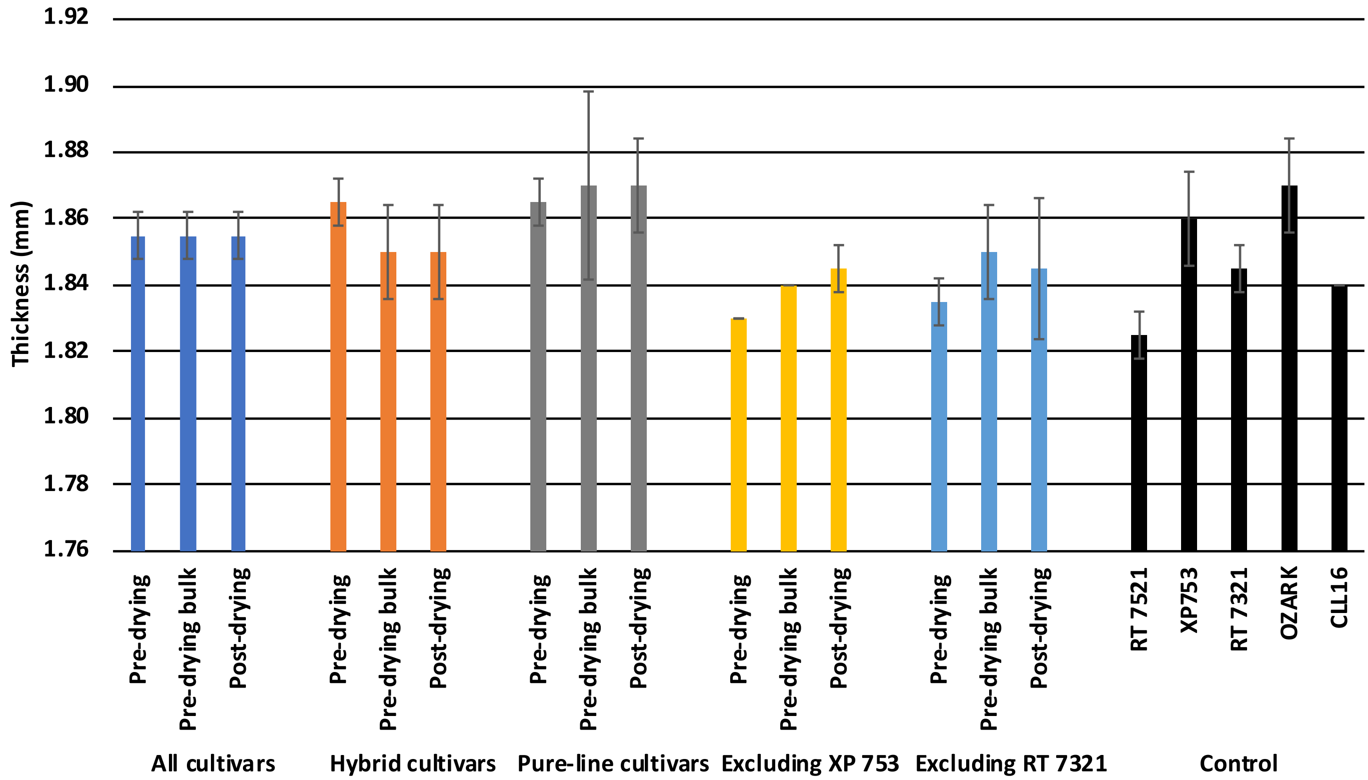

Fig. 2. The mean values of thickness for each blend and control.

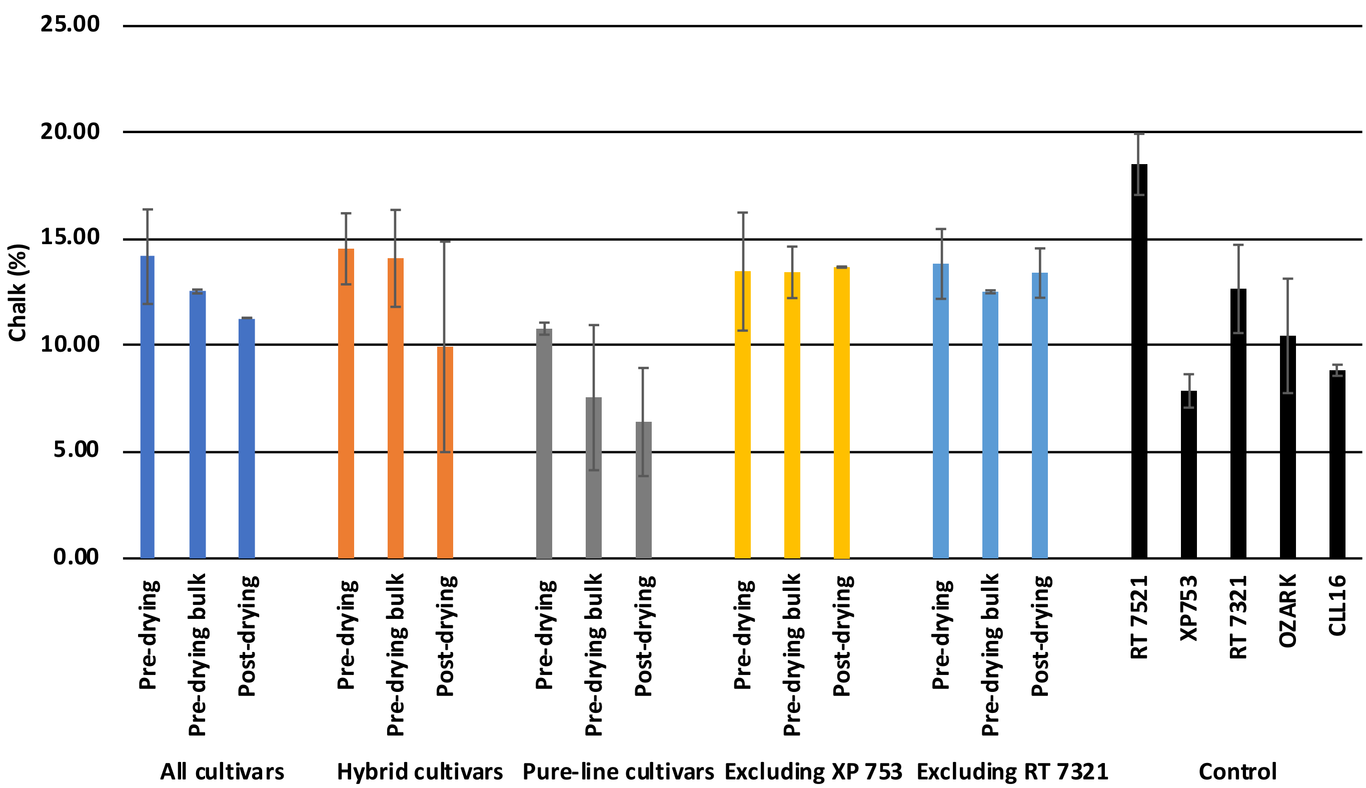

Fig. 3. The mean values of chalk percentage for each blend and control.

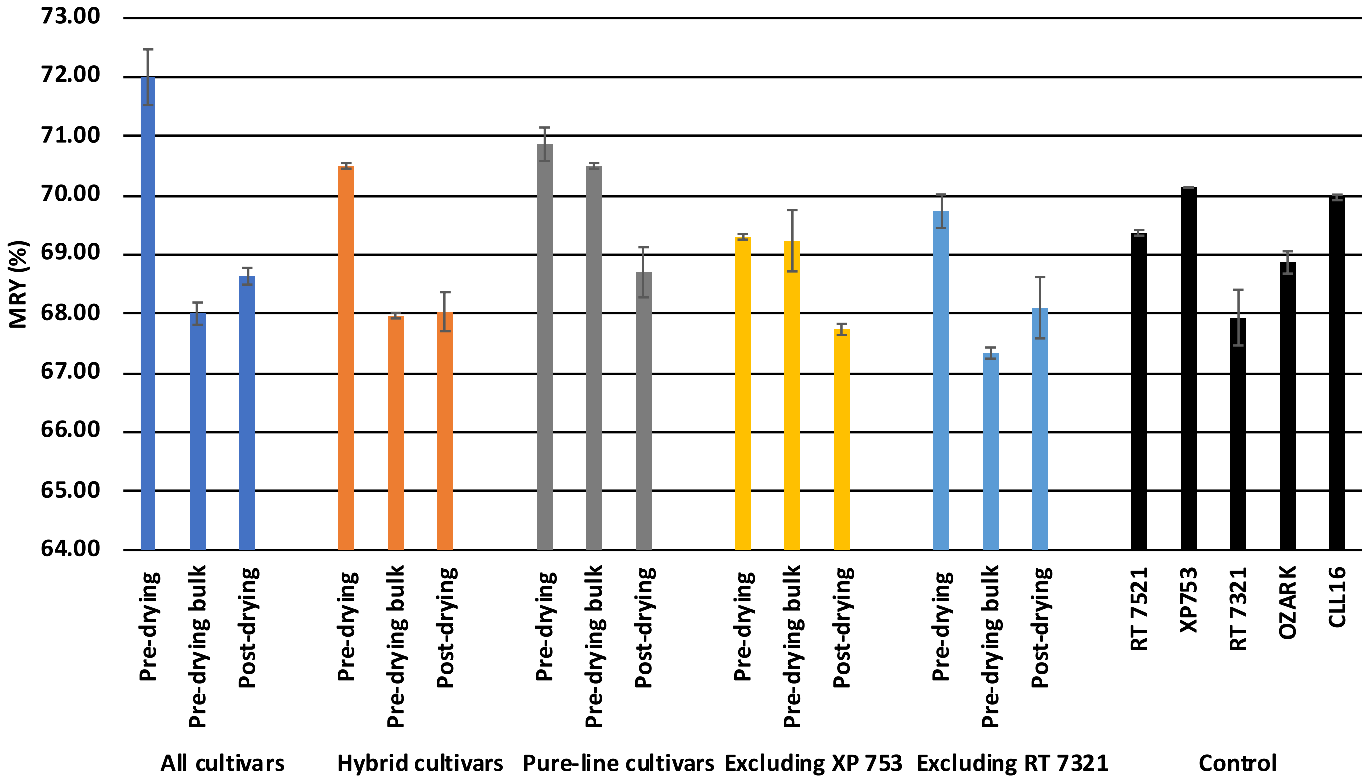

Fig. 4. The mean values of milled rice yield (MRY) for each blend and control.

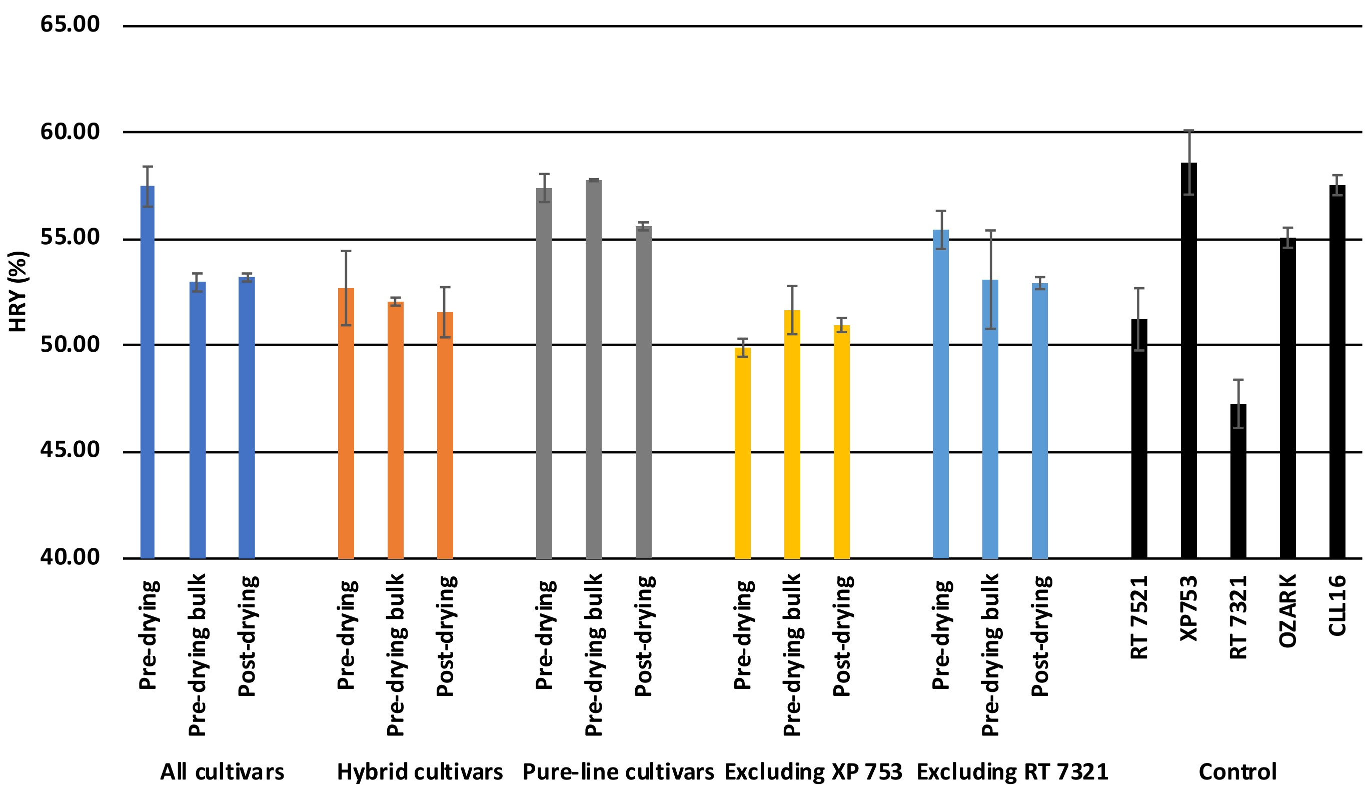

Fig. 5. The mean values of head rice yield (HRY) for each blend and control.

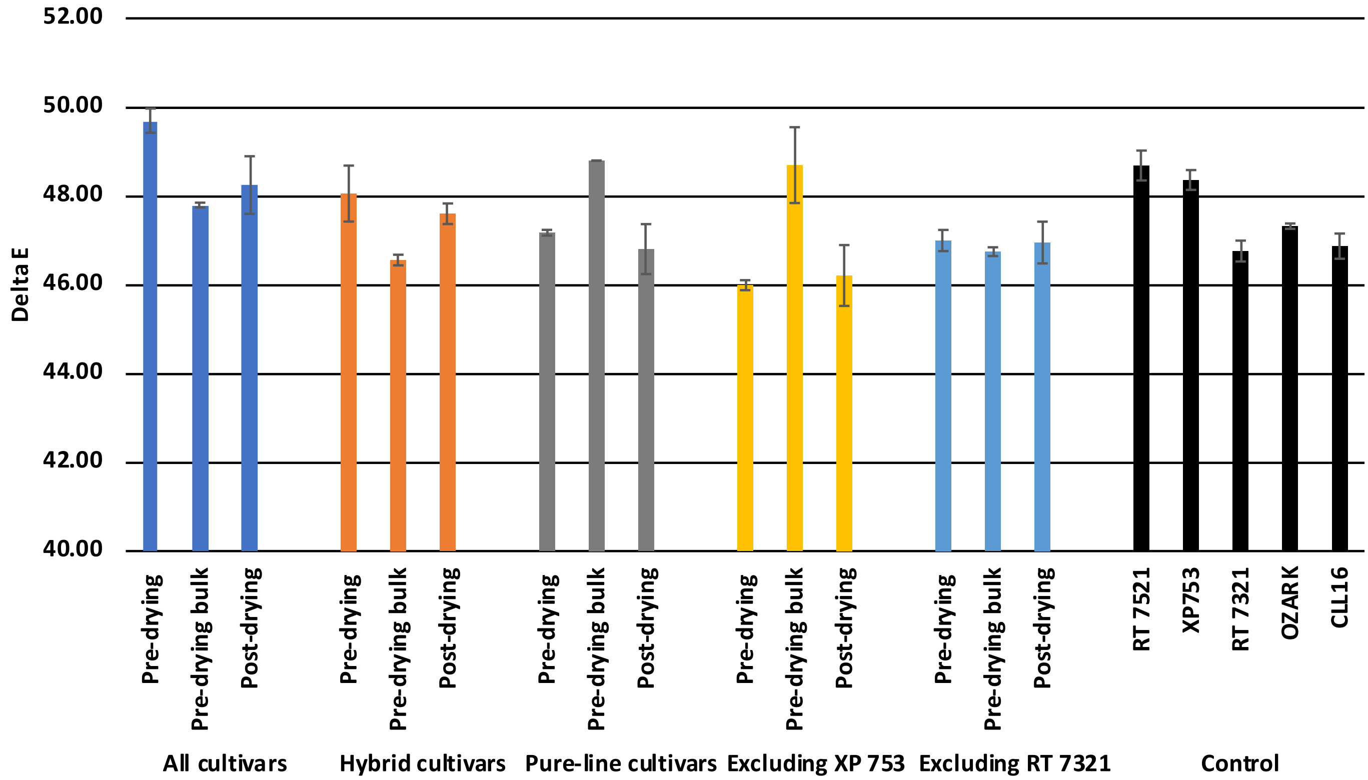

Fig. 6. The mean values of delta E for each blend and control.

World and U.S. Rice Baseline Outlook, 2023–2033

A. Durand-Morat[1] and W. Mulimbi[1]

Abstract

Global rice consumption reached a record level and surpassed production in the marketing year (MY) 2022. Rice prices from most origins and rice types increased in 2022, reaching record levels for medium-grain rice due to the drought conditions in California and Europe. The implementation of an export ban on white non-basmati exports by India in July 2023 disrupted the long-grain segment of the market in 2023, sending international prices up more than US$100/metric ton (MT) as importing countries struggled to source their rice needs. Although India is expected to lift the export ban in May of 2024, we are projecting the international price for long-grain rice, represented by Thailand's 100% B milled rice, to average $601/MT in MY 2023, a 25% increase relative to MY 2022. Under the assumption of India resuming trade in 2024, we project the international price for long-grain rice to decrease in MY 2024 and steadily increase thereafter at an average rate of 1.57% a year. Mainly because of the recovery of medium-grain production in California in 2023, we project the international price of medium grain in MY 2023 at $1141/metric ton, a 30% decrease relative to MY 2022. Over the projected period, we estimate the price of medium-grain rice to decrease by 1.02% a year on average. World rice production and consumption are projected to expand by 7.7% and 9.1% over the next decade, with India experiencing the largest expansion in both areas. Global rice trade is projected to reach 61 million MT by the end of the projected period.

Introduction

Global rice production and consumption have reached record levels in recent years. Global production in marketing year (MY) 2021 and 2022 is estimated at 513 million metric tons (MMT), driven primarily by good performances in India and China. Global consumption is growing even faster than production and has reached 521 MMT in MY 2022. Global consumption has surpassed global production in MY 2021 and 2022, drawing down ending stocks by 6% from 188 MMT in MY 2020 to 176 in MY 2022 (USDA, 2024).

Global rice trade reached a record of 54 MMT, or 10.6% of the global rice production in MY 2022. India led global rice exports with 20.2 MMT of rice exported, equivalent to a 37.2% market share. Other major exporters included Thailand (8.7 MMT), Vietnam (8.2 MMT), Pakistan (3.8 MMT), and the U.S. (2.0 MMT). On the import side, China (4.4 MMT), the Philippines (3.8 MMT), and Indonesia (3.5 MMT) were the largest importers of rice in MY 2022.

International prices for long-grain rice are being pushed up by India's trade policy measures, which included the implementation of export tariffs in September of 2022, followed by an export ban on white non-basmati rice in July 2023. The Food and Agriculture Organization (FAO) rice price index for Indica (long-grain) rice increased by 25% in the calendar year (CY) 2023 relative to CY 2022. Prices for Thai long-grain rice (100% B) and Vietnamese 5% long-grain rice have remained above $600/MT since August 2023. FAO's price index for Japonica rice increased 5.7% in CY 2023 relative to CY 2022, but there has been a significant drop in the export price from California as the new 2023 crop entered the market (FAO, 2024).

Procedures

The baseline estimates presented in this report are generated using the Arkansas Global Rice Model (AGRM), a partial equilibrium, non-spatial, multi-country/regional statistical simulation and econometric framework developed and maintained by the Arkansas Global Rice Economics Program (AGREP) at the University of Arkansas System Division of Agriculture Department of Agricultural Economics and Agribusiness. The AGRM model covers 70 countries and regions, accounting for more than 95% of the rice produced, consumed, and traded globally (Wailes and Chavez, 2011). The model is used to make 10-year market projections, including estimations of future rice area, yield, production, consumption, trade, stocks, and prices.

The AGRM model is calibrated using data from USDA-FAS (2024a and 2024b) and USDA-ERS (2024). The macroeconomic data (e.g., gross domestic product, exchange rate, and population growth) come from S&P Global, provided by the Food and Agricultural Policy Research Institute (FAPRI)-Missouri.[2] The baseline projections are grounded in a series of assumptions as of January 2024 about the general economy, agricultural policies, weather, and technological change. The basic assumptions are a continuation of existing policies, current macroeconomic variables, no new World Trade Organization's (WTO) trade reforms, and average normal weather conditions. Particularly important this year are our assumptions about the future of India's export ban on white, non-basmati rice. Based on consultation with experts, we assume that India will effectively lift the export ban in May of 2024, the time set by the government of India to review the impact of the policy.

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Results and Discussion[3]

The projected period is MY 2023 to MY 2033. Over the next decade, the international (free on board or FOB) price of long-grain rice, represented by Thailand's 100% B rice, is projected to increase on average 1.2% annually from its 2020–2022 level ($462/MT) and average US$527/mt by 2031–2033 (Fig. 1; Table 1). We project an increase in long-grain rice prices in MY 2023 as a result of India's ban on white, non-basmati exports. Under the assumption that India will resume exports in May of 2024, the price of long-grain is projected to decrease in MY 2024 and grow steadily thereafter. The international price of medium-grain[4] rice, represented by U.S. No.2 from California, is projected to decline by 2.96% annually on average over the next decade and reach US$942/mt in 2031–2033 relative to US$1260/mt in 2020–2022 (Fig. 1; Table 1). We project that the price of medium-grain rice will decrease steadily over the projected period.

The export price gap between U.S. and Thai long-grain rice, which reached a record high of $263/MT in MY 2022, is expected to ease in MY 2023 as Asian export prices increase due to India's export restrictions but increase again in MY 2024 as India comes back to the export market. In the long run, we project the price gap to decrease and reach less than $100/MT. We project U.S. long-grain export prices to decrease in order to remain export competitive. The increasing competition from Mercosur, primarily Brazil, observed in recent years may plateau as excess supply in Brazil stabilizes. With that said, it seems that an increase in U.S. rice production must be accompanied by a decrease in prices to make it possible for the U.S. to regain some market share lost to Brazil and Uruguay in traditional core markets such as Mexico and Central America.

Global rice output is projected to continue expanding over the next decade, supported by the increasing adoption of modern varieties and other improved production technologies, in many cases as part of strategic self-sufficiency policies in developing countries across Asia and Africa. World rice production is projected to expand by 36 MMT or 7.1% over the next decade relative to the average in MY 2020–2022, reaching 548 MMT in 2031–2033, led primarily by yield gains and a slight increase in area (Table 2; Fig. 2). India is projected to have the largest production growth in the coming decade. Total U.S. rice production is projected to increase by 11% over the same period (Table 3; Fig. 3).

Global rice consumption is projected to increase by 41.5 MMT relative to the average in MY 2020–2022, reaching 552 MMT on average in 2031–2033 (Table 2; Fig. 2). Over the next decade, world rice consumption will continue to be driven by population growth as the global average per-capita rice consumption declines from 64.9 kg/person in 2020–2022 to 64.0 kg/person in 2031–2033. Rising incomes dampen rice demand in Asian countries such as Japan, Taiwan, China, and South Korea, where rice is considered an inferior good. Moreover, demographic trends, such as decreasing and aging populations and increased health consciousness, cause a shift in preferences away from carbohydrates and towards protein-based diets, ultimately weakening rice demand in some countries. Global rice stocks are projected to decrease significantly in the coming decade, reaching 124 MMT by the end of the projected period (Table 2; Fig. 2).

India accounts for about 24% of the net growth in global rice consumption over the next decade. Regionally, the ECOWAS[5] region in West Africa accounts for 21% of the projected consumption growth over the next decade. U.S. domestic rice use will increase by 0.90 MMT (19.9 million cwt) over the next decade, reaching an average of 7.69 MMT (169.4 million cwt) in 2033–2034 (Table 3; Fig. 3).

We project that global rice trade will expand by 6 MMT over the next decade and reach 60.2 MMT on average in 2031–2033 (Table 1; Fig. 2). On the export side, we project that India will remain the largest exporter over the coming decade, supported by normal weather that will allow the country to maintain high production levels and excess supply. Likewise, we project Thailand to regain its position as the second-largest rice exporter, surpassing Vietnam.

For the U.S., total exports over the next decade are expected to increase by 517 thousand MT (11.4 million cwt), reaching 4.17 MMT (91.8 million cwt) in 2031–2033, while imports will increase by 463.6 MMT (10.2 million cwt), totaling 2.15 MMT (47.5 million cwt) a year in 2031–2033 (Fig. 3). For reference purposes, detailed U.S. rice supply and use data are presented in English units and on a paddy basis (rough rice equivalent) in Table 3. On the import side, China, the ECOWAS-7, and the Philippines are expected to be the leading rice importers by the end of the next decade. We project that the Philippines will become the largest single rice importer by the end of the projected period (4.8 MMT a year in 2031–2033), followed by China (4.0 MMT a year in 2031–2033) and Nigeria (3.0 MMT a year in 2031–2033).

Practical Applications

Understanding the market and policy forces driving the global rice market benefits Arkansas rice producers and other stakeholders. This ramification is especially true because Arkansas is the top rice-producing state in the U.S., accounting for nearly 51% and 57% of the country's total and long grain rice production, respectively, in 2020–2022. The dynamics of the international rice market primarily determine market prices received by Arkansas rice producers. The dynamics of the international rice market primarily determine market prices received by Arkansas rice producers. This outlook is intended to serve as a baseline reference for further policy scenario analysis and can be utilized by government agencies and officials, farmers, consumers, agribusinesses, and other stakeholders.

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[3] Although complete baseline projections for supply and demand variables are generated for all 70 countries/regions covered by AGRM, only selected variables for major countries are discussed in this report due to space considerations.

[4] In AGRM, medium-grain rice represents an aggregation of both medium- and short-grain rice.

[5] Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

Acknowledgments

The authors thank the University of Arkansas System Division of Agriculture for its support. We greatly appreciate the Arkansas rice farmers' support through the Rice Research and Promotion Board, which provided part of the funding for the annual development, update, and maintenance of the Arkansas Global Rice Model. The model was updated three times in 2023 and once in January 2024 in collaboration with FAPRI-Missouri, which provided the major portion of the funds for the global rice modeling program of AGREP.

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Table 1. Projected changes in world rice total net trade by top-ten countries (in 1,000 metric tons) with U.S. and global prices.

Country	2020–2022 Average	2031–2033 Average	Change	Country	2020–2022 Average	2030–2032 Average	Change
Exporters				**Importers**			
India	20,829	23,580	3,464	Philippines	3,183	4,828	1,645
Thailand	7,455	8,290	2,813	China	2,837	2,093	-744
Vietnam	5,475	6,029	1,832	Nigeria	2,308	3,000	692
Pakistan	4,147	4,630	-50	ECOWAS-7[a]	2,172	3,430	1,259
Myanmar (Burma)	1,910	1,833	142	EU and UK[b]	1,749	1,697	-52
Cambodia	1,767	2,357	1,269	Iraq	1,725	1,945	220
United States	1,371	1,408	955	Indonesia	1,496	1,666	170
Uruguay	899	1,072	611	Cote d'Ivoire	1,462	2,245	783
Paraguay	757	1,019	-256	Bangladesh	1,313	1,169	-144
Guyana	439	616	40	Saudi Arabia	1,294	1,498	205
Rest of the World	291	710	41	Rest of the World	25,799	27,973	2,174
Total Exports	**45,339**	**51,546**		**Total Imports**	**45,339**	**51,546**	

Prices (US$/metric ton)			
Long-grain International Rice Reference Price (Thailand 100% B)	462	5257	65
U.S. No. 2 long-grain FOB[c] Gulf Ports	684	616	-68
U.S. No. 1 medium-grain FOB California	1,260	942	-318

[a] Region including Benin, Burkina, Gambia, Guinea-Bissau, Niger, Togo, and Cape Verde.

[b] EU = European Union, UK = United Kingdom.

[c] FOB = free on board.

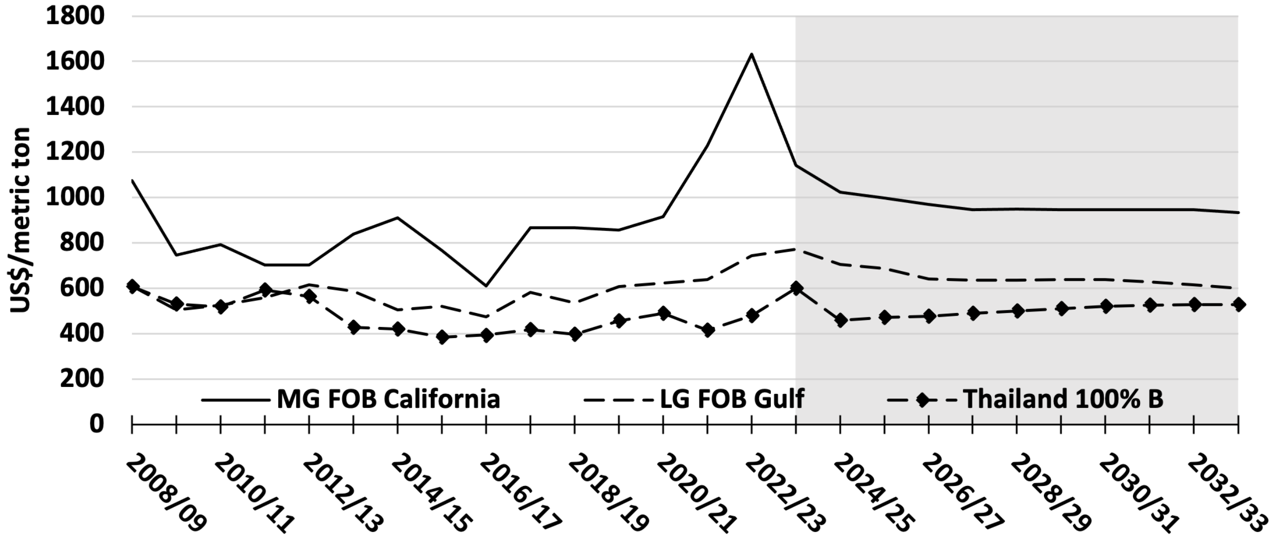
Table 2. Projected world rice supply and utilization (in 1,000 metric tons) and macroeconomic data.

Variable	2020–2022 Average	2031–2033 Average	Change
Area Harvested (1000 ha)	165,476	168,888	3,412
Yield (kg/ha)	3.09	3.24	0.15
Production	511,619	547,954	36,335
Beginning Stocks	184,264	125,851	-58,413
Domestic Supply	695,883	673,805	-22,078
Consumption	511,218	552,672	41,454
Ending Stocks	182,299	124,598	-57,701
Domestic Use	693,517	677,271	-16,246
Total Trade	54,172	60,160	5,988
Stocks-to-consumption Ratio (%)	35.66	22.54	-13.12
Annual population growth (%)	0.9	0.8	-0.10
Annual real GDP[a] growth (%)	2.09	2.58	0.49

[a] GDP = Gross domestic product.

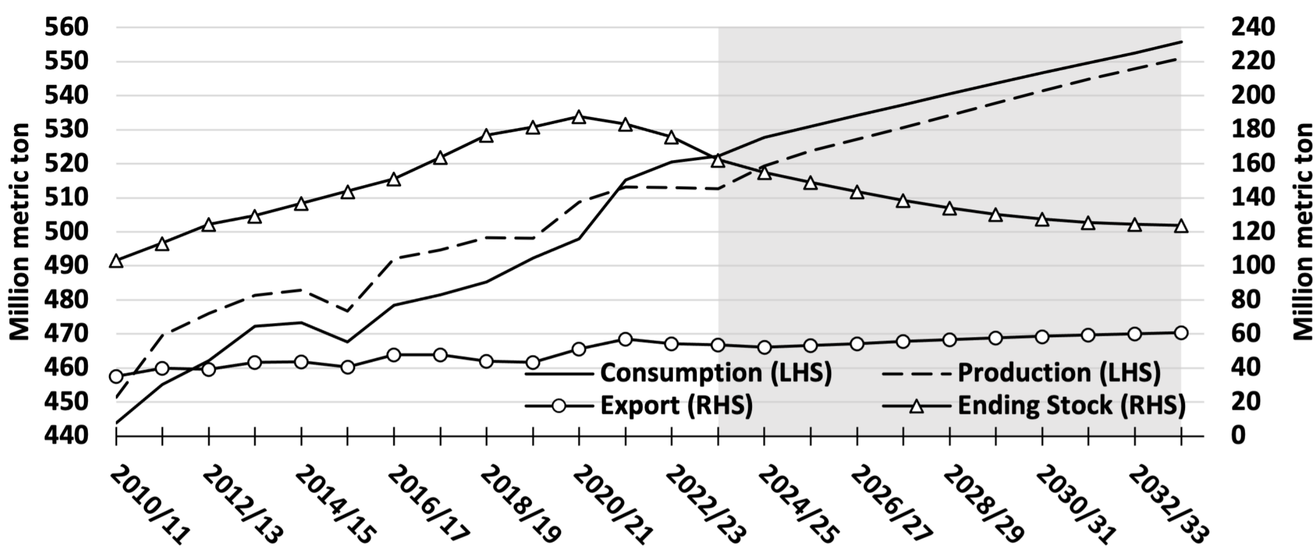
Table 3. United States rice supply and utilization (in paddy basis, million hundredweight unless specified otherwise) and prices.

Variable	2020–2022 Average	2031–2033 Average	Change
Yield (lb/ac, paddy basis)	7,570.8	7,956.5	385.7
Total Harvested Area (1000 ac)	2,547.7	2,695.6	148.0
Supply	265.9	306.8	40.9
Production	193.2	214.5	21.3
Beginning Stocks	35.5	44.8	9.3
Imports	37.3	47.5	10.2
Domestic Use	149.4	169.4	19.9
Exports	80.4	91.8	11.4
Total Use	149.4	169.4	19.9
Ending Stocks	35.6	45.6	10.0
Stocks-to-Use Ratio	0.2	0.2	0.0
		Market Prices (US$/cwt)	
Loan Rate	7	7	0.00
Season Average Farm Price	16.6	15.9	-0.74
Long-Grain Farm Price	14.3	14.7	0.33
Medium-Grain Farm Price	25.3	21.1	-4.18
Japonica Farm Price	30.2	24.1	-6.11
Southern Medium-Grain Farm Price	15.0	15.1	0.11



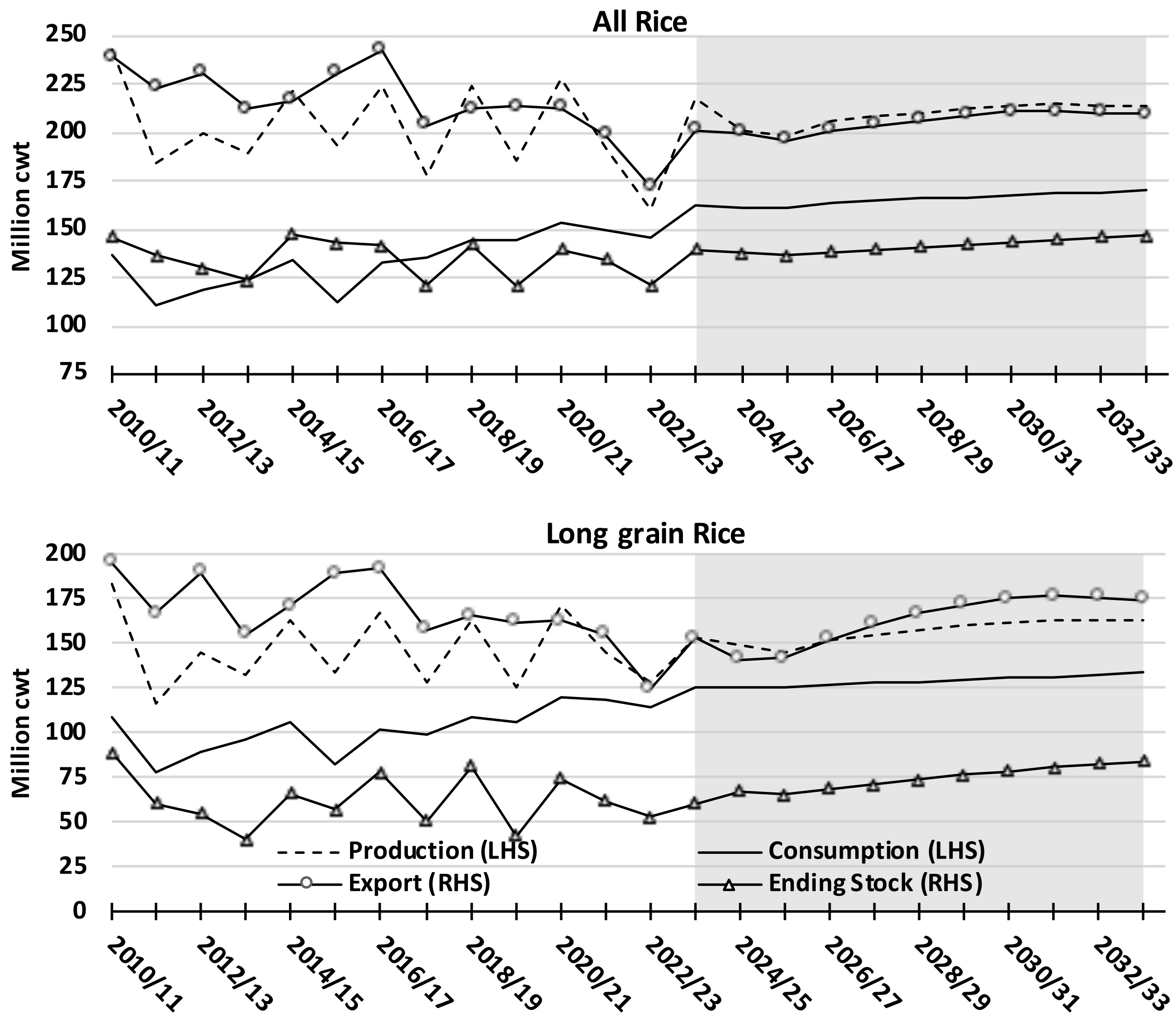
Source: USDA-ERS Rice Outlook, February 2024. AGRM projections January 2024.

Fig. 1. Annual Historical and Projected U.S. and Asian milled rice prices, US$ per metric ton, 2008–2033. The shaded area represents the projected period.



Source: USDA-ERS Rice Outlook, February 2024. AGRM projections January 2024.

Fig. 2. Global rice production, consumption, trade, and ending stocks, 2010–2033. The shaded area represents the projected period.



Source: USDA-ERS Rice Outlook, February 2024. AGRM projections January 2024.

Fig. 3. United States rice production, consumption, trade, and ending stocks, 2010–2033. The shaded area represents the projected period.

Rice Enterprise Budgets and Production Economic Analysis

B.J. Watkins[1]

Abstract

Crop enterprise budgets are developed to be flexible for representing alternative production practices and cropping systems of Arkansas producers. Interactive budget programs apply methods that are consistent over the top field crops grown in Arkansas. Production practices for base budgets represent University of Arkansas System Division of Agriculture Cooperative Extension recommendations from Crop Specialists and from the Rice Research Verification Program. Unique budgets can be customized by users based on either Extension recommendations or information directly from on-farm decision-making and production practices. The budget program is utilized to conduct economic analysis of field data in the Rice Research Verification Program. The crop enterprise budgets are designed to evaluate the solvency of various field activities associated with crop production. Costs and returns analysis with budgets allow for production economics analysis to investigate factors impacting farm profitability.

Introduction

Volatile input prices and supply availability of key herbicides and fertilizers present challenges for producers when deciding on cropping systems to utilize on-farm. A population decline in China, which is a large consumer of rice, can impact the ability of elevators to export rice at profitable levels. Low water levels on the Mississippi River were proven to cripple receiving inputs and exporting products to their desired markets in previous years and remain a concern moving forward. Rains and snowmelt in California allowed many acres to return to rice production, hampering the market for medium-grain rice in Arkansas. Producers need a means to calculate the costs and returns of production alternatives to estimate potential profitability capability with ever-changing export markets, consumer spending habits, and input cost spikes. The objective of this research is to develop an interactive computational program that will enable stakeholders of the Arkansas rice industry to evaluate production methods for comparative costs and returns to allow for evaluating the profitability of managerial decisions.

Procedures

Methods employed for developing crop enterprise budgets include input prices that are estimated directly from information available from suppliers and other sources, as well as costs estimated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates. Input prices, custom hire rates, and fees are estimated with information from industry contacts, bids received on material obtained for research plots, and online retailers. The methods of estimating these operating expenses presented in crop enterprise budgets are identical to those producers use to obtain cost information for their specific farms. These prices, however, fail to consider discounts from buying products in bulk, preordering, rebates, and other promotions that may be available at the point of purchase.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full-service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate the time requirements of an activity, which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2022). Labor costs in crop enterprise budgets represent time devoted; and, recently, labor costs associated with irrigation have been added to the budgets utilizing information received from Mississippi State University.

Ownership costs of machinery are determined by the capital recovery method, which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999). This measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders, as reported in October 2022. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, industry list prices, and reference sources (Deere and Company, 2022; MSU, 2022). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and commodity prices received data.

Results and Discussion

The Department of Agriculture and Natural Resources (ANR) develops annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production

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methods analyzed represent typical field activities as determined by consultations with Agronomists, Weed Scientists, Entomologists, Plant Pathologists, producers, county agents, and information from Crop Research Verification Program Coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years due to climactic conditions. Analyses are for generalized circumstances with a focus on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making related to acreage allocations among field crops. Results should be regarded only as a guide and a basis for individual farmers developing budgets for their production practices, soil types, and other unique circumstances.

Table 1 provides a summary of revenue and expenses of the 2023 rice enterprise budgets. Costs are presented on a per-acre basis with an assumed yield of 170 bushels for conventional varieties and 190 bushels for hybrid. The price received for 2023 was set at $6.75/bu. Program flexibility allows users to change total acres, as well as numerous variables in order to represent unique farm situations. Expected returns to total specified expenses range from $112.10 per acre (Provisia) to $179.65 per acre (Hybrid). The crop enterprise program includes budgets for Clearfield, Conventional, FullPage Hybrid, Hybrid, and Provisia seed technologies.

Practical Applications

The crop enterprise budget program has a state-level component that develops base budgets. County extension faculty can utilize base budgets as a guide to developing budgets that are specific to their respective counties, as well as customized budgets for individual producers. A county delivery system for crop enterprise budgets is consistent with the mission and organizational structure of the Arkansas Cooperative Extension Service.

The benefits provided by the economic analysis of alternative rice production methods provide a significant reduction in financial risk faced by producers. Arkansas producers have the capability by using the budget program to develop economic analyses of their individual production activities. Unique crop enterprise budgets developed for individual farms are useful for determining credit requirements. Flexible crop enterprise budgets are useful for planning and determining production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

Acknowledgments

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Table 1. Summary of Revenue and Expenses ($/acre), Rice, 2023.

Receipts	Clearfield	Conventional	Full Page Hybrid	Hybrid	Provisia
Yield (bu./ac)	170	170	190	190	170
Price ($/bu.)	6.75	6.75	6.75	6.75	6.75
Grower Share, %	100%	100%	100%	100%	100%
Crop Revenue	**1147.50**	**1147.50**	**1282.50**	**1282.50**	**1147.50**
Operating Expenses					
Input Costs	663.92	630.13	740.58	721.11	658.67
Other Operating Expenses	127.19	125.91	130.32	129.55	131.54
Total Operating Expenses	791.10	756.04	870.91	850.66	790.20
Post-harvest Expenses	102.60	102.60	114.67	114.67	102.60
Net Operating Expenses	**893.70**	**858.63**	**985.57**	**965.32**	**892.80**
Cash Land Rent	0.00	0.00	0.00	0.00	0.00
Returns to Operating Expenses	**253.80**	**288.87**	**296.93**	**317.18**	**254.70**
Fixed Costs	137.53	137.53	137.53	137.53	137.53
Total Specified Expenses[a]	**1027.82**	**996.16**	**1123.10**	**1102.85**	**1035.40**
Returns to Specified Expenses[b]	**119.68**	**151.34**	**159.40**	**179.65**	**112.10**

[a] Does not include land costs, management, or other expenses and fees not associated with production.
[b] Share rent and cash land rent are deducted from crop revenue.

Trend Analysis of Harvested Rice Acres in Northeast, East-Central, and Southeast Arkansas

K.B. Watkins[1] and B. Badarch[2]

Abstract

Arkansas' rice area has changed since the 1980s, with the prevailing perception that rice area has moved northward within the state. This study uses trend analysis to examine the movement of rice harvested area for all counties in Eastern Arkansas during the period 1980 through 2023 to determine which counties have expanded, leveled off, or declined in rice harvested area during this period. The results indicate that rice harvested area has been declining at a constant rate per year since 1980 in four counties in Southeast Arkansas (Desha, Ashley, Chicot, and Drew Counties), has reached a historical maximum during the 44-year period and is currently declining in six counties in East-Central Arkansas (Arkansas, Cross, Monroe, Phillips, Prairie, and St. Francis Counties), and has been expanding at a constant rate per year since 1980 in four counties in Northeast Arkansas (Mississippi, Greene, Jackson, and Independence Counties).

Introduction

Irrigation in Eastern Arkansas greatly depends on groundwater supplied by the Mississippi River Valley alluvial aquifer (MRVAA). Large groundwater withdrawals are placing significant downward pressure on this economically important source of irrigation water (ADA-NRD, 2023; Kresse et al., 2014). Rice uses the most water per acre of any irrigated crop grown in Arkansas and accounts for a significant portion of the groundwater withdrawn from the MRVAA (Reba et al., 2017). Two factors affect future irrigation water demand for rice in Arkansas: 1) the future availability of groundwater from the MRVAA (water availability) and 2) the future number of acres receiving irrigation water (land availability). This study focuses on the latter factor and evaluates harvested rice acre trends for Eastern Arkansas on a county basis. The objectives of this study are to conduct a close examination of historical rice acre trends occurring for Eastern Arkansas rice counties since the beginning of the 1980s and determine which counties are either expanding, leveling off, or declining in rice area.

Procedures

The study area for this analysis is Eastern Arkansas, specifically counties contained in Arkansas Statistical Reporting Districts 3 (Northeast Arkansas), 6 (East-Central Arkansas), and 9 (Southeast Arkansas) that are maintained by the United States Department of Agriculture National Agricultural Statistics Service (USDA-NASS). The period of study includes the years 1980 through 2023 and comprises a 44-year period. County-level rice harvested acres were collected for all 26 counties in eastern Arkansas for the period 1980–2023 (USDA-NASS, 2023). Missing county observations in the NASS data during this period were obtained from the USDA Farm Service Agency (USDA-FSA, 2023).

Four different harvested rice acre trend functions were estimated for each county: 1) linear, 2) linear-plateau, 3) quadratic, and 4) quadratic-plateau. A linear trend function indicates that rice harvested acres either increase or decrease at a constant rate per year throughout the 44-year period. A linear-plateau function indicates that rice harvested acres increase at a constant rate per year until a historic plateau is reached sometime during the 44-year period. Rice harvested acres then level off thereafter. A quadratic function indicates that rice harvested acres increase at a decreasing rate per year until a historic maximum is reached sometime during the 44-year period. Rice harvested acres decline thereafter. Finally, a quadratic-plateau function indicates that rice harvested acres increase at a decreasing rate per year until a plateau is reached during the 44-year period. Rice harvested acres level off thereafter. For more information on the specifics of these four estimated functions, see Watkins et al. (2010), where these same functions are used to determine economic optimum nitrogen rates for rice in Arkansas. The best function for each county was identified as 1) the function with the largest coefficient of determination (or R^2) and 2) a function for which either the coefficient for year or both the coefficient for year and the coefficient for year squared are statistically significant at the 0.05 level.

Results and Discussion

A summary of trends in Northeast Arkansas rice harvested acres is presented in Table 1. Rice area trends for Clay, Craighead, Lawrence, and Poinsett Counties were all quadratic, indicating that rice acres initially increased until an acre maximum was reached and thereafter declined during the 44-year period. The maximum areas predicted for these counties ranged from 75.3 thousand acres for Clay County to 118.7 thousand acres for Poinsett County. Randolph County exhibited a linear-plateau trend, indicating that rice harvested acres for this county increased until a historic plateau was reached within the 44-year period and then leveled off thereafter. The rice harvested acre plateau estimated for Randolph County is 33.5 thousand acres, indicating rice acres are expected to remain around 33.5 thousand acres during future years. The remaining five counties in Northeast Arkansas exhibited linear trend equations. The

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linear trend was positive for four of these five counties (Greene, Independence, Jackson, and Mississippi), implying rice harvested area has been rising at a constant rate per year for these counties since 1980. The positive trends for these four counties ranged from +0.09 thousand acres per year for Independence County to +1.23 thousand acres per year for Mississippi County. White County exhibited a negative trend in rice harvested acres (-0.54 thousand acres per year), indicating that rice harvested area for White County has been declining at a constant rate per year since 1980.

A summary of trends in East-Central Arkansas rice harvested acres is presented in Table 2. Six of the ten counties in East-Central Arkansas (Arkansas, Cross, Monroe, Phillips, Prairie, and St. Francis) exhibited quadratic trends in rice harvested acres, indicating rice harvested acres initially increased over time until a historical maximum was reached and then began to decline thereafter for each of these six counties. The maximum acres estimated for these six counties ranged from 27.8 thousand acres for Phillips County to 112.9 thousand acres for Arkansas County. Two counties (Lonoke and Woodruff) exhibited no measurable trend in rice harvested acres over the 44-year period. These results indicate that the mean number of acres for each of these two counties (52.2 million acres for Woodruff County and 73.9 thousand acres for Lonoke County) represents the best estimate for the expected number of acres to be harvested each year within these two counties. Crittenden County exhibited a linear-plateau trend, indicating rice harvested acres in Crittenden County increased at a constant rate and then leveled off during the 44-year period. The rice harvested acre plateau estimated for Crittenden County is 39.8 thousand acres, indicating rice acres should remain around 39.8 thousand acres during future years. None of the counties in East-Central Arkansas exhibited linear trends in rice harvested acres.

A summary of trends in Southeast Arkansas rice harvested acres is presented in Table 3. Five of the six counties in Southeast Arkansas exhibited linear trends in rice harvested acres, and in four of these counties, the linear trend was negative, ranging from -0.19 acres per year for Drew County to -0.52 acres per year for Desha County. Jefferson was the only county in Southeast Arkansas to exhibit a positive linear trend during the 44-year period (+0.48 acres per year), indicating that rice harvested area in Jefferson County has been rising since 1980. Lincoln County exhibited a quadratic trend in rice harvested acres during the 44-year period, indicating acres increased until a historical maximum was reached and then declined thereafter in this county. The maximum area predicted for Lincoln County was 32.2 thousand acres.

Practical Applications

The trend equations provide information about where the expansion or contraction of rice harvested area is happening in Eastern Arkansas. Rice harvested area in Southeast Arkansas is currently declining and has been declining since the early 1980s, with constant linear downward trends recorded in four of the six counties comprising this region. Alternatively, rice harvested area in most of East-Central Arkansas (six counties out of ten) has reached a historical maximum during the 44-year period and is now declining. Only in Northeast Arkansas is there evidence of continuing expansion in rice harvested area. Rice harvested area has been expanding at a constant rate per year since 1980 in Mississippi, Greene, Jackson, and Independence Counties, with the largest constant expansion rate (+1.23 acres per year) occurring in Mississippi County.

What has led to the trends observed in the Eastern Arkansas rice area since the 1980s? One likely factor is the increased profitability of other field crops grown in Arkansas. Soybeans and corn increased in value relative to rice during the last couple of decades, leading to area shifts away from rice to these other crops (Gautam and Watkins, 2021). Another likely factor is water availability. The four counties where the rice area has expanded since 1980 have ample groundwater availability as measured by the percent saturated thickness of the alluvial aquifer for these four counties. Mississippi County registered the largest aquifer saturated thickness percent of all counties in Eastern Arkansas during 2022 (91.5%). Similarly, aquifer saturated thickness percents in Greene, Jackson, and Independence Counties during 2022 were 72.8%, 72.3%, and 87.4%, respectively. In contrast, Arkansas, Prairie, and Lonoke Counties registered the lowest aquifer saturated thickness percents of all counties in Eastern Arkansas in 2022 (38.2%, 38.9%, and 43.8%, respectively) (ADA-NRD, 2023).

Acknowledgments

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Table 1. Summary of trends in Northeast Arkansas rice harvested acres by county, 1980–2023.

County	Average[a]	Trend Function	R^2	Intercept	Year	$Year^2$	Max/Plateau
	(1000 ac)						(1000 ac)
Clay	69.4	Quadratic	0.398	50.8	1.68	-0.029	75.3
Craighead	70.3	Quadratic	0.336	56.9	1.87	-0.043	77.3
Greene	60.6	Linear	0.590	41.1	0.86	---	---
Independence	9.3	Linear	0.240	7.3	0.09	---	---
Jackson	86.7	Linear	0.372	69.3	0.77	---	---
Lawrence	78.7	Quadratic	0.608	39.5	3.22	-0.050	91.6
Mississippi	33.2	Linear	0.793	5.6	1.23	---	---
Poinsett	109.3	Quadratic	0.289	83.0	2.82	-0.056	118.7
Randolph	26.9	Linear-Plateau	0.764	13.7	0.65	---	33.5
White	18.6	Linear	0.847	30.8	-0.54	---	---

[a] Average county rice harvested area for the period 1980–2023.

Table 2. Summary of trends in East-Central Arkansas rice harvested acres by county, 1980–2023.

County	Average[a]	Trend Function	R^2	Intercept	Year	$Year^2$	Max/Plateau
	(1000 ac)						(1000 ac)
Arkansas	99.7	Quadratic	0.462	88.4	2.65	-0.071	112.9
Crittenden	27.1	Linear-Plateau	0.676	5.8	1.32	---	39.8
Cross	81.3	Quadratic	0.436	58.4	3.50	-0.077	98.4
Lee	26.7	Linear	0.342	37.6	-0.41	---	---
Lonoke	73.9	No Trend	---	---	---	---	---
Monroe	43.1	Quadratic	0.266	33.1	1.44	-0.029	50.9
Phillips	21.6	Quadratic	0.147	15.6	0.82	-0.014	27.3
Prairie	61.9	Quadratic	0.255	55.3	1.11	-0.025	67.4
St. Francis	40.2	Quadratic	0.191	36.0	0.94	-0.023	45.8
Woodruff	52.2	No Trend	---	---	---	---	---

[a] Average county rice harvested area for the period 1980–2023.

Table 3. Summary of trends in Southeast Arkansas rice harvested acres by county, 1980–2023.

County	Average[a]	Trend Function	R^2	Intercept	Year	$Year^2$	Max/Plateau
	(1000 ac)						(1000 ac)
Ashley	15.1	Linear	0.725	24.5	-0.41	---	---
Chicot	34.1	Linear	0.316	42.3	-0.36	---	---
Desha	35.3	Linear	0.301	46.9	-0.52	---	---
Drew	13.6	Linear	0.428	17.7	-0.19	---	---
Jefferson	55.9	Linear	0.308	45.2	0.48	---	---
Lincoln	27.8	Quadratic	0.290	25.8	0.63	-0.018	31.2

[a] Average county rice harvested area for the period 1980–2023.

Factors Affecting Irrigation Water Application in Arkansas Rice Production

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Abstract

Sustainable rice production in Arkansas depends heavily on continued groundwater availability. However, this important resource is declining in much of Arkansas. Therefore, knowledge of the factors affecting applied irrigation water in rice production is essential for continued rice sustainability. This study uses regression analysis to evaluate the impacts of weather and field characteristics on applied irrigation water in Arkansas rice production. The results indicate that precipitation reduces the amount of irrigation water applied. The results also indicate that planting rice on marginal fields can result in significant wastage in applied water.

Introduction

Irrigation in Arkansas greatly depends on groundwater supplied by the Mississippi River Valley alluvial aquifer (MRVAA). Large groundwater withdrawals are placing significant downward pressure on this economically important source of irrigation water (ADA-NRD, 2023; Kresse et al., 2014). Rice uses the most water per acre of any irrigated crop grown in Arkansas and accounts for a significant portion of the groundwater withdrawn from the MRVAA (Reba et al., 2017). A better understanding of the variables affecting irrigation water application is imperative for ensuring the future sustainability of rice production in Arkansas. This study uses regression analysis to evaluate the factors affecting irrigation water application in Arkansas rice production.

Procedures

This study uses field-level data from 201 rice fields enrolled in the University of Arkansas System Division of Agriculture's Rice Research Verification Program (RRVP) for the period 2003–2023. A regression model is used to determine the impacts of field-level factors on irrigation water application in rice production. The regression model is specified as follows:

$$AIW_i = \beta_0 + \sum_{j=1}^{J} \beta_j X_{ji} + e_i, e_i \sim IN(0, \sigma^2)$$

Where i = 1 to 201 rice fields, AIW_i = applied irrigation water for rice field I (acre-inches per acre), X_{ji} = 1 to J explanatory variables associated with field i, β_0 and β_j are unknown parameters to estimate, and e_i is an error term for field i that is independently and normally distributed with zero mean and constant variance σ^2.

Summary statistics for irrigation water applied and explanatory variables used in the regression model are listed in Table 1. Explanatory variables included continuous variables associated with weather (total precipitation measured for the months of May, June, July, and August in inches; average temperatures for the months of May, June, July, and August measured in °F) and field size, along with several zero-one dummy variables describing the field characteristics hypothesized to affect irrigation water applied, including whether or not a hybrid rice variety is used, the soil texture of the field (silt loam, clay, sand), the topography of the field (contour levees with or without multiple inlet rice irrigation; straight levee fields with or without multiple inlet rice irrigation; zero-grade; furrow), the location of the field (East-Central Arkansas; Northeast Arkansas, Southeast Arkansas, or other regions in Arkansas), and whether or not the field may be characterized as marginal. Marginal fields are defined as fields for which irrigation water applied is greater than the mean plus 1.5 times the standard deviation. These fields registered extreme amounts of applied irrigation water due to problems with the field (permeability issues, rice replanting, disease pressure, etc.). The average applied irrigation water for all 201 fields was 28.15 acre-inches per acre (ac-in./ac), while the average applied irrigation water for marginal fields was double the overall average (56.5 ac-in./ac, Table 1).

Applied irrigation water amounts per rice field and data on rice field characteristics were obtained from various RRVP annual reports (UADA-CES, 2024). Only fields with irrigation water usage measured by flow meters were included in the study. Precipitation and average temperature data for the months of March through October were collected for each county and year in the study using the PRISM (Parameter-elevation Regressions on Independent Slopes Model) interactive tool (PRISM Climate Group, 2024). The PRISM tool allows the user to obtain spatial climate data for the conterminous United States.

Results and Discussion

The regression model measuring the impacts of weather and field characteristics on applied irrigation water in rice production is presented in Table 2. Field characteristics omitted for the regression

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model include non-hybrid rice varieties, silt loam textured soils, contour levee fields without multiple inlet rice irrigation, fields located in East-Central Arkansas, and non-marginal fields. The impacts of these variables are captured in the constant term of the regression model.

May and August precipitation have a statistically significant downward impact on applied irrigation water. However, the precipitation impacts differ for both months. May precipitation has a quadratic (nonlinear) impact on applied irrigation water (applied irrigation water decreases at an increasing rate with increasing precipitation), as is evident by the statistically significant positive coefficient for May precipitation squared in Table 2. Alternatively, August precipitation has a linear downward impact on applied irrigation water. Total applied irrigation water declines by -0.7954 ac-in./ac for every inch of precipitation falling in August (Table 2). The impacts of average temperature for May, June, July, and August were not statistically significant, indicating temperatures have little impact on applied irrigation water. Likewise, field size has no statistically significant impact on applied irrigation water.

The coefficient for hybrid rice was negative and statistically significant, indicating hybrid rice varieties reduce applied irrigation water relative to non-hybrid rice varieties, reducing total applied irrigation water by -2.59 ac-in./ac (Table 2). Nalley et al. (2014) found increased water efficiency for hybrid varieties due to a shorter growing season and, thus, less time under a flood for these variety types relative to non-hybrid varieties. The soil texture for the field had statistically significant impacts on applied irrigation water. Total applied irrigation water declined by -4.14 ac-in./ac on fields with clay textured soils, while total applied irrigation water increased by approximately +26 ac-in./ac on fields with sandy textured soils. The latter result highlights the reason why rice is rarely planted on sandy textured soils. Only 4 of the 201 fields in this study were sandy textured fields (Table 1).

Coefficients for straight levee rice fields and zero-grade rice fields were negative, indicating total applied irrigation water is reduced on these fields relative to contour levee rice fields. However, the negative coefficient for straight levee fields was only statistically significant when combined with multiple inlet rice irrigation (a reduction in total applied irrigation water of -3.23 ac-in./ac, Table 2). Zero-grade fields resulted in a statistically significant reduction in total irrigation water applied of -5.50 ac-in./ac (Table 2). The coefficient for furrow irrigation was not statistically significant.

Coefficients for "Northeast Arkansas," "Southeast Arkansas," and "Other Arkansas Regions" were all not statistically significant, indicating that field location has little if any impact on applied irrigation water in rice production. However, fields classified as "marginal" had a statistically significant positive impact on applied irrigation water. Growing rice on a marginal field increased applied irrigation water by approximately +29 ac-in./ac (Table 2). This result highlights the potential wastage of irrigation water when rice is planted on problematic fields.

Practical Applications

The results of this study present a couple of valuable takeaways. First, the results show that precipitation reduces applied irrigation water in rice production and provides evidence that rice producers take advantage of timely precipitation when irrigating their rice crop. Second, the results show that planting rice on problematic rice fields can lead to a significant wastage of water. Therefore, the choice of where rice is planted can greatly affect the amount of water applied to the rice crop in a growing season.

Acknowledgments

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Table 1. Summary of variables used in the regression analysis of irrigation water applied to University of Arkansas System Division of Agriculture Rice Research Verification Program fields.

Variable Type	N[a]	Mean	SD[b]
Applied Irrigation Water			
All Fields (ac-in./ac)	201	28.15	12.37
Non-Marginal Fields (ac-in./ac)	188	26.18	9.82
Marginal Fields (ac-in./ac)	13	56.50	10.81
Continuous Variables			
May Precipitation (in.)	201	5.89	3.21
June Precipitation (in.)	201	3.52	2.53
July Precipitation (in.)	201	4.24	2.10
August Precipitation (in.)	201	3.94	2.39
May Average Temperature (°F)	201	70.73	2.70
June Average Temperature (°F)	201	78.93	2.37
July Average Temperature (°F)	201	81.15	2.20
August Average Temperature (°F)	201	80.24	2.50
Field Size (ac)	201	54.28	29.72
Zero-One Dummy Variables			
Non-Hybrid Rice	117	0.58	---
Hybrid Rice	84	0.42	---
Silt Loam Textured Soils	106	0.53	---
Clay Textured Soils	91	0.45	---
Sandy Textured Soils	4	0.02	---
Contour Levees, No MIRI[c]	56	0.28	---
Contour Levees, MIRI	23	0.11	---
Straight Levees, No MIRI	40	0.20	---
Straight Levees, MIRI	40	0.20	---
Zero-Grade	23	0.11	---
Furrow (Row) Rice	19	0.09	---
East-Central Arkansas	71	0.35	---
Northeast Arkansas	71	0.35	---
Southeast Arkansas	47	0.23	---
Other Arkansas Regions	12	0.06	---
Non-Marginal Field	188	0.94	---
Marginal Field	13	0.06	---

[a] N = number of observations (or fields).

[b] SD = standard deviation.

[c] MIRI = multiple inlet rice irrigation.

Table 2. Regression Analysis of Irrigation Water Applied to University of Arkansas System Division of Agriculture Rice Research Verification Program fields.

Independent Variables	Coefficients	
May Precipitation (in.)	-2.7494[a]	***[b]
	(0.7004)	
May Precipitation^2 (in.)	0.1790	***
	(0.0481)	
June Precipitation (in.)	-0.3767	
	(0.2666)	
July Precipitation (in.)	0.1547	
	(0.3120)	
August Precipitation (in.)	-0.7954	***
	(0.2521)	
May Average Temperature (°F)	-0.1296	
	(0.2254)	
June Average Temperature (°F)	-0.1615	
	(0.3096)	
July Average Temperature (°F)	0.2933	
	(0.3653)	
August Average Temperature (°F)	-0.1341	
	(0.2942)	
Field Size (ac)	-0.0004	
	(0.0176)	
Hybrid Rice	-2.5902	**
	(1.2749)	
Clay Textured Soils	-4.1388	***
	(1.1605)	
Sandy Textured Soils	25.9556	***
	(6.2185)	
Contour Levees, MIRI [c]	0.0726	
	(2.0626)	
Straight Levees, No MIRI	-1.8803	
	(1.8035)	
Straight Levees, MIRI	-3.2310	*
	(1.9403)	
Zero-Grade	-5.5029	***
	(1.7978)	
Furrow (Row) Rice	1.0935	
	(2.4875)	

Continued

Table 2. *Continued.*

Independent Variables	Coefficients	
Northeast Arkansas	0.3773	
	(1.5990)	
Southeast Arkansas	1.7077	
	(1.7044)	
Other Arkansas Regions	-0.8771	
	(2.5108)	
Marginal Field	28.9773	***
	(3.1661)	
Constant	50.6192	
	(31.2303)	
Observations	201	
F-Statistic	14.0600	
R^2	0.6179	
Root Mean Square Error	8.1051	

[a] Values in parentheses are robust standard errors.

[b] Asterisks ***, **, and * represent statistical significance levels at the 1%, 5%, and 10% levels, respectively.

[c] MIRI = multiple inlet rice irrigation.

APPENDIX: RICE RESEARCH PROPOSALS

2023–2024 Rice Research Proposals

Principle Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
N. Bateman	B. Thrash and N. Joshi	Rice Insect Management	2 of 3	$130,000
K. Brye	D. Lunga and T. Roberts	Biochar Effects on Greenhouse Gas Emissions from Simulated Furrow-Irrigated Rice in the Greenhouse	1 of 1	$16,978
K. Brye	T. Roberts	Struvite Effects on N_2O Emissions from Row Rice in a P-Deficient Silt-Loam Soil	1 of 1	$17,475
T. Butts	T. Barber and J. Norsworthy	A Team Approach to Improved Weed Management in Rice	2 of 3	$250,000
G. Drescher	T. Roberts and J. Hardke	Rice Fertilization–Developing Novel Methods to Assess Nutrient Availability to Arkansas Rice	2 of 3	$58,000
J. Hardke	T. Roberts, X.Sha, C. De Guzman, and N. Bateman	Agronomic Production Practices for Rice	2 of 3	$99,500
J. Hardke	T. Roberts, X.Sha, C. De Guzman, and N. Bateman	DD50 Thermal Unit Thresholds and Seeding Date Effects for New Rice Cultivars	2 of 3	$63,000
J. Hardke	T. Roberts, X.Sha, C. De Guzman, and N. Bateman	Nitrogen Recommendations for New Rice Cultivars	2 of 3	$59,000
T. Roberts	G. Drescher and J. Hardke	Nitrogen Management Tools for Arkansas Rice Producers	2 of 3	$115,000
B. Watkins	A. Durand-Morat and R. Mane	Economic Analysis of Arkansas Rice Farms	2 of 3	$55,000
C. De Guzman	X. Sha, J. Hardke, Y. Wamishe, and P. Counce	Breeding and Development of Improved Long-Grain and Aromatic Rice Varieties	2 of 3	$310,000
J. Hardke	T. Roberts, X.Sha, C. De Guzman, and N. Bateman	Arkansas Rice Variety Advancement Trials	2 of 3	$94,000
J. Hardke	T. Roberts, X.Sha, C. De Guzman, and N. Bateman	Arkansas Rice Performance Trials	2 of 3	$100,000
X. Sha	C. De Guzman and J. Hardke	Quality Analysis for Rice Breeding and Genetics	2 of 3	$117,247
X. Sha		Development of Superior Medium-Grain and Long-Grain Rice Varieties for Arkansas and the Mid-South	2 of 3	$315,000
X. Sha		Breeding Hybrid Rice Varieties for Arkansas and Southern U.S.	2 of 3	$190,000
X. Sha	C. De Guzman	Puerto Rico Winter Nursery	1 of 3	$70,000
C. De Guzman	X. Sha	Rice Breeding and Pathology Technical Support	2 of 3	$145,000

Continued

2023–2024 Rice Research Proposals, continued

Principle Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
A. Rojas	C. Nicolli	Monitoring and Management of Fungicide Resistance of Sheath Blight in Arkansas	1 of 3	$22,000
J. Hardke	B. Watkins and R. Mazzanti	Rice Research Verification Program	2 of 3	$111,296
G. Atungulu		Study of Cultivar Attributes and Their Measurements to Improve Rice Milling and Functional Characteristics	2 of 3	$60,000
S. Lafontaine	G. Atungulu	Investigating the Impact of Rice Variety on the Volatile Profiles and Quality of Rice Malt, Rice, and Beverages (i.e., Beer, Nonalcoholic Beer, etc.)	1 of 1	$23,457
L. Nalley	A. Durand-Morat and. G. Atungulu	Segregating Rice Varieties for Milling and Marketing: The Potential Impact on Producer Returns and Export Market Opportunities in Arkansas	1 of 3	$35,852
A. Pereira	P. Counce	Improving Grain Yield and Quality Under High Nighttime Temperature Using Functional Gene Markers	1 of 3	$40,000
A. Durand-Morat	B. Watkins and R. Mane	Analysis of Farm Policy Programs and Competitiveness of Arkansas and U.S. Rice	1 of 3	$20,000
V. Ford	B. Watkins	Rice Enterprise Budgets and Production Economic Analysis	(Ongoing)	$7,500
C. Henry	K. Brye, R. Mane, and M. Reba	Climate Smart 300 Bushel Row Rice on 12 inches of Automated Irrigation	2 of 3	$85,000
			Total:	**$2,610,305**
Projects Completed and Not Resubmitted This Year				
A. Johnson	V. Boyett and X. Sha	Marker-Assisted Selection for Advanced Rice Breeding and Genetics (Completed Year 1)	Completed	$0