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of University Professor
Bobby R. Wells

This Research Series is dedicated to Dr. Bobby R. Wells who served as its editor from its inception in 1991 until his death in 1996.

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FOREWORD

The research reports in this publication represent one year of results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication dealing with soil fertility also appear in Arkansas Soil Fertility Studies 1996, Arkansas Agricultural Experiment Station Research Series 455. This duplication is the result of the overlap in research coverage between the two series and our effort to inform Arkansas rice producers of all the research being conducted with funds from the rice check-off.

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CONTENTS

ONGOING STUDIES: BREEDING, GENETICS AND PHYSIOLOGY

ONGOING STUDIES: PEST MANAGEMENT: WEEDS

ONGOING STUDIES: PEST MANAGEMENT: INSECTS

ONGOING STUDIES: PEST MANAGEMENT: DISEASE

ONGOING STUDIES: RICE CULTURE

ONGOING STUDIES: ECONOMICS

COMPLETED STUDIES

ONGOING STUDIES: BREEDING, GENETICS AND PHYSIOLOGY

UTILIZATION OF CHINESE RICE CULTIVAR GERMPLASM TO IMPROVE ARKANSAS RICE CULTIVARS:

Developing Physiological Criteria to Enhance Cultivar Development

P.A. Counce, K.A. Gravois, T.J. Siebenmorgen and T.A. Costello

ABSTRACT

The cooperative rice breeding program in Arkansas has developed valuable rice cultivars for many years. Knowledge of the rice plant's physiology can be harnessed to develop improved new cultivars. The grain-filling process begins when sucrose enters the endosperm of the developing rice kernel. At this point, the sucrose must be broken down into its component parts (glucose and fructose). Fructose is converted to glucose, which is the basic building block of starch. From this point, the metabolic steps lead to starch formation and continuation of the process of grain-filling. Sucrose breakdown is a potentially rate-limiting step this process. Our objectives were to identify why 'Gui-chao2' yields more than U.S. rice cultivars and lines and to compare the activities of several enzymes coupled to sucrose breakdown and subsequent metabolism of the products into starch. We found that 'Lemont', Gui-chao2, 'Qi-gui-zao' and their F-1 hybrids have higher sucrose synthase and pyrophosphate phosphofructokinase activity in some cases, but not in others. The data strongly suggest that Qi-gui-zao may share yield and sucrose synthase traits from Gui-chao 2, one of its parents. Consequently, much can be gained by efforts to understand the physiological differences between Gui-chao2 and Qi-gui-zao and the U.S. rice cultivars.

INTRODUCTION

Several Chinese rice cultivars are extremely high yielding (as much as 60 bu/acre more than U.S. rice cultivars). These Chinese cultivars offer potentially valuable germplasm resources for U.S. rice breeders because they generally have good agronomic traits (short stature, erect leaves, high yield potential and disease resistance). The Chinese cultivars probably have genes that are not contained in U.S. cultivars. It is likely that these genes can contribute additively to the yielding ability of the U.S. cultivars. The drawback with the Chinese cultivars is that their grain quality, milling yields and lodging resistance are below those of U.S. cultivars.

Our overall goal is to discover the yield-enhancing factors that are genetically transferable from the Chinese rice cultivars. These yield-enhancing factors may be the result of critical processes during grain-filling. Our immediate goal was to compare U.S. rice cultivars with these Chinese rice cultivars and try to determine the physiological basis for the differences. Ultimately, we hope to utilize the high-yield genes derived from the Chinese cultivars and develop new U.S. rice cultivars with superior quality and agronomic characteristics.

PROCEDURES

Experiment I

Field plots were established at the Northeast Research and Extension Center at Keiser, Arkansas, during 1996 on a Sharkey silty clay soil. The experimental design was a randomized complete block with six replications. 'Adair', 'Bengal', Gui-chao, Qi-gui-zao and Lemont cultivars were seeded in 6 ft x 25 ft plots, at a rate of 45 seeds/ft^2 in 7-in. drill rows. In Experiments I, III and IV, rice at the five- to seven-leaf growth stage was fertilized with 120 lb N/acre and flooded within a day. At 0.5-in. internode elongation stage of growth, an additional 30 lb N/acre was applied, and seven days later another 30 lb N/acre was applied to the crop. A flood was maintained until seven days after 50% heading for the latest heading entry in the experiment.

Yield components and harvest indices were determined by cutting at ground level 3.27 ft of the third row from the outside of each plot at maturity and adjusted to 12% moisture content basis. Grain yields were determined from the small plot combine harvest of a 28 in. by 20 ft area from the center of each plot.

Experiment II

In the greenhouse, we grew single rice plants in 2.5-gal containers. Plants were fertilized weekly with a solution of Miracle-Gro. Tillers were tagged and mapped as described in Counce et al. (1996). Five plants from each line were used for enzyme assays, and five plants were used for yield determinations.

Experiment III

The greenhouse-grown plants from Experiment II were transplanted to the field in June of 1996.

Experiment IV

Single rice seeds of Gui-chao2, Lemont/Gui-chao2 F-1, Gui-chao2/Lemont F-1 and Lemont were planted in 6-cm by 6-cm grids in the field in 1996 following the method described by Counce and Keisling (1995).

Enzyme Assays

In Experiments I, III and IV, panicles were tagged on the day of anthesis. Fourteen days after anthesis (10 days after anthesis in Experiment II), panicles were collected and placed on ice for subsequent enzyme analyses.

The enzyme extraction consisted of removing the endosperm from the developing kernels within 3 hours of collection. The endosperm was ground in liquid N_2 and extracted with a 200-mM Hepes extraction buffer followed by desalting and assay, as described by Xu et al. (1989). For the assay, the number of developing kernels and number of panicles were recorded for the assay so that enzyme activity could be expressed on fresh weight per kernel, per panicle or per mg protein basis. Enzymes assayed were sucrose synthase (SuSy), UDP glucose pyrophosphorylase, pyrophosphate phosphofructokinase, (PPiPFK) and NTP-phosphofructokinase. Enzyme assays were done within 7 hours of collection.

RESULTS AND DISCUSSION

Both Gui-chao2 and Qi-gui-zao yielded significantly more grain than the U.S. cultivars in the Experiment I field test (Table 1). Qi-gui-zao produced more culms/ft^2 and panicles/ft^2 than the U.S. cultivars. Gui-chao2 had more culms/ft^2 than Bengal and Lemont, but Gui-chao2 and Adair produced equal numbers of culms/ft^2. Qi-gui-zao and Bengal had more kernels/panicle than Adair. Individual kernel weights were greater for Gui-chao2 and Adair than for the other cultivars. Individual kernel weights were greater for Bengal and Lemont than for Qi-gui-zao. Endosperm sucrose synthase specific activity (activity per mg protein) was greater for Qi-gui-zao than for the other entries but the other four cultivars did not differ in sucrose synthase specific activity. Also, activity per kernel did not differ among the cultivars.

In the greenhouse and subsequently in the field (Experiment III), sucrose synthase activities did not differ among Lemont, Gui-chao2, Qi-gui-zao and their F-1 hybrids (Table 2). In the greenhouse, the Gui-chao2 hybrids tended toward having higher PPiPFK activity per kernel than the parents. In the field, the Gui-chao2/Lemont F-1 hybrid (G/L) had higher PPiPFK activity than Lemont and the Lemont/Gui-chao2 (L/G) F-1 hybrid. In the greenhouse, Qi-gui-zao either had or tended toward having higher PPiPFK activity per mg protein than the other lines. The enzyme PPiPFK is closely coupled in subsequent metabolism of the breakdown products of sucrose and is necessary for grain-filling.

In the grid planted rice in the field, sucrose synthase differences were not statistically significant (Table 3). PPiPFK activities per kernel were higher for Lemont and L/G than for G/L and Gui-chao2. PPiPFK activity per mg protein was higher for the hybrids than for Lemont, but PPiPFK activity did not differ between either hybrid and Gui-chao2.

Gui-chao2 was a parent of Qi-gui-zao (Fig. 1). Consequently, it may share the genes conferring Gui-chao2's higher yielding ability and sucrose synthase activity relative to U.S. cultivars.

Much of our research in the past year (and in the years to come) has been to develop satisfactory protein separation and purification protocols. This method will ultimately allow us to identify and isolate the protein or proteins related to Gui-chao2's high sucrose synthase activity. When we have purified the protein(s) in quantities of 1 to 2 mg, we can proceed to determine the amino acid sequence(s). The amino acid sequence(s) can be used to identify and locate the genes coding for the protein(s). After we identify the gene(s) we have the putative probe for testing the F-10 generation segregated population of F-2 derived lines for high versus low rice yield.

We also have advanced the F-2 derived lines from the Lemont/Gui-chao2, Gui-chao/Lemont and Lemont/Qi-gui-zao crosses to the F-5 generation. We received an antibody to maize sucrose synthase early in 1997 and have the promise of rice sucrose synthase antibodies as soon as they are available. These antibodies are needed to determine the amount of the different forms of sucrose synthase in the endosperm of the different lines.

SIGNIFICANCE OF FINDINGS

This is a long-term research project that has potentially great benefits to Arkansas rice growers in the future. If genes associated with physiologically high yield potential for rice can be identified, rice breeding efficiency can be increased. Early generation testing for these physiological genes can allow us to identify superior lines by using molecular markers and thereby improve breeding selection efficiency. This, in turn, will lead to development of higher-yielding cultivars for Arkansas rice growers. Three intensive research efforts in the U.S. are focused on identifying genes from Chinese rice cultivars with known biochemical value for photoprotection, grain-filling and source-sink characteristics (Fig. 2). Opportunities for productive cooperation are numerous and potentially very valuable to the Arkansas program. The expertise and equipment necessary for completion of all phases of this research are not at one location and the expense to assemble a team to attack the problem at one location is prohibitive. Therefore, the research problem must be approached as a collaborative effort between research and extension centers, universities, states, and committed scientists. An outline of U.S. research efforts on Chinese rice is shown in Fig. 2. Scientists in this group collaborate on all of these efforts.

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Table 1. Yield, yield components and endosperm sucrose synthase and pyrophosphate phosphofructokinase activity in Chinese and U.S. rice cultivars grown at Keiser, Arkansas, in 1996.

						Endosperm enzyme activity/min			
Cultivars	Grain yield	Culms	Panicles	Kernels/ Panicle	Ind. wt. /kernel	SuSy*	PPi PFK	SuSy	PPi PFK
U.S.	bu/acre	------no/ft²------		no.	mg	nmoles/mg protein		nmoles per kernel	
Adair	158bc[†]	58.8b	51.1b	60.7b	26.4a	73.1b	27.5a	18.2	109.8c
Bengal	166b	53.7c	46.5b	88.7a	24.9b	64.5b	15.7b	10.9	97.0b
Lemont	149c	54.7c	50.7b	71.5ab	24.5b	80.7b	17.4b	11.0	121.2a
Chinese									
Gui-chao2	192a	66.6ab	54.4ab	73.7ab	27.0a	99.6b	19.2ab	15.9	173.3ab
Qi-gui-zao	189a	78.5a	63.8a	81.8a	20.6c	172.8a	14.4b	13.5	175.0a

*SuSy = sucrose synthase and PPiPFK = pyrophosphate phosphofructokinase.

[†]Means in the same column followed by different letters are significantly different at the 5% level.

Table 2. Sucrose synthase and pyrophosphate phosphofructokinase (PPiPFK) activity for Chinese and U.S. rice cultivars and lines grown at Keiser, Arkansas in 1996.

	Enzyme activity			
	nmoles/kernel/minute		nmoles/mg protein/minute	
	Drilled-seeded rice in the field			
Cultivars/Lines	Sucrose Synthase	PPiPFK	Sucrose Synthase	PPiPFK
Single plants grown in the greenhouse				
Lemont	29.8a*	26.0ab	136.6a	143.4ab
F-1 Gui-chao2/Lemont	30.5a	27.1ab	135.5a	121.9b
F-1 Lemont/Gui-chao2	30.8a	31.9a	140.5a	142.9ab
F-1 Lemont/Qi-gui-zao	26.8a	27.8a	126.0a	132.1ab
Qi-gui-zao	22.1a	28.4ab	149.6a	191.3a
Gui-chao2	28.5a	23.9b	138.5a	112.2b
Single plants grown in greenhouse (above) and afterward transplanted to field				
Lemont	13.3a	26.8b	63.1a	186.9a
F-1 Gui-chao2/Lemont	15.0a	37.9a	71.4a	157.3a
F-1 Lemont/Gui-chao2	12.0a	27.2b	57.3a	137.9a
Gui-chao2	15.5a	34.8ab	68.1a	145.5a

*Means in the same column between horizontal lines followed by different letters are significantly different at the 5% level.

Table 3. Sucrose synthase and pyrophosphate phosphofructokinase (PPiPFK) activity for Chinese and U.S. rice cultivars grown at Keiser, Arkansas in 1996.

	Enzyme activity			
	nmoles/kernel/minute		nmoles/mg protein/minute	
	Drilled-seeded rice in the field			
Cultivars/Lines	Sucrose Synthase	PPiPFK	Sucrose Synthase	PPiPFK
Lemont	17.0a	45.2a	59.3a	182.2b
F-1 Lemont/Gui-chao2	17.5a	41.3a	94.6a	222.7a
F-1 Gui-chao2/Lemont	16.0a	34.5b	86.8a	186.1a
Gui-chao2	11.2a	38.6b	78.0a	199.5ab

*Values within the same column followed by different letters are significantly different at the 5% level.

The pedigree of Qi-Gui-Zao is as follows:

Gui-yang-ai 49 X Zhao-yang-zao 18
↓
Qi-you-zhan X Gui-chao 2
↓
Qi-gui-zao 25

The pedigree of Teqing is as follows:

Qingerai X Jidulun
↓
U* X Kuoyedao
↓
Teai X Yeqinglun
↓
Teqing

*U refers to a breeding line, not a named cultivar.

Fig. 1. Pedigrees of two Chinese rice cultivars.

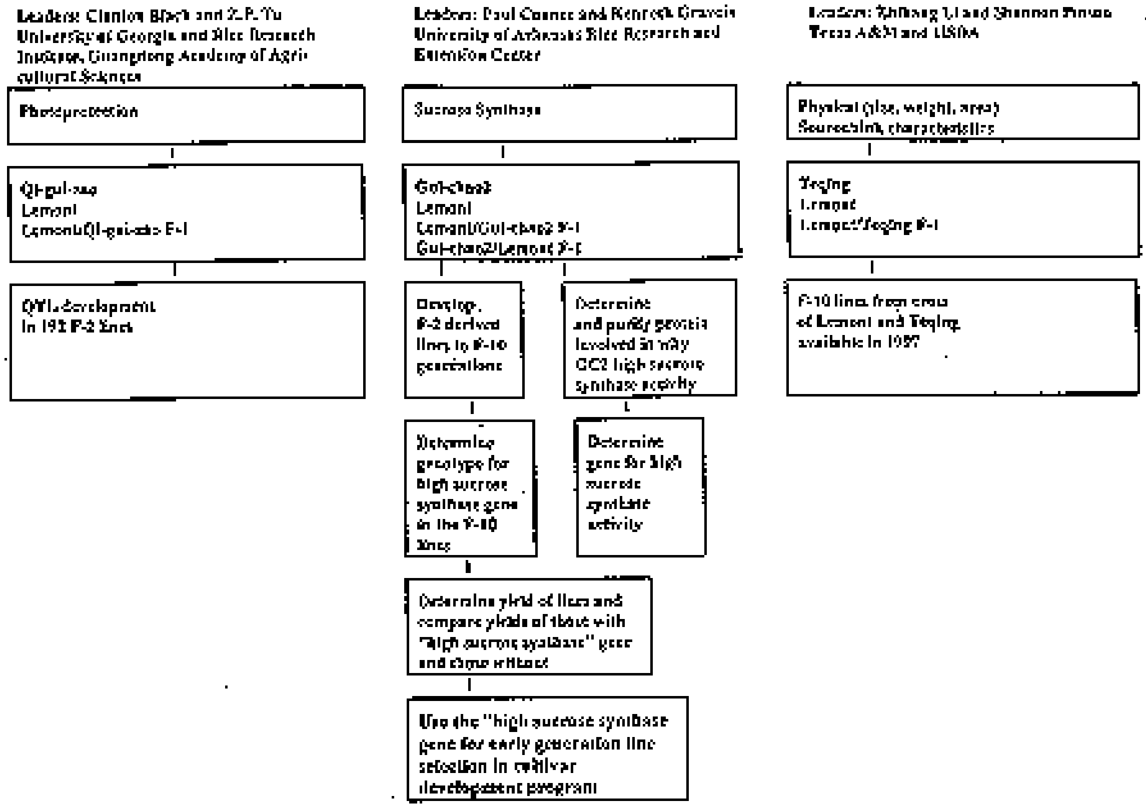

Fig. 2. Cooperative research efforts to find and transfer useful traits from Chinese rice cultivars and add them to U.S. rice cultivars.

EVALUATION OF JAPANESE CULTIVARS FOR GRAIN AND MILLING YIELD IN RICE

R.H. Dilday, W. Yan, K.A. Moldenhauer, K.A. Gravois and F.N. Lee

ABSTRACT

Eighty Japanese rice cultivars that were introduced recently into the USDA, ARS rice germplasm collection were evaluated at Stuttgart, Arkansas, in 1996. Based on previous data, the Japanese cultivars were separated into four maturity groups (Group 1 < 40 to 70 days, Group 2 = 71-80 days, Group 3 = 81-90 days and Group 4 > 90 days). 'Tomekichiwase' (44 days from emergence to heading), 'Wase Shiroke' (46), 'Norin 20' (46) and 'Ishikari-Shirage' (46) were the earliest maturing cultivars in Group 1. The only Japanese cultivar to significantly outyield the U.S. check cultivar in any of the maturity groups was Japan 92-09-31, which produced 11,517 kg/ha compared to 7892 kg/hz for the Orion check. It is being used in the breeding program for its yielding ability, but, unfortunately, it has atypical cooking quality characteristics.

INTRODUCTION

Annually about 20% of the rice (*Oryza sativa* L.) on the world market is produced in the United States (U.S.) (Anonymous, 1994). In recent years, the Japanese government has imported more rice from the U.S. However, traditional Japanese rice cultivars have grain and cooking qualities that are different from those found in the traditional southern U.S. medium-grain rice. Growing Japanese rice cultivars in the U.S. and exporting the grain to Japan could be an advantage to both the Japanese rice consumers and the U.S. rice industry. In fact, 'Koshihikari' and 'Akitakomochi', two popular rice cultivars grown in Japan, have been successfully grown in Arkansas and exported to Japan. The objective of this study was to evaluate Japanese cultivars that have been recently introduced into the U.S. and collect data concerning the yield potential of Japanese cultivars grown in Arkansas.

PROCEDURES

Eighty Japanese rice cultivars that were introduced recently into the USDA, ARS national plant germplasm system were evaluated at Stuttgart, Arkansas, in 1996. Some of the accessions came through quarantine, and others had already passed through quarantine and were obtained from Dr. Kent McKenzie, California Rice Experiment Station, Biggs, California. Based on previous data that were collected concerning the number of days from seedling emergence to heading, these cultivars were separated into four maturity groups (Group 1 < 40 to 70 days, Group 2 = 71 to 80 days, Group 3 = 81 to 90 days and Group 4 > 90 days). U.S. cultivars were included as checks in each maturity group.

The experimental design was a split-plot with four replications (maturity groups being the main plot). The test was seeded 1 May 1996 in six-row plots, 4 ft long with 8-in. row spacings. The seedlings emerged 9 May 1996. Four split applications of ammonia sulfate [preplant incorporated (30 lb N/acre), preflood (60 lb N/acre), 0.5-in. internode elongation (IE) (15 lb N/acre) and 10 days after 0.5-in. IE (15 lb N/acre)] were applied to Group 1 to 3. Five split applications [preplant incorporated (30 lb N/acre), preflood (45 lb N/acre), 0.5-in. internode elongation (IE) (15 lb N/acre), 10 days after 0.5-in. IE (15 lb N/acre) and 20 days after 0.5-in. IE (15 lb N/acre)] were applied to Group 4. Heading dates were recorded when 50% of the panicles had emerged. Plant height was measured from ground level to the tip of the panicle before harvest. All six rows were hand-harvested, and the grain was threshed and dried. Grain moisture was adjusted to 12% for yield analysis. Samples of 120 g each from all four replications were prepared and analyzed for milling yield and quality as outlined by Webb et al., 1982.

RESULTS AND DISCUSSION

The germplasm was separated into four maturity groups. However, yield data from only Groups 2, 3 and 4 will be reported because some accessions in maturity Group 1 were extremely early maturing and were severely damaged by birds.

Maturity Group 1

Tomekichiwase (44 days to heading), Wase Shiroke (46), Norin 20 (46) and Ishikari-Shirage (46) were the earliest-maturing Japanese cultivars in this group. No U.S. cultivar heads in 40 to 45 days after seedling emergence; therefore, Farm Buster, from the Arkansas breeding program, an early-maturing breeding line that heads in about 60 to 65 days after emergence, was used as the U.S. check. Plant height in maturity group 1 ranged from 73 to 93 cm with a mean of 82 cm.

Maturity Group 2

No Japanese cultivar significantly outyielded 'S-101', the U.S. Check cultivar in this gruop. Data are shown in Table 1.

Maturity Group 3

Only Japan 92-09-31 significantly outyielded 'Orion', the U.S. check cultivar in this group (see Table 1). Japan 92-09-31 is a high-yielding cultivar obtained from Japan that has produced significantly higher grain yields than either Mars or Orion from 1993 to 1995 (seven tests) in Arkansas (Yan et al., 1996). In 1996, this cultivar was included in maturity group 3 as a high-yielding check. Japan 92-09-31 produced 11,517 kg/ha and had a significantly higher grain yield than any other accession in any maturity group in 1996. It yielded 3625 kg/ha (45.9%) more than Orion and headed in 78 days. However, as previously reported, Japan 92-09-31 is a medium-grain cultivar with long-grain cooking quality (amylose content = 24%, alkali spreading value = 4.2, gelatinization temperature = intermedium and protein content = 8.3) and is not suitable for U.S. consumption.

Maturity Group 4

Nortai, the U.S. check cultivar in this group, headed in 90 days and yielded 9984 kg/ha. It was one of the highest-yielding U.S. cultivars in any maturity group in 1996. Its yield was significantly higher than that of any Japanese cultivars in this group (Table 1).

SIGNIFICANCE OF FINDINGS

New Japanese cultivars were evaluated for grain yield, plant height, maturity and milling yield, and they will be added to the USDA, ARS rice germplasm collection. The cultivars had a wide range in maturity, plant height, grain and milling yield, and some accessions appear to be adapted to southern U.S. environments, especially Arkansas. Tomekichiwase is an extremely early maturing cultivar (44 days to heading). Since the yield potential of Japan 92-09-31 appears to be very high, it is being used as a parent in the Arkansas cultivar development program, even though it has atypical cooking characteristics.

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Table 1. Grain yield, days from seedling emergence to heading, plant height and milling yield of Japanese rice cultivars evaluated at Stuttgart, Arkansas, in 1996.

Cultivar	Grain Type	Yield	Head	PHT	Milling Total	Milling Head
		kg/ha	day	cm	-------%------	
Maturity group 2						
Niiqatawase	S*	7032	75	97	71	69
Chiyonishiki	S	7620	75	96	71	69
Hatsukoshiji	S	7742	75	107	71	65
Nigataurase	S	7290	74	91	71	68
S-101	S	6916	70	82	69	65
LSD $_{(0.05)}$		1238	2	8	3	3
Maturity group 3						
Japan 92-09-31	S	11517	78	100	69	61
Yamalanishiki	S	7137	80	108	67	63
Aoisora	S	7179	89	88	68	65
Yukinosei	S	7196	80	113	71	68
Shimezumochi	S	7880	77	156	68	60
Orion	M	7892	80	109	67	64
LSD $_{(0.05)}$		1294	3	8	2	3
Maturity group 4						
Akenohoshi(Japan)	S	8181	97	93	65	60
Jugoyamochi	S	7062	100	96	68	63
Kijumochi	S	7450	100	100	69	62
Nihonbare	S	7277	90	93	68	65
Nortai	S	9984	90	109	69	66
LSD $_{(0.05)}$		1204	2	8	2	5

*S = short grain; M = medium grain.

EVALUATION OF LIBERTY-RESISTANT RICE IN ARKANSAS

K.A. Gravois, K.A.K. Moldenhauer, F.L. Baldwin and S.D. Linscombe

ABSTRACT

Herbicide-resistant crops permit the use of new herbicides previously detrimental to the crop. Liberty-resistant rice would permit the use of a broad-spectrum, nonselective herbicide able to control most of the major rice weeds, including red rice. In 1996, a Liberty-resistant rice trial was conducted at the Rice Research and Extension Center at Stuttgart, Arkansas. Yield decline was evident in most of the transformed rice lines of ‘Bengal’, ‘Cypress’ and ‘Gulfmont’, although not evident in the ‘Koshihikari’ lines. Initially, farmers may be willing to forfeit some yield potential for the benefit of weed control, especially control of red rice. The *bar* gene for resistance to the herbicide is inherited as a single dominant gene, and field screening for the gene is relatively easy. Thus, traditional breeding efforts to improve the yield potential of transformed varieties should be readily achievable.

INTRODUCTION

Liberty (glufosinate) is a non-selective, broad-spectrum herbicide that controls most of the weeds, including red rice, encountered in U.S. rice production. Recent successful commercialization of herbicide-resistant crops such as corn, soybeans and cotton has sparked interest in developing this technology for rice. AgrEvo USA owns both the herbicide Liberty and the *bar* gene, which confers resistance to Liberty when present in the crop. Recently, AgrEvo USA classified rice as a priority crop for the development of Liberty-resistant technology.

The *bar* gene confers resistance to the herbicide Liberty when the gene is part of the genetic make-up of the plant. The *bar* gene encodes the enzyme phosphinothricin acetyltransferase. Proper expression of the *bar* gene leads to detoxification of phosphinothricin and its derivatives, which are active ingredients in some commercial herbicides. Thus, if the *bar* gene is introduced into a rice cultivar, Liberty could be applied to the rice crop without harm, while controlling many major rice weeds, including red rice. The only current means of controlling red rice is by crop rotation and herbicidal control in the alternate crops.

In 1996, 14 rice lines transformed with the *bar* gene were evaluated at the Rice Research and Extension Center at Stuttgart, Arkansas. Our objective was to assess grain and milling yield and other agronomic traits for the 14 rice lines transformed with the *bar* gene compared to their respective nontransformed parent line.

PROCEDURES

The experiment was conducted during 1996 on a Crowley silt loam. Fourteen Liberty-resistant rice lines, transformed with the *bar* gene, were evaluated along with the nontransformed parents. The transformed lines included six Cypress lines, four Bengal lines, two Gulfmont lines and two Koshihikari lines. The lines were transformed via electric-discharge particle acceleration of immature zygotic embryos (Cristou et al., 1991). The experimental design was a randomized complete block (three replications) with a split plot arrangement of treatments. The whole plots were rates of Liberty (no Liberty, 1 lb ai/acre and 2 lb ai/acre). The subplots were the rice varieties. The plots were 12 ft long and 5 ft wide (7 rows on 8-in. centers). The test was planted 10 May 1996. The Liberty treatments were applied 15 June 1996 when the rice was in the four- to five-leaf stage, and the test was flooded 18 June 1996. Maturity was measured as days to 50% heading, and plant height was measured from the ground to the tip of the panicle. The plots were rated for lodging just before harvest. The Koshihikari plots were hand-harvested on 23 September 1996, and the remaining plots were combine-harvested 25 September 1996. Ten feet of the center five rows was harvested. The samples were dried, and yield was calculated as lb/acre and adjusted to 12% moisture content. Head rice was determined using 125-g samples of cleaned rough rice. The rough rice was hulled with a Satake huller, milled in a McGill #2 mill for 30 seconds and size separated. Whole milled kernels (head rice) and total milled rice (whole and broken milled kernels) were expressed as a percentage of the 125-g rough rice sample. Kernel weight was determined by counting and weighing 100 whole milled kernels.

RESULTS AND DISCUSSION

One of the most important issues when evaluating newly transformed varieties is to determine if the transformation process caused other varietal changes in addition to having the *bar* gene present. A significant variety x Liberty rate interaction would indicate that the rice varieties performed differently at the Liberty rates (Table 1). This interaction was significant for grain yield and kernel weight. A significant variety x Liberty rate interaction may indicate the presence of “yield drag” if the yield at the 0-Liberty rate was significantly higher than the 1-lb and 2-lb Liberty rates or if the yield of any transformed line was significantly lower than that of its nontransformed parent.

The effect of Liberty rate on rice variety performance for maturity, height, lodging and kernel weight is shown in Table 2. Within a variety, Liberty rate did not affect maturity and height. The difference between transformed lines and their nontransformed parent for maturity and height was negligible. Nontransformed Bengal and Cypress kernel weights were significantly greater than all of their transformed lines at each herbicide rate.

The effect of Liberty rate on rice variety performance for grain yield, head rice and total milled rice is shown in Table 3. Grain and milling yield in the transformed lines of Koshihikari was not significantly lower than that of the nontransformed parent. However, grain yield reductions (whether significant or numerically lower) were apparent for the transformed lines of Gulfmont, Bengal and Cypress. The milling yields of the Bengal transformed lines did not show significant reductions compared to the nontransformed Bengal. The transformed Gulfmont lines had significantly lower milling yields than the nontransformed Gulfmont at each herbicide rate. The majority of the transformed Cypress lines at the different Liberty rates exhibited significant milling yield reductions.

SIGNIFICANCE OF FINDINGS

The transformation of southern U.S. rice cultivars with the *bar* gene represents an unprecedented opportunity for the southern U.S. rice industry. The use of Liberty within the rice crop could give the industry weed control options once thought impossible. Instead of tolerating the presence of red rice, this weed can be controlled with Liberty rather than with crop rotation.

For the Liberty-resistant technology to be of full benefit to rice farmers, the varieties that have the *bar* gene should be agronomically similar to the nontransformed parent. Maturity and plant height changes in transformed varieties were small. Kernel weight tended to decrease in the transformed lines. The data indicate that most of the transformed lines of Cypress, Bengal and Gulfmont exhibited yield reductions when compared to the nontransformed parent. Data from the Koshihikari lines indicate that transformation does not always reduce yield.

Yield decline in newly transformed rice lines may be an issue. Initially, farmers may be willing to forfeit some yield potential for the benefit of weed control, especially control of red rice. The *bar* gene is inherited as a single dominant gene, and field screening for the gene is relatively easy. Thus, traditional breeding efforts to improve the yield potential of transformed varieties should be achievable.

None of the currently transformed lines tested here will be marketed because they do not have the desired profile to meet intellectual property rights standards. During spring 1996 'Kaybonnet', 'Drew' and two experimental varieties from Arkansas (RU9401188 and RU9501121) were sent to be transformed with a desirable profile. Small quantities of seed should be available for initial screening during the 1997 growing season. If seed can be adequately expanded, a small commercial acreage of Liberty-resistant rice could be seeded in 2001.

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Table 1. Analysis of variance for the Liberty rice trial conducted at Stuttgart, Arkansas, during 1996.

Source	df	Grain yield	Milling yield Head	Milling yield Total	Kernel weight	Maturity	Height
		Mean Squares					
Liberty rate	2	6571060.2	5.92	2.42	3.75	16.17*	115.83*
Rep	2	122720.0	2.81	0.89	0.20	0.12	58.85
Rep*Liberty rate	4	939961.5*	1.80	0.54	0.09	0.66	14.40
Variety	17	8066136.5**	99.9**	20.16**	21.64**	145.02**	67.62**
VarietyxLiberty rate	26	821701.9**	2.06	0.57	0.26*	1.82	22.86

*, ** indicate significance at the 0.05 and 0.01 probability levels, respectively.

Table 2. The effect of Liberty rate (lb ai/acre) on transformed and nontransformed rice lines for maturity, height lodging and kernel weight.

Variety/Liberty rate	Maturity 0 lb	Maturity 1 lb	Maturity 2 lb	Height 0 lb	Height 1 lb	Height 2 lb	Lodging 0 lb	Lodging 1 lb	Lodging 2 lb	Kernel weight 0 lb	Kernel weight 1 lb	Kernel weight 2 lb
	-------days------			-------cm------			-------%-------			-----------mg----------		
Koshihikari	82			114			70			19.8		
Koshihikari 496-2R-1	82	82	83	109	99	102	70	70	70	20.3	20.9	20.1
Koshihikari 496-4R-1	82	82	82	102	99	101	70	70	70	20.5	20.4	19.8
Gulfmont	87			103			0			19.4		
Gulfmont 517-7-R-1	88	89	88	106	109	104	0	0	0	19.0	18.9	19.3
Gulfmont 517-1-R-1	87	89	88	102	106	101	0	0	0	19.8	18.7	19.3
Bengal	80			103			13			20.4		
Bengal SX-2	79	80	80	103	99	101	0	27	0	18.9	18.7	18.9
Bengal HU-10	79	81	80	108	108	104	10	17	23	19.2	19.1	18.8
Bengal HC-11	79	79	80	109	103	107	30	3	0	19.1	19.5	19.2
Bengal HC-6	78	80	80	106	104	104	0	0	0	19.5	18.5	18.9
Cypress	88			109			40			18.2		
Cypress PB-6	89	88	89	112	107	109	20	0	10	16.0	16.3	16.5
Cypress PB-12	89	89	90	109	106	110	10	0	0	16.3	16.3	16.4
Cypress PB-13	89	88	89	111	110	106	40	0	0	16.6	16.7	16.3
Cypress PB-14	88	90	90	105	102	103	0	0	0	15.8	15.7	15.4
Cypress PB-15	88	91	92	109	97	101	0	0	0	16.5	15.8	15.7
Cypress PB-2	88	89	90	103	108	105	10	0	10	16.6	16.3	16.2

The LSD (P = 0.05) to compare two variety means at the same herbicide rate was 0.4 for kernel weight. The LSD (P = 0.05) to compare two herbicide means at the same or different variety was 1, 12 and 0.6 for maturity, height and kernel weight, respectively.

Table 3. The effect of Liberty rate (lb ai/acre) on transformed and nontransformed rice lines for grain yield and milling yield (head rice-total milled rice).

	Grain yield			Head - Total		
Variety/Liberty rate	0 lb	1 lb	2 lb	0 lb	1 lb	2 lb
	-------------lb/acre------------			--------------% - % -----------		
Koshihikari	5128			70-74		
Koshihikari 496-2R-1	5528	5064	5404	73-75	71-74	72-75
Koshihikari 496-4R-1	5778	5896	5531	71-74	72-74	72-75
Gulfmont	5657			68-73		
Gulfmont 517-7-R-1	5370	4757	5116	63-71	61-71	63-72
Gulfmont 517-1-R-1	5269	4798	5117	63-72	64-71	64-71
Bengal	7236			65-72		
Bengal SX-2	6664	5221	6192	67-72	66-72	66-72
Bengal HU-10	6786	6476	5941	66-72	66-72	66-72
Bengal HC-11	6306	6118	5812	66-72	67-73	67-72
Bengal HC-6	6161	6169	5741	67-72	67-72	65-71
Cypress	5227			65-71		
Cypress PB-6	4013	3758	3704	58-69	59-69	60-69
Cypress PB-12	4309	4291	4154	60-70	62-70	61-70
Cypress PB-13	4564	4713	4338	64-71	64-70	62-69
Cypress PB-14	4510	4328	4266	63-71	62-70	63-70
Cypress PB-15	4996	2004	1464	66-71	64-70	63-70
Cypress PB-2	4209	4189	3830	63-70	63-70	65-71

The LSD (P = 0.05) to compare two variety means at the same herbicide rate was 479 for grain yield. The LSD (P= 0.05) to compare two herbicide means at the same or different variety was 720, 1 and 1 for grain yield, head rice and total rice, respectively.

BREEDING AND EVALUATION FOR IMPROVED RICE VARIETIES - THE ARKANSAS RICE BREEDING AND DEVELOPMENT PROGRAM

K.A.K. Moldenhauer, K.A. Gravois, F.N. Lee, R.J. Norman, J.L. Bernhardt, B.R. Wells, M.M. Blocker and T.A. McMinn

ABSTRACT

The Arkansas rice breeding program is an ongoing program involving the development of new varieties, the testing of these varieties and the identification of important characteristics for further improvement. Disease resistance as well as high-yield potential, excellent milling yields, improved plant type (i.e., short stature, semi-dwarf, earliness, erect leaves) and superior quality (i.e., cooking, processing and eating) are all important components in this program. Currently there are several promising lines in all stages of this program. They are lines with improved plant type, high grain and milling yields, disease resistance and acceptable cooking quality. New cultivars will be released to rice producers in the future for the traditional Southern U.S. long- and medium-grain markets as well as for the emerging specialty markets.

INTRODUCTION

The rice breeding and genetics program at the University of Arkansas Rice Research and Extension Center (RREC) at Stuttgart, Arkansas, is by nature a continuing project with the goal of producing new, improved rice cultivars for the clientele in Arkansas and the Southern U.S. rice growing region. Releasing cultivars with standard cooking quality, excellent milling and grain yields and improved plant type and disease resistance has been the objective of this program. Through the years, improving disease resistance and/or tolerance has been a major goal. Blast resistance has been addressed through research by visiting scholars and graduate students and by the release of 'Katy'(Moldenhauer et al., 1990), 'Kaybonnet'(Gravois et al., 1994) and 'Drew'. Anther culture has also been utilized to speed up the breeding program for blast-resistant lines. Sheath blight tolerance has been an ongoing concern, and the cultivars produced by this program have had the best sheath blight tolerance of any in the U.S. A recurrent selection program for increased sheath blight tolerance, which is a long-term approach to increasing resistance, was implemented in 1983. Information on the recurrent selection program was presented in the 1993 Rice Research Series (Moldenhauer et al., 1994a). As interest in specialty rices has increased, the program has taken on the added task of working to develop agronomically acceptable rice cultivars that are aromatic or have Japanese quality. Significant yield increases have been realized with the release of the last four long-grain cultivars developed in this program, 'Adair'(Gravois et al., 1994), 'LaGrue' (Moldenhauer et al. 1994b), Kaybonnet and Drew. Other lines currently in the program have the potential to be new cultivars that will offer even further increases in yield potential.

PROCEDURES

The rice breeding program continues to utilize the best available parental material from all sources, including other breeding programs in the U.S., the USDA World Collection and International programs such as CIAT and IRRI. Crosses are made each year to incorporate genes for broad-based disease resistance, improved plant type (i.e., short-stature and semidwarf, earliness, erect leaves), superior quality (i.e., cooking, processing and eating) and N-fertilizer use efficiency into highly productive, well-adapted lines. Early generation selections are chosen from the various crosses each year, and these are advanced a generation at the winter nursery in Puerto Rico. As outstanding lines are selected and advanced, they are evaluated extensively for yield, milling and cooking characteristics, insect tolerance by the entomologist and disease resistance by the pathology group. The advanced lines (experimental varieties) are extensively evaluated for proper timing and rate of N-fertilization practices by the soil fertility group and for response to recommended weed control practices. The rice breeding program utilizes all feasible breeding techniques and methods, including hybridization, backcrossing, mutation breeding and biotechnology (anther culture, tissue culture and transgenic rice) to produce breeding material and new cultivars. Segregating populations and advanced lines are evaluated for grain and milling yields, quality traits, maturity, plant height and type and disease and insect resistance, as appropriate. The winter nursery in Puerto Rico is utilized to accelerate generation advance and breeders seed increases of potential cultivars. The state-wide rice performance testing program, which includes experimental rice varieties and promising new lines developed in the Arkansas program and from cooperating programs in the other rice-producing states, is carried out each year to select the best materials for future release and to provide producers with current information on rice performance of current cultivars.

RESULTS AND DISCUSSION

Drew, the new blast-resistant, high-yielding, long-grain rice cultivar developed in this project was released to qualified seed growers for the 1996 growing season. It originated from the cross 'Newbonnet'/Katy made in Stuttgart in 1986 and was selected from the 1989 panicle row STG89L24-139. It has high yield potential, straw strength and sheath blight tolerance similar to Newbonnet, blast resistance similar to Katy, straighthead reactions like 'Cypress' and 'Lemont' and excellent total and head rice yields. Data were presented on Drew in the 1995 Rice Research Series (Moldenhauer et al., 1996).

Currently there are several promising lines in the breeding program. They have come from all phases of the program (short-stature crosses, blast resistance crosses, recurrent selection for sheath blight, anther culture and earliness crosses). Among these are two semidwarf experimental varieties (RU9401188 and RU9501121) selected from a cross numbered 88427, which is from the recurrent selection program for sheath blight. These varieties are not sheath-blight tolerant, but they have excellent grain yields similar to LaGrue, good milling yields and the blast resistance of Katy. Both varieties have a kernel size larger than Katy and Kaybonnet. Breeder head rows of both new types were grown in 1996. A foundation seed field of RU9401188 will be grown in 1997. Currently these experimental varieties are in the Arkansas Rice Performance Trials (Table 1) and Uniform Regional Rice Nursery (URRN).

Five short-grain experimental varieties (RU9601081, RU9601093, RU9601096, RU9601099 and RU9601102) from Koshihikari crosses were also in the ARPT (Table 2) and URRN in 1996. Four of these lines were high yielding and had excellent milling yields with improved texture and taste for the Japanese market when compared to typical southern U.S. medium-grain cultivars. Initial sensory evaluation suggests that these lines are closer to the Japanese type of rice than are 'Mars' and 'Bengal'. Currently, they are being rescreened for quality characteristics. RU9601096 and RU9601099 will be in the ARPT and URRN in 1997. Through this program we hope to develop a high-yielding, agronomically adapted, Japanese-quality short- or medium-grain rice that will be acceptable to the Japanese market.

Another exciting entry in the ARPT in 1996 was RU9601053, a short-season experimental variety with the parentage Newbonnet/3/Lebonnet/9902//Labelle. It yielded as well as LaGrue and had good milling yields in the 1996 ARPT (Table 1). It is short statured and may carry the semidwarf gene. Like LaGrue this variety may be susceptible to the common blast races. Further evaluations will be made on it in 1997.

There are many lines in the Stuttgart Initial Test that are showing outstanding yield potential. They will be in the Arkansas Rice Performance Trials and the Uniform Regional Rice Nursery in 1997. One of these has shown some potential alleopathic properties. Utilizing germplasm that Dr. Dilday has shown to have allelopathy is another effort being implemented in this project. Crosses were made in 1991 with some of this material. One line, which performed very well in the preliminary plots this year, will be in the SIT in 1997, and several others will be in the preliminary test in 1997. These lines are currently being screened to see if they carry the genes for allelopathy.

Rice blast (*Pyricularia grisea*) can be a devastating disease in Arkansas. Races IB-49 and IC-17 are currently the major races in Arkansas. Studies are being conducted to look at the inheritance of rice blast races IE-1k and IB-33. IE-1k and IB-33 are two races of the pathogen that could become a problem in the future; therefore, we are studying the inheritance of resistance to these blast races and collecting lines that have resistance to these races. A program is also underway to incorporate the genes for blast resistance from Raminad Strain #3, an international rice blast differential that has resistance to all of the races in the Southern U.S. The resistant lines from this study will be included in the breeding and testing program and evaluated for cooking quality and agronomic characteristics.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding program is to develop cultivars with maximum yield and good levels of disease resistance for release to Arkansas rice producers. The release of Drew to qualified seed growers for the 1996 growing season and the existence of the potential release RU9401188 is an example of the continued progress that is being realized through this program. Improved lines from this program will continue to be released as cultivars in the future. They will have the characteristics of improved disease resistance, plant type, and grain and milling yields. In the future new rice cultivars will be released, not only for the traditional Southern U.S. long- and medium-grain markets but, for specialty markets as they arise.

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Table 1. Data from the 1996 Arkansas Rice Performance Trials for three experimental varieties and five check cultivars.

Cultivar/ variety	Grain type	Yield	Height	Maturity 50% HD	Kernel weight	Milling HR:TOT
		bu/acre	in.	days	mg	
RU9401188	L	167	37	79	16.20	62-71
RU9401121	L	171	38	79	17.00	60-71
RU9601053	L	178	38	81	18.60	65-74
LaGrue	L	177	41	81	18.40	65-72
Jodon	L	159	35	81	17.80	64-72
Kaybonnet	L	136	40	82	14.90	67-73
Laffite	M	165	36	80	18.00	69-73
Bengal	M	187	35	81	20.70	68-74
$C.V._{(0.05)}$		10.2	3.8	2.4	3.40	3.6-0.5
$LSD_{(0.05)}$		11	1	1	1.15	5-1

Table 2. Data from the 1996 Arkansas Rice Performance Trials for five lines from crosses involving Koshihikari as a parent and two check cultivars.

Cultivar/ variety	Grain type	Lodging	Yield	Height	50% HD	Kernel weight	Milling HR:TOT
		%	bu/acre	in.	days	mg	
Koshihikari	M	60.8	126	41	81	18.90	71-75
M202	M	34.2	151	38	72	21.20	65-71
RU9601081	M	5.0	169	38	73	20.00	69-75
RU9601093	M	8.3	173	38	75	19.30	71-75
RU9601099	M	0.0	173	38	75	20.10	71-75
RU9601096	M	0.0	169	35	74	19.30	69-75
RU9601102	M	61.7	131	43	74	18.50	67-75
$C.V._{(0.05)}$			10.7	4.4	2.2	4.40	3.4-1.1
$LSD_{(0.05)}$			11	1	1	1.67	5-2

ONGOING STUDIES: BREEDING, GENETICS AND PHYSIOLOGY

RICE GENETICS AND GERMPLASM ENHANCEMENT

J. Neil Rutger

ABSTRACT

Twelve semidwarf mutants induced in tall Arkansas cultivars were observed in 1995 and 1996 plantings at Stuttgart, Arkansas. These mutants have height reductions ranging from 9 to 25%. Nine additional semidwarfs were observed for the first time in 1996. Preliminary genetic studies on the first 12 mutants, plus five in the second group, indicate that 16 have semidwarfing genes different from, and one the same as sd 1, the semidwarfing gene used worldwide. Several of these semidwarfs have been provided to University of Arkansas colleagues for further evaluation and use.

One putative photosensitive genetic male sterile (pgms) mutant has been identified. The pgms types are potentially useful for simplifying hybrid rice seed production. Investigations on developing apomixis, for true-breeding hybrid rice, are underway.

INTRODUCTION

The present project was initiated in late 1993 with the broad aims of identifying useful genes, determining their inheritance and using them to develop or enhance germplasm that is useful to rice breeders, and ultimately, to rice growers. The project is not directly funded by the Arkansas Rice Research and Promotion Board but benefits indirectly from interactions with other projects funded by the Board. Efforts consist of near-term and long-term objectives.

A principal near-term objective is to induce semidwarf mutants in tall Arkansas cultivars in order to quickly produce useful semidwarf germplasm in otherwise well-adapted varieties. The induced mutation approach to producing semidwarfs worked well for improving lodging resistance and increasing yield of tall cultivars in California, where the first semidwarf cultivar, 'Calrose 76', was a direct mutation from the tall cultivar 'Calrose' (Rutger, 1992). Although Calrose 76 itself was grown on a limited scale, its greatest value was as a semidwarf parent source, which has been used by rice breeders to produce eight additional semidwarf cultivars in California. Calrose 76 carries the same semidwarfing gene, sd 1, as the Green Revolution varieties from the tropics; the main advantage of Calrose 76 was that it was produced in already adapted germplasm, over a six-year period, thus saving time over conventional crossing and back-crossing to introduce the gene from tropical germplasm. Semidwarfs in California, whether from the induced mutation source or from the tropical varieties, show a 15% yield advantage over the tall cultivars that they replaced. Development of semidwarfs, coupled with matching management practices, are important ingredients to high yields.

A principal long-term objective is to develop better genetic mechanisms for producing hybrid rice. Hybrid rice is grown on some 37 million acres in China and yields 15 to 20% more than conventional pure-line varieties. Chinese breeders have accomplished hybrid rice through discovery of a genetic mechanism, called 3-line or cytoplasmic male sterility, and then by developing labor-intensive techniques to ensure the amounts of cross-pollination needed to produce hybrid seeds. The requirements for large amounts of labor, together with less-than-satisfactory grain quality, have hindered the spread of hybrid rice beyond China. The 3-line system requires three breeding programs, one to develop sterile lines, one for maintainer lines and one for restorer lines. A better genetic mechanism, called 2-line or thermo- or photoperiod-sensitive genetic male sterility (tgms or pgms), is being developed in China and has been investigated in California (Rutger and Schaefer, 1994; Oard et al., 1991). Since the 2-line method requires only two breeding programs--one for steriles and one for restorers--it has time- and labor-saving advantages over the 3-line method. The 2-line systems from China are unavailable, and those investigated in California still have problems, so in the present project the approach is to develop additional 2-line systems through induced mutation of Southern U.S. cultivars. Even better than the 2-line system would be the 1-line, or apomixis, system. Apomixis is a genetic tool for producing true-breeding hybrids, i.e., a grower could save and plant back his seed from year to year. Though widely known in warm-season grasses, apomixis has yet to be satisfactorily developed for grain crops such as rice and wheat. Apomixis in rice is being aggressively sought worldwide. Success most likely will involve international cooperation and use of molecular techniques to transfer genes from known apomictic grasses into rice. Current efforts in the present project center upon international cooperation and preparation of genetic stocks suitable for receiving transgenes. In the future it is hoped that a molecular geneticist can be added to the National Rice Germplasm Evaluation and Enhancement Center (NRGEEC) at Stuttgart, Arkansas, in order to utilize molecular techniques to develop apomixis in rice.

PROCEDURES

Near-Term Objective: Semidwarf Mutants in Arkansas Cultivars

Seeds of current Arkansas cultivars were irradiated to induce semidwarf mutants. In the first year, approximately 4,000 seeds of each cultivar were treated with 20 kR and another 4,000 with 25 kR of gamma rays at the University of California - Davis cobalt 60 facility. The first or M1 generation of one cultivar, 'Orion', was grown in the 1993/94 winter nursery in Puerto Rico. The M1 generations of five other varieties, 'Kaybonnet', 'Alan', 'LaGrue', 'Millie' and 'Adair', were grown at Stuttgart in the regular summer nursery in 1994. Seeds for the M1 generations were planted at an approximate rate of 10 seeds/linear foot in rows spaced 1 ft apart. This was expected to produce a total of 2,000 to 3,000 mature plants/treatment. Approximately 1,000 M1 panicles of each variety (except Orion, for which only 182 panicles were available), each representing a different M1 plant, were picked at maturity, for subsequent M1 panicle-to-M2 row seeding.

The M2 generation of Orion was grown in rows 5 ft long, spaced 1 ft apart in the 1994 Stuttgart nursery, and the M2 generations of the other varieties were grown in rows 7 ft long, spaced 1 ft apart, in the 1994/95 Puerto Rico winter nursery. At maturity, panicles were taken from semidwarf plants in M2 rows observed to be segregating for two or more semidwarfs per row. Genetic studies on these selected semidwarfs were initiated as they became available, first by comparison with the original tall parent, and then by crossing with known sd 1 sources from California: 'S-101', 'Calmochi-101' and 'ED7'.

Using similar procedures in subsequent years, additional semidwarfs were selected from the cultivars Kaybonnet, LaGrue, Adair, 'Katy', 'Tebonnet' and 'Kashmir Basmati'. A procedural change was to use only a 20-kR dosage of irradiation, since 25 kR was observed to be an overdose, i.e., virtually all seedlings were killed at this rate.

Long-Term Objective: Better Genetic Mechanisms for Hybrid Rice

Using procedures similar to those for semidwarf selections, putative male sterile mutants were identified in 1995 M2 and M3 populations at Stuttgart, from Adair, Millie, LaGrue, Kaybonnet, Tebonnet, 'Bengal', 'Cypress' and Katy. These mutants were propagated by selecting fertile sibs in rows segregating for male sterility. Progenies of two-thirds of these fertile sibs should again segregate for sterility, if it is conventional genetic male sterility. The progeny tests were grown in the 1995/96 Puerto Rico winter nursery, which serves as a short-day screen for pgms identification, i.e., pgms mutants are expected to revert to fertility under short days.

Known apomicts of *Pennisetum* and *Tripsaccum* spp. were collected as possible pollen donors of apomixis in crosses with rice. A rice male sterile with genetic markers was selected for use as a female parent in such crosses.

RESULTS AND DISCUSSION

Near-Term Objective: Semidwarf Mutants in Arkansas Cultivars

Two semidwarf mutants were selected from Orion in the 1994 Stuttgart M2 nursery, and 122 semidwarfs were selected from Kaybonnet, Alan, LaGrue, Millie and Adair in the 1994/95 Puerto Rico M2 winter nursery. These 124 were grown at Stuttgart in 1995 and pared down to 14, which appeared normal except for reduced plant height. Further studies at Stuttgart in 1996 narrowed this down to 12 semidwarf mutants, which are listed in Table 1. Height reduction of these mutants relative to their tall parents ranged from 9% (KBNT-65) to 25% (ADAR-22). The recessive nature of these 12 mutants was determined by the observation that approximately one-fourth of the M2 plants in a panicle row were semidwarf, the remainder being tall. The recessive inheritance of three mutants, KBNT-4, ORIN-41 and ORIN-172, was further confirmed by observation of F2 populations resulting from crosses to the tall parents. The preliminary genetic analyses of allelism of these 12 mutants with sd 1, the semidwarfing gene used worldwide, indicate that only 1 mutant, ORIN-172, is allelic to sd 1. The significance of the sd 1 gene is that to date it has been the only one that confers a yield advantage to semidwarfs (Rutger, 1992). Of course, that finding may change as additional nonallelic sd sources are identified, especially in studies such as the present one, where larger numbers of semidwarfs are being produced than in previous studies (Rutger, 1992). Therefore, continued evaluations of the agronomic worth of these mutants, as well as further genetic analyses, are needed.

Nine more semidwarfs were identified in 1996 M4 populations (Table 2). These mutants will be further examined in 1997, along with 15 putative semidwarf mutants selected from the M2 generation of the extremely tall aromatic variety, Kashmir Basmati. Preliminary genetic analyses of five of the mutants in Table 2 indicate that all are nonallelic to sd 1.

Several of the semidwarfs in Table 1 have been provided to University of Arkansas colleagues (Dr. Kenneth Gravois, Dr. Karen Moldenhauer, Dr. Fleet Lee, Dr. Richard Norman) for additional evaluations.

Long-Term Objective: Better Genetic Mechanisms for Hybrid Rice

In the 1995 Stuttgart nursery, 141 putative male steriles were identified. These were narrowed down to 41 that failed to show segregation in the 1995/96 winter nursery (short-days) in Puerto Rico. This reversion to fertility under short days was the predicted reaction for pgms types. However, when these 41 were progeny tested in the 1996 Stuttgart nursery (long-days), only one, 96/1388, met the criterion for pgms, that is, some all-sterile progenies at Stuttgart. Further evaluations in short- and long-day conditions are underway to confirm these observations.

Regarding apomixis, a conventional male sterile line has been prepared that carries recessive marker genes for glabrous leaves, semidwarfism and waxy endosperm. The next step is to double the chromosome number of this line, to make it tetraploid, for use as a female in intergeneric hybrids with known apomicts of *Pennisetum* and *Tripsaccum* spp. Also, a cooperative study on possible apomixis in rice is underway with a visiting scientist from China.

SIGNIFICANT FINDINGS

In near-term studies, semidwarf mutants that have been induced in tall Arkansas rice cultivars should have applications in rice breeding programs. Semidwarfs, coupled with matching management practices, are keys to increased rice yields.

In long-term studies, investigations of better genetic mechanisms for hybrid rice production are in early phases and will be the subject of continued research.

ACKNOWLEDGMENTS

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Table 1. Characteristics of 10 semidwarf mutants from long-grain cultivars and two semidwarf mutants from a medium-grain cultivar, averaged over two years, 1995 and 1996, at Stuttgart, Arkansas.

Mutant No.*	Parent height	Mutant height	Reduction from parent	Segregation indicating recessiveness	Allelic to sd 1?[†] F_1	Allelic to sd 1?[†] F_2
	cm	cm	%			
KBNT-4	112	92	18	yes	no	no
KBNT-5	112	87	22	yes	no	
KBNT-11	112	92	18	yes	no	
KBNT-65	112	102	9	yes	no	
LGRU-12	112	87	22	yes	no	
LGRU-13	112	87	22	yes	no	
LGRU-14	112	95	15	yes	no	
ADAR-10	120	104	13	yes	no	
ADAR-22	120	91	25	yes	no	
MILL-5	115	100	13	yes	no	
ORIN-41	108	87	19	yes		no
ORIN-172	108	94	13	yes		yes

*KBNT = Kaybonnet; LGRU = LaGrue; ADAR = Adair; MILL = Millie; and ORIN = Orion.

[†]Blank cells indicate that data have not been collected. sd 1 = semidwarf gene 1.

Table 2. Nine additional semidwarf mutants observed in 1996 at Stuttgart, Arkansas.

Mutant	Generation	Parent height	Mutant height	Reduction from parent	Segregation indicating recessiveness	Allelic to sd 1[‡]? F_1	Allelic to sd 1[‡]? F_2
		cm	cm	%			
KBNT-x	M4	114	99	13	yes	no	
KBNT-y	M4	114	107	6	yes	no	
KBNT-19	M4	112	64	43	yes		no
LGRU-2	M4			15*	yes	no	
ADAR-13	M4			15*	yes	no	
KATY-1	M4			15*	yes		
KATY-45	M4			30*	yes		
TBNT-24[†]	M4			20*	yes		
TBNT-54	M4			15*	yes		

*Estimated reductions.

[†]KBNT = Kaybonnet; LGRU = LaGrue; ADAR = Adair; TBNT - Tebonnet.

[‡]sd 1 = semidwarf gene 1.

RICE INJURY ASSOCIATED WITH SALINITY, pH AND PROPANIL APPLICATIONS

J.K. Curless R.E. Talbert and W.H. Baker

ABSTRACT

Field and growth chamber studies evaluated rice interactions with salinity, pH and propanil. The salt used was calcium chloride ($CaCl_2$) at various rates. Two pH levels were examined at each test location. 'Kaybonnet' rice cultivar was grown. Propanil was applied at two- and four-leaf rice stages using the highest rate recommended. Results indicated no interaction among salinity, pH and propanil in either the field or growth chamber studies. Salinity was the main factor contributing to increased rice injury and reduced yield. There was little or no injury to rice attributed to propanil in these studies.

INTRODUCTION

Chloride soluble salts, calcium, magnesium, potassium and sodium in irrigation water and natural soil deposits have contaminated some areas in rice-growing regions of the Mississippi Delta. The highly water-soluble salts move within the soil profile depending on soil moisture due to evaporation and precipitation. When conditions are dry (during early developmental stages in rice), salts move to near the soil surface, directly interacting with roots. Seedling rice under salt stress conditions may exhibit additional stunting or leaf tip burn when herbicides are applied. This study examined six salinity rates under two pH levels at two locations and how propanil interacts with seedling rice when these stress conditions exist.

PROCEDURES

Field plot studies were conducted at the Rice Research and Extension Center, Stuttgart, Arkansas (Crowley silt loam) and Pine Tree Experiment Station, Colt, Arkansas (Calhoon silt loam) during 1996. The study was a split plot design with four replications. Two pH levels at each location were evaluated, the original and increased pH from calcium carbonate ($CaCO_3$) application. $CaCO_3$ was applied in mid-February at 11.2 ton/ha at Stuttgart and 2.8 ton/ha at Pine Tree. The pH levels were 5.4 and 6.0 for Stuttgart and 7.0 and 7.5 for

Pine Tree. Calcium chloride ($CaCl_2$) rates were 0, 560, 1120, 2240, 5600, and 11200 kg/ha. $CaCl_2$ was applied before planting and tiller incorporated to a 15-cm depth. 'Kaybonnet' rice was seeded on 17 May at Stuttgart and 24 May at Pine Tree and maintained under conventional production practices. Plots were nine 22-cm drilled rows 5 m long. there were four replications. Once a week prior to flooding (permanent flood, established 26 June at Stuttgart and 25 June at Pine Tree), each plot was soil sampled at the 0- to 5- and 5- to 12-cm depths to quantify amount and location of $CaCl_2$ in the root zone. Plant heights were recorded prior to propanil application and seven days after final treatment. Propanil was applied broadcast at 4.48 kg/ha on rice at the two- and four-leaf stages. Plots were visually rated at approximately 0, 7, 14, 21 and 72 days after initial treatment (Fig. 1 and 2) and the four center rows harvested for yield determination. A growth chamber study evaluated the same factors as above except propanil and no propanil treatments were compared. Plant heights and injury ratings were taken every seven days, and dry weight of the rice plants seven days after the second propanil application.

RESULTS AND DISCUSSION

Figures 1 and 2 illustrate rice injury ratings over the growing season. Both figures represent how rice injury increases as $CaCl_2$ rate increases. These figures show little (at Stuttgart) to no (at Pine Tree) significant influence from propanil applications to rice plants under various salinity conditions. Injury decreased after propanil applications (Fig. 2). It was felt this injury reduction was due to a combination of plant tillering and less direct $CaCl_2$ effects. Overall rice injury on the Crowley silt loam was less after the flooding event. The extremely wet conditions during the early season may have reduced $CaCl_2$ and root interactions.

Salinity was the only factor contributing significantly to rice yield reductions at both locations (Fig. 3). Yields were consistently greater on the Crowley silt loam (Stuttgart) than the Calhoun silt loam (Pine Tree), regardless of salinity rate. No influences on rice yield were found in either soil due to pH level or the interaction of pH and salinity.

In the growth chamber experiment, untreated rice was compared to propanil-treated rice grown in both soils under all pH and salinity levels. At the 2240 kg/ha level of $CaCl_2$, there was increased but not dramatic leaf burning from the two applications of propanil as compared to the untreated (Table 1). The injury at 5600 kg/ha $CaCl_2$ was inconsistent between propanil-treated and untreated. Rice seedling dry weights were not affected by pH or propanil treatment (Table 2). Salinity was the only significant factor contributing to reduced rice growth in both soils over 28 days in the growth chamber study.

SIGNIFICANCE OF FINDINGS

Salinity was found to be the primary factor influencing rice growth and yield potential. Although propanil does have injury potential when applied under stressful environmental conditions, no additional injury or yield reductions appeared to be associated with propanil applications under salinity stress. Producers may not have to alter postemergence use of propanil in areas where high salinity rates exist. Their future options are to consider use of salt-tolerant rice cultivars should be considered in known areas of contamination and attempts made to improve water management techniques.

Table 1. Rice injury seven days after second application of propanil as affected by preplant $CaCl_2$ application on Calhoun silt loam (Pine Tree, Arkansas) and Crowley silt loam (Stuttgart, Arkansas) in growth chamber study.

	Calhoun sil		Crowley sil	
$CaCl_2$	None	Propanil	None	Propanil
kg/ha	----------------------------------	%injury	----------------------------------	
0	0	0	0	2
560	2	5	5	6
1120	2	5	5	6
2240	13	35	24	28
5600	71	61	41	64
11200	100	100	100	100
$LSD_{(0.05)}$	4		4	

Table 2. Rice dry weight seven days after second application of propanil as affected by main factors of salinity, propanil application and pH level on Calhoun silt loam (Pine Tree, Arkansas) and Crowley silt loam (Stuttgart, Arkansas) in growth chamber study.

	Soil series	
Item	Calhoun silt loam	Crowley silt loam
	---------------------g/pot	---------------------
$CaCl_2$ (kg/ha)		
0	0.55	0.77
560	0.59	0.77
1120	0.59	0.74
2240	0.45	0.58
5600	0.35	0.38
11200*	0.00	0.00
$LSD_{(0.05)}$	0.11	0.18
Propanil application		
None	0.55	0.68
Treated	0.49	0.61
$LSD_{(0.05)}$	NS	NS
pH level		
Original	0.52	0.67
High	0.51	0.63
$LSD_{(0.05)}$	NS	NS

*No rice stand established and data from this treatment not included in statistical analysis.

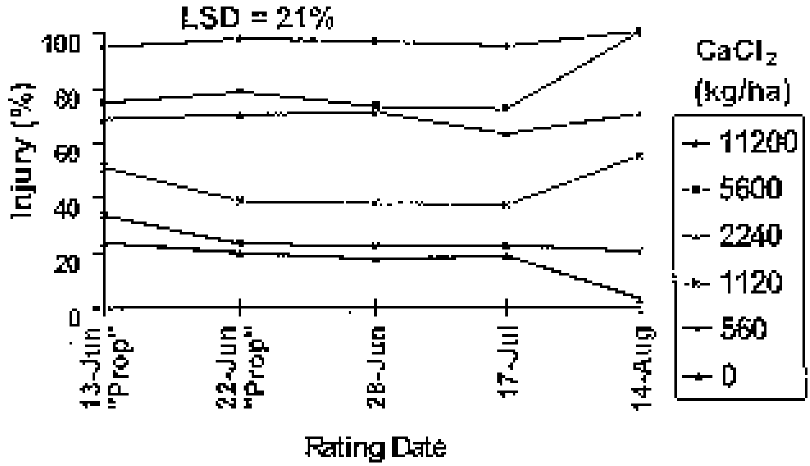

Figure 1. Rice injury from various concentrations of $CaCl_2$ averaged over two pH levels on Calhoun silt loam (Pine Tree), 1996. Propanil at 4.48 kg/ha applied 13 and 22 June 1996.

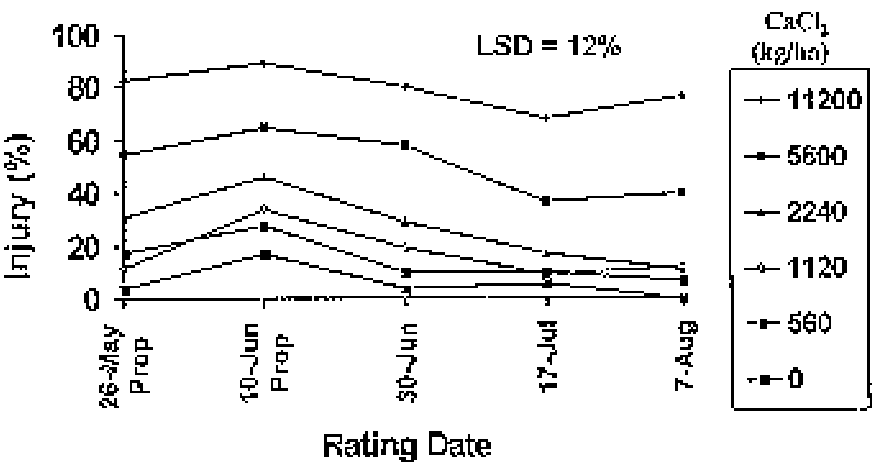

Figure 2. Rice injury from various concentrations of $CaCl_2$ averaged over two pH levels on Crowley silt loam (Stuttgart), 1996. Propanil at 4.48 kg/ha applied 26 May and 10 June 1996.

ALLELOPATHIC ACTIVITY IN RICE TO DUCKSALAD AND BARNYARDGRASS

R.H. Dilday, W. Yan, K.A.K. Moldenhauer, K. Gravois, T. Lavy, F. Baldwin and D. Gealy

ABSTRACT

Rice germplasm accessions were evaluated for allelopathic activity in rice (*Oryza sativa* L.) to ducksalad [*Heteranthera limosa* (Sw.) Willd.] and barnyardgrass [*Echinochloa crus=galli* (L.) Beauv.]. Also, preliminary data involving germplasm enhancement and breeding for allelopathy to ducksalad are reported. An experiment was designed to separate competition and interference from allelopathy to ducksalad by applying glyphosate to rice at the two-leaf and at the four- to six-leaf stage. Our data showed no significant difference in ducksalad growth or plant density among plots where glyphosate was applied on 31 May (two-leaf stage), which was 16 days after emergence. However, differences in ducksalad growth and development were observed among plots treated with glyphosate on 20 June (four- to six-leaf stage), which was 36 days after emergence. The greatest number of ducksalad plants occurred in the blank plots (137 ducksalad plants/plot). T65x2/TN-1 (PI 312777) plots had the least number of ducksalad plants (28). 'Rexmont' plots had significantly more ducksalad plants (87) than PI 312777 but significantly fewer ducksalad plants than the blank plots (LSD = 32). Two experiments were designed to evaluate rice accessions for allelopathy to barnyardgrass. 'Gui-Chao', IR 788, 'Panbira', 'Iari 6636', GPNO 7018, 'Pa Shin Tsao' and 'Lambaygue No. 1' had significantly fewer barnyardgrass plants than either 'Kaybonnet' or the blank plots.

INTRODUCTION

Allelopathy is postulated to be one mechanism by which weeds affect crop growth and occurs widely in natural plant communities (Bell and Koeppe, 1972; Gressel and Holm, 1964; Whittaker and Feeny, 1971). Putnam and Duke (1974) postulated that "wild types" of existing crops may have possessed high allelopathic activity and that this character was reduced or lost as they were hybridized and selected for other characteristics.

Although the term *allelopathy* was coined by Molisch in 1937, the concept of allelopathy is a very old component of agricultural science. For example, Theophrostus (c.300 B.C.) referred to "phytotoxicity" among plants in *Enquiry into Plants*. Furthermore, the Greek philosopher Democritus reported the use of naturally occurring plant products as a practical method of controlling weeds. He stated that trees could be killed by treating their roots with a mixture of lupine flowers soaked in hemlock juice. Plinius (first century A.D.) referred to several examples of apparent allelopathic interactions in *Natural History*. He stated that plants such as chickpea, barley, fenugreek and vetch could scorch-up corn land (Rizvir and Rizvir, 1992).

Putman (1986) state that chemicals with allelopathic potential are present in virtually all plant tissues, including leaves, flowers, fruits, stems, roots, rhizomes and seeds. Allelochemicals are released by such processes as volatilization, root exudation, leaching and decomposition of plant residues (Rice, 1984; Putnam, 1986). Much of the evidence indicates that several chemicals are released together and may exert toxicities in an additive or synergistic manner. To date all cases of alleged allelopathy that have been throughly studied appear to involve a complex of chemicals. In no case has one specific phytotoxin been proven to be solely responsible for interference by a neighboring plant.

More than 50 weed species infest direct-seeded rice and cause major losses in U.S. rice production (Smith et al., 1977). Ducksalad, an aquatic weed that can reduce rice yields by 27-30% when competing with rice in a water-seeded culture (Smith et al., 1977; Smith, 1988), is second only to barnyardgrass as the most frequently reported weed in rice fields, followed by hemp sesbania [*Sesbania exaltata* (Raf.) Rydb, ex A.W. Hill], bulrushes (*Scirpus spp.*), red rice (*Oryza sativa* L.), broadleaf signalgrass [*Braachiaria platphylla* (Griseb.) Nash] and sprangletop (*Leptochloa* spp.) (Chandler, 1981).

The objectives of this study were 1) to demonstrate allelopathic activity in rice to ducksalad after applying a non-selective herbicide to rice and 2) to evaluate rice germplasm for allelopathic activity to barnyardgrass.

PROCEDURES

Ducksalad

Eight germplasm accessions that vary in allelopathic activity to ducksalad based on previous tests and a U.S. cultivar plus one blank plot (no rice planted) were included in this experiment (Table 1). Three of the germplasm accessions originated at the International Rice Research Institute (IRRI), Philippines; three were from Colombia; and two were from Taiwan. The experimental design was a split-plot (four replications) with the herbicide spray dates being the main plot. Each entry was seeded in 9-row plots 12 ft long with 8-in. row spacings on 9 May 1996, and the seedlings emerged on 15 May 1996.

Glyphosate was applied at a rate of 2.0 lb ai/acre at two different dates. Spray date 1 was 31 May 1996 when the rice was at the two-leaf stage or after accumulation of 482 DD50 heat units. Spray date 2 was 20 June 1996 when the rice was at the four- to six-true-leaf stage and 1023 DD50 heat units had accumulated. A permanent flood was applied one day after the herbicide applications. The main plots (spray dates 1 and 2) were separated by levees. A 12-in.-diameter plastic cylinder was placed in the center of the plot of each entry, and the number of ducksalad plants in the cylinder was recorded on 2 August 1996.

Breeding Enhancement

As part of the variety development program, PI 338046, an accession that has shown allelopathic activity to ducksalad, was hybridized with 'Adair', 'Alan', 'Katy', Lemont/RA73, M-201/Katy and 'Newbonnet' in 1991. The F_1 of each was grown in the greenhouse in the winter of 1991-1992, the F_2 in the field at Stuttgart in 1992, the F_3 in Puerto Rico in the winter of 1992-1993, and the F_4 and F_5 at Stuttgart in 1994 and 1995, respectively. Seven F_6 lines were field evaluated for agronomic characteristics such as grain and milling yield, days from emergence to heading, plant height and lodging in 1995. The center four rows of each plot (4.2 ft x 12.4 ft) were harvested for grain yield. Also, the seven lines were evaluated for allelopathic properties to ducksalad in plastic pots, 15.0 in. diameter, in the greenhouse in the winter of 1995-1996.

Barnyardgrass Test 1

Eight germplasm accessions and a U.S. cultivar were evaluated for allelopathic activity to barnyardgrass. Three accessions originated at IRRI, two were from China, two were from Taiwan, and one was from Brazil. The experimental design (randomized complete block with four replications) included a blank or no-rice plot. Prior to seeding the rice, barnyardgrass seeds were broadcast at a rate of 1.5 gallons/acre and incorporated with a harrow, and a second application of barnyardgrass seed (0.75 gallons/acre) was made after seeding the rice. Eighty grams of rice (116 lb/acre) were seeded in nine-row plots 12 ft long with 8-in. row spacing on 24 May 1996, and the seedlings emerged on 29 May 1996. A 15-in.-diameter plastic cylinder was placed in the center of each plot, and the number of barnyardgrass plants within each cylinder was recorded on 19 June 1996. Barnyardgrass plants were harvested from each cylinder, and dry weights were recorded at maturity. Three split applications of ammonia sulfate [pre-flood (60 lb N/acre), 0.5-in. internode elongation (IE) (30 lb N/acre) and 10 days after 0.5-in. IE (30 lb N/acre) were applied.

Barnyardgrass Test 2

A total of 4240 germplasm accessions from the USDA, ARS rice world collection were evaluated for allelopathic activity to barnyardgrass in 1994. Twenty-one of the accessions that showed apparent allelopathic activity to barnyardgrass were included in the 1996 test. Also, a U.S. cultivar and one blank plot (no rice seeded) were included in the test. Each accession was seeded on 24 May 1996 in six-row (3 g of rice per row) plots 4 ft long with an 8-in. row spacing. The seedlings emerged 29 May 1996, and a 15-in.-diameter plastic cylinder was placed in the center of each plot. The number of barnyardgrass plants in each cylinder was recorded on 19 June for analysis.

RESULTS AND DISCUSSION

Ducksalad

Separating interference and competition from allelopathy can be difficult, but the separation is important when selecting rice germplasm with allelopathic activity to specific weeds. Ducksalad seed will germinate about five to seven days after applying a permanent flood in rice fields with natural infestations of ducksalad. Therefore, glyphosate was applied at two growth stages of the rice plant to determine if enough allelochemical could accumulate in the soil prior to flooding to inhibit germination, growth or development of ducksalad.

The results of our tests showed no differences in ducksalad growth or plant density among the plots that were treated with glyphosate on 31 May, which was 16 days after emergence. However, differences in ducksalad growth and development were observed among plots that were treated with glyphosate on 20 June, which was 36 days after emergence. Data collected from the latter spray date (date 2) showed that the largest number of ducksalad plants occurred in the blank plots (137 ducksalad plants/plot) (Table 1). Conversely, T65x2/TN-1 (PI 312777) from Taiwan had the least number of ducksalad plants (28). A U.S. cultivar, Rexmont with 87, had significantly more ducksalad plants than PI 312777, but significantly fewer plants than the blank plots (LSD = 32). Therefore, these data suggest that rice accessions that produce allelochemicals must have more than 16 days to accumulate enough allelochemicals in the soil to inhibit germination, growth or development of ducksalad.

Breeding/Enhancement

Individual F_2 populations from hybrids involving PI 338046 with Adair, Alan, Katy, Lemont/RA 73, M-201/Katy and Newbonnet were evaluated in the field at Stuttgart in 1992. IR 8 and TN-1 are in the parentage of PI 338046. Therefore, PI 338046 or IR 8x2//85894 A4-18-1*2/TN-1 has 2 (IR 8 and TN-1) parents that have previously been identified as possessing allelopathic potential to ducksalad. Seven F_6 lines from the cross PI 338046//Lemont/RA 73, PI 338046/Alan, PI 338046//M-201/Katy and PI 338046/Katy were field evaluated in a replicated test in 1995. One line from the cross PI 338046/Katy (Stg 94L42-130) was the highest-yielding entry (8823 lb/acre) in the Arkansas Performance Test in 1995. It exceeded the yield of Katy (7025 lb/acre) by 1798 lb/acre. Also, in a greenhouse test in 1995-96, Stg 94L42-130 had significantly fewer ducksalad plants (35) than the non-allelopathic check, Rexmont (97), $LSD_{0.05}$ =31.

Barnyardgrass

One of the most economically important weeds in rice is barnyardgrass. Therefore, a systematic evaluation of the USDA, ARS rice germplasm collection for allelopathic activity in rice to barnyardgrass is part of the rice germplasm evaluation program. Preliminary results are encouraging from field tests. For example, in test 1, field plots of Gui-Chao from China and IR 788 from IRRI had significantly fewer barnyardgrass plants than field plots of Kaybonnet or the blank plots (Table 2). Furthermore, the barnyardgrass biomass harvested from the Gui-Chao plots was significantly less than the barnyardgrass biomass from the plots with no rice. In test 2, plots of Vansi Sel., Nilo 48A, 'Bak Kye', 'Sapan Kwai 5', 'C63-5717', T65*2/TN-1, Panbira, Iari 6636, GPNO 7018, Pa Shin Tsao and Lambaygue No. 1 had significantly fewer barnyardgrass plants than the plots with no rice (Table 3).

SIGNIFICANCE OF FINDINGS

Using allelopathy as a weed control strategy in rice is relatively new. In fact, apparent allelopathy in rice to ducksalad was first observed in the field at Stuttgart, Arkansas, in 1985. Rice germplasm has been identified that has apparent allelopathic properties to ducksalad and barnyardgrass. Preliminary data suggest that the growth and development of the rice plant must exceed the two-leaf stage for enough allelochemicals to accumulate in the soil to inhibit germination, growth and development of ducksalad. Also, germplasm possessing allelopathic properties has been recovered in segregating populations involving hybrids of allelopathic X non-allelopathic germplasm. Research programs on rice allelopathy are being developed in Australia, Brazil, China, Colombia, Egypt, India, Japan, Korea, Philippines, Thailand and Taiwan. Internationally, allelopathy is a new weed control strategy for rice, and most of the field data to date have been generated here in Arkansas. Weed control through allelopathy has the potential to reduce the use of herbicides and, potentially, reduce environmental contamination.

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Table 1. Rice germplasm with significantly fewer ducksalad plants than 'Rexmont' or no rice plots in a 12-in.-diameter cylinder after treating the germplasm with glyphosate (2.0 lb ai/acre).

PI No.	Name	Origin	Ducksalad
			No.
	Blank		137
502968	Rexmont	U. S.	87
338046	IR644-1-63-1-1	IRRI	70
350468	IR 781	IRRI	53
414715	Colombia 3	Colombia	53
366150	SH 30-21	Taiwan	50
414714	Colombia 2	Colombia	44
319703	Ica 5	Colombia	41
312777	T65*2/TN-1	Taiwan	28
$LSD_{(0.05)}$			32

Table 2. Rice germplasm that had significantly fewer barnyardgrass plants than 'Kaybonnet' and the blank plots in a 15-in.-diameter cylinder placed in the center of nine-row plots 12 ft long at Stuttgart, Arkansas, in 1996.

		Barnyardgrass	
Name	Origin	Number	Weight
			g
Kaybonnet	U. S.	43	72
Blank		42	89
IR 788	IRRI	26	87
Gui-Chao	China	23	51
$LSD_{(0.05)}$		15	30

Table 3. Rice germplasm that had significantly fewer barnyardgrass plants than the blank plots in a 15-in.-diameter cylinder placed in the center of six-row plots 4 ft long.

PI or CI	Name	Origin	Barnyardgrass
			No.
Blank			43
	Kaybonnet	U. S.	38
12225	Vansi Sel.	India	28
315644	Nilo 48A	El Salvador	28
157251	Bak Kye	Korea	27
294406	Sapan Kwai 5	Thailand	27
9594	C63-5717	U. S.	25
312777	T65*2/TN-1	IRRI	25
294370	Panbira	Pakistan	24
353725	Iari 6636	India	24
182256	GPNO 7018	Turkey	24
160423	Pa Shin Tsao	China	23
180177	Lambaygue No. 1	Peru	19
LSD $_{(0.05)}$			13

INFLUENCE OF TEMPERATURE ON EMERGENCE OF RED RICE ECOTYPES UNDER WATER-SEEDED CONDITIONS

Nestor E. Saldain, Ronald E. Talbert and Dave R. Gealy

ABSTRACT

Growth chamber experiments were conducted at the University of Arkansas at Fayetteville in 1996 to assess the emergence of three red rice (*Oryza sativa L.*) ecotypes as affected by air day/night temperature regimes, soil types, flooding methods and seeding depths under water-seeded conditions. Emergence of all red rice ecotypes was reduced but not prevented by continuous flooding in either of the soils. Emergence of the Arkansas (AR) ecotype from the soil surface or 0.8-in. depth was better at 89/59°F than at 72/50 or 91/68°F day/night temperatures. Emergence of Louisiana (LA) ecotype increased when temperature increased from 72/50°F to 91/68°F. The Mississippi (MS) ecotype emergence was greater at 89/59°F than at lower or higher temperatures at 0.4- and 0.8-in. seeding depths. With the 0.8-in seeding depth in the Crowley silt loam, increased temperature from 89/50 to 89/59°F night/day temperatures enhanced emergence of the LA and MS ecotypes. With the 0.8-in seeding depth in the Crowley silt loam, emergence of the AR ecotype was less at 89/59°F than 89/50°F day/night temperatures. The LA and MS ecotypes had similar emergence at both temperatures.

INTRODUCTION

Studies have shown that emergence of red rice biotypes is associated with depth of seeding, soil moisture, temperature and oxygen supply. Under greenhouse conditions, Smith and Fox (1973) reported that strawhull red rice had 70% emergence from a 10-cm soil depth when soil was saturated for 14 days after seeding. Wague (1992) showed that nondormant seeds of strawhull and blackhull ecotypes emerged 56 and 64%, respectively, when buried 1.25 cm in pots with soil under 6 cm of flood water for 30 days. In Louisiana, Griffin et al. (1986) found higher red rice stand establishment when warm weather occurred after seeding, especially when a prolonged drainage period was used in water-seeded conditions. In Arkansas, Saldain et al. (1996) observed that increased red rice emergence was associated with higher temperatures in the mid-July than in the early-June seeding in water-seeded culture with pinpoint flooding. The objective of this study was to assess the emergence of red rice ecotypes as affected by air temperatures, soil types, irrigation methods and seeding depth under water-seeded culture.

PROCEDURES

Growth chamber experiments were conducted at the University of Arkansas at Fayetteville in 1996. Plastic pots were filled with air-dried soil. The soil was allowed to absorb water for 24 hours, seeded on the surface with 20 nondormant, dry red rice seeds and then filled to specified depths with air-dried soil. Each combination of soil type, flooding method and seeding depth was placed in a 6-gal plastic container for flooding with 4-in. of water. Pinpoint flooding treatment was done by draining five days after seeding; then the soil was kept saturated. Flooding was gradually reestablished after five days. A seedling was considered emerged when it reached a 0.8-in height. Germination and vigor tests of the red rice seed were done prior to seeding (Table 1). In experiment I, emergence of Arkansas (AR), Louisiana (LA) and Mississippi (MS) ecotypes were compared at day/night temperatures of 72/50, 89/59 and 91/68°F, with pinpoint and permanent flooding, in Sharkey clay and Crowley silt loam soils, and at seeding depths of 0, 0.4 and 0.8 in ('Alan' rice was included as a reference). In experiment II, the emergence of three red rice ecotypes was assessed in Sharkey clay and Crowley silt loam soils under pinpoint and continuous flooding, and at 89/50 and 89/59°F day/night temperatures. The seeding depth was 0.8 in.

RESULTS AND DISCUSSION

Experiment I

There was a significant interaction among the red rice ecotypes, day/night air temperatures and seeding depths at 25 days after seeding (DAS, Table 2). Averaged over soil type and flooding method, emergence of the AR ecotype from the soil surface and the 0.8-in. seeding depth was best at 89/59°F. The LA ecotype emergence increased as the temperature was raised. Emergence of the MS ecotype was optimum at 89/59°F. The MS ecotype had higher emergence than the other ecotypes at the 0.4-in. seeding depth at 72/50 and 89/59°F. At 89/59°F the MS ectoype emerged from the 0.8-in. seeding depth (45%) better than the other ecotypes. Emergence of all ecotypes was very poor (0 to 7%) at the low temperatures (72/50°F). At the highest temperatures, there was greater emergence of the MS and LA biotypes than the AR biotype. Emergence of red rice interacted among soil types, ecotypes, and seeding depths (Table 3). At the soil surface, emergence of the LA ecotype was higher than that of the AR and MS ecotypes in a Crowley silt loam. The LA ecotype was not significantly different from the MS ecotype but had a higher emergence than the AR ecotype in the Sharkey clay. At 0.8 in. in the Crowley silt loam, emergence of the AR ecotype was lower than that of the LA and MS ecotypes. Emergence of the MS ecotype was higher than that of the AR and LA ecotypes in the Sharkey clay. The response of the AR ecotype to flooding method was not different in the two soil types (Table 4). Emergence of the LA and MS ecotypes was reduced by continuous flooding compared to the pinpoint flooding in the Crowley silt loam. There were no significant differences between flooding methods for any of the ecotypes in the Sharkey clay. However, red rice emergence still averaged from 26 to 65% under the two flooding methods.

Experiment II

Emergence of the AR ecotype was significantly greater at 50°F than at 59°F night temperature in the Crowley silt loam, but not in the Sharkey clay (Table 5). However, night temperatures did not affect emergence of the LA and MS ecotypes in the Crowley silt loam. Emergence of the MS and LA ecotypes increased in Sharkey clay as the night temperature increased from 50 to 59°F.

SIGNIFICANCE OF FINDINGS

The reduction in emergence of red rice obtained by continuous flooding is dependent on red rice ecotype and soil type, although emergence was not prevented by continuous flooding in either of the soils. The air temperature regimes after seeding affected the potential of red rice emergence, but its expression was somewhat dependent on ecotype.

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Table 1. Laboratory germination and vigor tests of red rice ecotypes at 77°F in the dark (AOSA* 1983) and grain weight.

Red rice ecotypes	Germination	Seedling dry weight[†]	Grain weight
	%	mg	g/1000
Arkansas	93	3.8	27.5
Louisiana	100	4.6	25.0
Mississippi	95	4.6	21.8

*Association of Official Seed Analysts.

[†]Shoot + root per viable seed.

Table 2. Red rice emergence at 25 days after seeding as influenced by air temperature, ecotype and seeding depth under water-seeded conditions. AAREC.* Fayetteville, Arkansas, 1996 (averaged over soil types and flooding methods).

Day/night air temperature	Red rice ecotypes	Seeding depth, in 0	0.4	0.8
°F			%	
72/50	AR[†]	63	12	2
	LA[‡]	89	16	0
	M5S[§]	82	40	7
89/59	AR	70	21	12
	LA	95	51	13
	MS	92	88	45
91/68	AR	58	21	3
	LA	98	69	17
	MS	87	25	22
L.S.D.$_{0.05}$			9	

*Arkansas Agricultural Research and Extension Center
[†]Arkansas ecotype.
[‡]Louisiana ecotype.
[§]Mississippi ecotype.

Table 3. Red rice emergence at 25 days after seeding as influenced by soil type, ecotype and seeding depth under water-seeded conditions. Average of three controlled temperature regimes and two flooding methods, 1996.

Soil type	Red rice ecotypes	Seeding depth, in. 0	0.4	0.8
			%	
Crowley	Arkansas	67	13	2
silt loam	Louisiana	96	45	14
	Mississippi	88	70	19
Sharkey clay	Arkansas	60	23	9
	Louisiana	92	46	6
	Mississippi	87	65	30
LSD$_{0.05}$			7	

Table 4. Red rice emergence at 25 days after seeding as influenced by soil type, flooding method and ecotypes under water-seeded conditions. Average of three controlled temperature regimes and three seeding depths, 1996.

Soil type	Flooding method	Red rice ecotypes Arkansas	Louisiana	Mississippi
			%	
Crowley	Pinpoint	33	54	65
silt loam	Continuous	28	42	56
Sharkey	Pinpoint	28	52	58
clay	Continuous	26	51	60
LSD$_{0.05}$			6	

Table 5. Red rice emergence at 25 days after seeding as affected by night air temperature, ecotypes and soil type under water-seeded conditions. Average of irrigation methods, 1996.

Soil type	Night air temperature	Red rice ecotypes Arkansas	Louisiana	Mississippi
	^{0}F		%	
Sharkey	50	0	1	0
clay	59	10	16	52
Crowley	50	20	12	51
silt loam	59	3	14	39
$LSD_{0.05}$			13	

CHARACTERIZATION AND CONTROL OF PROPANIL-RESISTANT BARNYARDGRASS.

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ABSTRACT

The development and spread of propanil resistance in barnyardgrass (*Echinochloa crus galli L.*) has been increasing each year. Since its initial confirmation in Arkansas in 1990, barnyardgrass resistant to propanil has been confirmed in 155 populations (10 new populations were added in 1996) in 18 counties. A more efficient assay using chlorophyll fluorescence was developed for distinguishing propanil-resistant and -susceptible barnyardgrass leaf tissue. Both biotypes could be distinguished in one to five days after the tissue was sampled. Characterization of propanil-resistant barnyardgrass indicated no consistent trends in barnyardgrass vigor between resistant and susceptible biotypes. Propanil in combination with Sevin (carbaryl), Facet (quinclorac), anilophos and piperophos gave adequate control of propanil-resistant barnyardgrass. Very effective alternative herbicides for propanil-resistant barnyardgrass control in rice include Facet (quinclorac), Prowl (pendimethalin) and Command (clomazone). Reduced rates of Facet alone or in combination with Prowl, Bolero (thiobencarb) and Command were also very effective for the control of resistant barnyardgrass.

INTRODUCTION

The repeated use of propanil since its release into the United States in 1962 has led to the development of resistance. Some producers have grown rice in rotation with soybeans for up to 20 years, with two applications of propanil preflood each year rice is grown. In 1990, plants from seeds collected from rice fields in northeastern Arkansas were found to be resistant to rates up to 10 lb/acre of propanil (Smith and Baltazar, 1993).

The mechanism of resistance in propanil-resistant barnyardgrass is similar to the selectivity mechanism in rice, that is, the propanil is metabolized in the rice tissue by the enzyme aryl acylamidase before it can act on the photosynthesis system (Carey, 1994). Compounds that competitively inhibit aryl acylamidase decrease propanil selectivity. Sevin, a carbamate insecticide, decreases activity of this enzyme in both rice and barnyardgrass and increases the activity of propanil on both species.

Other herbicides controlled propanil-resistant baryardgrass in rice (Baltazar and Smith, 1994). Propanil in tank mixtures with Facet, anilophos and piperophos applied postemergence (POST); Facet applied at reduced rates alone or in combination with Bolero, Prowl and Command applied delayed preemergence (DPRE); Command alone applied PRE, DPRE and early postemergence (EPOST); and Arrosolo plus Prowl applied POST consistently controlled propanil-resistant barnyardgrass.

Objectives of this research were 1) to evaluate the susceptibility to propanil and compare the growth and development of ten propanil-resistant and -susceptible biotypes of barnyardgrass, 2) to determine if propanil-resistant and -susceptible barnyardgrass tissue could be distinguished several days after sampling, 3) to evaluate the potential of Facet, Sevin, anilophos and piperophos tank mixed with propanil for the control of propanil-resistant and -susceptible barnyardgrass and injury to rice and 4) to evaluate propanil-resistant barnyardgrass control with alternative rice herbicides.

PROCEDURES

Biochemical Confirmation of Propanil R-barnyardgrass

Propanil-resistant and -susceptible barnyardgrass was seeded in pots and placed in the growth chamber under controlled conditions. The resistant biotype was treated with 4 lb ai/acre propanil at the two-leaf stage to ensure resistance. Above-ground biomass from both biotypes were harvested and placed in plastic zip-lock bags containing enough water to keep the plants viable. Plants were removed, and leaf segments were clipped from the widest fully expanded leaf at 0, 24, 48, 72 and 96 h after barnyardgrass leaf tissue was sampled. Leaf segments were incubated in 100 µM propanil or deionized water (check) for 2 h followed by a 22-h incubation in water before fluorescence of the leaf tissue was measured for 60 sec using the plant productivity fluorometer. Inhibition of photosynthesis in treated suseptible tissue was determined by comparing to untreated standards.

Characterization of Biotypes

An experiment was conducted in 1995 and 1996 at the Main Agricultural Experiment Station at Fayetteville, Arkansas, to evaluate the susceptibility to propanil and compare the growth and development of seven propanil-resistant and -susceptable biotypes of barnyardgrass. Plots were a single row of ten barnyardgrass plants spaced 10 in. apart in four replications. Propanil-treated and -untreated plots were included. Propanil was applied at 5.3 lb/acre at the two-leaf stage and repeated at the four-leaf stage of growth. Percentage control of propanil-resistant and -susceptible barnyardgrass was rated 3, 7, 14 and 21 days after seeding. Individual plant heights were measured at 38 and 81 days after seeding.

Additives with Propanil

'Kaybonnet' rice was seeded at Lonoke (plots 13 7-in. rows, 20 ft long) and Stuttgart, Arkansas (plots nine 7-in. rows, 20 ft long), on 27 April and 3 May 1996, respectively. Propanil-resistant and -susceptible barnyardgrass was drilled in two separate rows perpendicular to the rice. Treatments were in an RCB design with four replications. All treatments were applied to three- to five-leaf barnyardgrass. At Lonoke, a natural population of weeds was present at the time of application. These weeds included: four- to six-leaf broadleaf signalgrass, five-leaf fall panicum, four-leaf eclipta, three- to four-leaf rice flatsedge and five- to six-leaf yellow nutsedge. Annual spikerush emerged soon after application. All compounds were applied at two rates, alone and in combination with propanil at 0, 1.5 (1/2X rate) and 3 (1X rate) lb ai/acre. Visual observations for percentage control of barnyardgrass and percentage injury to rice were made at 21 days after treatment (DAT). Grain was harvested from the center (four rows at Stuttgart, eight rows at Lonoke) of each plot and adjusted to 12% moisture.

Evaluation of Other Herbicides

Reduced Rates of Facet DPRE and EPOST. A field experiment was conducted in 1996 at the Rice Research and Extension Center in Stuttgart, Arkansas, on a Crowley silt loam. Kaybonnet rice was drill seeded in plots with nine 7-in. rows, 20 ft long, on 15 May 1996. Propanil-resistant and -susceptible barnyardgrass was seeded in two separate rows across the plot area. Reduced rates of Facet alone and in combination with Prowl, Bolero and Command were applied DPRE (five days after seeding). Treatments were in an RCB design with four replications.

Percent control of each biotype and rice injury ratings were taken 14 and 28 DAT. Rough rice yield was also taken as previously described.

Application Timing of Command. An experiment was conducted in 1996 on the Rice Research and Extension Center in Stuttgart, Arkansas, to evaluate application timing of Command for propanil-resistant and -susceptible barnyardgrass control. Kaybonnet rice was seeded on 15 May 1996 in plots as previously described. Propanil-resistant and -susceptible barnyardgrass was seeded the same day in rows perpendicular to the rice. Command at 0.5 lb/acre was applied preplant incorporated (PPI), PRE, DPRE and EPOST. Percent visual control and injury ratings were taken 5 WAP (weeks after planting). Rough rice yield was also taken and adjusted to 12% moisture as previously described.

Sevin Mixed with Propanil. Experiments were conducted in 1996 in the field at the Rice Research and Extension Center at Stuttgart, Arkansas, to evaluate various rates of Sevin as a synergist with propanil for control propanil-resistant barnyardgrass. Propanil-resistant and -susceptible barnyardgrass was seeded in two separate rows across the plot area. Plots and experimental design were as previously described. Either single application at the two-leaf or sequential applications at the two- and four-leaf stages of barnyardgrass were included with these treatments. Standard herbicide systems for the control of propanil-resistant barnyardgrass were also included for making comparisons.

Percentage control of propanil-resistant and -susceptible barnyardgrass and rice injury was visually rated at 21 days after two-leaf barnyardgrass treatments (DAT). Rough rice yield was determined.

RESULTS AND DISCUSSION

Biochemical Confirmation of Propanil R-barnyardgrass

Both biotypes could be distinguished by fluorescence testing in one to five days after the tissue was sampled (Fig. 1). Tissue samples can be harvested soon after propanil failure with a biotype confirmation being made within the following few days. Fluorescence from the susceptible biotype did not vary significantly over the periods tested. However, fluorescence from the resistant biotype increased at a linear rate over time. This could be attributed to degradation of the leaf tissue and decreased aryl acylamidase activity. Due to the linear increase in fluorescence from the resistant biotype, difficulty in separating the two biotypes could occur if the tissue requires more than four days for transport.

Characterization of Propanil-Resistant Biotype

In 1995, the level of control ranged from 19% for the resistant barnyardgrass from Poinsett County to 83% for the susceptible barnyardgrass from Lafayette County (Table 1). The levels of control were higher in 1996, ranging from 34% for the resistant plants to 91% for the most susceptible.

Biotypes could be classified into three categories: susceptible, moderately resistant and highly resistant. Propanil-resistant barnyardgrass tolerated 5.3 lb/acre propanil. Surviving susceptible barnyardgrass plants recovered rapidly from treatment with propanil and grew vigorously during the rest of the growing season. Although there were few differences in height between biotypes (Table 2), this was not consistent between years. There were no consistent trends in barnyardgrass vigor between resistant and susceptible biotypes.

Additives with Propanil

Only the superior treatments incuded in this study are listed in Table 3. A significant interaction existed between treatments and location. At Stuttgart, phytotoxicity to rice occurred from 3 lb/acre propanil plus 0.3 lb ai/acre Sevin, but injury was not present from other combinations at 21 DAT. Propanil at the standard rate of 3 lb/acre failed to control either biotype. The combination of propanil at 3 lb/acre plus anilophos at 0.3 lb ai/acre controlled >80% of the resistant biotype. Similar rates of the propanil/piperophos combination provided 60 to 83% control of the resistant biotype. Highest rice yields were from rice treated with 1.5 lb/acre propanil plus 0.22 lb/acre Facet (5700 lb/acre), 3 lb/acre propanil plus 0.22 lb/acre Facet (5600 lb/acre) and 3 lb/acre propanil plus 0.3 lb/acre anilophos (6000 lb/acre).

The rice at Lonoke was also injured by propanil plus Sevin but recovered by 35 DAT (data not shown). Other treatments did not cause significant injury to rice. All treatments containing the 3 lb/acre propanil plus additive gave adequate control of both biotypes at Lonoke. Propanil plus Facet was the best treatment of those containing 1.5 lb/acre propanil, controlling 86% and 93% the resistant and susceptible biotypes, respectively. Highest rice yields were from rice treated with 1.5 and 3 lb/acre propanil plus 0.22 lb/acre Facet and 3 lb/acre propanil plus 0.3 lb/acre piperophos. Lower yields at Lonoke could be attributed to higher weed pressure and lower soil fertility than at Stuttgart.

Evaluation of Other Herbicides

Reduced Rates of Facet, DPRE. There was no difference in the response of propanil-resistant and -susceptible barnyardgrass to other herbicides. Reduced rates of Facet to 0.09 lb/acre were effective in controlling resistant and susceptible barnyardgrass in rice, DPRE (Table 4). Control of propanil-resistant and -susceptible barnyardgrass was antagonized by mixtures of Facet and Bolero applied DPRE (Table 5). Prowl at 1 lb/acre mixed with Facet at 0.19 to 0.38 lb/acre, DPRE, provided excellent control of propanil-reistant and -susceptible barnyardgrass.

Application Timings of Command. Command at 0.5 lb/acre applied PPI, PRE, DPRE and EPOST gave excellent control of resistant and susceptible barnyardgrass (Table 6). Bleaching of rice was excessive with Command applied PPI but was tolerated by rice applied PRE, DPRE and EPOST. Rough rice yields were not reduced by the early injury sustained by rice from the PPI application.

Sevin Mixed with Propanil. Rice injury and yield reductions from Sevin plus propanil can be minimized by using Sevin at 0.03 to 0.1 lb ai/acre with 3 lb/acre of propanil (Table 7). As low as 0.01 lb/acre of Sevin caused observable injury to Kaybonnet rice, and injury increased to 38% with a single application and 66% with two applications of 0.3 lb ai/acre of Sevin. Sevin, 0.03 to 0.3 lb/acre, with one or two applications was very effective in controlling resistant barnyardgrass. Two applications were generally more effective than a single application, especially at 0.003 to 0.01 lb ai/acre carbaryl.

SIGNIFICANCE OF FINDINGS

Propanil-resistant barnyardgrass is becoming a more widespread and intense problem in Arkansas. The new chlorophyl fluorescence assay for confirmation of propanil-resistance in barnyardgrass will provide a method for direct plant tissue determination of propanil-resistance. This technology should also aid in the screening process for improved synergists to propanil. Anilophos or piperophos mixed with propanil creates the possibility of more synergists with propanil. The work with Sevin as a synergist with propanil continues to be promising because this compound is already labeled for use in rice. Other systems for controling propanil-resistant barnyardgrass that show promise include DPRE applications of Prowl or Facet alone or these plus Bolero in combination. Command was a very promising herbicide for control of propanil-resistant barnyardgrass; therefore, research with this herbicide should continue.

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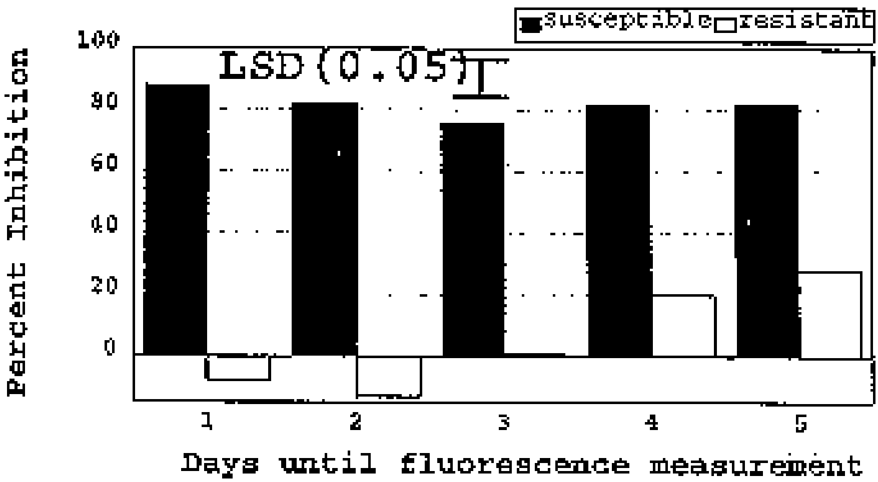

Fig. 1. Inhibition of electron transport in propanil-resistant and -susceptible barnyardgrass tissue as affected by days after harvest.

Table 1. Percentage of control based on average ratings 3, 7, 14 and 21 days after initial treatment of propanil-resistant and -susceptible barnyardgrass biotypes using 5.3 lb/acre propanil at the two- and four-leaf stage of barnyardgrass, Fayetteville, Arkansas, 1996.

Biotypes	1995	1996
	-----------------% Control----------------	
S-Lafayette	83	91
S-Arkansas	77	87
R-Cross I	28	56
R-Cross II	22	39
MR-Poinsett-0-0	49	88
MR-Poinsett-0-4	66	90
MR-Poinsett-4-4	26	66
R-Poinsett	19	34
LSD $_{(0.05)}$	9	9

Table 2. Height of various barnyardgrass biotypes as affected by propanil treatment at 81 days after seeding, Fayetteville, Arkansas, 1996.

	1995		1996	
Biotypes	Treated	Untreated	Treated	Untreated
	----------------------------------cm------------------------------------			
S-Lafayette	47	68	69	74
S-Arkansas	40	69	75	79
R-Cross I	64	75	99	85
R-Cross II	66	71	78	81
MR-Poinsett-0-0	63	81	80	80
MR-Poinsett-0-4	55	68	80	83
MR-Poinsett-4-4	64	77	85	83
R-Poinsett	67	66	81	90
LSD $_{(0.05)}$	11		15	

Table 3. Effects of various additives with propanil on the control of propanil-resistant and -susceptible barnyardgrass, injury to rice at 21 DAT*, and grain yield at two locations in 1996.

		RBYG† control		SBYG‡ control		Rice injury		Grain yield (lb/acre)	
Treatment	Rate	Lon§	Stutt¶	Lon	Stutt	Lon	Stutt	Lon	Stutt
	lb/acre	--------------------------%--------------------------						------lb/acre-----	
Weedy check	-----	0	0	0	0	0	0	600	2800
Propanil	3.0	31	10	71	40	3	0	2700	4400
Facet	0.22	71	69	78	83	0	0	2700	5000
Propanil +	1.5	86	74	93	83	6	0	3800	5700
Facet	0.22								
Propanil +	3.0	76	69	93	73	3	0	3800	5500
Facet	0.074								
Propanil +	3.0	94	76	97	85	1	0	4100	5600
Facet	0.22								
Propanil +	3.0	96	55	98	76	16	24	2600	4000
Sevin	0.3								
Propanil +	3.0	83	60	83	76	3	0	4200	5300
Piperophos	0.3								
Propanil +	3.0	91	86	91	75	1	0	3000	6000
Anilophos	0.3								
LSD $_{(0.05)}$#		18	16	13	17	7	3	2260	1500

*DAT = days after three- to five-leaf barnyardgrass treatment
†RBYG = propanil-resistant barnyardgrass
‡SBYG = propanil-susceptible barnyardgrass
§Lon = Lonoke, Arkansas
¶Stutt = Stuttgart, Arkansas
#LSD $_{(0.05)}$ = least significant differences between treatments at each location

Table 4. Effect of reduced rates of Facet applied DPRE on propanil-resistant and -susceptible barnyardgrass in rice, Stuttgart, Arkansas, 1996.

	Barnyardgrass		Rice	
Treatment, lb/acre	Resistant	Susceptible	Injury	Yield
	----------------------------%----------------------------			lb/acre
Untreated Check	0	0	0	4400
Facet, 0.375	99	100	0	5400
Facet, 0.25	100	100	1	5700
Facet, 0.17	98	100	0	5300
Facet, 0.09	81	90	0	5300
LSD $_{(0.05)}$	5	2	NS	800

Table 5. Effect of alternative herbicides alone and in combination with reduced rates of Facet for control of propanil-resistant and -susceptible barnyardgrass (4 WAT), Stuttgart, Arkansas, 1996.

Treatment	Rate	Barnyardgrass Resistant	Barnyardgrass Susceptible	Rice Yield
	lb/acre	-------% Control------		lb/acre
Untreated Check	0	0	0	4400
Bolero	4	46	45	5500
Prowl	1	98	99	5700
Facet	0.375	99	100	5400
Command	0.5	100	100	5700
Prowl + Facet	1 + 0.375	100	100	5700
Prowl + Facet	1 + 0.19	100	100	5600
Prowl + Facet	1 + 0.09	100	100	5800
Bolero + Facet	2 + 0.375	100	100	5400
Bolero + Facet	2 + 0.19	79	80	4800
Bolero + Facet	2 + 0.09	0	0	5000
LSD $_{(0.05)}$		5	2	800

Table 6. Application timing of Command for propanil-resistant and -susceptible barnyardgrass control in rice, Stuttgart, Arkansas, 1996.

Treatment	Barnyardgrass Resistant	Barnyardgrass Susceptible	Rice Injury	Rice Yield
lb/acre	---------------------%-------------------			lb/acre
Untreated Check	0	0	0	4400
Command (4 EC), 0.5, PPI	100	100	34	5500
Command (3 ME), 0.5, PRE	100	100	14	5900
Command (3 ME), 0.5, DPRE	100	100	11	5700
Command (3 ME), 0.5, EPOST	100	100	12	5800
LSD $_{(0.05)}$	5	2	4	800

Table 7. Control of propanil-resistant barnyardgrass and rice injury 21 days after initial treatment and grain yield from single or sequential treatments of propanil plus Sevin, Stuttgart, Arkansas, 1996.

Rate of Sevin plus Propanil, 3 lb/acre	Barnyardgrass control Single	Barnyardgrass control Sequential	Rice injury Single	Rice injury Sequential	Yield Single	Yield Sequential
lb ai/acre	------------------------%-----------------------				------lb/acre------	
Check	0	0	0	0	2620	2620
0	0	25	0	0	3680	3520
0.001	18	60	5	8	3120	3780
0.003	34	81	5	13	3560	3720
0.01	40	79	13	13	3360	3670
0.03	80	9	5	45	3740	4160
0.1	99	100	25	43	3660	3900
0.3	99	100	38	66	3910	2290
LSD $_{(0.05)}$	28		13		560	

EVALUATION OF FACET GRANULES IN RICE

E.P. Webster, F.L. Baldwin, R.E. Talbert and J.D. Beaty

ABSTRACT

Research to evaluate Facet granules (Facet G) was conducted at the University of Arkansas Pine Bluff Research Station at Lonoke, Arkansas; the Southeast Research and Extension Center at Rohwer, Arkansas; and the Rice Research and Extension Center at Stuttgart, Arkansas. Facet G and Facet DF (dry flowable) were applied, preemergence (PRE), delayed PRE (DPRE) and early postemergence (EPOST) at 0.25, 0.375 and 0.5 lb ai/acre at Lonoke and Rohwer and at 0.18 and 0.375 lb ai/acre at Stuttgart. Broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash] control was evaluated at 2 and 5 weeks after the EPOST treatment (WAT) at Lonoke. Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] control was evaluated at 3 and 5 WAT at Rohwer and 2 and 4 WAT at Stuttgart. Rice (*Oryza sativa* L.) yields were taken at all locations. At Lonoke, 2 WAT, broadleaf signalgrass was controlled 84 to 99% for all treatments, except Facet G EPOST at all rates. Facet G EPOST at 0.25, 0.375 and 0.5 lb ai/acre showed 59, 65 and 56% control of broadleaf signalgrass, respectively. At 5 WAT, residual activity from both formulations of Facet at all application timings gave 88 to 100% control. Rice yields ranged from 150 to 175 bu/acre for all treatments, except Facet G applied EPOST at all rates. At Rohwer, 3 WAT, weed control ranged from 64 to 94%. In general, both Facet formulations at 0.25 and 0.375 lb ai/acre gave lower control than 0.5 lb ai/acre at all application timings. At 5 WAT, Facet G and DF PRE resulted in variable control of barnyardgrass. Rice yields ranged from 95 to 120 bu/acre for all treatments, and the nontreated check produced a yield of 20 bu/acre. At Stuttgart, 2 WAT, barnyardgrass control ranged from 83 to 96% for all treatments. At 5 WAT, control ranged from 83 to 95%. For all treatments, rice yielded from 110 to 130 bu/acre for all treatments, compared to 50 bu/acre for the nontreated check.

INTRODUCTION

The increase of propanil-resistant barnyardgrass in Arkansas (Curless and Talbert, 1996) has caused producers to look for alternative herbicides for control (Talbert et al., 1995). Facet (quinclorac) has been an available option. Facet has had well-publicized problems in the vegetable growing regions of Arkansas, especially on tomatoes. Facet investigations evaluating a new granular (G) formulation began in 1995. Facet is currently available in a dry flowable (DF) formulation that must be dissolved in water and applied by ground or aerial liquid spray applicators.

Facet has been restricted from use, based on distances from populated areas, when wind speeds are high and in the direction of these areas. In 1997, Facet will have an increased distance restriction when it is tank-mixed with any emulsifiable concentrate. The Facet G formulation should allow producers to apply Facet, reduce the chance of spray drift to non-target crops and continue to supply excellent weed control.

However, the use of the new formulation will be limited compared to the versatility of the DF formulation. Since Facet G has different particle sizes, obtaining an even distribution can be difficult. The uneven distribution can cause problems with too much Facet in certain locations, resulting in hot spots, or the lack of Facet in locations, resulting in reduced or no weed control. Weed control by Facet G when applied early postemergence (EPOST) can be reduced if weeds are emerged at application. The use of Facet G will also eliminate the highly effective tank-mix options available with Facet DF.

PROCEDURES

Research was conducted at the University of Arkansas Pine Bluff Research Station at Lonoke, the Southeast Research and Extension Center at Rohwer, and the Rice Research and Extension Center at Stuttgart, Arkansas. A randomized complete block design was used with four replications. Lonoke and Stuttgart tests were on a silt loam soil and the Rohwer test on a silty clay soil. The seeding date at Lonoke was 27 April, at Stuttgart 15 May and at Rohwer 16 May 1997. Lonoke and Stuttgart tests were seeded with the rice cultivar 'Kaybonnet', and Rohwer was seeded with 'Lemont'.

Facet G and Facet DF were applied preemergence (PRE), delayed PRE (DPRE) and EPOST at 0.25, 0.375 and 0.5 lb ai/acre at Lonoke and Rohwer, and at 0.18 and 0.375 lb ai/acre at Stuttgart. Facet DF applied EPOST contained 1 pt/acre crop oil concentrate at all locations. Facet G was applied broadcast by hand, and Facet DF applications were made with a CO_2 backpack sprayer at 15 GPA at Lonoke and Rohwer and at 20 GPA at Stuttgart.

Broadleaf signalgrass control was evaluated at two and five weeks after the EPOST treatment (WAT) at Lonoke. Barnyardgrass control was evaluated at 3 and 5 WAT at Rohwer, and 2 and 4 WAT at Stuttgart. Rice yields were taken at all locations. Data were subjected to ANOVA, and treatment differences were compared by Fisher's protected LSD Test at the 5% significance level.

RESULTS AND DISCUSSION

At Lonoke, 2 WAT, broadleaf signalgrass control was 84 to 99% for all treatments, except Facet G EPOST at all rates (Table 1). Facet G EPOST at 0.25, 0.375 and 0.5 lb ai/acre gave 59, 65 and 56% control of broadleaf signalgrass, respectively. Facet DF at the same rates resulted in 89, 90 and 95% control, respectively. The reduction in control from the Facet G is due to lack of control of emerged grasses. However, control had increased significantly at 5 WAT.

At 5 WAT, residual activity from both formulations of Facet at all application timings gave 88 to 100% control. The EPOST applications of Facet G increased control due to the residual activity on later germinating grasses.

Rice yields ranged from 150 to 175 bu/acre for all treatments, except Facet G applied EPOST at all rates. The EPOST applications produced yields ranging from 95 to 115 bu/acre. The nontreated check yielded 75 bu/acre. These data indicate that EPOST applications may give reduced control, and rice yields can be reduced due to competition from the weeds.

At Rohwer, 3 WAT, control from all treatments ranged from 64 to 94% (Table 1). In general, both Facet formulations at 0.25 and 0.375 lb ai/acre tended to give lower control at all application timings. Facet at 0.5 lb ai/acre at Rohwer showed control ranging from 83 to 94%. The higher rate was needed on the clay soil at Rohwer. The Facet G formulation did not show a reduction in control at the early rating at Rohwer compared to Lonoke.

At 5 WAT, Facet G and DF PRE gave variable control of barnyardgrass. Facet G EPOST required the 0.5 lb ai/acre rate to equal the control by the DF formulation. Rice yields ranged from 95 to 120 bu/acre for all treatments, and the nontreated check produced a yield of 20 bu/acre.

At Stuttgart, at 2 and 4 WAT, barnyardgrass control was more consistent with both formulations of Facet compared to the results at Lonoke and Rohwer (Table 2). At 2 WAT, barnyardgrass control ranged from 83 to 97% for all treatments (Table 2). At 5 WAT, control ranged from 83 to 95%. Rice yields ranged from 110 to 130 bu/acre for all treatments, compared to 50 bu/acre for the nontreated check. At Stuttgart, this research indicates little difference in weed control and grain yield between the Facet formulations.

SIGNIFICANT FINDINGS

This research indicates that Facet G may be a good replacement for Facet DF. The Facet G, when applied EPOST, will need to be applied in a timely manner to maximize weed control and grain yields. If the Facet G is applied on already emerged grasses, control will be less than from treatment with Facet

DF. This technology needs to be refined; however, a granular formulation of Facet is needed in rice production to reduce off-site movement of the herbicide.

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Table 1. Grass control and grain yield with Facet formulation treatments at Lonoke and Rohwer, Arkansas, 1996.

				Lonoke*			Rohwer		
				Broadleaf signalgrass			Barnyardgrass		
Herbicide	Rate	Timing	Form	2 WAT[†]	5 WAT	Yield	3 WAT	5 WAT	Yield
	lb ai/acre			------%-----		bu/acre	------%-----		bu/acre
Facet	0.25	PRE	G[‡]	93	96	160	83	75	110
Facet	0.25	PRE	DF	99	100	175	76	61	105
Facet	0.375	PRE	G	89	98	155	84	86	105
Facet	0.375	PRE	DF	96	100	170	70	36	95
Facet	0.5	PRE	G	91	100	150	84	79	115
Facet	0.5	PRE	DF	99	100	165	83	68	95
Facet	0.25	DPRE	G	86	96	160	64	55	95
Facet	0.25	DPRE	DF	95	99	170	80	71	100
Facet	0.375	DPRE	G	84	99	165	85	79	120
Facet	0.375	DPRE	DF	96	100	165	80	80	115
Facet	0.5	DPRE	G	88	99	160	88	86	120
Facet	0.5	DPRE	DF	98	99	150	89	95	120
Facet	0.25	EPOST	G	59	88	115	86	70	100
Facet	0.25	EPOST	DF[§]	89	95	155	91	85	110
Facet	0.375	EPOST	G	65	89	110	78	63	95
Facet	0.375	EPOST	DF	90	100	160	90	86	115
Facet	0.5	EPOST	G	56	90	95	88	78	120
Facet	0.5	EPOST	DF	95	99	165	94	93	116
Nontreated				0	0	75	0	0	20
$LSD_{(0.05)}$				10	6	15	9	19	25

*Lonoke seeded with ‘Kaybonnet’; Rohwer seeded with ‘Lemont’.

[†]WAT = Weeks after early postemergence (EPOST) treatment.

[‡]G = granular formulation.

[§]DF formulation applied EPOST contained 1 pt/acre crop oil concentrate.

Table 2. Barnyardgrass control and rice grain yield with Facet formulation treatments at Stuttgart, Arkansas, 1996.

				Stuttgart*		
				Barnyardgrass		
Herbicide	Rate	Timing	Form	2 WAT†	4 WAT	Yield
	lb ai/acre			---------%---------		lb/acre
Facet	0.18	PRE	G‡	83	89	125
Facet	0.18	PRE	DF	97	86	125
Facet	0.375	PRE	G	96	95	120
Facet	0.375	PRE	DF	95	95	110
Facet	0.18	DPRE	G	93	93	125
Facet	0.18	DPRE	DF	93	93	120
Facet	0.375	DPRE	G	95	88	115
Facet	0.375	DPRE	DF	95	93	115
Facet	0.18	EPOST	G	84	83	130
Facet	0.18	EPOST	DF§	95	91	120
Facet	0.375	EPOST	G	96	90	125
Facet	0.375	EPOST	DF	94	90	110
Nontreated				0	0	50
LSD = $_{(0.05)}$				5	7	20

*Stuttgart seeded with ‘Kaybonnet’.

†WAT = Weeks after early postemergence EPOST treatment.

‡G = granular formulation

§DF formulation applied EPOST contained 1 pt/acre crop oil concentrate.

POTENTIAL FOR COMMAND USE IN RICE

E.P. Webster, F.L. Baldwin, R.E. Talbert and J.D. Beaty

ABSTRACT

Field studies were established at the University of Arkansas Pine Bluff Research Station at Lonoke, Arkansas; the Southeast Research and Extension Center at Rohwer, Arkansas; and the Rice Research and Extension Center at Stuttgart, Arkansas, in 1996 to evaluate the potential for Command (clomazone) use in rice (*Oryza sativa* L.). Command was applied preplant incorporated (PPI) using the 4 EC formulation, preemergence (PRE), delayed PRE (DPRE) and early postemergence (EPOST) using the 3 ME formulation. Command rates were 0.4, 0.5 and 0.6 lb ai/acre at all application timings. Facet (quinclorac) at 0.38 lb ai/acre at Lonoke and Stuttgart and 0.5 lb ai/acre at Rohwer PRE and Bolero at 4.0 lb ai/acre DPRE were applied for comparison purposes. Broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash] at Lonoke and Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] at Rohwer and Stuttgart control ratings were taken. Crop injury and yield were also evaluated. At Lonoke, broadleaf signalgrass control was 90% or above for all treatments at 3 WAT, except Command applied EPOST at all rates and Bolero applied DPRE. At 14 WAT, Command applied PPI, PRE or DPRE had 94 to 100% control of broadleaf signalgrass. Rice yields ranged from 40 bu/acre for the nontreated to 170 bu/acre for Command at 0.5 lb/acre DPRE. At Rohwer, 3 and 10 WAT, all Command treatments had 79 to 93% control of barnyardgrass. Rice injury was limited, and all herbicide treatments resulted in higher yields than the nontreated. At Stuttgart, 2 and 4 WAT, propanil-resistant and -susceptible barnyardgrass control was 100% for all Command treatments. Rice injury was significant with PPI and EPOST applications of Command, but grain yields were not significantly reduced.

INTRODUCTION

Command (clomazone) was first labeled for use in soybeans in 1985 for control of annual grasses and broadleaves (WSSA, 1994). In the late eighties, Command was being evaluated for use in cotton (Marth et al., 1990). However, when Command is applied in a cotton production system, an organophosphate insecticide must be used in-furrow to safen cotton against Command. Research evaluating Command use in rice began in 1994 (Mitchell and Hatfield, 1996).

The increase of propanil-resistant barnyardgrass in Arkansas (Curless and Talbert, 1996) has caused producers to look for alternative herbicides for control (Talbert et al., 1995). Facet (quinclorac) has been an option available to producers. Command also has potential to be a replacement for propanil when resistant barnyardgrass is present. Facet has had well-publicized problems in the vegetable growing regions of Arkansas, especially on tomatoes. Command has also had problems with off-site movement (Kendig et al., 1994); however, with education, incorporation (Webster et al. 1995) and the new micro-encapsulated formulation (Stringer et al., 1996), off-site movement has been reduced. The new formulation and ability to incorporate Command may allow it to be used when Facet is restricted. Command is being evaluated for potential use as a preplant incorporated (PPI), preemergence (PRE), delayed PRE (DPRE) or an early postemergence (EPOST) application. A rate of 0.4 lb ai/acre has shown results similar to those of other herbicides used for weed control in rice (Mitchell and Hatfield, 1996).

PROCEDURES

Research was conducted at the University of Arkansas Pine Bluff Research Station at Lonoke, the Southeast Research and Extension Center at Rohwer, and the Rice Research and Extension Center at Stuttgart, Arkansas. The studies were a randomized complete block design with four replications. Soil at Lonoke and Stuttgart is a silt loam and at Rohwer a silty clay soil. The seeding dates were 27 April at Lonoke, 15 May at Stuttgart and 16 May 1996 at Rohwer. At Lonoke and Stuttgart the cultivars were 'Kaybonnet' and 'Lemont', respectively.

Command was applied PPI, PRE, DPRE and EPOST at 0.4, 0.5 and 0.6 lb ai/acre. The 4 EC formulation was used for Command PPI, and the 3 EC formulation with all other timings. Facet and Bolero were used for comparison purposes. Facet was applied PRE at 0.38 lb ai/acre on the silt loam soils at Lonoke and Stuttgart and at 0.5 lb ai/acre on the silty clay soil at Rohwer. Bolero was applied DPRE at 4.0 lb ai/acre at all locations. All herbicide applications were made with a CO_2 backpack sprayer at 15 gal/acre (GPA) at Lonoke and Rohwer and at 20 GPA at Stuttgart.

Broadleaf signalgrass control and rice injury were evaluated at 3 and 14 weeks after the EPOST treatment at Lonoke. Barnyardgrass control and rice injury were evaluated at 3 and 10 weeks after treatment (WAT) at Rohwer. Propanil-resistant and -susceptible barnyardgrass control were evaluated at 2 and 4 WAT, and rice injury was evaluated at 2 and 3 WAT at Stuttgart. Rice yields were taken at all locations. Data were subjected to ANOVA, and treatment differences were compared by Fisher's protected LSD Test at the 5% significance level.

RESULTS AND DISCUSSION

At Lonoke, 3 WAT, broadleaf signalgrass control was 90% or above for all treatments, except Command EPOST at all rates and Bolero DPRE (Table 1). Rice injury was less than 15% for any treatment. This early rating indicates that broadleaf signalgrass control and rice injury are not dependent on rate or application timing. The low rate of Command at 0.4 lb/acre had equal control compared to the high rate of 0.6 lb/acre when applied PPI, PRE and DPRE. However control decreased when applied EPOST.

At 14 WAT, residual activity from Command PPI, PRE or DPRE gave 94 to 100% control of broadleaf signalgrass. The continued high control of broadleaf signalgrass at 14 WAT indicates the excellent potential that Command has in a rice production system. Rice injury was 3% with Command EPOST at 0.4 and 0.5 lb/acre; however, all other application timings and rates showed no observable injury.

Rice grain yields ranged from 40 bu/acre for the nontreated to 170 bu/acre for Command DPRE at 0.5 lb/acre. Command EPOST all rates, Command PRE at 0.4 lb/acre, Command PPI at 0.5 and 0.61 bu/acre, Bolero at 4.0 lb/acre and the nontreated produced significantly lower yields than the Command DPRE at 0.5 lb/acre. All other treatments had yields not significantly different from the Command DPRE at 0.5 lb/acre.

At Rohwer, 3 WAT, all treatments showed 79 to 93% control of barnyardgrass, except Bolero and the nontreated (Table 2). Command PPI at 0.4 lb/acre resulted in 5% injury, but no other treatment had any rice injury at this time.

At 10 WAT, the residual activity of Command remained high. All Command applications controlled barnyardgrass from 79 to 93%. Command PPI and EPOST both at 0.6 lb/acre showed 91 and 93% control, respectively. No rice injury was observed at this time. All treatments resulted in higher grain yields than the nontreated; however, there were no significant differences among the herbicide treatments for grain yield.

At Stuttgart, 2 and 3 WAT, propanil-resistant and -susceptible barnyardgrass control was 100% for all Command treatments (Table 3). Barnyardgrass control with Facet was 96 to 100% control for the resistant and susceptible lines. Bolero did not have adequate control of either barnyardgrass.

Significant rice injury resulted from all rates of Command PPI at 2 and 3 WAT. At 2 WAT, injury ranged from 79% with Command PPI at 0.5 lb/acre to no injury with Command DPRE at 0.4 lb/A. At 3 WAT, rice injury remained significant; however, injury was below 45% for all treatments. The high injury observed did not significantly reduce rice grain yields compared to other treatments in the study. These data indicate that rice can be significantly injured by Command; however, the high injury did not translate into significant yield reductions in this case.

SIGNIFICANCE OF FINDINGS

This research indicates that Command has potential as a herbicide in a rice production system. Command has excellent activity on many grasses at the rates evaluated in these studies. The reduced rates, application timings and the new micro-encapsulated formulation can greatly reduce the off-site movement of Command, and it can be a viable option to replace Facet in problem areas. This research also indicates that Command can be used on many soil types and provide excellent broad-spectrum weed control. Excess injury has been observed; however, little to no reduction in yield occurred.

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Table 1. The influence of Command formulation and application timing on broadleaf signalgrass control, rice grain injury and yield at Lonoke, Arkansas, 1996.

			Lonoke*				
			Broadleaf signalgrass		Rice Injury		
Treatment	Rate	Timing	3 WAT†	14 WAT	3 WAT	14 WAT	Yield
	lb ai/acre		--------------------%--------------------				lb/acre
Command 4 EC	0.4	PPI	96	98	6	0	150
Command 4 EC	0.5	PPI	98	98	11	0	145
Command 4 EC	0.6	PPI	96	94	6	0	145
Command 3 ME	0.4	PRE	91	96	6	0	140
Command 3 ME	0.5	PRE	91	100	13	0	160
Command 3 ME	0.6	PRE	91	98	6	0	155
Command 3 ME	0.4	DPRE	94	100	10	0	155
Command 3 ME	0.5	DPRE	90	100	8	0	170
Command 3 ME	0.6	DPRE	94	100	6	0	155
Command 3 ME	0.4	EPOST	79	66	4	3	90
Command 3 ME	0.5	EPOST	83	89	4	3	135
Command 3 ME	0.6	EPOST	89	91	5	0	125
Facet	0.38	PRE	98	100	10	0	160
Bolero	4.0	DPRE	69	0	6	0	110
Nontreated			0	0	0	0	40
LSD = $_{(0.05)}$			9	10	8	2	20

*Lonoke seeded ‘Kaybonnet’

†WAT = Weeks after early postemergence (EPOST) treatment.

Table 2. The influence of Command formulation and application timing on barnyardgrass control, rice injury and grain yield with Command at Rohwer, Arkansas, 1996.

			Rohwer*				
			Barnyardgrass		Rice Injury		
Treatment	Rate	Timing	3 WAT†	10 WAT	3 WAT	10 WAT	Yield
	lb ai/acre		--------------------%--------------------				lb/acre
Command 4 EC	0.4	PPI	84	84	0	0	140
Command 4 EC	0.5	PPI	93	88	0	0	135
Command 4 EC	0.6	PPI	91	91	0	0	130
Command 3 ME	0.4	PRE	83	83	5	0	130
Command 3 ME	0.5	PRE	79	85	0	0	130
Command 3 ME	0.6	PRE	88	88	0	0	135
Command 3 ME	0.4	DPRE	80	84	0	0	135
Command 3 ME	0.5	DPRE	79	81	0	0	130
Command 3 ME	0.6	DPRE	90	84	0	0	135
Command 3 ME	0.4	EPOST	93	84	0	0	130
Command 3 ME	0.5	EPOST	89	79	0	0	135
Command 3 ME	0.6	EPOST	91	93	0	0	130
Facet	0.38	PRE	83	80	0	0	125
Bolero	4.0	DPRE	71	75	0	0	135
Nontreated			0	0	0	0	70
LSD = $_{(0.05)}$			9	10	4	0	20

*Rohwer seeded ‘Lemont’.

†WAT = Weeks after early postemergence (EPOST) treatment.

Table 3. The influence of Command formulation and application timing on barnyardgrass control, rice injury and grain yield with Command at Stuttgart, Arkansas.

			Stuttgart*						
			Barnyardgrass						
			2 WAT[†]		4 WAT		Rice Injury		
Formulation	Rate	Timing	R[‡]	S	R	S	2 WAT	3 WAT	Yield
	lb ai/acre		%						lb/acre
Command 4 EC	0.4	PPI	100	100	100	100	43	18	130
Command 4 EC	0.5	PPI	100	100	100	100	79	43	115
Command 4 EC	0.6	PPI	100	100	100	100	74	39	110
Command 3 ME	0.4	PRE	100	100	100	100	3	0	110
Command 3 ME	0.5	PRE	100	100	100	100	10	4	130
Command 3 ME	0.6	PRE	100	100	100	100	11	5	115
Command 3 ME	0.4	DPRE	100	100	100	100	0	0	125
Command 3 ME	0.5	DPRE	100	100	100	100	3	0	110
Command 3 ME	0.6	DPRE	100	100	100	100	3	1	130
Command 3 ME	0.4	EPOST	100	100	100	100	9	6	120
Command 3 ME	0.5	EPOST	100	100	100	100	29	18	120
Command 3 ME	0.6	EPOST	100	100	100	100	35	38	125
Facet	0.38	PRE	96	96	100	100	0	0	130
Bolero	4.0	DPRE	51	54	55	68	0	0	120
Nontreated			0	0	0	0	0	0	105
LSD = $_{(0.05)}$			12	3	14	9	13	8	20

*Stuttgart seeded ‘Kaybonnet’.

[†]WAT = Weeks after early postemergence (EPOST) treatment.

[‡]R = Propanil-resistant barnyardgrass, S = Propanil-susceptible barnyardgrass.

WEED CONTROL IN LIBERTY-TOLERANT RICE

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ABSTRACT

Genetically transformed rice varieties, tolerant to glufosinate (Liberty), have the potential to allow improved weed control in dry-seeded rice. Preliminary research, with glufosinate for red rice (*Oryza sativa*) and general weed control in genetically transformed rice varieties, was conducted in Arkansas. Glufosinate was applied alone and also as a tank mix with propanil (Stam) and quinclorac (Facet). Glufosinate used alone provided better control when sequentially applied at low rates compared to single applications at higher rates. Near 100% control of red rice and other common rice weeds was achieved with sequential applications of glufosinate alone and with all of the tank mixes.

INTRODUCTION

Weeds are the number one yield constraint in Southern rice production. Of these weeds, red rice is the most difficult to control. To date, there are no effective control measures in dry-seeded rice. Propanil-resistant barnyardgrass (*Echinochloa crus-galli*) is increasing. Broadleaf weed control often requires herbicides such as 2,4-D that are difficult to use near susceptible crops. New technology is needed. Genetically transformed rice varieties tolerant to glufosinate (Liberty) have potential to provide this technology. Preliminary research, with glufosinate for red rice and general weed control in genetically transformed rice varieties, was conducted in 1996.

MATERIALS AND METHODS

A red rice control study was conducted in transformed ‘Gulfmont’, and a red rice grower demonstration was conducted in transformed ‘Cypress’ at Stuttgart, Arkansas. Broadleaf signalgrass *(Brachiaria platypylla*), hemp sesbania (*Sesbania exalta*) and morningglory (*Ipomea lacunosa* and *hederaceae*) control was evaluated in transformed Gulfmont at Lonoke, Arkansas.

Rice at both locations was drill seeded. The experimental design was a randomized complete block with four replications. Red rice at Stuttgart was over seeded prior to final seed bed preparation. The weed spectrum at the

Lonoke location was a severe native infestation of broadleaf signalgrass and several broadleaf species. Herbicide treatments were applied with either a back-pack or tractor-mounted sprayer using a spray volume of 10 gallons per acre (GPA) at Stuttgart and 15 GPA at Lonoke. Treatments in the studies were applied at early postemergence (two- to three-leaf rice), before flood (just prior to flooding) and both. Only visual ratings were taken in the red rice studies since they were destroyed prior to harvest to prevent any potential outcrossing.

RESULTS AND DISCUSSION

Red rice treatments and data from the study at Stuttgart are presented in Table 1. Treatments and data from the general weed control study conducted at Lonoke are presented in Table 2. Two applications of glufosinate, at 0.375 lb ai/acre and higher, provided near 100% control of red rice.

Control of broadleaf signalgrass, hemp sesbania and morningglory was excellent with two applications of glufosinate at 0.375 lb/acre and higher (Table 2). Several of the combination treatments (either tank mixes or sequential treatments using other herbicides) also provided excellent control. No crop injury was observed with any treatment at any location. Yields were low in the transformed Gulfmont seeded at Lonoke. The primary reasons were likely late seeding and disease pressure. Due to the outstanding control of red rice and other common rice weeds in these preliminary studies, research will be greatly expanded in 1997.

SIGNIFICANCE OF FINDINGS

Liberty-tolerant rice is the first of several emerging new rice technologies that have the capability to control a broad spectrum of weeds, including red rice, in dry-seeded rice. This has the potential to be the greatest herbicide break-through in rice since the development of propanil treatments in the early 1960's.

Table 1. Strawhulled red rice control in Liberty-tolerant 'Gulfmont' rice, Stuttgart, Arkansas, 1996.

Herbicide	Rate	Timing	Red rice control 7/15	Red rice control 8/13	RR dry wt. % of UTC
	lb ai/acre				%
UTC*	-	-	0	0	100
Liberty	0.25	3 LF[†]	95	64	6
Liberty	0.25	BF[‡]	.	76	3
Liberty	0.375	3 LF	100	90	6
Liberty	0.375	BF	.	63	5
Liberty	0.375 fb 0.375	3 LF/BF	99	98	0
Liberty	0.5	3 LF	100	93	3
Liberty	0.5	BF	.	78	3
Liberty	0.5 fb 0.5	3 LF/BF	99	100	0
Liberty	0.75	3 LF	100	96	1
Liberty	0.75	BF	.	97	0
Liberty	0.75 fb 0.75	3 LF/BF	99	100	0
Liberty	1.0	BF	.	97	0
$LSD_{0.05}$			9.4	15.6	5.4

*UTC = untreated check.
[†]3 LF = three leaf, applied 7/1/96.
[‡]BF = before flood, applied 7/15/96.

Table 2. Weed control and grain yield in Liberty-tolerant 'Gulfmont' rice, Lonoke, Arkansas, 1996

Herbicide and Rate (lb ai/A)	Timing	% Control 6/24/96 BRAPP*	% Control 6/24/96 IPOHE	% Control 6/24/96 SEBEX	Yield
					bu/acre
UTC[†]		0	0	0	36
Liberty 0.375 fb 0.375	2-3 Lf[‡]/BF[§]	100	100	100	84
Liberty 0.5 fb 0.5	2-3 LF/BF	97	98	100	82
Liberty 0.75 fb 0.75	2-3 LF/BF	97	98	100	83
Stam 2.0 + Liberty 0.25 fb 2.0 + 25	2-3 LF/BF	100	100	100	97
Stam 2.0 + Liberty 0.375 fb Stam 2.0 + Liberty 0.375	2-3 LF/BF	100	98	100	89
Stam 3.0 fb Liberty 0.375	2-3 LF/BF	95	100	100	81
Stam 3.0 fb Liberty 0.5	2-3 LF/BF	100	100	100	80
Stam 3.0 fb Liberty 0.75	2-3 LF/BF	100	100	100	75
Facet 0.375 fb Liberty 0.5	Delayed Pre[¶]/BF	100	100	100	74
Facet 0.188 + Prowl 1.0 fb Liberty 0.5	DlyPre/BF	100	100	100	91
Liberty 0.375 + Facet 0.25	2-3 LF	100	100	100	87
Liberty 0.5 + Facet 0.25	2-3 LF	100	100	100	91
Liberty 0.75 + Facet 0.25	2-3 LF	100	100	97	72
$LSD_{0.05}$		4.9	2.1	2.6	20.2

*BRAPP = broadleaf signalgrass; IPOHE = morningglory; SEBEX = hemp sesbania.
[†]UTC = untreated check
[‡] 2-3 LF = two- to three-leaf, applied 6/12/96
[§]BF = before flood, applied 6/20/96
[¶]Delayed Pre applied 5/31/96

SCREENING RICE LINES FOR SUSCEPTIBILITY TO DISCOLORED KERNELS

J.L. Bernhardt, K.A.K. Moldenhauer and K.A. Gravois

ABSTRACT

Rice lines were evaluated for susceptibility to causes of kernel discolorations. Advanced rice lines in the Arkansas Rice Performance Trials and experimental varieties in the Uniform Regional Rice Nursery were compared to check cultivars for susceptibility to feeding by rice stink bugs, to infection with fungi and bacteria after rice stink bug feeding, to kernel smut infection, to causes of other kernel discolorations and linear damage. In 1996 the levels of rice stink bug activity and kernel smut infection were the highest recorded since the evaluations were begun in 1988. Medium-grain cultivars 'Lafitte', 'M202', 'Koshihikari' and 'Bengal' had very high amounts of kernel discoloration due to rice stink bugs and other causes. Long-grain cultivars 'LaGrue', 'Katy' and 'Kaybonnet' had low amounts of kernel discolorations due to rice stink bug. LaGrue, M202, 'Millie', 'Alan', Lafitte and 'Cypress' were heavily damaged by kernel smut. Lafitte, M202 and Koshihikari also had high levels of linear damage. Yearly evaluations of rice lines and check cultivars in the Arkansas Rice Performance Trials and the Uniform Regional Rice Nursery are given to rice breeders and can be used to help in the selection of lines to continue in the breeding program. Rice growers can use the information to choose cultivars and use management practices that will reduce quality reductions due to discolored kernels.

INTRODUCTION

Research has shown that rice lines have varying levels of susceptibility to organisms that discolor kernels. In the field, most kernel discolorations are caused by fungi alone, such as kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] or by fungi introduced by the rice stink bug [*Oebalus pugnax* (F.)]. Rice stink bugs are commonly found in all Arkansas rice fields after panicle emergence. Adults and nymphs feed on developing rice kernels after the mouthparts have pierced the hull. Hulls are not discolored by rice stink bug feeding. Successful feeding can occur on developing kernels shortly after floret fertilization and on all stages through the soft dough stage. The stage of development determines the amount and type of damage. Feeding during the early stages arrests any further development of the kernel and results in a total loss of the grain. Feeding during the kernel-fill stages often results in only a portion of the contents being removed. Very often after the hull is pierced by rice stink bugs, fungi gain entry, and the infection results in a discoloration of the kernel. The amount of damage by rice stink bugs often influences the acceptability and value of rough rice.

Research emphasis has been placed on the development of a control strategy that integrates control methods such as rice stink bug parasites, insecticides, and rice lines with reduced susceptibility to the rice stink bug. Thus, a portion of the entomology research program in rice is for the evaluation of rice lines for susceptibility to rice stink bug feeding and other causes of kernel discoloration. The overall objective of this part of the total program is to provide information to breeders and, perhaps, to safeguard against the release of more susceptible varieties than exist at the present time, to evaluate rice lines released from other breeding programs and to evaluate the available rice germplasm for sources of resistance.

To accomplish the objectives, rice grain samples must be obtained from several sources and evaluated for the amount of discolored kernels caused by rice stink bugs and pathogens. Results from the evaluations of rice lines are compared and conclusions made on their relative susceptibility to damage. This report is a summary of the annual evaluation of rice lines in breeding programs for resistance to the rice stink bug and other causes of kernel discolorations.

PROCEDURES

Samples of experimental varieties and lines from the following sources and years were evaluated: 1) the rice breeding program of the University of Arkansas placed in the Arkansas Rice Performance Trials (ARPT) (1988-1996); 2) breeding programs of other universities and private seed companies entered in the ARPT (1988 - 1996); and 3) those in the Uniform Regional Rice Nursery (URRN) (1993-1996). Locations of the ARPT were the Rice Research and Extension Center, Stuttgart, Arkansas (RREC, Arkansas County); Jackson County near Tupelo, Arkansas; and the Southeast Branch Experiment Station, Rohwer, Arkansas (SEBES, Desha County). Locations of the URRN were RREC in Arkansas (1993-1996); Rice Research Station, Crowley, Louisiana (1994-1996); Texas Agricultural Experiment Station, Beaumont, Texas (1994-1996); and Delta Research and Extension Center, Stoneville, Mississippi (1995-1996). A yearly accounting of the number of entries, replications and locations for the ARPT and URRN evaluations are given in Table 1. Among the entries in the ARPT and URRN were check cultivars used for comparisons. Although not all evaluations are complete, data from check cultivars and advanced rice lines (experimental varieties) in the ARPT from 1992 through 1996 are included in this report.

Uncleaned rough rice samples were taken and then hulled. Brown rice was passed three times through an electronic sorting machine that separated discolored kernels from other kernels. The discolored kernels were examined with magnification to determine the cause of the discoloration. The categories of discolored kernels were 1) kernels discolored by rice stink bug feeding, 2) kernels infected with kernel smut, 3) all other discolorations of which most had the discoloration confined to the bran layer and 4) linear discolored kernels. Linear discolored kernels had a straight (linear) 'cut' in the kernel that was surrounded by a dark brown to black area (Douglas and Tullis, 1950). The amount of discolored kernels in a category was weighed and expressed as a percentage of the total weight of brown rice.

RESULTS AND DISCUSSION

Rice Stink Bug

Large field tests such as the ARPT rely on natural infestations of the rice stink bug. In 1996, infestations of the rice stink bug must have been high because overall amounts of damage were the highest recorded since these studies were initiated in 1988 (see Table 2). General trends noted in other years of the ARPT and other varietal studies (Bernhardt, 1992) remained the same. For example, the amount of discolored kernels in medium-grain was 85% more than that in the long-grain types. Also, long-grain cultivars that routinely have less damage from rice stink bug, such as 'Katy' and 'LaGrue', had the lowest amounts of damage of any long-grain entries tested in 1996.

Several cultivars were new to the ARPT in 1996. The medium-grain cultivars 'Lafitte' (LA) and 'M202' (CA) and the Japanese cultivar 'Koshihikari' and the long-grain cultivars 'Jodon' (LA) and 'Jefferson' (TX) were evaluated. Of these five, only Jefferson had a level of damage that was as low as LaGrue and Katy.

The cultivar 'Drew' was released in 1996. It has resistance to rice blast disease, excellent milling yields, sheath blight tolerance, less kernel smut than 'Newbonnet' and a grain size and yield potential greater than that of Katy. Drew has been in the ARPT since 1992 and has averaged slightly more damage from rice stink bugs than Katy, but less than Newbonnet and 'Cypress'.

Two experimental varieties, RU9401188 and RU9501121, were advanced to potential release status. Levels of discolored kernels from rice stink bug feeding in both varieties in 1995 were not consistent with levels found in 1996 (Table 2). Both appear to be more susceptible to rice stink bug damage than LaGrue and Kaybonnet. Neither appeared highly susceptible to kernel smut and linear damage.

Kernel Smut

It is believed that kernel smut infects the open flower at anthesis and then grows in the developing kernel (Cartwright et al., 1994). Often when the whole kernel is consumed, only black spores remain within the hulls. Our method of sample preparation removes that type of infected kernels but often detects kernels that have been only partially consumed by kernel smut infection. The incidence of partially consumed kernels was considerably higher in the 1996 samples (Table 3). Overall amounts of kernels damaged by kernel smut were the highest recorded since these studies were initiated in 1988. Cultivars with high levels were LaGrue, M202, 'Millie', 'Alan', Lafitte, Jefferson, and Cypress (highest to lowest value). These data generally agree with kernel smut susceptibility ratings given by pathologists.

Other Discolored Kernels

Our method of evaluation of rice also detects kernels that are discolored by something other than rice stink bugs or kernel smut. These kernels are placed in a category called other damage. The discoloration is most often confined only to the bran layer. Causes for most of the bran discolorations have not been identified. However, a portion of the bran discoloration has been associated with severe brown spot (*Helminthosporium*) on the hull. Other discolorations appear to be common to a cultivar/variety or caused by an interaction between cultivar/variety and weather conditions. The amount of kernels in this category varies from year to year even within a cultivar/variety (Table 4). However, certain types appear to be more susceptible than others. For example, the medium-grain M202, Koshihikari and Bengal had very high levels of bran discolorations in 1996.

Linear Discolorations

This type of discoloration was as described by Douglas and Tullis (1950). The damage is characterized as a linear 'cut' across the kernel that exposes the white kernel, and the area around the cut is either very dark brown or black. Kernels are weakened at the cut and frequently break during milling. The discoloration is not limited to the bran, and milling does not eliminate the discoloration. Between 1988 and 1994, only one rice cultivar, 'Mercury', had levels of linear damage that were much higher than the others. In 1995, Louisiana released a new cultivar called Lafitte. The parents of Lafitte were Mercury and Koshihikari. In evaluations of the 1995 URRN samples, Lafitte was found to have very high amounts of linear damage. Results of the 1996 ARPT evaluations for linear damage show that Koshihikari, M202 and Lafitte are much more susceptible to conditions that cause the discolorations (Table 4). It is suspected that high temperatures during grain fill or maturation cause more linear damage in susceptible types.

Uniform Regional Rice Nursery

The evaluation of entries in the URRN continues to provide a good comparison of the susceptibility to rice stink bug damage of check cultivars and experimental varieties from breeding programs in Arkansas, Louisiana, Mississippi and Texas. These data are especially important when a cultivar is released from another state. Arkansas farmers are quick to try a new rice cultivar, regardless of the origin, especially if the farmer thinks the new type has advantages over other cultivars. Prior knowledge of the susceptibility of any new releases to rice stink bug damage and other kernel discolorations could be used by Arkansas farmers to make informed decisions on the choice of cultivar to grow. Evaluations of 1996 URRN samples are incomplete.

SIGNIFICANCE OF FINDINGS

Evaluations of advanced rice lines provide rice breeders with information on the susceptibility of lines to rice stink bug damage. Breeders can then use the information in the selection of lines for further tests and the elimination of lines that are clearly more susceptible to damage than those lines that exist at the present time. Rice growers can use the information to select varieties and use management practices that will reduce quality reductions due to discolored kernels. For example, medium-grain rice varieties such as Bengal, Lafitte, M202 and Koshihikari are very susceptible to rice stink bug damage and other types of kernel discolorations. Thus, careful scouting and insecticide treatment for rice stink bug, when necessary, would prevent excessive discounts due to discolored kernels.

Often a variety is released from another state without extensive information on how susceptible that variety is to discolored kernels under Arkansas growing conditions. When lines in the URRN are evaluated in Arkansas, the susceptibility to rice stink bug damage and other causes of kernel discolorations can be assessed before a line is released. Thus, valuable information is made available to Arkansas rice growers to use when making variety selections.

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Table 1. Number of locations, rice cultivars and experimental varieties, and replications for evaluations of rice samples from the Arkansas Rice Performance Trials (ARPT) and Uniform Regional Rice Nursery (URRN).

Number of	ARPT					URRN			
	1992	1993	1994	1995	1996	1993	1994	1995	1996
Locations	3	3	3	3	3	1	3	4	4
Rice Lines	36	63	60	60	60	80	80	80	80
Reps	4	3	3	3	3	3	3	4	4

Table 2. Average percent, by weight, of kernels discolored by rice stink bugs in brown rice samples of rice cultivars and experimental in the Arkansas Rice Performance Trials (ARPT).

Maturity group,	Grain	Year				
cultivar and variety	Type	1992	1993	1994	1995	1996
Mid-Season						
Cypress	L	0.44	1.30	0.59	0.99	1.62
Newbonnet	L	0.44	1.50	0.64	1.02	1.40
Lemont	L	0.30	1.14	0.43	0.74	1.40
Katy	L	0.21	0.98	0.41	0.51	0.85
Drew	L	0.27	0.82	0.48	0.67	1.26
Short-Season						
Lafitte	M	-	-	-	-	1.29
Mars	M	0.60	1.48	0.63	0.73	-
Bengal	M	1.24	2.36	1.42	1.69	2.18
Jodon	L	-	-	-	0.58	1.04
Kaybonnet	L	0.31	0.92	0.28	0.48	0.93
LaGrue	L	0.30	0.78	0.31	0.51	0.71
RU9401188	L	-	-	-	0.47	1.62
RU9501121	L	-	-	-	0.78	1.32
Very-Short-Season						
Jefferson	L	-	-	-	-	0.87
M202	M	-	-	-	-	2.41
Millie	L	0.36	1.15	0.54	0.35	1.26
Alan	L	0.56	1.65	0.84	0.66	1.49
Adair	L	0.50	0.70	0.67	0.39	1.33
Koshihikari	M	-	-	-	-	2.06

Table 3. Average percent, by weight, of kernels discolored by kernel smut in brown rice samples of rice entries in the Arkansas Rice Performance Trials (ARPT).

Maturity group, cultivar and variety	Grain Type	Year				
		1992	1993	1994	1995	1996
Mid-Season						
Cypress	L	.023	.075	.000	.006	.202
Newbonnet	L	.031	.123	.000	.008	.132
Lemont	L	.013	.035	.006	.003	.053
Katy	L	.009	.007	.030	.002	.038
Drew	L	.010	.025	.042	.005	.058
Short-Season						
Lafitte	M	-	-	-	-	.230
Mars	M	.005	.031	.002	.005	-
Bengal	M	.006	.016	.000	.002	.033
Jodon	L	-	-	-	.002	.019
Kaybonnet	L	.006	.021	.000	.001	.056
LaGrue	L	.035	.090	.000	.011	.471
RU9401188	L	-	-	-	.002	.024
RU9501121	L	-	-	-	.001	.025
Very-Short-Season						
Jefferson	L	-	-	-	-	.254
M202	M	-	-	-	-	.397
Millie	L	.013	.081	.136	.005	.351
Alan	L	.010	.034	.171	.006	.316
Adair	L	.011	.062	.078	.001	.074
Koshihikari	M	-	-	-	-	.023

Table 4. Average percent, by weight, of linear discolorations and kernels discolored by other causes in brown rice samples of entries in the Arkansas Rice Performance Trials (ARPT).

Maturity group, cultivar/variety	Grain Type	Other causes of discolored kernels Year 1992	1993	1994	1995	1996	Linear Year 1996
Mid-Season							
Cypress	L	0.26	1.12	0.55	0.83	2.00	.007
Newbonnet	L	0.18	1.19	0.52	0.8	1.36	.085
Lemont	L	0.14	1.67	0.75	0.68	1.66	.008
Katy	L	0.03	0.5	0.28	0.41	1.07	.019
Drew	L	0.1	0.34	0.17	0.27	0.69	.014
Short-Season							
Lafitte	M	-	-	-	-	1.39	.231
Mars	M	0.19	0.73	0.32	0.53	-	-
Bengal	M	0.7	1.79	0.95	1.43	2.49	.119
Jodon	L	-	-	-	0.74	1.74	.013
Kaybonnet	L	0.14	0.37	0.15	0.29	0.64	.018
LaGrue	L	0.11	0.58	0.23	0.41	0.83	.016
RU9401188	L	-	-	-	0.63	2.29	.003
RU9501121	L	-	-	-	1.2	2.34	.012
Very-Short-Season							
Jefferson	L	-	-	-	-	1.42	.061
M202	M	-	-	-	-	6.69	.261
Millie	L	0.16	0.65	0.54	0.47	1.11	.075
Alan	L	0.15	1.01	0.64	0.73	2.08	.047
Adair	L	0.31	1.04	0.53	0.7	1.71	.044
Koshihikari	M	-	-	-	-	3.12	1.10

CONSERVATION TILLAGE AND SHEATH BLIGHT OF RICE IN ARKANSAS

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ABSTRACT

A long-term field experiment on conservation tillage and sheath blight was continued in 1996 at the Pine Tree Experiment Station, Colt, Arkansas. Cultivars 'Katy' and 'Lacassine' were planted on conventional, stale-seedbed and no-till seedbeds in large, permanent plots with separate water systems on Site 2, and Hutcheson soybeans were drill planted on Site 1. Levels of *Rhizoctonia solani* sclerotia in plot seedbeds were determined prior to seeding, with Site 2 having 3-15 viable sclerotia/kg dry soil depending on the treatment. Lower levels were found in conventional seedbed plots regardless of rice cultivar in the rotation. Sheath blight incidence for Site 2 (percent infected tillers) was 1.5, 4 and 3.5% for Lacassine and 0.8, 1.2 and 1.5% for Katy on conventional, stale-seedbed and no-till treatments, respectively. Where present, vertical development of sheath blight in the Lacassine plots ranged from 5-7 on a 0-9 scale. Rice yields were 133, 126 and 93 bu/acre for Katy and 153, 169 and 81 bu/acre for Lacassine on conventional, stale seedbed and no-till plots, respectively. All soybean plots on Site 1 yielded well (55-59 bu/acre) and were relatively unaffected by disease.

INTRODUCTION

Severity and importance of rice diseases change over time in response to changes in rice production practices by growers. Sheath blight was once considered a curiosity until farmers adopted semidwarf cultivars, denser stands, shorter crop rotations and increased nitrogen rates. These practices increase the severity of many rice diseases, including blast, sheath blight, stem rot and kernel smut--all of which are now epidemic in Arkansas in any given year.

Over the past few years, Arkansas rice growers have continued to adopt even shorter rotations and reduced tillage practices, primarily for economic and soil conservation reasons (USDA SCS, 1992). In many areas, the most common crop rotation is rice-soybean-rice with the only seedbed preparation done in the fall. This "stale seedbed" is left undisturbed until the following spring when the weed cover is killed with an application of glyphosate, and rice (or soybeans) is seeded into the undisturbed seedbed with minimum-tillage seeding equipment. In some instances, growers are experimenting with "no-till" rice where the crop is seeded directly into the previous crop residue with no tillage at all. Previous studies have been conducted in Arkansas and Louisiana (Bollich et al., 1992; Smith, 1993) on the effect of reduced tillage on fertilizer, weed control and other agronomic practices in rice with little or no consideration of rice diseases. Since survival between crops of the sheath blight fungus has been linked to infected rice residue, it is reasonable to expect increased sheath blight problems where the residue is not effectively destroyed. This concept is supported by research in other crops; for example, current severity of tan spot of wheat in the midwestern U.S. is a direct consequence of adoption of reduced tillage practices (Hosford, 1976; Watkins et al., 1978). However, diseases such as take-all of wheat have declined where reduced tillage has been adopted (Brooks and Dawson, 1968). In California, recent evidence on stem rot suggests that reduced tillage practices in continuous rice culture may not result in increased disease severity, depending on in-season rice management and the buildup of beneficial fungi (Cartwright, 1992). Since so little information is available, this research project was undertaken to determine the effect of reduced tillage practices on stem and sheath diseases of rice in a rice-soybean-rice rotation so that reliable information would be available to growers before these practices become widely adopted.

PROCEDURES

A long-term field experiment was established at the Pine Tree Experiment Station, Colt, Arkansas, on a site with a history of rice and soybean cropping. Large permanent plots (20 x 50 ft) with separate water systems to prevent exchange of soil, water and inoculum were installed on two adjacent sites.

The experimental design was a 2 x 3 factorial in a randomized complete block design with four replications (Fig. 1). Factors were cultivar (Katy and Lacassine) and tillage practices (conventional, stale seedbed and no-till). Agronomic practices were according to current University of Arkansas Extension guidelines, and the rotation was rice and soybeans in alternate years. Site 1 had rice in 1993, 1995 and 1997 and site 2 in 1994, 1996 and 1998. Hutcheson soybeans were drill planted on the plots in non-rice years.

Prior to planting, twenty 3-in.-dia. x 2-in.-deep soil cores were randomly collected from each plot, bulked and dried in the greenhouse for two weeks. Bulk samples were wet sieved according to the method of Lee (Lee, 1980) to estimate number of sclerotia of *Rhizoctonia solani* AG1-IA (the sheath blight fungus).

Conventional seedbeds were prepared by fall and spring tillage as needed, while stale seedbed preparation involved only fall tillage. Glyphosate was applied approximately seven days before planting to kill existing vegetation on stale-seedbed and no-till plots.

Rice was seeded on 27 April 1996 using a minimum tillage drill with 7-in. row spacings. As before, all plots were watered and managed separately after planting to prevent exchange of soil- or water-borne inoculum between plots. 'Hutcheson' soybeans were planted on Site 1 in May using the drill and row spacings above. Plots were monitored periodically for disease development throughout the growing season. Final disease incidence and severity data for the rice plots were estimated at grain maturity on randomly collected tillers from each plot. Grain was combine harvested and weighed, and values were adjusted to 12% moisture for analysis. Precautions were taken during harvest to retain rice and soybean residue within respective plots in order to prevent cross contamination between treatments.

RESULTS AND DISCUSSION

Viable sclerotia of *R. solani* collected from Site 2 ranged between 3 and 15/ kg dry soil, depending on the treatment, with levels in the Lacassine x stale and no-till seedbeds higher than the Lacassine x conventional plots (Table 1). These levels were about the same as in the previous year (Table 1).

Final incidence for sheath blight for three years and both sites (when in rice) are listed in Table 2. No significant difference in sheath blight incidence was noted on Site 2 in 1996 (Table 2). Sheath blight severity was low, probably due to the cool, dry weather later in the season (Table 2). Rice yield on the no-till plots on Site 2 was significantly lower than for the other tillage treatments for both cultivars, but this was attributed to poor stands as a result of seedling diseases shortly after seeding. Cold, wet conditions hampered germination and emergence of rice in the no-till plots, and resulting stand density was very low and erratic. This may also explain the overall low yields in the test, since stand density was less than normal across all treatments.

Soybean yields for Site 1 averaged 55-59 bu/acre, with a slight trend for higher yields on the conventional and stale seedbed plots (Table 3). No significant diseases were noted in the soybeans, although some plants had limited aerial blight later in the season.

SIGNIFICANCE OF FINDINGS

The tendency toward higher sheath blight incidence on stale seedbed and lower yield on no-till plots was again observed in 1996. These observations continue to be a cause for future concern. However, results thus far illustrate the likelihood of producing adequate yields in spite of increased disease pressure, if reasonable stand density and nitrogen management are maintained. Further research in this area should be continued, and improved control options for sheath blight should be investigated.

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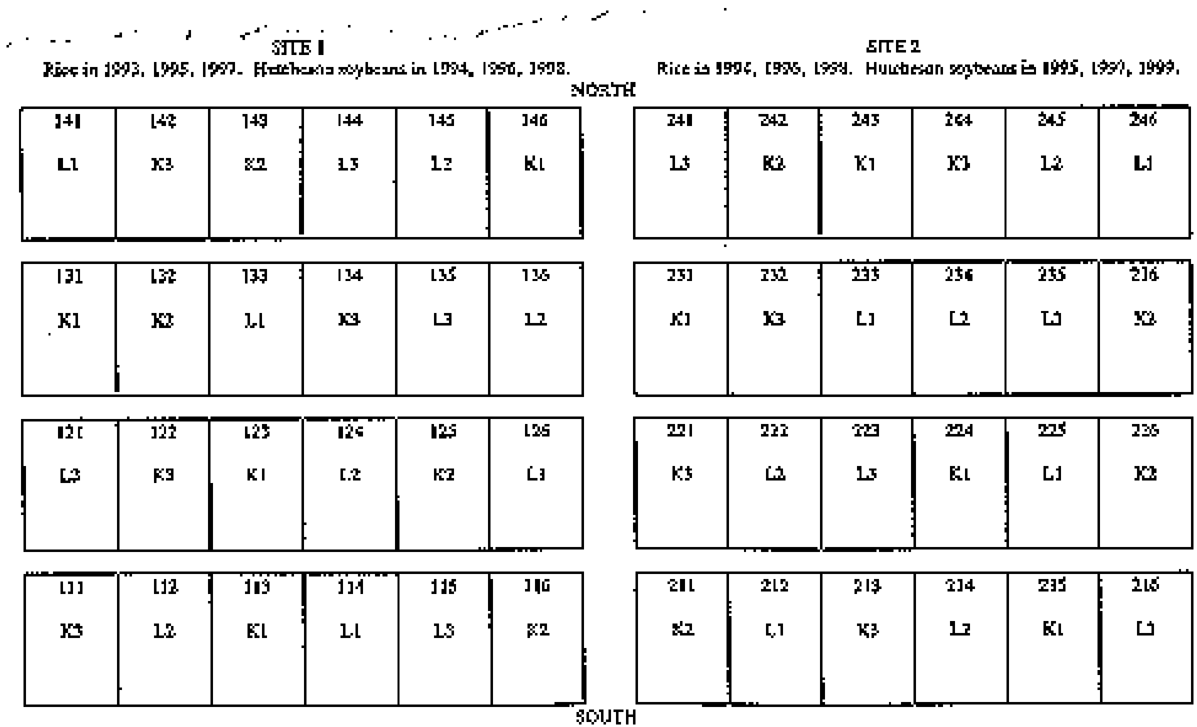

Notes: Plot numbers coded as follows: First number = site (1 or 2), second number = rep (1,2,3 or 4), third number = plot (1,2,3,4,5 or 6) e.g. Plot 311 = site 3, rep1 and plot 1 or sw corner plot in site 1. Treatment codes are for rice years, i.e. K = cultivar Katy and L = cultivar Lacassine and numbers following these letters represent tillage treatments - 1 = conventional seedbed; 2 = stale seedbed (fall tillage only, spring burndown); 3 = no till seedbed (spring burndown). In non-rice years, all plots are drill planted to Hutcheson soybeans, but tillage treatments remain the same. Plots measure 20' x 50' and feature permanent levees with separate water systems to prevent exchange of soil, crop residue, and soil-borne inoculum of rice pathogens.

Fig. 1. Layout of long-term experiment on effect of reduced tillage on rice sheath blight.

Table 1. Sclerotial levels of *Rhizoctonia solani* (sheath blight fungus) detected in preplant soil samples from reduced-tillage-experiment field plots at the Pine Tree Station, Colt, Arkansas.

		Viable sclerotia /kg dry soil (mean) Site 1			Viable sclerotia /kg dry soil (mean) Site2		
Rice cultivar	Tillage	1993	1994	1995	1994	1995	1996
Katy	Conventional	1	2 a	2 a	7 a	3 a	3 a
Katy	Stale seedbed	ND	8 a	2 a	9 a	5 a	3 a
Katy	No-till	1	9 a	4 a	11 a	8 a	5 a
Lacassin	Conventional	ND	8 x	2 x	9 x	7 x	5 x
Lacassine	Stale seedbed	2	8 x	2 x	11 x	18 x	12 y
Lacassin	no-till	1	9 x	4 x	7 x	15 x	15 y

*Means followed by the same letter within cultivar by column are not significantly different according to Tukey's HSD test (P = 0.05). ND = none detected.

Table 2. Sheath blight incidence and severity data at grain maturity for various rice diseases in reduced-tillage-experiment field plots at the Pine Tree Station, Colt, Arkansas.

		Final sheath blight indicence and severity							
Cultivar	Tillage trt.	Site 1 -1993		Site 1 -1995		Site 2-1994		Site 2-1996	
		% IF*	Severity (0-9)	% IF	Severity (0-9)	% IF	Severity (0-9)	% IF	Severity (0-9)
Katy	Conventional	1.0 a	3	2 a	3	1.0 a	3	0.8 a	3
Katy	Stale seedbed	0.5 a	3	5 a	3	0.5 a	3	1.2 a	3
Katy	No-till	0.5 a	3	2 a	3	0.5 a	3	1.5 a	3
Lacassin	Conventional	3.0 x	4	9 x	5	3.0 x	7	1.5 x	5
Lacassine	Stale seedbed	7.5 x	5	19 y	7	7.5 x	7	4.0 x	7
Lacassine	No-till	1.5 x	4	11 x	5	1.5 x	7	3.5 x	5

*% IF = percent infected tillers. (% IF means followed by the same letter within cultivar and column are not significantly different according to Tukey's HSD test (P = 0.05)).

Table 3. Yield data (bu/acre at 12%) for reduced-tillage-experiment at Pine Tree Station, Colt, Arkansas (Sites 1 and 2).

		Site 1				Site 2		
	Rice	Rice	Soybeans	Rice	Soybeans	Rice	Soybeans	Rice
Tillage trt.	cultivar	1993	1994	1995	1996	1994	1995	1996
Conventional	Katy	148 a*	61 a	133 a	58 a	165 a	76 a	133 a
Stale-seedbed	Katy	158 a	64 a	134 a	58 a	156 a	73 ab	126 a
No-till	Katy	159 a	68 a	99 a	57 a	161 a	68 b	93 b
Conventional	Lacassine	176 x	61 x	151 x	60 x	201 x	71 x	153 x
Stale-seedbed	Lacassine	180 x	64 x	149 x	58 x	188 y	74 x	169 x
No-till	Lacassine	160 y	68 x	108 y	53 x	177 y	69 x	81 y

*Statistical analysis using Tukey's HSD means separation test conducted within cultivar. Means followed by the same letter within cultivar and column are not significantly different (P = 0.05).

RICE DISEASE MONITORING IN ARKANSAS

**R.D. Cartwright, C.E. Parsons, W.J. Ross,
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ABSTRACT

The Arkansas rice disease monitoring project was continued in 1996 to determine the identity, distribution and severity of rice diseases in the state and to evaluate newly released and current cultivars under on-farm conditions. Monitoring plots consisted of 16 rice cultivars/experimental varieties seeded in four replications at seven locations. Sheath blight was again the most widespread and severe disease statewide, especially on the highly susceptible and widely grown cultivar 'Cypress,' but was less severe than normal due to cool temperatures in late July and August. Blast was severe in certain areas, notably on 'M204' in the northeastern part of the state, where this extremely susceptible cultivar was being tried by a few growers. However, dry weather during heading limited neck blast statewide. Kernel smut was severe at several locations and in numerous fields, probably influenced by untimely light rains during flowering.

INTRODUCTION

Rice diseases vary greatly due to geographic location and rice production practices. In 1985, there were 74 major diseases of rice reported around the world caused by various agents including virus/mlos, fungi, bacteria, nematodes and physiological imbalances (Ou, 1985). Since that time, several new diseases have been reported as rice cultivars and cultural practices continue to evolve (Webster and Gunnell, 1992; Cartwright et al., 1994).

In the U.S., there are currently five major diseases (sheath blight, blast, stem rot, kernel smut and seed/seedling disease) all caused by fungi and one major physiological disorder (straighthead) (Webster and Gunnell, 1992). In addition, brown spot of rice can be of major importance on potassium-deficient rice, as observed in Arkansas in 1994 (Cartwright et al., 1995). There are also numerous minor diseases principally caused by fungi, although a bacterial and a nematode disease also have been reported (Webster and Gunnell, 1992). In addition, there remain several diseases of yet unknown cause that have been noted recently.

In Arkansas, all major fungal diseases and straighthead are common and many other minor fungal diseases are present. The Arkansas rice disease monitoring project continues to better define rice diseases in the state and their relative severity (Cartwright et al., 1994, 1995).

Monitoring of plant diseases is time-consuming but valuable and is performed to better understand the spectrum of disease problems on a particular crop and the potential for diseases to change in importance due to changes in production practices of the crop over time. Monitoring must be yearly and long-term and must use consistent methods to be of value. If monitoring is done properly, the information gathered can help guide research and suggest better disease control options. Monitoring serves as our first line of defense in the ongoing battle with rice diseases, and one of the most valuable functions of this research is early identification of new rice plant diseases or increased importance of an existing minor disease. Early warning allows researchers to develop information on the disease and devise control methods before it causes major losses to producers.

PROCEDURES

A set of 16 rice cultivars/experimental varieties with varied susceptibility to rice diseases was seeded in grower fields in Clay, Cross, Lawrence, Lonoke, Poinsett, White and Woodruff counties. Grower fields were selected by cooperating Extension agents based on disease history, cultural practices and previous observations. Cultivars were seeded in plots of seven rows x 16 ft and replicated four times in a randomized complete block design. Fertilization and other management practices were conducted by the grower with the rest of the field. No fungicides were applied to any of the test plots. Plots were examined periodically for diseases beginning at internode elongation, and final disease incidence and severity data were taken at grain maturity for each cultivar based on randomly collected tillers from each plot. Plots were harvested by plot combine and reported yields adjusted to 12% moisture.

RESULTS AND DISCUSSION

Plot yields varied considerably among locations as previous years and certain cultivars were more stable than others. We have previously defined this stability in yield as “risk” and use the coefficient of variation (C.V.) in yield across locations as a simple way to report it (Cartwright et al., 1995). Growers can thus use both yield potential and “risk potential” (yield stability) to evaluate the various cultivars they might wish to grow. For example, ‘M202‘--a California cultivar--varied in yield across locations in 1996 from a low of 110 bu/acre at the Poinsett County site to 191 bu/acre at the Woodruff County location where disease was minimal (Table 1). This instability resulted in a “risk” value of 19, one of the highest of all cultivars tested. In contrast, ‘Drew’ had a “risk” value of only five, indicating stable yields across all locations. While not infallible, this information is vital to growers who are experiencing less margin for error in their rice production practices each year. In time, the data from this study should provide a very reliable way of selecting an appropriate rice variety for almost any situation in the state. Table 2 lists the combined and summarized yield and risk information from 1994 - 1996.

Numerous diseases of known or unknown cause were observed in the monitoring plots, depending on location and cultivar (Table 3). Lodging was noted as well (Table 3). Of the major diseases, sheath blight was most severe at the Lawrence and Cross County locations. Sheath blight incidence and severity were again highest on semidwarf cultivars and lower on medium-grain and tall cultivars (Table 3). Vertical development of sheath blight on infected tillers is a measure of severity and possibly an estimate of cultivar resistance to this disease (Ahn et al., 1986). Symptom height was usually 60-70% of tiller height on semidwarf cultivars such as Cypress and 30-60% on taller types (Table 3). Severity of sheath blight was lower in 1996 than in 1995.

Neck blast was noted primarily at the Clay and White County locations. M202, ‘LaGrue’ and ‘Newbonnet’ were most heavily damaged with ‘Katy’, ‘Kaybonnet’, Drew and others suffering little to no damage at these sites (Table 3). Neck blast was also noted at the Clay and White County sites on ‘Jefferson’, the new release from Texas that was thought to be highly resistant to blast. Until we know more about this cultivar under Arkansas conditions, growers should treat it as susceptible to blast.

Kernel smut was observed at several sites in 1996. It was most severe on Newbonnet, LaGrue, the experimental varieties RU9401188 and RU9501121, Cypress, ‘Jodon’ and Jefferson while Kaybonnet and Drew had noticeable levels of smutted panicles as well (Table 3). Smut remained at low levels on ‘Lacassine’, ‘Lemont’, ‘Bengal’, ‘Mars’ and Katy (Table 3).

Most other foliar diseases of rice were less common in 1996 probably due to the cool and dry conditions later in the season. The new disease, Fusarium sheath rot--first identified in 1993 by this project--was almost nonexistent. Scab, caused by a different *Fusarium* sp., was widespread and at higher levels than normal on ‘Bengal’.

SIGNIFICANCE OF RESULTS

Results demonstrate the broad spectrum of rice diseases present in the state and their varying intensity as influenced by cultivar, location and management practices. The disease monitoring project permits accumulation of comparative data from year to year and helps researchers focus on research needs and approaches. This research also provides supplemental data on cultivar reaction to diseases (under grower conditions) to the disease resistance research program, helps assess the overall impact of diseases on rice production in a given year and provides early detection of new diseases or changes in current diseases. This project has added significant new information to our understanding of the susceptibility of current cultivars/experimental varieties to stem rot and brown spot under potassium deficient conditions. It has provided considerable practical information on kernel smut resistance in cultivars and on susceptibility to other less well-known diseases in the state. It continues to provide "hands-on" experience to farmers, county agents, consultants and others on identification and management of the many rice diseases in Arkansas. Finally, it has provided the only information in the U.S. on the new rice disease, Fusarium sheath rot.

ACKNOWLEDGMENTS

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Table 1. Rough rice yields of 14 cultivars and two experimental varieties grown in disease-monitoring plots in 1996.

Cultivar/ exp. var. or entry	Location: Clay Co. Goodman	Cross Co. Wilson	Lawrence Co. Worlow	Lonoke Co. Stecks	Poinsett Co. Reddman	White Co. Langston	Woodruff Co. Key	Summary across all sites: Mean Yield	CV*
	---	---	---	---	bu/acre	---	---	---	%
Bengal	140	175	163	175	194	154	193	171	12
Cypress	160	148	152	136	172	147	168	155	8
Drew	171	167	162	175	186	165	180	172	5
Jefferson	148	158	149	98	127	149	162	142	16
Jodon	153	165	157	154	193	87	179	156	22
Katy	146	151	143	140	161	137	170	150	8
Kaybonnet	172	163	153	160	178	159	171	165	5
Lacassine	154	147	154	166	185	168	182	165	9
Lafitte	181	156	162	165	194	167	175	172	7
LaGrue	149	188	185	168	208	179	191	181	10
Lemont	141	150	145	115	156	158	176	149	13
M202	132	134	168	167	110	141	191	149	19
Mars	150	195	162	153	209	132	185	169	16
Newbonnet	125	160	158	173	166	167	187	162	12
RU9401188	181	182	173	177	199	176	192	183	5
RU9501121	168	179	165	163	202	175	180	176	7
Mean Yield by Location	155	164	160	155	178	154	180		

*CV = Coefficient of variation for yield across all locations. The higher the number, the greater the variation in yield - thus the less dependable the cultivar across differing environments.

Table 2. Summary yield and yield stability data from disease monitoring plots grown at eight locations in 1995.

	Sorted by yield (high to low)					Sorted by risk (CV*) - (low to high)			
Exp. variety,	Yield			Mean yield	Exp. var.,	Yield			Mean yield
cultivar or entry	1994	1995	1996	1994-1996	cultivar or entry	1994	1995	1996	1994-1996
	----bu/acre----					----bu/acre----			
Bengal	181	164	171	172	Drew	11	10	5	9
LaGrue	167	146	181	165	Kaybonnet	13	12	5	10
Drew	165	144	172	160	LaGrue	19	11	10	13
Mars	166	140	169	158	Katy	16	15	8	13
Kaybonnet	165	138	165	156	Cypress	26	9	8	14
Jodon	157	132	156	148	Lacassine	20	18	9	16
Lacassine	160	112	165	146	Jodon	19	10	22	17
Katy	149	128	150	142	Bengal	24	16	12	17
Lemont	147	126	149	141	Lemont	24	20	13	19
Cypress	140	127	155	141	Mars	21	24	16	20
Newbonnet	141	118	162	140	Newbonnet	28	34	12	25
RU9401188			183		RU9401188			5	
RU9501121			176		RU9501121			7	
Lafitte			172		Lafitte			7	
M202			149		M202			19	
Jefferson			142		Jefferson			16	

* CV = coefficient of variation for yield across locations.

Table 3. Summary disease incidence and severity data for various rice cultivars/experimental varieties at seven monitoring locations in Arkansas, 1994 - 1996.

Cultivar/	SHBI*			SHB-HT			NB			KS			SR-DI		
variety	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
Bengal	54	71	35	0.5	0.5	0.4	1	44	18	10	12	4	1.5	2.5	1.6
Cypress	46	100	64	0.6	0.7	0.6	6	10	2	38	100	68	2.1	2.2	1.6
Jodon	44	100	78	0.7	0.7	0.6	9	50	20	41	100	50	1.6	2.4	2.2
Katy	47	100	37	0.4	0.6	0.4		0	0	8	4	12	1.4	2.3	1.1
Kaybonnet	33	100	41	0.5	0.6	0.5	1	1?	0	24	32	30	1.9	2.5	1.4
Lacassine	47	100	50	0.6	0.7	0.6	3	55	24	6	8	4	1.4	1.8	1.6
LaGrue	37	100	55	0.4	0.6	0.4	4	35	36	67	83	72	2.1	2.3	2.4
Lemont	43	100	52	0.6	0.7	0.6	1	70	16	7	10	6	1.5	1.8	1.2
Mars	33	67	34	0.3	0.4	0.3	9	35	8	15	24	6	1.5	1.5	1.4
Newbonnet	42	87	33	0.3	0.55	0.3	10	100	40	64	51	38	1.8	2.4	1.8
Drew	48	78	28	0.3	0.5	0.4		0	0	33	41	34	2.4	1.9	1.6
RU9401188			38			0.4			0			50			2.2
RU9501121			46			0.5			0			75			2.0
Lafitte			60			0.4			0			24			1.6
M202			42			0.4			100			36			1.4
Jefferson			54			0.5			12			40			1.2

continued

Table 3. - continued.

Cultivar/	BS			BSHR			FSHR			NBLS			SCAB		
variety	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
Bengal	45	20	16	40	2	4	2	24	2		0	0	26	6	20
Cypress	2	6	6	35	26	8		10	0		2	0	6	2	12
Jodon	14	10	8	50	40	6		4	0	100	36	12	28	16	10
Katy	36	50	60	40	20	2		6	0	82	100	100	2	12	6
Kaybonnet	55	100	100	60	30	2		1	0	95	100	100	2	1	2
Lacassine	27	60	22	100	14	2		2	0		2	4	2	2	2
LaGrue	6	14	16	20	24	2		4	2	47	20	10	19	2	6
Lemont	3	30	14	55	68	6		2	0	40	12	8	2	2	2
Mars	28	60	20	24	30	2	1	1	0		0	2	31	1	8
Newbonnet	13	30	40	4	6	4		2	0	84	100	100	17	2	2
RU9201176	16	39	100	22	11	2		1	0		100	100	33		2
RU9401188			26			2			0			6			4
RU9501121			24			2			0			8			6
Lafitte			80			6			0			20			12
M202			12			2			6			2			26
Jefferson			6			8			0			2			2

continued

Table 3. continued.

Cultivar	LS			SCLD			LODG		
or entry	1994	1995	1996	1994	1995	1996	1994	1995	1996
Bengal	9	1	2	4		0			6
Cypress	46	24	40	8	2	0			16
Jodon	48	36	36		8	0			10
Katy	34	50	24		4	0	10	80	100
Kaybonnet	51	40	20	22	8	0	13	100	100
Lacassine	26	18	20	60	4	0			2
LaGrue	25	24	12		8	0	10	4	20
Lemont	25	48	24			0			0
Mars	40	20	20			0	25	60	100
Newbonnet	36	12	32		2	0	13	12	24
RU9201176	42	83	46		1	0	5	5	12
RU9401188			32			0			32
RU9501121			20			0			60
Lafitte			12			0			50
M202			12			0			20
Jefferson			6			0			0

*SHBI = average sheath blight incidence (% infected tillers); SHBHT = severity of sheath blight as ratio of disease symptom height/infected tiller height (e.g. .5 = disease symptoms 50% of tiller height); SR-DI = stem rot disease index (1= no disease, 5 = tiller killed prematurely). Unless otherwise noted, the remainder of the data represents % infected tillers. NB = neck blast;; KS = kernel smut; BSHR = black (crown) sheath rot; BS = brown spot; NBLS = narrow brown leaf spot; SCAB = scab; LS = leaf smut; FSHR = fusarium sheath rot; SCLD = leaf scald; LODG = lodged (% of plot).

ARTIFICIAL INOCULATION OF KERNEL SMUT OF RICE IN ARKANSAS

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ABSTRACT

For many years, kernel smut of rice has been a major disease problem in Arkansas, causing widespread yield and quality losses on many cultivars, including 'Cypress', 'Alan', 'Newbonnet', 'LaGrue' and 'RT7015'. In 1996, severity in grower fields was again heavily influenced by excessive nitrogen fertilization, especially on cultivars such as Cypress and LaGrue. Cypress was also heavily damaged in continuous-rice, water-seeded systems. Research on development of a more natural mist inoculation technique for screening smut-resistant rice germplasm continued with an experimental method tested for the second year at the Pine Tree Experiment Station. Nine cultivars were inoculated (or not) during late boot to early heading and maintained under two environments--misted nightly or not--until hand harvested, and level of smut was determined. The misted/inoculated treatment resulted in the highest levels of kernel smut. Field resistance ratings and results from this method were in close agreement.

INTRODUCTION

Kernel smut of rice was sporadically severe on several rice cultivars in Arkansas in 1996, causing significant yield losses in some fields and resulting in low-quality grain delivered to the mills. Severity was heavily influenced by nitrogen fertilization, especially on the newer rice cultivars, Cypress and LaGrue. Severity was also noticeably higher on the continuous-rice, water-seeded systems preferred by a few growers.

Kernel smut is caused by the fungus, *Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc. (= *Neovossia horrida* (Takah.) Padwick & A. Khan) (Whitney, 1989), which closely resembles the karnal bunt of wheat fungus, *Tilletia indica* Mitra (= *Neovossia indica* (Mitra) Mundkur) (Royer and Rytter, 1988). It was previously believed that *T. barclayana* infects the open rice flower only at anthesis, grows within the developing rice kernel as mycelium and eventually consumes the endosperm, converting it into numerous spherical, black teliospores (chlamydospores) that survive on seed and residue and in the soil (Whitney and Frederiksen, 1975). Our research has determined that the fungus is capable of infecting florets before anthesis and confirms that the process is enhanced by high moisture during the heading phase.

Kernel smut infection has historically been difficult to induce under controlled conditions; however, improvements in the boot injection technique (Lee et al., 1992) used originally in karnal bunt of wheat research have resulted in a useful method to study certain aspects of this disease (Whitney and Frederiksen, 1975). Using this method, it has been clearly demonstrated that cultivars resistant in the field are not resistant when injected with kernel smut inoculum in the boot (Lee et al., 1992). This method has shown that very few germplasm sources are resistant to kernel smut using the boot injection technique, and a more natural inoculation procedure to screen germplasm should improve discovery of "field-resistant" germplasm.

After considerable work with the boot injection method, it was decided in 1993 to attempt development of a more natural inoculation procedure. The basic development of a mist inoculation method was done in the greenhouse at Fayetteville, Arkansas, about 200 mi from the major rice production area of Arkansas, and has been previously reported (Cartwright et al., 1995).

PROCEDURES

The field experiment for testing the mist inoculation method was established at the Pine Tree Experiment Station, Colt, Arkansas, in May 1996. Nine cultivars were hand-seeded in single 3-ft rows, and each plot was positioned to receive either nightly mist (12 hrs) or no mist using overhead mist nozzles connected to a charcoal filtered water supply and timer. Plastic walls separated each plot to maintain environmental integrity. Plants were inoculated by spraying a suspension of secondary sporidia (10^5 - 10^6 per ml) of the kernel smut fungus (isolate 4T3) onto the swollen "boot" until run-off and continuing at two- to three-day intervals for a total of three inoculations. One-half the plots in each mist regime were not inoculated as controls. Inoculum was prepared each day and kept cold until just before use. Some plants were entering anthesis at the last inoculation. Inoculation was done in the afternoon and mist treatments applied immediately after the first inoculation and continued nightly until all cultivars had finished flowering. Plots were misted daily from 8 p.m. to 8 a.m. Ten random panicles were collected from each row when the base florets of each panicle were filled and firm, stored in paper bags and number of smutted grains per panicle determined using the KOH method (Lee et al., 1992).

RESULTS AND DISCUSSION

Results of the mist inoculation experiment at Pine Tree Station are presented in Table 1. Level of kernel smut under the misted, inoculated plots was consistently higher than with other treatments. The non-misted, inoculated plots had lower levels of kernel smut, demonstrating the necessity for additional moisture during the heading phase on inoculated rice (Table 1). These results were consistent for the non-inoculated plots under both mist regimes. Both nightly mist and inoculation are critical for consistent disease pressure. 'Lemont' and 'Katy', the two most field-resistant cultivars available, were found resistant by this method, maintaining a low smut level of 2.5 smutted grains/panicle or less (Table 1). By contrast, the known susceptible cultivars Cypress and Newbonnet averaged 11.0 and 13.8 smutted grains/panicle (Table 1). This method may require further refinement, but it appears to offer a reasonably practical and reliable means of screening germplasm for kernel smut resistance under field conditions.

SIGNIFICANCE OF RESULTS

Development of this field screening technique will greatly enhance the ability of the Arkansas Rice Breeding Program to develop improved, kernel smut-resistant varieties. Currently, kernel smut resistance of any developed U.S. rice varieties is largely unknown at release and subsequently determined by growers--a less-than-ideal situation. Successful implementation of this technique at Stuttgart should allow the development of truly smut-resistant cultivars prior to release and aid in more consistent and reliable research on this difficult-to-study plant disease.

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Table 1. Results of inoculation of rice cultivars with the kernel smut fungus using a mist inoculation method under field conditions - 1996.

	Mist		No Mist		
Cultivars	Inoculated	Not Inoculated	Inoculated	Not Inoculated	Rating[†]
Bengal	1.7*	0.8	1.1	0.1	R
Cypress	11.0	1.6	4.2	0.6	VS
Katy	2.0	0.6	0.4	0.1	VR
Kaybonnet	3.7	0.9	2.2	0.4	MS
Lemont	2.5	0.6	1.3	0.8	VR
M202	8.9	2.2	6.8	0.6	VS
Mars	2.3	0.8	1.5	0.2	VR
Newbonnet	13.8	1.4	8.2	0.7	VS
Drew	5.1	0.7	3.3	0.1	MS

* Data = no. of smutted grains per panicle based on 10 panicles/plot.

[†]Ratings represent designations as determined by previous field observations with VS = very susceptible; S = susceptible; MS = moderately susceptible; MR = moderately resistant; R = resistant; VR = very resistant.

THE EFFECT OF NITROGEN FERTILIZATION ON THE EPIDEMIOLOGY OF RICE BLAST DISEASE IN SMALL PLOTS IN ARKANSAS

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ABSTRACT

The effect of nitrogen fertilization on rice blast development on eight rice cultivars was measured in replicated field tests conducted at the University of Arkansas Pine Tree Experiment Station, Colt, Arkansas in 1996. For each cultivar, one third of the plots received the recommended amount of nitrogen applied in a three-way split with the largest amount of N applied at preflood and the remaining 60 units applied after internode elongation in two equal applications 10 days apart. Another third received the recommended amount of N, all applied in a single preflood application. The remaining third received the recommended amount of N plus an additional 50%, all applied in a single preflood treatment. The results of the 1996 experiments illustrate five important points: 1) the disease progress curve for rice blast is a unimodal curve regardless of N levels applied; 2) applications of N above the recommended amount for a cultivar significantly increased severity and incidence of leaf blast on susceptible cultivars; 3) differential cultivar responses to increased N levels were detected and disease was significantly more severe on the highly susceptible cultivars; 4) N applications early in the season do not appear to increase the incidence of neck blast; and 5) high-incidence collar rot infections were significantly correlated to higher levels of neck rot infections.

INTRODUCTION

Rice blast is recognized as one of the most destructive diseases of rice (*Oryza sativa* L) because of its ability to become epidemic and to cause significant reductions in yield (Webster and Gunnel, 1992; Kingsolver et al., 1984; Torres and Teng, 1993). The pathogen, *Magnaporthe grisea* Cav., infects the rice plant at all developmental stages, from seedling stages though grain formation, to cause leaf blast, collar rot, neck blast and panicle blast (Webster and Gunnel, 1992; Kingsolver et al., 1984). Rice blast epidemics are more severe in temperate and sub-tropical ecosystems but also can flourish in other environments if blast-susceptible cultivars are widely grown and/or if effective management strategies for control are not implemented (Kingsolver et al., 1984).The disease has become important in Arkansas on the high-yielding, blast-susceptible cultivars, such as ‘Newbonnet’ (Lee, 1994).

Several factors may contribute to the occurrence and severity of rice blast in Arkansas. Cultural practices such as specific water management and reduced seeding densities can be effective management tools to help control leaf and neck blast (Cloud and Lee, 1993; Kim and Kim, 1990; Amin and Katyal, 1979; Kim et al., 1992; Jayachandran-Nair and Chakrabarti, 1980). The amounts and timing of nitrogen (N) fertilization may affect the severity of rice blast in Arkansas (Templeton et al., 1970). Applications of N fertilizer in amounts that are excessive appear to increase the susceptibility of the rice plant (Kingsolver et al., 1984; Sridhar, 1972; Kurschner et al., 1992). Kurschner et al. (1992) reported that while N is essential for productivity, the severity of blast also increases with the amount of N applied. However, leaf blast was also suppressed if application of N was delayed until late in the season at the end of vegetative phase. Amin and Venkatorao (1979), Templeton et al. (1970) and Kurschner et al. (1992) reported that split applications of N that did not encourage excessive vegetative growth early in the season reduced the severity of rice blast. Correa and Zeigler (1991) reported that highly significant yield reductions were associated with high levels of blast development and that increased disease levels were associated with increased N levels. Others have noted that N fertilizations increased the size of leaf blast lesions (Matsuyama and Dimond, 1973; Kaur et al., 1979).

Quantitative information describing how rice blast develops in Arkansas with regard to various environmental and cultural factors is not available. Most cultivars are considered to be susceptible to the contemporary rice blast populations (races) in Arkansas, although the effects of disease resistance and N fertilization on disease development during the growing season are unquantified.

Four specific objectives were addressed in the following experiments: 1) to determine how rice blast develops on selected cultivars with different levels of resistance; 2) to determine if rice blast epidemics develop continuously throughout the season; 3) to determine the effect of N fertilization on rice blast development on selected cultivars; and 4) to evaluate the relationship between flag leaf collar rot and neck rot incidence. Two previous reports have been published describing similar research conducted in 1994 and 1995.

MATERIALS AND METHODS

Eight rice cultivars of diverse genotypes, maturities and susceptibilities to *M. grisea* were seeded in a replicated field trial at the Pine Tree Experiment Station at Colt, Arkansas, 3 June 1996 (Table 1). The experimental sites were precision leveled for optimum water management and were bordered by trees on the eastern and northern sides.

Nitrogen (urea) treatments were applied in a split-plot design with four replications per cultivar in subplots that were drill-seeded at 110 lb/acre in 5 x 16-ft plots of 9 rows spaced 7 in. apart. In Arkansas, the amount of N recommended for each cultivar is based primarily on yield responses, and each cultivar may have a specific N requirement for optimum yield (Norman et al., 1995). In our test, one-third of the plots, for each cultivar, received the recommended amount of N applied in a three-way split application with the largest amount applied at pre-flood and the remaining 60 units applied after internode elongation in two applications 10 days apart. Another one-third of the plots received the recommended amount of N, but it was all applied as a single pre-flood application. The remaining one-third of the plots received 50% more than the recommended amount of N, again all applied as a single treatment at pre-flood.

Inoculation of Spreader Plots

Even though the experimental site has a history of rice blast epidemics, blast was initiated artificially by inoculation of susceptible cultivars ('M201', 'M203' and 'L203') seeded in spreader plots surrounding the cultivars. Spreader plots were seeded at a rate of 110 lb/acre in 5 x 16-ft plots of 9 rows at 7-in. row spacing. Spreader plants were inoculated at the mid-tillering stage of development with three virulent races of *M. grisea* (IB49, IC17 and IB1) that are commonly found in Arkansas. Inoculum consisted of conidia of *M. grisea* harvested separately from seven- to ten-day-old cultures grown on PDA (Potato Dextrose Agar; Difco) under continuous illumination at 25°C. Conidia of all three races were adjusted to 500,000 conidia/ml and were combined just prior to inoculation. Xanthan gum (0.4 g/L) and Silwet L77 (0.2 ml/L) were added to the spore suspensions just before inoculation. Two inoculations (seven days apart) were made to initiate rice blast in spreader plots. Inoculations were made between 10:00 p.m. and midnight using compressed air applicators. The morning following the inoculation, plots were covered with a shade cloth to maintain moisture and to reduce daytime temperatures within the plant canopy. The cloth was removed after one day. These inoculations provided adequate levels of disease (> 5% incidence) in test plots by the mid-tillering stage of plant development. Disease ratings were made one week after inoculation to determine disease incidence and disease uniformity in the spreader plots. The plots were drained three times for approximately 5 to 10 days each during the growing season to induce rice blast development prior to panicle primordia growth stage, but the flood was maintained at 2 to 4 in. thereafter until harvest.

Disease Progress

Leaf blast, collar rot and neck blast were measured weekly in all test plots. Each leaf on 12 randomly selected plants in each subplot was examined to determine the number of lesions, lesion size, sporulation, lesion age and location of lesions of rice blast. The occurrence of collar rot infections was also recorded for each leaf, and the size of lesions was measured on each rice plant sampled. Flag leaf collar rot and neck blast were recorded at the end of the season when 50 panicles and collars were examined for disease symptoms in each subplot.

In this report, total lesion area refers to the total area of each plant infected with *M. grisea.* Disease incidence is the percentage of plants that were infected. Disease progress curves were constructed from disease incidence and total lesion area data.

The effects of N on leaf blast development were determined using two different approaches. The first approach utilized the area under the disease progress curve (AUDPC) to determine the effects of N on disease development over the entire growing season. Secondly, a critical point analysis was used to compare the effects of N on the incidence of leaf blast at mid-season (when leaf blast incidence was at its highest) and on the amount of leaf blast prior to panicle emergence. These two critical points were chosen because each may contribute to the amount of secondary inoculum and subsequent infection of collars and necks near the end of the season. Both approaches were statistically analyzed with the T-test and GLM procedures in SAS (SAS Institute, 1990).

Yield data were collected at grain maturity to determine the relationship between neck blast and yield loss. Plots were harvested with a Kubota plot harvester in 2.5 x 12-ft sections within the centers of the plots. Moisture content of grain at harvest was obtained using a John Deere moisture meter. All subplot yields were standardized to a 12% moisture level and reported in bu/acre.

RESULTS AND DISCUSSION

Disease Progress for Leaf Blast

In general, disease progress for all cultivars and N treatments followed a basic unimodal pattern (Fig. 1). The incidence of leaf blast increased from the low levels recorded early in the season to the highest levels recorded during the mid-season. The incidence of leaf blast gradually declined thereafter in nearly all treatments and cultivars. Similar results were obtained when plotting the data for the total lesion area, except for 'Cypress', which showed low total lesion areas (Fig. 2). Similar disease development was also observed in 1993, 1994 and 1995. (TeBeest et al., 1994, 1995; Long et al., 1996). This type of disease progress curve has previously been described for rice blast in other regions of the world (Hwang et al., 1987; Kim and Kim, 1990; Bastianns, 1993). The decline in disease development late in the season has been attributed to plants becoming more resistant to infection as they mature and/or to changes in environmental conditions (Hwang et al., 1987; Koh et al., 1987; Bonman et al., 1989).

Leaf Blast Development on Different Cultivars

The incidence of disease differed somewhat among cultivars with Cypress showing lower incidence in the three N treatments (Fig. 1). For 'Lacassine', 'Alan' and especially Cypress, the total lesion area was significantly less, most notably at the high rate of N (Fig. 2). Cypress appeared to be more resistant than the other cultivars, except 'Kaybonnet', to blast especially for total lesion area (Fig. 2). Kaybonnet is resistant to all the races used in this test, and no lesions were found on any plants of this cultivar. Similar results were observed in 1994 and 1995 (TeBeest et al., 1995; Long et al., 1996). Also, AUDPC values for disease incidence and total lesion area per plant varied among cultivars and to the various N applications (Tables 2-3).

The Effects of Nitrogen Fertilization

The effects of applying extra N at the pre-flood stage on the incidence of leaf blast over time were similar in 1994, 1995 (Long et al., 1996) and 1996. In each of these years, there were large increases in disease (disease incidence and total lesion areas per plant) on the most susceptible cultivars, Newbonnet, 'RT7015', 'Adair' and Alan compared to Cypress in treatments with increased levels of N. The application of N above the recommended rates generally increased disease incidence and the total lesion area for all cultivars except Kaybonnet (Figs. 1 and 2; Tables 2 and 3). Similarly, an increase in the amount of disease was also evident when the amount of N recommended for three split applications was applied in a single preflood application.

AUDPC values for disease incidence data indicated that the high N treatment showed significantly greater incidence in all cultivars except 'Mars', 'Lacassine' and Kaybonnet (Table 3). AUDPC values for total lesion area indicate significant differences among N treatments, for all cultivars, except Kaybonnet.

Critical point analysis of peak leaf blast incidence during mid-season indicated that a three-way-split application of N generally resulted in lower leaf blast incidence and total lesion area per plant (Figs. 1 and 2; Tables 4 and 5). Differences in disease incidence between high and normal N levels applied as a single application were observed only in cultivars RT7015 and Cypress. However, significant differences between N treatments in most cultivars, except Kaybonnet, were observed for total lesion area per plant data.

Likewise, critical point analysis of disease incidence data collected at the end of the season indicated significantly less disease in the three-way-split N application (Tables 6 and 7). Significant differences between the single application treatments for disease incidence were observed in all cultivars except Adair and Kaybonnet, with the high-N treatment having the highest disease levels in most cases. When the recommended rate of N for three split applications was applied in a single application on Lacassine, there was significantly higher disease incidence than the three-split application (Table 7). Also, a significant difference was detected for total lesion area for Lacassine in the extra N application treatment.

Development of Collar Rot

In 1996, the incidence of collar rot infections was lower than that observed in 1995 (Long et al., 1996) although there was a tendency for the more susceptible cultivars to have more collar rot symptoms, as was observed also in 1995 (Tables 8 and 9). Collar rot infections appeared to be more prevalent on Adair, Newbonnet and Lacassine than on the other cultivars. The effects of N on collar rot symptoms were significant only between the extra N application and the 3-split application treatment for the highly susceptible cultivar Newbonnet.

Development of Neck Rot

The incidence of neck rot infection was higher in 1996 than in 1995 (Long et al., 1996) on all cultivars. The incidence of neck rot was generally higher for the susceptible cultivars Newbonnet, Adair, RT7015, Lacassine and Alan in 1996 (Table 9). The only significant difference in the incidence of neck rot among N treatments was observed in Newbonnet between the extra N and the 3-way-split N treatment (Table 9). The lowest incidence of neck rot was found to be associated with the three-way split application of N for all cultivars except Alan (Table 9).

Relationship Between Leaf Blast and Neck Rot

A high incidence of neck rot was not significantly correlated with high leaf blast incidence during the 1996 experiments, although in previous years, field studies have shown a positive correlation between leaf blast infection and neck rot in areas with high levels of disease (Long, 1996). Inter-plot interference and differences in plant maturities may have contributed to differences in the results of small plot experiments and large-scale field studies (Long, 1996).

Relationship Between Collar Rot and Neck Rot

In 1996, for all N treatments, we found a significant correlation between the incidence of flag leaf collar rot and neck rot (Fig. 3) just as we had observed in 1994 and 1995 (TeBeest et al., 1995; Long et al., 1996). Positive correlations between flag leaf collar rot and neck rot may have important implications in predicting the occurrence and incidence of neck rot and resulting yield losses (Kingsolver et al., 1984; Torres and Teng, 1993).

Yield Reductions

Differences between N treatments within cultivars for grain yield were inconclusive in 1996 as in 1995 (Long et al., 1996). Yields in the small plots were extremely variable among and within cultivars. This variability may have resulted from interplot interference and differences between experimental and control plots. For example, the flood depth in control plots was maintained at 6 to 8 in. throughout the season while experimental plots were drained periodically to induce rice blast development.

SIGNIFICANCE OF RESULTS

A simple unimodal disease progress curve appears to describe how leaf blast develops in Arkansas. Each year, blast disease, measured as disease incidence, total lesion area and the number of lesions per plant, increased from initial low levels early in the season to the highest levels during mid-season and then declined gradually thereafter. Thus, if an accurate estimate of the potential severity of rice blast disease in its neck blast phase is to be obtained by scouting fields, scouting must be completed when leaf blast is at its highest, during midseason.

In most cases, there was a significant increase in the incidence of disease, total lesion area and the mean number of lesions per plant whenever the amount of N recommended to be applied in three split applications was applied in a single preflood application. The data also suggest that applying excessive amounts of N early in the growing season may have potentially adverse effects. These results are consistent with other studies that have reported similar effects of early application of N on rice blast development and on the reduction of rice blast when using split-applications. Each year the most susceptible cultivars, Newbonnet, RT7015 and Adair, showed larger increases in disease in response to increased levels of N than the more resistant cultivars Lacassine and Cypress.

The incidence of collar rot and neck blast did not appear to be influenced significantly by N treatments, although collar rot and neck blast symptoms were generally higher on rice plants receiving N above the recommended amounts. A high incidence of flag leaf collar rot was significantly correlated to the high incidence of neck blast at all N levels. Since neck blast is closely correlated with yield losses, early and high incidence of collar rot may be an indication of potential significant yield reductions despite mid-year reductions in the visible incidence of leaf blast that we observed annually. The incidence of neck rot was highly correlated in 1994, 1995 and 1996 with the incidence of leaf blast in commercial fields. However, we must still clearly define the relationship between the early incidence of blast on leaves with the incidence of neck infections later in the season.

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Table 1. Nitrogen (N) fertilization treatments and resistance to rice blast for cultivars used in 1996 field tests conducted at the Pine Tree Experiment Station, Colt, Arkansas.

Cultivar	3-split nitrogen application*	Early application of nitrogen[†] (normal nitrogen)	Early application of nitrogen[‡] (>50% nitrogen)	Resistance[§]
		Treatment 1	Treatment 2	Treatment 3
Adair	(120) 60-30-30 (units[¶])	120 (units)	180 (units)	S
Alan	(135) 75-30-30	135	203	S
Cypress	(150) 90-30-30	150	225	MR
Kaybonnet	(135) 75-30-30	135	203	R
Lacassine	(150) 90-30-30	150	225	MR
Mars	(110) 50-30-30	110	165	MR
Newbonnet	(135) 75-30-30	135	203	VS
RT7015	(135) 75-30-30	135	203	VS

*Nitrogen (urea) applied at the recommended N rate in 3 split appplications. The largest amount of the N was applied as urea before the first permanent flood at the mid-tillering stage. The remaining 60 units were applied at mid-season (i.e. internode elongation stage) in two applications of 30 units ten days apart. All plots were 5 ft wide and 16 ft long.

[†]Nitrogen (urea) recommended for 3 split applciations is applied in a single application before the first permanent flood during mid-tillering stage of plant development.

[‡]Nitrogen (urea) applied at 50% above the recommended N rate in a single application before the first permanent flood during mid-tillering stage of plant development.

[§] Summary by degree of susceptibility: R= resistant, S= susceptible (M= moderately and V= very)

[¶]Unit = total nitrogen (lb of N/acre)

Table 2. Analysis of variance of the area under the disease progress curves (AUDPC) for disease incidence and total lesion area caused by *M. grisea* for eight cultivars with three N rates at Colt, Arkansas, 1996.

Source of variation 1996	AUDPC's* for % incidence†		AUDPC's for total lesion area‡	
	F-value	Tabular F	F-value	Tabular F
Cultivar	845.24	0.0001	807.73	0.0001
Nitrogen	1510.10	0.0001	2109.74	0.0001
CultivarxNitrogen	83.88	0.0001	112.40	0.0001
	C.V. = 8.718554		C.V. = 8.771784	

*AUDPC = Area under the Disease Progress Curve by days
†Disease incidence = the percentage of diseased plants among all plants sampled.
‡Total lesion area = the average sum of the area of lesions found on sampled plants.

Table 3. T-test analysis of the area under the disease progress curve (AUDPC) values for the incidence and total lesion area per plant caused by *M. grisea* on the eight cultivars and three nitrogen (N) fertilization treatments at the Pine Tree Experiment Station, Colt, Arkansas, 1996.

	AUDPC's* for % incidence†			AUDPC's for total lesion area‡		
Cultivars	Normal N 3 split	Normal N single	High N single	Normal N 3 split	Normal N single	High N single
Adair	2216.38	2828.00	3059.88	879.40	2337.10	5168.00
Alan	1949.50	2746.98	3194.54	702.30	1555.60	3552.50
Cypress	489.30	1141.35	2268.61	94.30	242.20	775.40
Kaybonnet	0.00	0.00	0.00	0.00	0.00	0.00
Lacassine	2683.80	2980.86	2710.40	567.10	2346.90	3280.30
Mars	1628.38	2804.03	2950.33	510.80	1759.50	4079.20
Newbonnet	2495.15	3030.83	3434.64	1803.10	4946.90	7344.70
RT7015	1570.28	2648.28	3155.60	586.90	1875.90	3743.30
$LSD_{(0.05)}$		177.51			248.07	

*AUDPC = Area Under the Disease Progress Curve by Day.
†Disease incidence = the percentage of diseased plants among all plants sampled.
‡Total lesion area = the amount of diseased tissue per plant.

Table 4. Analysis of variance for the critical point analysis (mid-season) for disease incidence and total lesion area per plant caused by *M. grisea* for eight cultivars and three nitrogen (N) treatments at Colt, Arkansas, 1996.

Source of variation 1996	% Incidence*		Total lesion area†	
	F-value	Tabular F	F-value	Tabular F
Cultivar	1302	0.0001	805	0.0001
Nitrogen	2190	0.0001	1243	0.0001
	C.V. = 1.982863		C.V. = 8.030080	

*Disease incidence = the percentage of diseased plants among all plants sampled.
†Total lesion area = the amount of diseased tissue per plant.

Table 5. Statistical analysis of the peak leaf blast data point (mid-season) for disease incidence and total lesion area per plant caused by *M. grisea* for eight cultivars at Colt, Arkansas, 1996.

	% Incidence*			Total lesion area†		
Cultivars	Normal N 3 split	Normal N single	High N single	Normal N 3 split	Normal N single	High N single
Adair	78	100	100	49	121	215
Alan	79	94	96	43	51	119
Cypress	20	47	80	4	13	44
Kaybonnet	0	0	0	0	0	0
Lacassine	100	100	100	32	109	137
Mars	61	99	99	32	75	203
Newbonnet	88	100	100	126	273	376
RT7015	47	81	98	35	112	210
LSD $_{(0.05)}$		3.3			14.573	

*Disease incidence = the percentage of diseased plants among all plants sampled.

†Total lesion area = the amount of diseased tissue per plant.

Table 6. Analysis of variance of the end of the season leaf blast data for disease incidence and total lesion area per plant caused by *M. grisea* for eight cultivars and three nitrogen (N) treatments at Colt, Arkansas, 1996.

Source of	% Incidence*		Total lesion area†	
variation 1996	F-value	Tabular F	F-value	Tabular F
Cultivar	286	0.0001	276	0.0001
Nitrogen	928	0.0001	2087	0.0001
	C.V. = 7.459229		C.V. = 11.07120	

*Disease incidence = the percentage of diseased plants among all plants sampled.

†Total lesion area = the amount of diseased tissue per plant.

Table 7. Statistical analysis of the end of the season leaf blast data for disease incidence and total lesion area per plant caused by *M. grisea* for eight cultivars grown at Colt, Arkansas, 1996.

	% Incidence*			Total lesion area†		
Cultivars	Normal N 3 split	Normal N single	High N single	Normal N 3 split	Normal N single	High N single
Adair	24	47	47	1.50	6.00	32.6
Alan	20	50	87	1.00	8.20	17.4
Cypress	0	13	27	0	0.78	2.80
Katy	0	0	0	0	0	0
Lacassine	48	77	43	2.80	5.20	19.0
Mars	0.15	40	55	1.60	9.00	8.10
Newbonnet	32	53	96	1.10	12.3	37.6
RT7015	28	42	73	1.70	8.00	26.0
LSD $_{(0.05)}$		7.04			2.63	

*Disease incidence = the percentage of diseased plants among all plants sampled.

†Total lesion area = the amount of diseased tissue per plant.

Table 8. Analysis of variance for neck blast and flag leaf collar rot incidence observed at the end of the season for eight cultivars and three nitrogen (N) treatments at Colt, Arkansas, 1996.

Source of variation	% Neck blast infections F-value	% Neck blast infections Tabular F	% Collar rot infections F-value	% Collar rot infections Tabular F
Cultivar	19.30	0.0001	23.03	0.0001
Nitrogen	2.16	0.1226	2.40	0.0982
Cultivar x Nitrogen*	0.75	0.7381	0.5300	0.9240
	CV = 48.72		CV =36.76	

*Cultivar to nitrogen interaction for eight cultivars and three nitrogen treatments in small plots.

Table 9. Percent flag leaf collar rot and neck blast for the eight cultivars and three nitrogen (N) fertilization treatments in tests at Colt, Arkansas, 1996

	Collar rot infections (%)			Neck blast infections (%)		
Cultivars	Normal N 3 split	Normal N single	High N single	Normal N 3 split	Normal N single	High N single
Adair	63.8	63.8	86.3	72.5	78.8	90.0
Alan	17.5	31.3	23.8	70.0	63.8	67.5
Cypress	15.0	12.5	25.0	17.5	21.3	38.8
Kaybonnet	0.0	0.0	0.0	0.0	0.0	0.0
Lacassine	56.3	57.5	73.8	50.0	62.5	68.8
Mars	31.3	30.0	53.8	36.3	25.0	42.5
Newbonnet	48.8	68.8	81.3	60.0	77.5	90.0
RT7015	22.5	33.8	33.8	70.0	55.0	75.0
LSD $_{(0.05)}$		26.4			25.7	

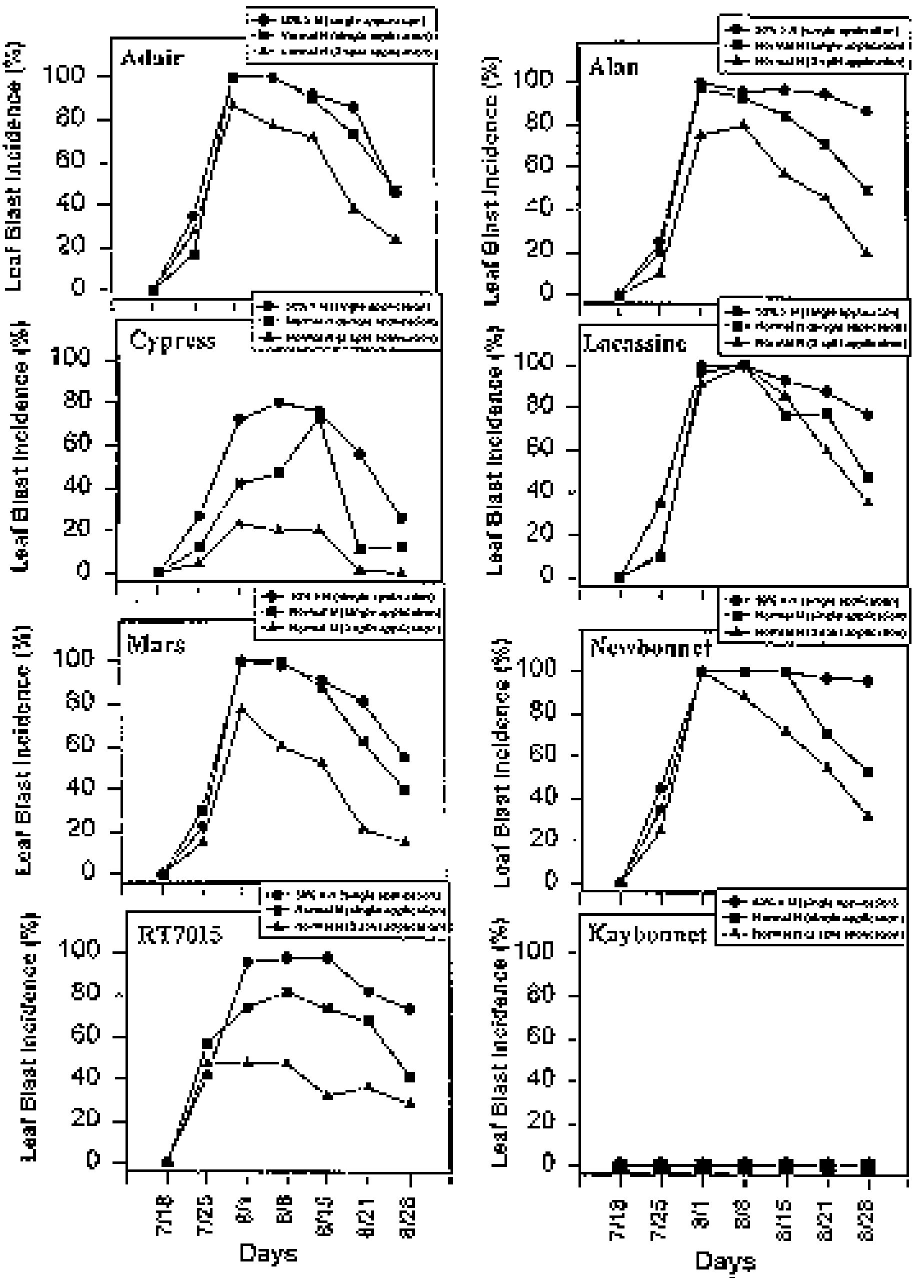

Figure 1. Disease progress curves for leaf blast incidence (%) on eight cultivars fertilized at the recommended N rate in three-way-split applications, a single preflood applciation or as a single application of 50% above the recommended nitrogen (N) rate at Colt, Arkansas, 1996.

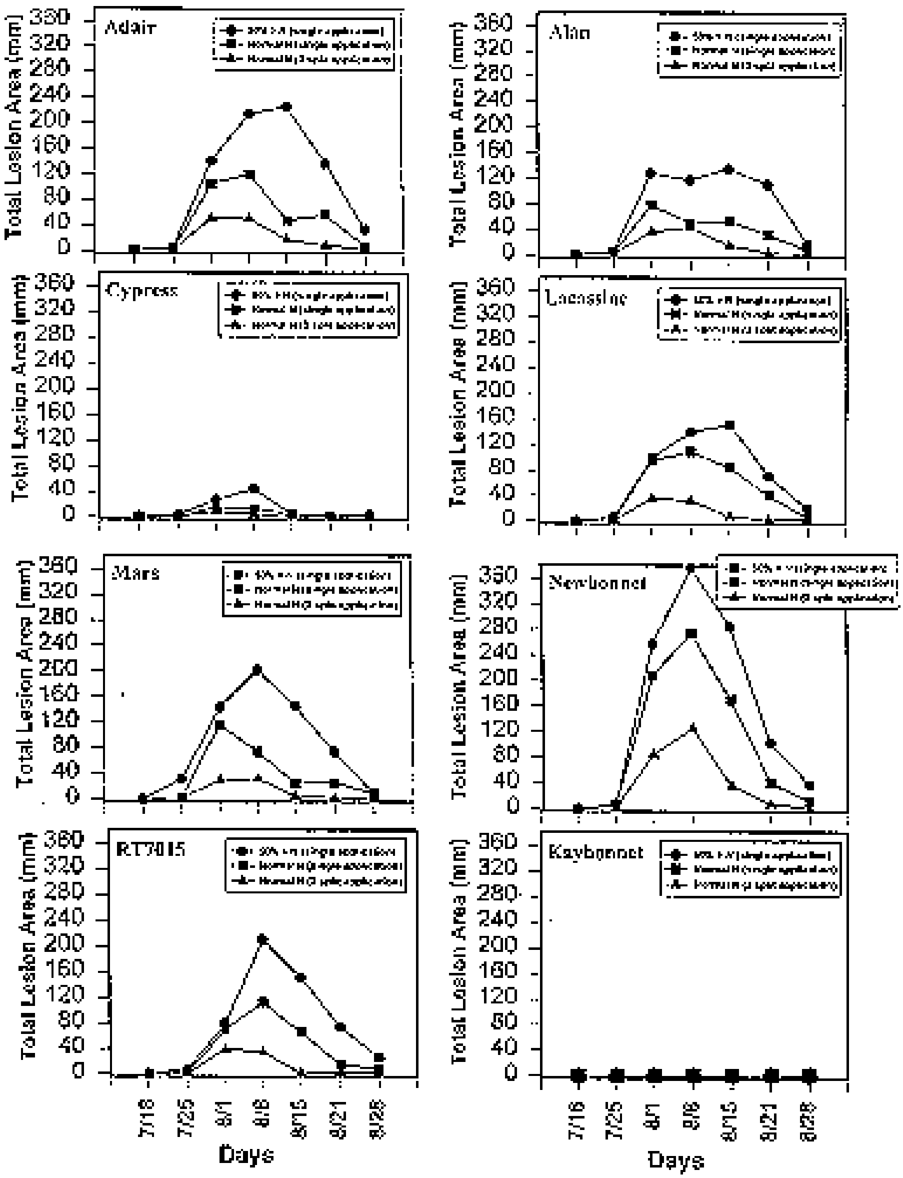

Figure 2. Disease progress curves for total lesion area (leaf blast) on eight cultivars fertilized at the recommended N rate in three-way-split applications, a single preflood application or as a single application of 50% above the recommended nitrogen (N) rate at Colt, Arkansas, 1996.

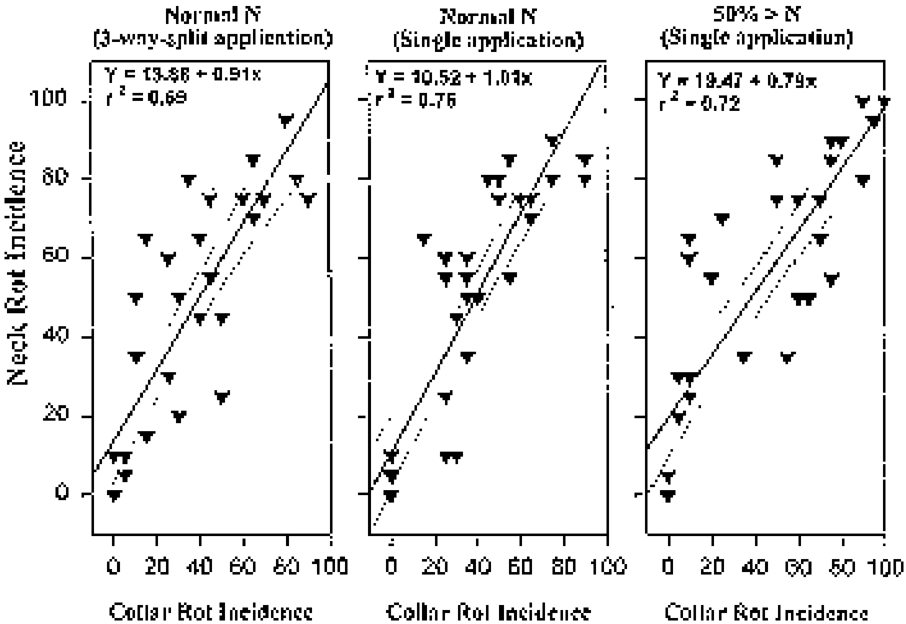

Figure 3. Linear regression analysis of the relationship between the incidence of flag leaf collar rot and neck rot on seven cultivars at three nitrogen (N) levels at Colt, Arkansas, 1996.

A POSSIBLE EXPLANATION FOR POTASSIUM DEFICIENCY IN RICE

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ABSTRACT

A study was initiated to compare the maximum rates of K uptake by several rice cultivars. The research is intended to determine if a relationship exists between cultivar susceptibility to K deficiency and the maximum rate at which K can be taken up by roots. Potassium depletion studies were conducted in a growth chamber for several rice cultivars and compared with field observations of visual K deficiency symptoms. Results suggest an apparent positive relationship between the rate at which a cultivar can absorb K and the susceptibility of the cultivar to K deficiency. 'Bengal' had the highest maximum rate of K uptake and most frequently exhibited visual K deficiency symptoms under field conditions. Another cultivar, 'Lemont', exhibited less frequent K deficiency symptoms in the field and had a lower maximum rate of K uptake than Bengal.

INTRODUCTION

The rice plant must expend metabolic energy to absorb certain nutrients such as N, P and K. This type of absorption is referred to as active uptake and is in contrast to passive uptake, which does not require metabolic energy by the plant. Depletion studies allow researchers to calculate the rate at which plants can absorb nutrients that are actively taken up by roots. Our studies, although limited, have shown that rice plants differ in the maximum rates of K uptake. However, we have not related K uptake rates to the ability of a plant to compete for nutrients under field conditions. Plants that have the capability of absorbing K at high rates may deplete soil solutions of K quickly if the soil buffering capacity is low. On these soils, cultivars with high rates of K uptake may be more susceptible to K deficiencies.

Sudies were initiated to quantify the maximum rates of K uptake by several rice cultivars and to compare these values with visual observations of K deficiency symptoms. If a relationship exists, producers can select cultivars that respond better to soils that test low in plant-available K.

PROCEDURES

Nutrient depletion studies were conducted in a growth chamber at Fayetteville, Arkansas, with a 16-hour day temperature of 30°C and an 8-hour night temperature of 27°C. In separate studies, seeds of Bengal, Lemont, 'Mars', 'Katy', 'Newbonnet' and 'Jasmine 85' were germinated in pots filled with gravel and water. Ten days after germination, one seedling was placed into a 4-L pot containing quarter-strength nutrient solution. This solution was changed every four days and pH maintained at 5.0. Upon first tiller, the seedling was transplanted to half-strength nutrient solution, changed every two days, and pH maintained at 5.0. When the plant had reached active tillering, full-strength solution was used. The plant was allowed to grow for 60 days prior to the initiation of the depletion.

At 24 hours, prior to the depletion, the plant was transferred to a 2-L pot and starved of K by replacing the nutrient solution with solution that did not contain K. The solution was then replaced with solution that contained 40 µmol/L of K as K_2SO_4. The solution was sampled for 13 hours with a peristaltic pump set to collect 0.2 ml/min into a fraction collector set to change at 30-min intervals. Volume was maintained in the pot by pumping deionized water into a plastic bag located in the pot. K concentrations in solution samples were measured by atomic absorption spectrophotometry.

Upon completion of the depletion, plants were harvested and shoots were separated from roots. Fresh weight of the roots was determined and root length was measured by the line intersect method of Tennant (1975). Average root radius (r_0) and root surface area (A) was calculated as described by Barber (1995). A depletion curve was developed and kinetic uptake parameters were calculated as explained by Claasen and Barber (1974).

RESULTS AND DISCUSSION

Table 1 shows the maximum rate of K uptake (Imax) measured for each of the rice cultivars. Bengal had the highest rate of K uptake of the cultivars, followed by Lemont and Mars. This suggests that under similar concentrations of soil solution K, Bengal has the capacity to absorb K at a faster rate than the other rice cultivars. Under situations of low plant-available K concentrations or where soil buffering of K is low, Bengal may exhaust limited supplies of K quicker than other cultivars.

Visual K deficiency symptoms in the field have been most widespread with Bengal. Lemont has exhibited fewer instances of K deficiencies in the field, while the remaining cultivars evaluated in this study rarely exhibit K deficiencies in the field (personal communication, Nathan Slaton). Although preliminary in nature, this information would suggest that there may be a relationship between the rate at which a cultivar absorbs K and the susceptibility of that cultivar to K deficiencies.

We are currently conducting depletion studies with the cultivars 'Cypress', 'Lagrue' and 'Kaybonnet'. If similar relationships are found, greenhouse studies will be conducted on low K soils in order to induce K deficiencies and relate the severity of the deficiency with the rates of K uptake.

SIGNIFICANCE OF FINDINGS

These results suggest a relationship between the rate of K uptake by a cultivar and its susceptibility to K deficiency. If this relationship is found to be consistent among all cultivars, it will help explain differences in visual deficiency symptoms for K under field conditions. A knowledge of the potential susceptibility to K deficiency will be a valuable tool for selection of appropriate cultivars to grow on soils that are low in plant-available K.

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Table 1. Maximal potassium (K) influx of several rice cultivars grown in a growth chamber at Fayetteville, Arkansas, 1996.

Cultivar	I_{max}*	Visual K deficiencies[†]
	$nmol/m^2$ s	
Newbonnet	8.3	few
Jasmine 85	9.3	few
Katy	12.1	few
Mars	21.8	few
Lemont	28.9	frequent
Bengal	51.7	very frequent

*I_{max} = .

[†]These responses were based on 2 years of field observations made by Nathan Slaton and are not quantitative in nature. They are used only to determine a possible relationship between I_{max} and susceptibility to K deficiency.

ENVIRONMENTAL IMPLICATIONS OF PESTICIDES IN RICE PRODUCTION

T.L. Lavy, R.A. Dewell, J.D. Mattice, R.J. Norman and B.W. Skulman

ABSTRACT

Since maintaining high water-quality standards in the state remains a top priority, monitoring for pesticides in water sources must continue. Determining the type, concentration and dissipation characteristics of any pesticides present in water supplies is essential to the overall assessment and decision processes concerning water quality.

Six independent rice production locations in Arkansas, Conway, Faulkner and Lonoke Counties were monitored in 1996. Irrigation, runoff and pond water samples were collected every 10 to 14 days between permanent flood establishment and draining. Quantification and confirmation of pesticide residues were obtained by HPLC and GC/MS analysis. The lower limit of quantitation for all pesticides was 2.0 µg/L in water. Pesticides selected for monitoring were determined after assessing state recommendations and our analytical capabilities. The selected compounds included: Benlate, Bolero, 2,4-D, Facet, Furadan, Grandstand, Londax, malathion, MCPA, methyl parathion, Ordram, Prowl, Rovral, Sevin, Stam, Tilt and Whip.

A greenhouse/laboratory study was also conducted to further evaluate the persistence of several of the most commonly used and/or detected pesticides. Aquatic dissipation of Facet, 2,4-D, Benlate, Furadan, Stam, Ordram, Bolero and Prowl was investigated under 16 different water/sediment treatments.

Since each field location was independently managed, individual results are site specific. 2,4-D, Benlate, Ordram, Stam, Facet, Bolero, Londax and Prowl were the pesticides actually applied during the season. When detected, these pesticides were usually present at trace levels in tailwaters shortly after application. However, we did not find any evidence suggesting a buildup of any pesticide in the reservoirs over time. Facet residues in the tailwaters were considerably more persistent (4 to 6 weeks) than the other detected compounds (less than 2 weeks). Similar results were obtained in the greenhouse dissipation experiment. Across all water treatments, Facet residues underwent the least

dissipation during the eight-week study. Stam and Prowl disappeared rapidly from all treatment systems.

INTRODUCTION

The detection of pesticides in agricultural runoff and water supplies has resulted in concern from both the general public and numerous environmental groups. Typically, pesticide residues in surface water supplies have been associated with the commonly used corn and soybean herbicides, such as atrazine, metolachlor and alachlor. However, in recent years, low levels of several rice pesticides have also been detected in various water supplies.

Water quality issues revolving around Ordram and Bolero residues began to attract attention in the early 1980's in California. As a result, regulations were implemented that required specified water holding periods prior to release back into the Sacramento River (Ross and Sava, 1986). In the early 1990's, similar compounds were also reported in the Mississippi River and its tributaries (Pereira and Hostettler, 1993). Recent reports from California suggest that decreasing concentrations of Ordram and Bolero at downstream locations of the Sacramento River result primarily from dilution and not from aquatic degradation (Crepeau et al., 1995).

Specific objectives of this research were: 1) to monitor tailwaters and confined surface water irrigation sources for pesticide residues and assess dissipation trends and 2) to determine the dissipation mechanisms involved with the pesticides frequently detected in collected water samples.

PROCEDURES

Six sampling locations were established utilizing water management systems that had the potential to pump and recycle rice irrigation water from confined reservoirs used to collect tailwater drainage from the rice production field. Tailwaters, pond and irrigation water samples were collected on a bimonthly schedule that began with permanent flood establishment. Water samples (900 mL) were transported, on ice, from the sampling locations to the Altheimer Laboratory, Fayetteville, Arkansas, for extraction and analysis. At the time of sample collection, additional pesticide-fortified samples were also prepared from each location to monitor the stability of the selected pesticides in water during transport. Based on state recommendations and our analytical capabilities, the following 17 pesticides were selected for analysis: Benlate, Bolero, 2,4-D, Facet, Furadan, Grandstand, Londax, malathion, MCPA, methyl parathion, Ordram, Prowl, Rovral, Sevin, Stam, Tilt and Whip. From this screening list, Benlate, 2,4-D, Ordram, Stam, Facet, Bolero and Prowl were actually applied at one or more locations during 1996. All samples were prefiltered through Whatman GF/F filter paper (0.7-µm particle retention) to remove any suspended sediment. Filtered water (250 mL) was extracted using a 47-mm vacuum extraction manifold equipped with Empore C-18 extraction disks. Analytes were eluted with methanol and analyzed using high-performance liquid chromatography (HPLC). Samples resulting in a positive HPLC detection were then subjected to gas chromatography/mass spectrometer (GC-MS) analysis for final confirmation.

In a greenhouse study, 16 water systems were used to investigate the effects of various environmental factors on the dissipation trends of commonly detected rice pesticides under aquatic conditions. The 16 systems included all combinations of the following factors: deionized or pond water, sediment or no sediment, light or dark conditions and static or dynamic (bubbling air) systems. Individual water systems were prepared in 1-gal fish bowls and contained 3 L of either deionized or pond water. The systems containing sediment were prepared by adding actual pond sediment from Arkansas County to the bowls (sediment volume = 600 mL). Aquarium pumps were used to provide a continuous supply of air to half of the systems. Two replications of each treatment were randomly arranged on benches in the greenhouse with one bench having a black plastic cover over it to eliminate sunlight. Facet, 2,4-D, Benlate, Furadan, Stam, Ordram, Bolero and Prowl were added to each system to obtain an initial concentration of 50 μg/L. Water samples (250 mL) were collected 1 h, 3, 7, 14, 28 and 56 d after treatment and analyzed by HPLC to determine the concentrations of pesticide remaining over time. Three separate runs of this experiment have been conducted. Data from the third run are still under evaluation. Data from the first two runs are presented in this paper.

RESULTS AND DISCUSSION

Since each location was independently managed, individual results are site specific. 2,4-D, Benlate, Bolero, Facet, Grandstand, Londax, Ordram, Stam and Prowl residues were detected during the 1996 growing season. Shortly after flood establishment, trace levels of Bolero, Facet and Stam were detected in tailwaters. Similarly, post-flood applications of 2,4-D, Benlate, Grandstand, Londax and Ordram resulted in trace level detections in tailwaters shortly after application. As in previous years, these tailwater residues did not lead to a pesticide buildup in adjacent reservoirs used for water collection.

Facet residues in tailwaters were more persistent (four to six weeks after flood establishment) than the other detected compounds, which tend to persist less than two weeks in water. In some instances, Facet residues were detected in irrigation water coming from nearby water sources (sloughs or bayous). Residues in these waters are probably the result of runoff water coming from neighboring rice fields. Similarly, the low-level Prowl concentrations probably resulted from applications to nearby soybean fields.

In the greenhouse study, Stam, Prowl and Bolero dissipated readily from all water systems. Facet, Furadan and 2,4-D were the most persistent pesticides based on overall mean values. Due to this experiment being conducted inside the greenhouse, the effect of photodegradation could not be accurately evaluated since the greenhouse covering filters out most of the ultraviolet rays ($\lambda <$ 385 nm). Both Facet and 2,4-D are known to undergo indirect photodegradation in environmental water systems. Therefore, the limited dissipation of these compounds is not surprising.

Table 1 contains slope estimates for the regression equation:

$$\ln ppb = k * (time)$$

The negative values indicate that pesticide loss is occurring from the water treatments and the magnitude of each value indicates the rate of loss (i.e., ignoring the negative sign, larger numbers indicate increased losses). Simple correlations were not evident to help explain which factors were most influential in the aquatic dissipation of these compounds. Results from the greenhouse study confirm the complexity of evaluating environmental water samples. General trends can be predicted such as adsorption of Benlate to sediment. However, the effect of this variable is greatly influenced by the other factors present (sunlight, water type and bubbling air). Another factor typically mentioned in aquatic pesticide dissipation is the volatile characteristics of thiocarbamate herbicides such as Ordram and Bolero. However, as with the sediment factor, the effect of volatility varies with individual water treatment combinations.

SIGNIFICANCE OF FINDINGS

Even though some pesticides were detected in the tailwaters shortly after application, we see no evidence to show a pesticide buildup in the reservoirs. Overall, the dissipation of rice pesticides from water is very rapid; this is evident from observing residues at one sampling time and not detecting the pesticide two weeks later. As expected, the period of highest pesticide concentration in water occurs shortly following pesticide application. Therefore, containment of water on the field should be emphasized immediately following postemergence applications to flooded rice. Flushing early in the season is most likely to cause loss of pesticides from preflood applications. Depending on application timing and flushing, the potential exists for rice pesticides to be present in surface waters used to irrigate other crops.

ACKNOWLEDGMENTS

The authors would like to acknowledge the cooperation of all our cooperators for allowing us to collect water samples from their production systems. The financial support of the Rice Research and Promotion Board and Arkansas Water Resources is also appreciated.

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Table 1. Range of slope estimates for aquatic dissipation of rice pesticides from all water systems in two different greenhouse experiments (ln ppb = k * time) at Fayetteville, Arkansas.

	Slope Estimates (k)					
	Minimum		Maximum		Mean[1]	
Pesticide	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Benlate	-0.008	-0.003	-0.312	-1.004	-0.073	-0.135
Bolero	-0.073	-0.023	-0.723	-0.785	-0.307	-0.317
2,4-D	-0.005	-0.003	-0.127	-0.104	-0.052	-0.041
Facet	-0.004	-0.005	-0.035	-0.048	-0.012	-0.014
Furadan[†]	NA	-0.003	NA	-0.303	NA	-0.039
Ordram	-0.041	-0.036	-0.232	-0.285	-0.131	-0.103
Prowl	-0.184	-0.334	-0.528	-0.932	-0.343	-0.651
Stam	-0.106	-0.047	-0.728	-0.918	-0.330	-0.354

*Averaged across all water treatment systems.

[†]Furadan was not evaluated in the first run of this greenhouse experiment.

ONGOING STUDIES
RICE CULTURE

1996 RICE RESEARCH VERIFICATION TRIALS

W.L. Mayhew, C.E. Wilson and T.E. Windham

ABSTRACT

One field in each of eight Arkansas counties was enrolled in the 1996 Rice Research Verification Trials (RRVT). The counties participating were Arkansas, Clay, Craighead, Desha, Greene, Lincoln, Lonoke and Prairie. Four different cultivars were seeded in eight production fields that totaled 437 acres with an average of 55 acres/field. Grain yield, reported at 12% moisture, averaged 146.7 bu/acre and ranged from 118 to 169 bu/acre. One field was a no-till water-seeded field following rice, and one field was planted into a stale seedbed. Two fields utilized the single pre-flood method of nitrogen (N) fertilizer application. Returns were calculated using a $4.50/bu selling price and a 25% crop rent and included all operating and ownership costs associated with production. Returns from the eight fields ranged from $30.27 to $210.49 and averaged $124.35/acre.

INTRODUCTION

The Rice Research Verification Trials (RRVT) were initiated in 1983 and to date have included 138 commercial fields in the program. The RRVT uses an interdisciplinary approach that stresses management intensity to maximize net returns. The objectives of the program are to demonstrate research results in commercial fields, identify gaps in production research, accumulate an economic database for rice production, assist in technology transfer and provide rice production training to county Extension agents.

PROCEDURES

Each RRVT field was selected prior to seeding. Farm cooperators agreed to pay production expenses, provide crop expense data for economic analysis and implement each recommended production practice in a timely manner from seedbed preparation through harvest. A designated county agent from each participating county assisted the RRVT coordinator in collecting data, scouting the field and maintaining regular contact with the grower. Management decisions were made based on current University of Arkansas research-based Extension recommendations. Additional assistance was provided by the appropriate Extension specialist or Experiment Station researcher as needed.

Eight RRVT fields were established during 1996 on a total of 437 acres. Counties participating in 1996 included Arkansas, Clay, Craighead, Desha, Greene, Lincoln, Lonoke and Prairie. Cultivars included three long-grain cultivars, 'Kaybonnet', 'Cypress' and 'LaGrue',and a medium-grain cultivar, 'Bengal'. In Greene County, rice was seeded with a no-till water-seeded system following rice, and at Prairie County, the rice was planted into a stale seedbed. The single pre-flood method of N fertilizer application was used in Lonoke and Lincoln counties. The acreage, soil series, previous crop, yield and cultivar are listed for each field in Table 1. The stand density, seeding rate, fertilizer rates and important dates are listed in Table 2.

Various combinations of pesticides were used in 1996 (Table 3). All fields received herbicide applications with most programs utilizing a residual compound. Two fields and the border of a third field received an insecticide application. Ten acres of one field received a fungicide application.

RESULTS AND DISCUSSION

Grain yield in 1996 averaged 147 bu/acre with a range of 118 to 169 bu/acre (Table 1). This yield was 10 bu/acre higher than the reported state average yield of 136.7 bu/acre. The Desha County field produced the lowest yield at 118 bu/acre. Since it was difficult to establish and maintain a flood on this field, there was a reluctance to drain for a possible straighthead situation due to herbicides applied into the flood water. The decision was made to hold the flood. Straighthead was quite evident on about one-third of the field, and this lowered the yield considerably.

The Arkansas County field produced exceptional rice and had the highest yield of 169 bu/acre. One 30-acre portion of the 108-acre field reportedly produced in excess of 190 bu/acre. However, 10 to 15 acres of the field had been recently graded. Chicken litter and mixed fertilizer were applied to these cut areas of the field, but productivity was still less than for the uncut areas of the field.

In the Greene County field, rice was water-seeded into a no-till seedbed following rice, and it produced 166 bu/acre. Rice water weevils reached threshold levels, and the field was subsequently drained due to stubble and floating algae, which could have potentially reduced the activity of an insecticide. While the field was drained, a herbicide application was made, and additional N fertilizer was added. This approach worked well but did allow some red rice to emerge.

The Lonoke County field produced 165 bu/acre with some yield reduction apparent from lack of flood control on the lower end of the field. Rice leaf blast was detected in this area of the field; however, no neck blast was detected after heading. A single pre-flood application of N was planned, but, due to streaking of the N fertilizer application, plant area board measurements indicated a need for an additional nitrogen that was applied at midseason.

The Craighead County field, which produced 151 bu/acre, presented several challenges to management. First, there were four different emergence dates in the field, and second levees were lost on over half of the field prior to flooding. The field was an excellent example of a real-world situation in which management for the whole field was critical.

In Lincoln County a single pre-flood N application produced 144 bu/acre of grain. Yields were disappointing, but reasons for the low yield were not readily apparent.

The Prairie County field was planted in a stale seedbed and produced 135 bu/acre. The field had a severe yellow nutsedge problem that was realized soon after seeding. Although control was successful, infestation was initially so threatening that the grower discussed abandoning the stand and starting over.

The Clay County trial produced 125 bu/acre in a field that was precision graded three years ago. The field had cuts up to 15 ft at that time. Chicken litter and mixed fertilizer were once again applied to this field. Although the cut areas are improving over time, about 6 acres in 1996 produced no rice. Additionally, the growth of the rice was very slow prior to flooding. In this situation it was necessary to spoon feed nitrogen to encourage plant growth.

ECONOMIC ANALYSIS

The returns from the 1996 RRVT fields ranged from $30.27 to $210.49 and averaged $124.35/acre (Table 4). These returns include all operating and ownership costs associated with production and a 25% crop rent, while assuming a selling price of $4.50/bu. The breakeven price with land cost ranged from $2.81 to $4.17/bu. These numbers reflect that different farmers and even different fields require vastly different prices to break even.

SIGNIFICANCE OF FINDINGS

The 1996 RRVT fields yielded an average 147 bu/acre. This was 10 bu/acre higher than the estimated state average, indicating that greater yield potential is available to Arkansas rice growers who use higher levels of management.

Recommended disease thresholds utilized in the 1996 RRVT proved to be effective, and only 10 acres in the program were sprayed with a fungicide while good yields were maintained.

The returns ($124.35/acre) associated with the 1996 RRVT show that rice can be extremely profitable without government payments as long as prices remain good.

The 1996 RRVT demonstrated that there is a tremendous amount of variability when looking at returns from rice. Growers must be aware of where their breakeven points are for their specific situations.

The Craighead, Clay and Prairie County fields were all prime examples of real world situations where management had to account for whole field decisions under adverse conditions. Management must focus on the bottom line and subsequently make decisions based on improving the chances of higher net returns.

Table 1. Acreage, soil series, previous crop, yield and cultivar of the 1996 Rice Research Verification Trials.

County	Acres	Soil series	Previous crop	Cultivar	Yield* Grain	Yield* Milling
Arkansas	108	Crowley & Stuttgart silt loam	Soybean	Kaybonnet	169	----
Clay	68	Bosket sandy loam	Rice	Kaybonnet	125	68/74
Craighead	78	Jackport silty clay loam	Rice	Bengal	151	70/75
Desha	43	Rilla silt loam	Soybean	Kaybonnet	118	----
Greene	33	Alligator silty clay loam	Rice	Bengal	166	68/75
Lincoln	40	Perry clay	Soybean	Cypress	144	62/68
Lonoke	35	Perry silty clay	Soybean	LaGrue	165	64/71
Prairie	32	Stuttgart & Crowley silt loam	Soybean	Kaybonnet	135	62/69
Average	55				147	

*Grain yields are reported in bu/acre at 12% moisture; milling yield = whole kernel/total percentages.

Table 2. Stand density, seeding rate, fertilizer rates* and important dates during the 1996 Rice Research Verification.

County	Stand density	Seeding rate	Nitrogen rate urea (45%)†	Fertilization $N\text{-}P_2O_5\text{-}K_2O$	Seeding date	Emerge date	Harvest date
	plant/ft²	----------	lb/acre	----------	----	month/date	----
Arkansas	14	104	170-100-100	167-40-60	4/24	5/5	9/9
Clay	21	90	65-180-65 (34 acres)-70-70	188-38-75	4/27	5/6	9/23
Craighead	18	90	280-65-65	185-0-0	5/11	5/18	10/12
Desha	18	90	163-65-65	132-40-60 (P, K 10 acres)	4/26	5/5	9/6
Greene	15	135	235-100	150-46-0	5/11	5/20	10/14
Lincoln	16	110	270-130 (6 acres)	130-0-0	5/18	5/26	9/30
Lonoke	23	158	250-75	146-45-0	4/19	5/4	9/11
Prairie	21	110	190-65-65	144-0-0	4/20	4/29	9/10

*If only a portion of a field was treated, the acreage is given; otherwise assume the entire field was treated.

†The N Fertilizer rate applied at different times is as follows: preflood lb N/acre - 0.5-in. internode elongation (IE)-½" I.E. + 10 days.

Table 3. Pesticide* treatment, rate per acre and dates of application on the 1996 Rice Research Verification Fields.

County	Pesticide, rate per acre and date of application
Arkansas	Propanil 4 qt (5/10); Propanil 4 qt (5/21); Londax 0.75 oz (5/21) 30 acres.
Clay	Propanil 4 qt + Prowl 2.4 pt (5/17); Methyl Parathion 1 pt (8/2) 12 acres.
Craighead	Propanil 4 qt (6/1); Facet 0.25 lb + Propanil 3 qt; Sodium Chlorate 4 qt (10/1).
Desha	Facet 0.25 lb + Prowl 1 pt (4/27); Karate 1 oz (5/10); Londax 1 oz (6/12); Ordram 15G 27 lb (6/26).
Greene	Roundup Ultra 1.5 pt (5/1) 5 acres; Roundup Ultra 1.25 pt + Bolero 8EC 4 pt (5/4); Grandstand 0.67 pt + Propanil 3 qt (6/17).
Lincoln	Propanil 3 qt + Bolero 8EC 4 pt (5/29); Storm 1.5 pt (6/18); Ordram 15G 12.5 lb (6/26); Rovral-4E 1.5 pt (7/20) 10 acres; Methyl Parathion 1 pt (9/3).
Lonoke	Facet 0.25 lb + Prowl 2.4 pt (5/4); Propanil 2 qt + Grandstand 0.67 pt (6/20).
Prairie	Arrosolo 4 qt + Prowl 2.4 pt + Londax 0.5 oz (4/30); Propanil 4 qt + Londax 0.5 oz (5/31); 2,4-DB 2 pt (6/21).

*Date of treatment are in parentheses. If only a portion of a field was treated, the acreage is given; otherwise assume the entire field was treated.

Table 4. Selected economic information from the 1996 Rice Research Verification Trials.

County	Total specified operating cost*	Total specified ownership cost†	Breakeven price‡	Breakeven price with land cost§	Returns above total cost¶
	$/acre	$/acre	$/bu	$/bu	$/acre
Arkansas	326.68	62.10	2.30	3.07	181.60
Clay	324.84	65.65	3.12	4.17	31.39
Craighead	301.06	60.47	2.39	3.19	148.10
Desha	306.31	61.67	3.12	4.16	30.27
Greene	302.66	47.10	2.11	2.81	210.49
Lincoln	315.21	68.67	2.66	3.55	102.79
Lonoke	296.79	61.69	2.17	2.90	198.40
Prairie	307.65	56.21	2.70	3.59	91.77
Average	310.15	60.45	2.53	3.37	124.35

*Specified out-of-pocket expenses, such as seed, fertilizer, herbicides, irrigation, etc.

†Ownership cost such as depreciation and interest on equipment, taxes and insurance.

‡Price per bushel required by the farmer to equal total operating and ownership cost.

§Breakeven price per bushel over total specified cost and a 25% crop share land rent.

¶A 25% crop share rent was assumed as a land charge and a $4.50 selling price was assumed. No cost sharing was assumed.

DEVELOPMENT OF THE DD50 DATABASE FOR NEW RICE CULTIVARS

R.J. Norman, N.A. Slaton, K.A.Gravois, and K.A.K. Moldenhauer

ABSTRACT

The DD50 computer program, to be effective, must be continually updated as new cultivars are named and released. We conduct studies each year to gather development data for promising new lines. In 1996 the study, conducted on a Crowley silt loam at the University of Arkansas Rice Research and Extension Center, included two seeding methods (drill and water), two seeding dates and three replicates. The drill-seeded study had eight cultivars/varieties whereas the water-seeded study contained five of the most common cultivars. Data from this study will be combined with data from previous years to formulate updated threshold values for the 1997 DD50 computer program.

INTRODUCTION

The DD50 computer program has been one of the most successful programs developed by the University of Arkansas Division of Agriculture. At present, approximately 70% of the Arkansas rice farmers utilize this program as a management tool in rice production. The program requires data for all cultivars with plant development based on accumulation of DD50 units from date of emergence. These data are developed by conducting studies that include all promising new rice varieties for two to three years prior to naming and releasing the variety as a cultivar. When the new cultivar is released to farmers, the data developed from these studies are used to provide threshold DD50 values in the computer program. Therefore, the objective of this study is to develop databases for promising new rice varieties, to verify databases for existing cultivars and to assess the effect of seeding date and method (i.e., dry and water) on DD50 accumulations.

MATERIALS AND METHODS

The 1996 study was conducted at the University of Arkansas Rice Research and Extension Center (RREC), Stuttgart, Arkansas, on a Crowley silt loam soil. Eight cultivars/varieties were seeded in the drill-seeded portion of the study on 17 April and 16 May. Five cultivars were seeded on 18 April and 17 May in the water-seeded study. The rice was seeded at a rate of 100 lb/acre in nine row plots (7-in. spacing), 15 ft in length. The design of the experiment for each study and seeding date was a randomized complete block with three replications. The cultural practices were as normally conducted for either drill- or water-seeded rice culture. Data collected included: maximum and minimum daily temperatures, length of elongating internodes at three-day intervals beginning 35 days after seeding emergence, date of 50% heading and grain yields at maturity. The temperature data were then converted into DD50 accumulations from seedling emergence until the developmental stage of interest.

RESULTS AND DISCUSSION

The DD50 accumulations for the cultivars/varieties as influenced by seeding date and method are shown in Table 1 (emergence to 0.5-in. internode elongation) and Table 2 (emergence to 50% heading). The cultivars/varieties when drill-seeded in April had rather similar DD50 accumulations from emergence to 0.5-in. internode elongation or from emergence to 50% heading, with the exception of 'Laffite', which required slightly fewer DD50 accumulations to reach these growth stages. Almost all cultivars/varieties required fewer DD50 accumulations to reach 0.5-in. internode elongation and 50% heading when drill-seeded in May compared to April, except for Laffite, which required less in April than in May. All of the cultivars/varieties when drill seeded in May had similar DD50 accumulations from emergence to 0.5-in. internode elongation, except 'Cypress' and 'Kaybonnet', which required approximately 150 to 200 fewer DD50 accumulations to reach 0.5-in. internode elongation. The cultivars/varieties varied more in their DD50 accumulations required to reach 50% heading when drill-seeded in May compared to when drill-seeded in April, but the differences still were not that extensive.

All cultivars, with the exception of 'Jefferson', were water-seeded. In general, water-seeding in April enabled the cultivars to reach the two critical growth stages with fewer DD50 accumulations than when they were drill-seeded in April. When seeded in May, the number of DD50 accumulations to reach the two growth stages for the cultivars was similar for the two seeding methods. Thus, only when seeded in April did some of the cultivars need different DD50 thresholds when water-seeded than when drill-seeded.

SIGNIFICANCE OF FINDINGS

The data from 1996 will be used to refine the DD50 thresholds for 'Bengal', Cypress, 'Drew' and Kaybonnet, to establish thresholds for Laffite and Jefferson and to differentiate thresholds between drill- and water-seeded rice.

Table 1. DD50 accumulations from emergence to 0.5-in. internode elongation as influenced by cultivar, method of seeding and date of emergence, Rice Research and Extension Center, Stuttgart, Arkansas, 1996.

	Drill-seeded		Water-seeded	
Cultivar/variety	28 April*	26 May	30 April	23 May
	----------DD50----------			
Bengal	1445	1328	1121	1207
Cypress	1413	1147	1247	1207
Drew	1445	1328	1217	1207
Jefferson	1445	1384	----	----
Kaybonnet	1413	1177	1121	1178
Laffite	1367	1384	1247	1328
RU9401188	1445	1355	----	----
RU9501121	1413	1328	----	----

*Emergence dates.

Table 2. DD50 accumulations from emergence to heading as influenced by cultivar, method of seeding and date of seedling emergence, Rice Research and Extension Center, Stuttgart, Arkansas, 1996.

	Drill-seeded		Water-seeded	
Cultivar/variety	28 April*	26 May	30 April	23 May
	----------DD50----------			
Bengal	2231	2141	2097	2073
Cypress	2263	2229	2066	2164
Drew	2295	2171	2007	2164
Jefferson	2168	2047	----	----
Kaybonnet	2295	2077	1948	2103
Laffite	1967	2109	1948	2073
RU9401188	2199	2109	----	----
RU9501121	2229	2141	----	----

*Emergence dates.

GRAIN YIELD RESPONSE OF NEW RICE CULTIVARS/ VARIETIES TO NITROGEN FERTILIZATION

R.J. Norman, C.E. Wilson, Jr., N.A. Slaton, K.A. Gravois and K.A.K. Moldenhauer

ABSTRACT

The cultivar x nitrogen (N) fertilizer interaction study determines the proper N fertilizer rates for the new rice cultivars across the array of soil and climatic conditions that exist in the Arkansas rice growing region. The new blast-resistant cultivar, 'Drew', responded similarly at each of three locations in 1996 when the N fertilizer was applied in a single preflood (SPF) compared to a three-way split (3WS) application. In 1994 and 1995, Drew responded better when the N fertilizer was applied in a SPF application compared to a 3WS application at all locations. This new cultivar usually achieved peak grain yields at all locations with a SPF application of 90 to 120 lb N/acre or a 3WS application of 120 to 150 lb N/acre. 'Laffite', a new semidwarf cultivar from Louisiana, and RU9501188, a blast-resistant experimental variety from Arkansas, responded similarly or better when the N fertilizer was applied in a SPF application compared to a 3WS application and usually reached peak grain yields when 90 to 120 lb N/acre was applied.

INTRODUCTION

The major strength of the rice-soil fertility research program has been the delineation of N fertilizer response curves for the promising new rice cultivars. This study determines the proper N fertilizer rates for the new cultivars across the array of soils and climatic conditions that exist in Arkansas. Promising new experimental varieties from breeding programs in Arkansas, California, Louisiana, Mississippi and Texas are entered into this study. The Arkansas breeding program has the new long-grain, blast-resistant rice cultivar, Drew, in this study for its third and final year, and the blast-resistant experimental variety, RU9501188, in this study for the first time. The Louisiana program has the new semidwarf long grain cultivar, Laffite, in this study for the first time.

PROCEDURES

Locations where the cultivar x N rate study were conducted and corresponding soil type are as follows: Rice Research and Extension Center (RREC), Stuttgart, Arkansas, Crowley silt loam (Typic Albaqualf); Northeast Research and Extension Center (NEREC), Keiser, Arkansas, Sharkey clay (Vertic Haplaquept); and the Southeast Branch Experiment Station (SEBES), Rohwer, Arkansas, Perry Clay (Vertic Haplaquept). The experimental design was a split plot with four replications. The main plot was application method, and the subplot was N fertilizer rate. The two N application methods used were a SPF and the recommended 3WS method. Nitrogen fertilizer rates used were 0, 60, 90, 120, 150 and 180 lb N/acre. The rice was drill seeded at a rate of 100 lb/acre in nine-row plots (row spacing of 7 in.), 15 ft in length. All plots were flooded at each location when the rice was at the four- to five-leaf stage and remained flooded until the rice was mature. At maturity, 12 ft of the center four rows of each plot were harvested, the moisture content and weight of the grain were determined, and yields were calculated as lb/acre at 12% moisture. Statistical analyses were conducted with SAS, and mean separations were based upon protected LSD where appropriate.

RESULTS AND DISCUSSION

The blast-resistant rice cultivar, Drew, responded similarly at each of three locations when the N fertilizer was applied in a SPF or in a 3WS application (Table 1). In 1994 and 1995, Drew responded better when the N fertilizer was applied in a SPF application compared to a 3WS application at all locations (Norman et al., 1995, 1996). This indicates that the yield potential of Drew is very much set by the preflood N application and that probably at least two-thirds of the N applied to Drew should be applied at preflood or that at least 90 lb N/acre should be applied preflood. In 1994 and 1995, Drew usually reached top grain yields when 90 to 120 lb N/acre was applied in a SPF application compared to 120 to 150 lb N/acre when the N was applied in a 3WS application. In 1996, Drew required 90 to 120 lb N/acre to reach peak grain yields at all locations (Table 2).

Laffite, a new semidwarf cultivar from Louisiana, was studied at only two Arkansas locations in 1996 because of a limited amount of seed. Laffite responded better when the N fertilizer was applied in a SPF application compared to a 3WS application at RREC (Table 3). At SEBES, Laffite responded similarly with both N application methods. Laffite grain yields showed no significant increases at either location when more than 120 lb N/acre was applied (Table 4).

A blast-resistant experimental variety from Arkansas, RU9501188, was studied for the first time in 1996 and, due to a limited amount of seed, was studied only at RREC. Rice line RU9501188 responded better when the N fertilizer was applied in a SPF application compared to a 3WS application (Table 5). Grain yields of RU9501188 showed no significant increase when more than 90 lb N/acre was applied in a SPF application, whereas 120 to 150 lb N/acre was required to reach top grain yields when the N fertilizer was applied in a 3WS application (Table 6).

SIGNIFICANCE OF FINDINGS

The new blast-resistant cultivar, Drew, usually responded better when the N fertilizer was applied in a SPF application but has also produced excellent yields when the N fertilizer was applied in a 3WS application. The preflood N sets the yield potential of Drew, and a preflood N application of about 90 lb N/acre should be applied for Drew to reach its full yield potential. Laffite, a new semidwarf cultivar from Louisiana, and RU9501188, a blast-resistant experimental variety from Arkansas, responded similarly or better when the N fertilizer was applied in a SPF application compared to a 3WS application and usually reached peak grain yields when 90 to 120 lb N/acre was applied.

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Table 1. Influence of nitrogen (N) fertilizer application method on grain yields of 'Drew' rice at three locations in 1996.

Application method	Grain yields NEREC*	RREC	SEBES
	------lb/acre------		
SPF[†]	9146	7563	6671
3WS	8937	7248	7371
$LSD_{(0.05)}$	ns[‡]	ns	ns

*NEREC = Northeast Research and Extension Center; Keiser, Arkansas; RREC = Rice Research and Extension Center, Stuttgart, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.

[†]SPF = Single preflood; 3WS = Three-way split.

[‡]ns = not significant.

Table 2. Influence of nitrogen (N) fertilizer rate on grain yields of 'Drew' rice at three locations in 1996.

Application	Grain yields		
rate	NEREC*	RREC	SEBES
lb/acre	-----------	lb/acre	-----------
0	3717	5065	6176
60	8308	6905	6555
90	9803	7809	7875
120	10933	7774	7779
150	10835	8087	6576
180	10645	7624	6656
$LSD_{(0.05)}$	685	541	838

[z]NEREC = Northeast Research and Extension Center; Keiser, Arkansas; RREC = Rice Research and Extension Center, Stuttgart, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.

Table 3. Influence of nitrogen (N) fertilizer application method on grain yields of 'Laffite' rice in 1996.

Application	Grain yields	
method	RREC*	SEBES
	-----------lb/acre	-----------
SPF[†]	8215	7321
3WS	7576	7484
$LSD_{(0.05)}$	324	ns[‡]

*RREC = Rice Research and Extension Center, Stuttgart, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.

[†]SPF = Single preflood; 3WS = Three-way split.

[‡]ns = not significant.

Table 4. Influence of nitrogen (N) fertilizer application rate on grain yields of 'Laffite' rice in 1996.

Application	Grain yields	
rate	RREC*	SEBES
lb/acre	-----------lb/acre	-----------
0	2286	4757
60	6642	7292
90	7819	7557
120	8804	8178
150	8690	8328
180	8925	8277
$LSD_{(0.05)}$	642	771

*RREC = Rice Research and Extension Center, Stuttgart, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.

Table 5. Influence of nitrogen (N) fertilizer application method on grain yields of experimental variety RU9501188 at the Rice Research and Extension Center, Stuttgart, Arkansas, in 1996.

Application method	Grain yields
	lb/acre
SPF*	7609
3WS	7214
$LSD_{(0.05)}$	280

*SPF = Single preflood; 3WS = Three-way split.

Table 6. Influence of nitrogen (N) fertilizer application rate and method on grain yields of experimental variety RU9501188 at the Rice Research and Extension Center, Stuttgart in 1996.

Application rate	Grain yields SPF[z]	3WS
lb N/acre	----------lb/acre----------	
0	2764	
60	7443	6259
90	8212	7472
120	8184	7795
150	8582	8378
180	8049	8389
$LSD_{(0.05)}$	658	

[z]SPF = Single preflood; 3WS = Three-way split.

AMENDMENT OF ALKALINE SOILS WITH ELEMENTAL SULFUR

N.A. Slaton, R.J. Norman, S. Ntamatungiro and C.E. Wilson, Jr.

ABSTRACT

Alkaline soil conditions have resulted in numerous rice nutritional disorders in Arkansas during the past 30 years. Previously, these nutritional problems could be alleviated by application of zinc or phosphorus fertilizers to the rice crop. Recent field observations suggest that soil alkalinity is the common factor among fields suffering from "postflood rice syndrome." Postflood rice syndrome is thought to be an imbalance of multiple nutrients as a result of reduced availability under alkaline soil pH conditions. One possible means of alleviating this problem is to acidify alkaline soils using elemental sulfur. Application of 1000 lb/acre of elemental sulfur (S) dust was effective in reducing soil pH 1.2 to 2.5 units in 210 days in laboratory incubation. Field studies showed similar results. Sulfur products having larger particle size require more time to reduce soil pH due to less exposed surface area and, thus, a lower rate of oxidation. Based on buffer pH curves, application rates of 250 to 1000 lb/acre of elemental S dust are required to lower soil pH. Application of 1000 lb/acre of elemental S dust tended to increase grain yield at one of three locations during 1996. Application of 4000 lb/acre of elemental sulfur resulted in stand loss and reduced yields caused by soil salinity. Based on preliminary data, acidification of alkaline soils shows promise for improving rice growth and yield. Additional research is required to determine the appropriate rates and the time required for various S products to effectively lower soil pH.

INTRODUCTION

Use of subsurface water high in bicarbonates for irrigation of rice and soybean crops in Arkansas has resulted in alkaline (pH > 7.0) soil conditions. In 1995, a survey of soils from rice fields suffering from poor growth after flooding, termed "postflood rice syndrome," suggested that alkaline pH was the consistent, common factor among these fields (Slaton et al., 1996). "Postflood syndrome" is the term used to describe symptoms of bronzing, reduced tillering and poor root development of rice from alkaline fields. Rice tissue (whole plant) from fields suffering from postflood syndrome typically have high calcium and iron concentrations. A review of literature fails to adequately describe the plant nutrient concentrations associated with this syndrome. However, it is suspected that reduced nutrient availability, due to alkaline soil pH, is a major factor contributing to this malady. Nutrients such as phosphorus (P), zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) decrease in availability as pH increases. The objectives of this research project were 1) to determine if reducing the soil pH improved rice growth, nutrient uptake and yield; 2) to evaluate several elemental S products and rates for their effectiveness in reducing soil pH; and 3) to evaluate soil nutrient availability and pH change in S-amended soils.

MATERIALS AND METHODS

Soil from several Arkansas rice fields was collected during the winter of 1996 to determine buffer curves for soil acidification. Soil (Hilleman silt loam) collected from Cross and Poinsett County farms were selected to determine pH buffer curves. Sulfuric acid was added to 25 g of soil at rates ranging from 0 to 18 meq H^+/lb soil. Deionized water was added to bring each sample to a 50-ml solution volume, resulting in a 1:2 soil to solution ratio. Samples were incubated for three days after addition of acid. Measurements of electrical conductivity ($EC_{1:2}$) and pH($_{1:2}$) were taken daily.

Laboratory incubation studies using the Cross County soil were conducted to determine oxidation rates, $pH_{1:1}$, $EC_{1:1}$ and soil nutrient availability as influenced by two elemental S products applied at four rates (0, 1000, 2000 and 4000 lb/acre). The two elemental S products used for this study were wetable S dust (Martin Chemical Inc., Houston, Texas) and Tiger 90 (Sunbelt Chemicals Inc., Atmore, Alabama). Each elemental S product had an analysis of 90% S. Sulfur rate and product effect on nutrient availability and S oxidation rates are not yet complete. Sulfur rate and product effect on soil pH will be discussed in this report.

Field studies were initiated at four locations to determine effect of soil acidification on total dry matter production (TDM) and grain yield. Three elemental sulfur sources were applied to soil and incorporated 16 February 1996. Sulfur sources included the two previously described sources and an additional product, which will be termed S chips (Martin Chemical Inc., Houston, Texas). Sulfur rates and products used in the field studies are listed in Table 1. Soil samples were taken from individual plots prior to treatment and at 29, 54, 77 and 97 days after S application. The 97-day samples were taken 23 May 1996 prior to flooding. Total dry matter production was determined from aboveground plant material taken on 3-ft rows at midtillering (MT), late tillering (LT) and internode elongation (IE) at the Cross and Poinsett County locations. Plant material was oven-dried at 60°C to a constant moisture and weighed. Plant nutrient analysis is not yet complete. Grain yield was determined by harvesting the four middle rows measuring 12 ft in length with a small plot combine at three of the four locations and expressed on a 12% moisture basis. The experiment was arranged in a randomized complete block design with four replications.

RESULTS AND DISCUSSION

Soil Acidification Buffer Curves

Buffer curves for two silt loam soils indicated application rates of sulfuric acid equivalent to 1000 lb/acre of elemental S lowered soil pH 1.2 to 2.5 pH units. Laboratory incubation studies, using the Cross County soil, found that pH was lowered from 7.2 to 4.5 by application of 1000 lb/acre of elemental S dust after 210 days (Fig. 1). Data for S application effect on soil pH from field soil samples are shown in Fig. 2. The buffer curve, field and soil incubation data for the Cross County soil indicate similar reductions in pH for the 1000 lb S dust/acre treatment.. Tiger 90 S applied at 1000 lb/acre lowered pH from 7.2 to 6.3 during the same 210-day period in the lab incubation study. In comparison, 1000 lb S dust/acre required only 15 days to lower soil pH to below 6.3

Silt loam soils used for rice production in Arkansas have low buffering capacity, indicating that soil pH can be quickly changed by application of sulfur dust. Oxidation rate of S determines the S product's ability to reduce soil pH. In general, the smaller the S particle size, the faster the oxidation rate. Relative sizes for two of the S products are provided in Table 2. The average size of more than 98% of the Tiger 90 granules is between 2 and 4.76 mm in diameter compared to 78% of the S dust particles being between 0.25 and 0.42 mm in diameter. The smaller particle size of the dust means that it has a greater total surface area for microbial breakdown to occur. Rates lower than 1000 lb S/acre were not used in the laboratory incubation study; however, the buffer curve using sulfuric acid suggests that rates as low as 250 to 500 lb S may be adequate for reducing soil pH to below pH 7.0. Three factors that must be considered when determining S application rate are economics, S product (particle size or rate of pH reduction) and depth of alkaline pH. Cost estimates for elemental S from several Arkansas fertilizer dealers are approximately $400/ton. Logistics of field application and cost reduction will need to be incorporated into later research and cooperative efforts between industry and research personnel.

Field Studies - Total Dry Matter and Grain Yield

Sulfur application significantly affected TDM for the MT and LT growth stages at the Poinsett County site and for the LT growth stage at the Cross County location (Table 3). At Poinsett County, application of 1000 or 2000 lb S dust/acre significantly increased TDM compared to the untreated check at both MT and LT. At the Cross County site, the 1000-lb S dust/acre treatment did not differ significantly from the untreated check. S rates higher than 1000 lb S dust/acre caused significant decreases in TDM at LT. Consequently, a lower rate of S application may have been adequate to lower the soil pH due to the low buffering capacity of the soil. Sulfur application did not significantly increase grain yields at any of the three locations (Table 4). However, a trend for increased grain yields with application of the lower S rates did occur at the Poinsett County site. Compared to the untreated check, application of 4000 lb S dust/acre did significantly decrease yields at both the Craighead and Poinsett County locations. The high rate of S increased soil salinity to levels that reduced stand at all locations, which contributed to overall yield reductions. The high rate of S dust was used to examine the potentially harmful effects of excessive S application. Sulfate is very mobile (susceptible to leaching) in the soil and should pose no significant long-term effects from high rates of elemental S. Both the Cross and Poinsett County locations had pH in excess of 7.0 to a depth of 12 in. (data not shown). Sulfur rates greater than 1000 lb/acre would be needed to reduce soil pH for this depth of soil. Deep tillage would assist in mixing elemental sulfur throughout the profile but would need to be performed after initial breakdown of the S.

SIGNIFICANCE OF RESULTS

Application of elemental S at rates of 250 to 1000 lb/acre can significantly reduce soil pH on alkaline soils based on pH buffer curves. Data from the first year of research suggest that acidification of these problem soils tends to improve rice growth. The advantages of improving early-season growth and plant vigor are important factors for management of water, nitrogen, weed control, etc. Further research is required to determine exact S rates needed to effectively reduce pH and increase grain yield. Due to the costs and hazards associated with elemental S, research and industry must cooperate in future efforts to find an economical S source that can be safely and easily applied.

ACKNOWLEDGMENTS

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Table 1. Sulfur products and rates used in 1996 field studies.

Elemental sulfur product	Elemental sulfur rate
	lb/acre
Untreated check	0
S Dust*	1000
S Dust*	2000
S Dust*	4000
S Chips*	2000
Tiger 90†	2000

*Martin Chemical Inc., Houston, Texas.
†Sunbelt Chemicals Inc., Atmore, Alabama.

Table 2. Particle size determination of two sulfur sources used in research studies during 1996.

Mesh Size	Diameter	Total collected by each mesh size	Cumulative thru mesh size
	mm	%	%
Sulfur Dust*			
40	0.42	0	100
60	0.25 - 0.42	21.6	78.4
100	0.15 - 0.25	37.0	41.4
	< 0.15	41.4	0
Tiger 90†			
4	> 4.76	0.2	98.8
10	2 - 4.76	98.2	1.6
	< 2	1.6	0

*Martin Chemical Inc., Houston, TX
†Sunbelt Chemicals Inc., Atmore, AL

Table 3. Summary of dry matter production from four sulfur tests at the three growth stages during 1996.

Sulfur rate	Sulfur product	Location, total dry matter (lb/acre) Cross Co. (Reddmann) MT*	LT	IE	Poinsett Co. (Massengill) MT1	LT2	IE
0	None	458	2540	3978	284	2936	4496
1000	Dust	607	2204	3397	713	4092	4804
2000	Dust	457	1663	3259	506	4363	4201
4000	Dust	462	1129	2725	101	851	2706
2000	Tiger 90	513	2971	3584	473	3158	3900
2000	Chips	424	2367	4789	385	3878	5070
$LSD_{(0.05)}$		184	717	0.556	235	976	2295
Pr > F		0.3785	0.067	2348	0.0013	0.0001	0.329
%C.V.		25.1	22.2	43.3	38.0	19.5	35.0

*MT = 2 weeks postflood or midtillering; LT = 4 weeks postflood or late tillering; IE = Internode elongation

Table 4. Summary of grain yields from three sulfur tests during 1996.

		Grain yields (bu/acre)		
Sulfur rate	Sulfur product	Craighead Co. (Greer)	Pine Tree Experiment	Poinsett Co. (Massengill)
0	None	115.4	152.3	161.0
1000	Dust	110.8	141.0	183.9
2000	Dust	106.7	134.7	183.6
4000	Dust	92.6	126.6	108.7
2000	TigerPaw 90	108.3	155.6	176.3
2000	Chips	120.2	142.2	170.4
$LSD_{(0.05)}$		16.0	22.7	35.9
Pr > F		0.038	0.128	0.0038
%C.V.		9.74	10.6	13.7

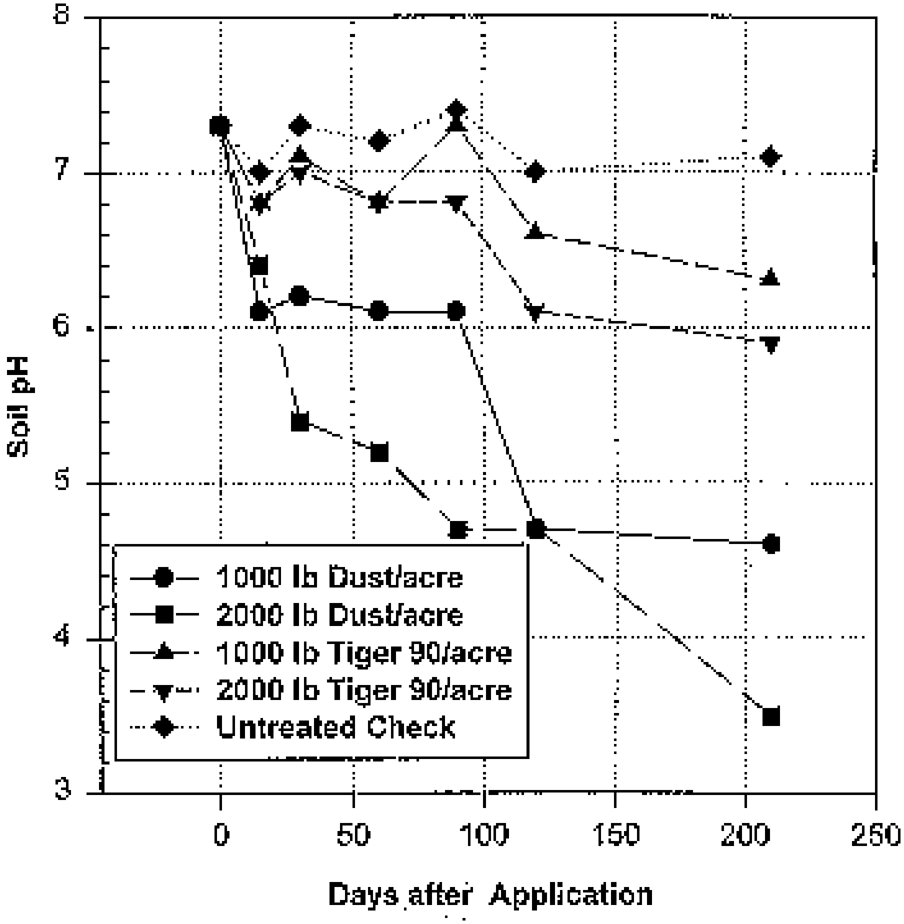

Fig. 1. Effect of sulfur application on soil pH in a laboratory incubation study (25°C).

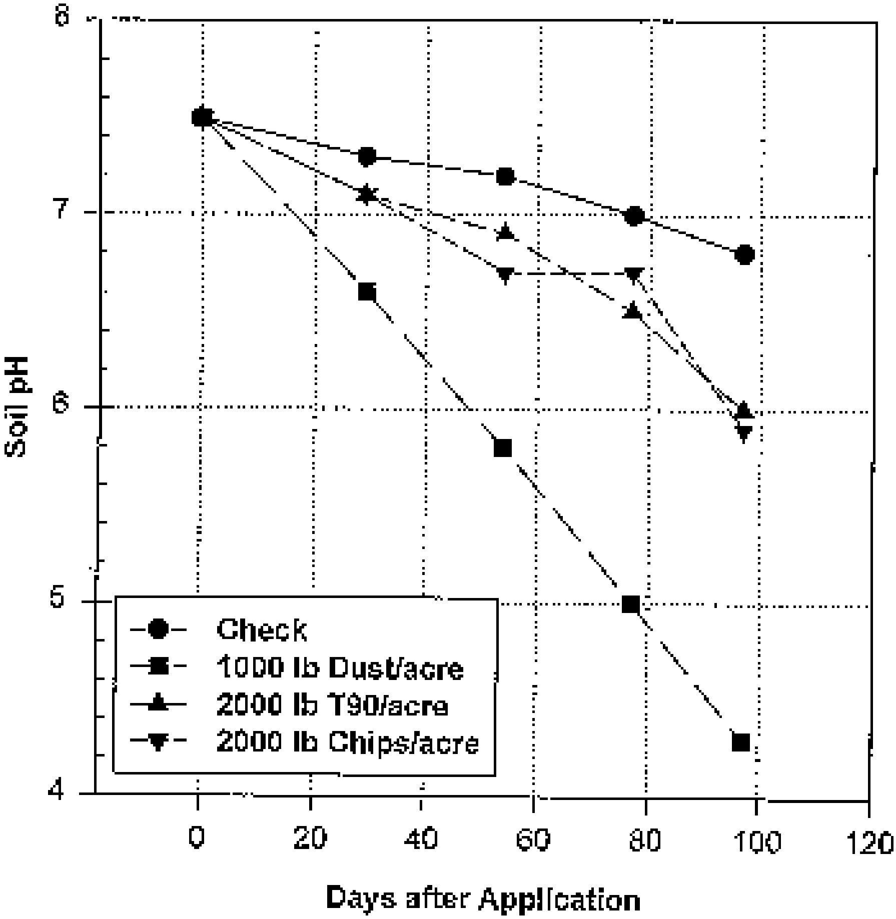

Fig. 2. Effect of application of three sulfur products on soil pH in a Cross County rice field.

SALT MOVEMENT AND RICE SALINITY STRESS AS AFFECTED BY TILLAGE

C.E. Wilson, Jr., T.C. Keisling and D.L. Frizzell

ABSTRACT

Rice plants (*Oryza sativa*, L.) are extremely sensitive to salinity, or excessive accumulation of soluble salts, during the seedling growth stage. Recent observations have been made by producers, county agents and researchers that the use of conservation tillage systems, particularly no-till systems, may increase the level of salinity in the rice root zone. With the use of conservation tillage steadily increasing in rice production, it becomes extremely important to determine if these practices increase salinity, to determine the mechanisms involved and to develop management strategies to overcome the problem. A two-year study was initiated in the fall of 1994 to evaluate salinity injury and salt movement within the soil profile under different tillage regimes. A conventional system, a para-till operation, a chisel plow operation and a no-till system were implemented in the fall, and bromide (Br^-) was applied to monitor salt movement. 'Kaybonnet' rice was grown during 1995 and 1996, and soil samples were collected from each plot at the two- to three-leaf growth stage. Soil analyses during 1995 indicated that no-till systems may increase the probability of salinity injury to rice at the seedling stage due to the increased accumulation of nitrate (NO_3^-). Reduced rice grain yields from 1995 and 1996 in the no-till treatment substantiate this conclusion.

INTRODUCTION

Considerable rice acreage is affected each year by the accumulation of soluble salts in the rice root zone when the rice is at the seedling growth stage. Current management practices provide minimum protection from damage as a result of salinity. Research is underway to develop management strategies to reduce losses due to salinity.

The use of conservation tillage practices in rice production has increased substantially during the past few years. While these practices tend to reduce labor, improve surface water quality and, potentially, reduce production costs, observations by producers, researchers and Extension agents indicate that salinity stress to the rice plant may be enhanced. Since the micropores in the soil are not disturbed as they are under conventional tillage, it is hypothesized that water and salt movement toward the soil surface is facilitated. Subsequently, the salt may tend to accumulate more at the soil surface under conservation tillage practices. The objectives of the study were 1) to evaluate the effects of various tillage systems on salinity stress and yield of rice and 2) to evaluate the effects of various tillage systems on salt movement within the soil profile.

MATERIALS AND METHODS

The study was conducted at the Pine Tree Branch Experiment Station (PTBS) near Colt, Arkansas, during 1995 and 1996 on a soil complex consisting of a Calloway silt loam (fine-silty, mixed, thermic Glossaquic Fragiudalfs), Calhoun silt loam (fine-silty, mixed, thermic Typic Glossaqualfs) and Henry silt loam (coarse-silty, mixed, thermic Typic Fragiaqualfs) in areas that had a history of salinity injury to rice. The experiment was arranged in a randomized complete block design with three replications. Four tillage treatments (conventional, para-till, chisel plow and no-tillage) were implemented during the fall of 1994 and 1995 in areas that had been previously cropped to soybeans (*Glycine max*, L. Merr.). The plots were 60 ft wide and 120 ft long during 1995 and 40 ft wide and 120 ft long during 1996. The conventional plots were disked in the fall and then disked and floated in the spring prior to seeding. The para-till deep-tillage plots were tilled with a para-till subsoil implement in the fall. The chisel plow deep-tillage plots were tilled with a chisel plow in the fall to attempt deep tillage. The para-till and chisel plow treatments were also disked and floated in the spring prior to seeding. No tillage operations were utilized for the no-till treatment. An application of Round-up D-PAK was applied at a rate of 20 oz. per acre to remove winter vegetation. 'Kaybonnet' rice was seeded at a rate of 40 seeds/ft^2 in 6-in. row spacing with a no-till drill. Grain yields were determined at maturity by harvesting a 20 ft x 100 ft section of each plot with a commercial combine and then weighing on a grain cart with a computerized weight system attached.

Potassium bromide (KBr) was applied in the fall of 1994 and 1995 to serve as a tracer. The bromide (Br^-) reacts similarly to chloride (Cl^-) with respect to movement within the soil profile, allowing the determination of salt movement within the soil profile. Soil samples were collected from each plot when the rice reached the two- to three-leaf growth stage. The soil cores were separated into increments of 0-2.5, 2.5-5, 5-7.5, 7.5-15, 15-30 and 30-45 cm (0-1, 1-2, 2-3, 3-6, 6-12, 12-18 in., respectively). The soils were then analyzed for chloride (Cl^-), bromide (Br^-), nitrate (NO_3^-) and sulfate (SO_4^{-2}) with an ion chromatograph. Analysis of soils collected in 1996 is incomplete at this time.

RESULTS AND DISCUSSION

Tillage had no effects on Cl^- concentration in the soil but did significantly influence the distribution of NO_3^- within the soil profile during 1995 (Fig. 1). The data illustrate that any of the tillage operations were sufficient to reduce NO_3^- accumulation near the soil surface (Fig. 1B). However, compared to the other tillage treatments, the no-till system contained almost twice as much NO_3^- (Fig. 1) and had a significantly higher electrical conductivity(E.C.) in the top 2.5 cm (1 in.) from the soil surface (Fig. 2). Significant stand reduction was observed in the no-till treatment while only minor injury was observed in the deep-tilled or conventionally tilled plots during 1995 and 1996. Since amounts of Cl^- and SO_4^{-2} were not significantly different among the tillage treatments, this suggests that NO_3^- was the major ion contributing to the increased salinity damage observed under the no-till system.

A significant reduction in grain yield was observed for rice produced under the no-till system compared to the tillage systems in both 1995 and 1996 (Table 1). The interaction between year and treatment was not significant, so no LSD is given for the individual years. A trend for increased yields as a result of deep tillage was also observed. The reduction in grain yields observed in the no-till treatment probably can be attributed largely to increased salinity injury. The soil data support the conclusion that increased levels of NO_3^- led to higher levels of salinity injury and subsequent stand loss. However, the trend for improved yields following the deep tillage operations was not attributable to decreased salinity. The distribution of salt in the profile was very similar for all of the tillage operations. Therefore, the data suggest that the potential benefit observed from the deep tillage operations was due to alteration of soil physical properties, perhaps enhancing root growth.

The yield reduction associated with the no-till system is important. With increased emphasis on conservation tillage practices, it becomes necessary to understand all of the factors that lead to this yield reduction. It is apparent from the salt distribution in the soil profile that NO_3^- accumulation was much greater in the no-till system. Apparently, the residue from the previous crop was decomposing and mineralizing nitrogen to form NO_3^- near the soil surface. With the tillage treatments, the soil pores are disrupted, the residue is incorporated, and the NO_3^- is more evenly distributed in the soil plow layer. These data suggest that in soils with potential for salinity injury, it may be advantageous to avoid no-till systems. This, however, does not preclude the use of conservation tillage practices such as stale seedbed systems following fall or early spring tillage. More research is needed in this area to better understand these effects.

SIGNIFICANCE OF FINDINGS

It is apparent that no-till systems may encourage salinity injury to rice seedlings as the result of NO_3^- formed during decomposition of residue from the previous crop. Significant yield reductions were observed with no-till operations, suggesting that some tillage may be advantageous. Fall or early spring tillage and stale-seedbed seeding may decrease this problem. It is apparent that ways of depleting the NO_3^- from the soil, such as flooding, water seeding, etc., for no-till systems need to be investigated. It is not apparent from this study what effects reduced tillage may have compared to no-till.

Table 1. Influence of tillage operations on rice grain yields at Pine Tree Experiment Station, Colt, Arkansas.

Tillage operation	Grain Yields 1995	1996	Combined
	---lb/acre---		
Conventional	6431	6673	6552
Chisel Plow	7560	6668	7025
Para-till	7135	7205	7170
No-till	6271	5420	5846
$LSD_{(0.05)}$			654

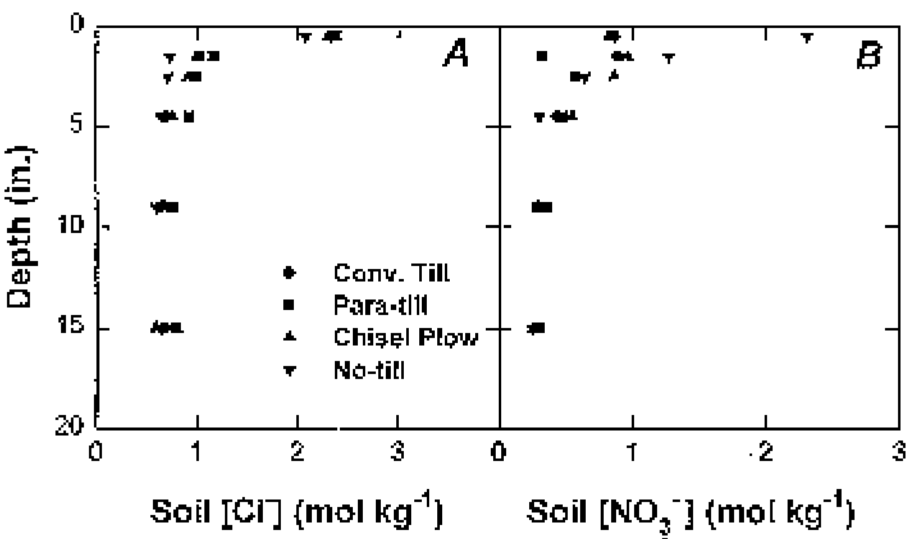

Fig. 1. Distribution of chloride (Cl^-), and nitrate (NO_3^-) molar concentrations with respect to soil depth as a function of tillage operations during 1995.

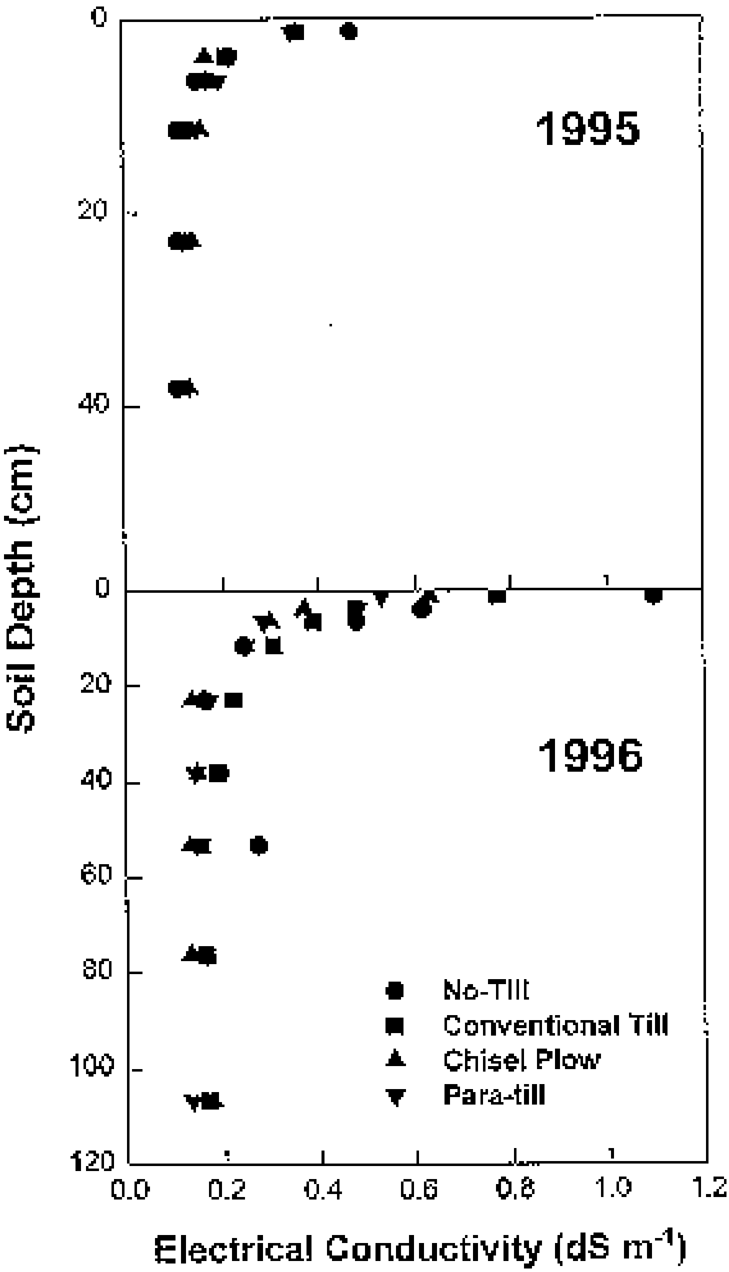

Fig. 2. Soil electrical conductivity (E.C.) with respect to soil depth and tillage operations during 1995 and 1996.

PHOSPHORUS FERTILIZER MANAGEMENT ON ALKALINE SOILS

C.E. Wilson, Jr., N.A. Slaton, S. Ntamatungiro, R.J. Norman, D.L. Frizzell and B.R. Wells

ABSTRACT

Rice production on alkaline, or high-pH, soils is commonly limited by zinc (Zn) and phosphorus (P) availability. As soil pH increases, the availability of many nutrients is reduced, despite ample amounts of total nutrients in the soil. In addition, P levels in the soil are sometimes relatively low. This study was conducted to evaluate rice response to P and potassium (K) fertilization. Field studies were conducted on production fields that had a history of alkaline soil problems and on acidic soils. Rice response to P fertilizer was more likely when the soil pH was high. Response to K fertilizer was observed on the low-pH soil. A grain yield increase was observed at one location due to Zn fertilizer. The influence of soil pH on P fertilizer response suggests that producers should obtain representative soil samples for determination of soil pH, P and K levels within a single field.

INTRODUCTION

Rice production on alkaline soils, those with high pH levels, has historically shown a Zn deficiency. However, availability of P to the plant is also greatly affected by soil pH. The optimum soil pH range for maximum P availability is 6.0 to 6.5. When the soil pH is below this range, P is bound in compounds that most plants cannot utilize. However, after flooding, many of these compounds become available. Subsequently, the availability of P to the rice plant is usually sufficient for optimum growth.

When the soil pH is greater than 6.5, the P is also bound in compounds that plants cannot utilize, similar to very low pH ranges. However, the compounds that form at high soil pH levels are not affected by flooding. The availability of P does not increase after establishment of the permanent flood, and, therefore, the potential for P deficiency increases. This situation is most important when the soil test level of P is low.

The objectives of this study were 1) to compare rice response to P, K and Zn fertilizer on high-pH soils and low-pH soils when the soil test levels of these nutrients are low and 2) to compare different P fertilizer sources on alkaline soils.

MATERIALS AND METHODS

Field studies were implemented during 1996 on production fields in Craighead County seeded with 'Bengal' rice and Cross County seeded with 'Alan' rice to evaluate the effects of P fertilizer source on rice grain yields. The soil pH in Craighead County was 8.0; the soil pH in Cross County was 6.1. Plots were established in each location measuring 8 ft wide (7-in. row spacing) and 16 ft long. Three P sources were applied at rates of 0, 40 and 80 lb P_2O_5/acre to the soil surface following seeding, but prior to seeding emergence. The three sources were triple super phosphate (TSP; $Ca(H_2PO_4)_2$), diammonium phosphate (DAP; $(NH_4)_2HPO_4$) and monoammonium phosphate (MAP; $NH_4H_2PO_4$). Two zinc (Zn) rates (0 and 1 lb Zn/acre) were applied at the three-leaf growth stage as a liquid Zn EDTA chelate (10% Zn). The experiment was arranged in a randomized complete block design with two factors.

Plant samples were collected from each plot at mid-tillering (MT), panicle differentiation (PD) and three weeks after 50% heading (HDG) to determine nutrient uptake. Grain yields were determined at maturity by harvesting a 12-ft length of the four center rows with a small-plot combine and corrected to 12% moisture.

An additional study was implemented at two locations in Cross County and Poinsett County with differing soil pH levels and other chemical characteristics to evaluate the influence of K fertilizer sources (Table 1). The treatments consisted of two P rates (0 and 40 lb P_2O_5/acre), three K sources (muriate of potash, KCl; potassium sulfate, K_2SO_4; and potassium nitrate, KNO_3) and three K rates (0, 60 and 120 lb K_2O/acre). Plot implementation and collection of samples were the same as previously described.

RESULTS AND DISCUSSION

The P fertilizer source did not significantly affect rice grain yields at either of the two locations during 1996 (Table 2). A trend was observed at Craighead County for the highest yields with TSP and the lowest yields with MAP. Application of P fertilizer did not significantly influence grain yields during 1996 at either of two locations (Table 3). However, a trend was observed at Craighead County for increased grain yields with an application of 40 lb P_2O_5/acre compared to the control. In addition, increasing the P rate significantly increased total dry matter (data not shown).

A significant response to Zn fertilizer was observed at Craighead County during 1996 (Table 4). The soil pH at this location was 8.0 (Table 1), which suggests that a Zn response would be likely. In recent years, many of the problems that have been field diagnosed as Zn deficiency have not responded to Zn applications. Many studies have recently been conducted evaluating rice response to Zn fertilization and, although the rice may become “sick,” Zn has not consistently corrected the problem (Slaton et al., 1995, 1996). Results from the current study demonstrate that although Zn fertilizer does not correct all problems associated with alkaline soils, the potential for Zn deficiency still exists on these soils.

A significant increase in grain yields was observed with application of K fertilizer at Poinsett County during 1996 (Table 5). However, a similar increase was not observed on the alkaline soil located in Cross County. The only effect of potassium source was a significant increase in yield with KNO_3 compared to the other sources at Cross County (Table 6). A significant increase in grain yields was observed with a P application at the Cross County location (Table 7). In contrast, a trend for reduced yields was observed on the Poinsett County field. This supports the need for P on alkaline soils but also suggests that applications of P on low-pH soils may actually be detrimental.

SIGNIFICANCE OF FINDINGS

Alkaline soil creates nutrient imbalances and, as such, can create a number of different problems. The data suggest that when the soil pH is high (> 7.0), careful attention should be given to soil P levels as well as the need for Zn fertilization. Soil pH, rather than soil test P level, appears to be the most sensitive parameter for determination of rice response to P fertilization. Rice seems to be much more sensitive to P availability at high soil pH levels than at low soil test levels. While P and Zn fertilization is needed on these soils, this “fixes” the nutrient imbalance created by the alkaline soil conditions only temporarily. The only long-term solution for this problem is acidification of these soils to lower the pH to an acceptable range (6-6.5) and change water sources to a source that does not contain a large concentration of bicarbonate.

ACKNOWLEDGMENTS

This project was partially funded by producer’s check-off funds distributed by the Arkansas Rice Research and Promotion Board, Potash and Phosphate Institute and fertilizer tonnage fees. Sincere appreciation is extended to these entities for their generous support. Special thanks are also extended to the individual producers for cooperation in conducting this research on their farms and to the following county Extension agents: David Annis and Rick Wimberly, Cross County; Phil Sims and Brad Koen, Arkansas County; Van McNeely and Rick Thompson, Poinsett County; and Branon Thiesse, Craighead County.

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Table 1. Selected soil chemical characteristics at four of the phosphorus (P) and potassium (K) fertilizer experiments conducted during 1996.

	Soil Test Parameter					
				Mehlich III Extract		
Location	Study	pH	EC	P	K	Ca
			µS/cm	------------- mg/kg	------------	
Cross	P source	6.1	136	11	116	830
Craighead	P source	8.0	481	16	41	1685
Poinsett	K source	5.3	146	7	49	953
Cross	K source	7.9	374	8	133	1989

Table 2. Influence of phosphorus (P) source on rice grain yields during 1996.

	Grain yields	
P Source*	Craighead Co.	Cross Co.
	------------------- lb/acre	-------------------
TSP	7364	6037
DAP	7245	6005
MAP	7040	6063
$LSD_{(0.05)}$	432	418
C.V.	10.3%	11.9%

*TSP = Triple superphosphate; DAP = Diammonium phosphate; MAP = monoammonium phosphate

Table 3. Influence of phosphorus (P) rate on rice grain yields during 1996.

	Grain yields	
P rate	Craighead Co.	Cross Co.
lb P_2O_5/acre	-----------------------lb/acre	--------------------
0	7066	6027
40	7414	6174
80	7169	5909
$LSD_{(0.05)}$	432	418

Table 4. Influence of zinc (Zn) application on rice grain yields during 1996.

	Grain yields	
Zn rate	Craighead Co.	Cross Co.
lb Zn/acre	-----------------------lb/acre	------------------
0	6941	6285
1	7492	5791
$LSD_{(0.05)}$	353	341

Table 5. Influence of potassium (K) rate on rice grain yields.

K rate	Grain yields	
	Cross Co.	Poinsett Co.
lb K_2O/acre	------------------------lb/acre-------------------	
0	4586	5868
60	4664	6625
120	4460	7037
$LSD_{(0.05)}$	428	542

Table 6. Influence of potassium (K) source on rice grain yields.

K source	Grain yields	
	Cross Co.	Poinsett Co.
	--------------------lb/acre----------------------	
KCl	4437	6568
K_2SO_4	4411	6431
KNO_3	4860	6532
$LSD_{(0.05)}$	428	542

Table 7. Influence of phosphorus (P) rate on rice grain yields.

P rate	Grain yields	
	Cross Co.	Poinsett Co.
lb P_2O_5/acre	----------------------lb/acre--------------------	
0	3723	6710
40	5416	6310
$LSD_{(0.05)}$	350	443

second proof

ONGOING STUDIES
RICE QUALITY

EVALUATION OF AN EQUILIBRIUM-BASED, ON-FARM DRYING AND AERATION CONTROLLER

A.G. Cnossen, B.P. Marks, T.J. Siebenmorgen and D.R. Gardisser

ABSTRACT

Two cultivars of rough rice (a medium grain,'Bengal', and a long grain, 'Cypress'), from the 1996 harvest, are being stored in three on-farm bins (one of Bengal, two of Cypress) near DeWitt, Arkansas. A Sentry-Pac™ drying/aeration control system is controlling the operation of the bin fans, based on equilibrium moisture conditions. Samples are collected periodically from six locations in each bin, and the moisture content, temperature and functional characteristics of the rice are evaluated. Preliminary results indicate that the equilibrium conditions may be cultivar-dependent. Current and future work is focusing on computer simulations for evaluating the effectiveness of the system over a range of Arkansas weather and harvest conditions.

INTRODUCTION

Rice quality changes continuously through the entire postharvest system, from the moment the rice enters the tank in a combine, through transportation, drying, storage, milling and up to the moment of consumption. Some of these changes are negative, while others can be positive. This fact distinguishes rice from the other cereal grains, where most of the current research and extension information focuses only on the loss of quality during postharvest handling and storage. Consequently, there is a need for better research and extension information to be developed specifically for rice, in which both positive and negative changes in quality are evaluated during postharvest operations.

The overall goal of this on-going study is to document the performance of an on-farm drying/aeration controller (i.e., the Sentry-Pac™ system) in a bin drying and storage field study. The specific objectives are:

1. To validate previous and on-going laboratory studies, with respect to changes in rice quality;
2. To evaluate the control system performance, with respect to rice quality, economics and effectiveness in controlling moisture content; and

3. To distribute on-farm results to producers for improved management practices.

This paper reports the preliminary results of this project, based on experimental data from the 1996 harvest and drying season.

PROCEDURES

In October 1996, three on-farm bins (30 ft in diameter, 20 ft deep) near DeWitt, Arkansas, were loaded with rice at harvest. One bin was loaded with the medium-grain cultivar Bengal (Bin 1), and two bins were loaded with the long-grain cultivar Cypress (Bins 2 and 3). The average intitial moisture contents (MC) of the rice in Bins 1, 2 and 3 were 20.2, 15.7 and 14.7%, respectively.

Samples of rice were taken as the bins were loaded and are taken periodically (3, 6, 9, 12, 16 and 24 weeks), from depths of 3 and 6 ft. The samples are removed, via a deep-bin probe, near the north wall, in the center and near the south wall of the bin (Fig. 1). At each sampling time, the temperature of the rice in the bins is also measured, by means of a deep-bin temperature probe. The probed samples are analyzed for moisture content (air oven method, 130°C for 24 h), individual kernel moisture content (via an electronic meter), water activity (via a Rotronics water activity meter) and functional properties of head rice yield, amylography and cooking behavior.

Head rice is defined as those kernels that are at least three-fourths of the original kernel length (USDA, 1979). In the laboratory, samples are hulled in a laboratory huller and milled in a McGill #2 mill. Head rice is then separated from brokens on an inclined shaker table. Head rice yield is the mass percentage of rough rice remaining as head rice.

With respect to the amylography test, the pasting properties are measured (i.e., peak, pasting and final viscosities) in a Brabender viscoanalyzer. Head rice is ground in a Udy cyclone mill with a 0.5-mm screen, and an 8% dry matter slurry is tested. The slurry is heated from 30° C to 95° C at 3° C/min, held at 95° C for 10 min, then cooled to 50° C at -3° C/min. For cooking properties, the water absorption (increase/initial) and the volume expansion ratio (final/initial) are measured by cooking 10 g of head rice in excess boiling water for 20 min, then draining.

The fans on the three test bins are controlled by the Sentry-Pac drying/aeration control system. The equilibrium-based Sentry-Pac algorithm calculates the equilibrium moisture content (EMC) of rice for any air conditions, utilizing the Chung equation (ASAE, 1994). When the ambient conditions are at an EMC below the setpoint, the controller runs the fans. The setpoint EMC, temperature limits and relative humidity limits are set by the operator. The moisture isotherms (i.e., EMC curves) for the rice in the test bins are being compared to the EMC equation used by the Sentry-Pac controller algorithms, in order to evaluate whether the rice control program is sufficiently effective across grain types and harvest moisture contents. The system was set for drying to 12.5% moisture content. The operation and management procedures used by the producer are being monitored.

After the 24-wk data are collected, the experimental moisture and temperature data will be used to validate a computer drying/aeration model (AERATE) for on-farm drying of rice in Arkansas. The computer model will then be utilized to evaluate the economic effectiveness of the controller system over a range of Arkansas harvest and weather conditions.

RESULTS AND DISCUSSION

Moisture and Temperature History

By the end of November (60-day storage), the moisture content in the bins had reached 13 to 16%. However, on December 19th (the fourth sampling time, 80-day storage) the moisture content near the north wall in Bin 1 (Bengal) had increased to 19.5% (Fig. 2). A temperature difference between the north side and the south side of the bin may have caused convection currents in the grain, accompanied by moisture migration from higher temperature to lower temperature areas. Such a temperature difference may have resulted under circumstances of insufficient fan runtime. However, on December 19th, no temperature difference was measured between the north wall and the south wall. This scenario, and possible causes for the moisture migration, are being further investigated.

Evaluation of Equilibrium Conditions

Comparison of the moisture isotherms for the rice in the bins with the EMC equation used in the controller algorithm shows a difference in measured and calculated EMC. For Bengal, over all collected samples to date, the measured MC was 1 to 3 MC% greater than the EMC predicted on the basis of the rice water activity. For Cypress, the measured EMC was 1 to 2 MC% greater than the EMC calculated from water activity. The significance of these deviations between experimental data and the control equations will be further analyzed in 1997.

Functional Properties

Experimental data are currently being collected. No analyses have been made yet on the amylography tests (e.g., peak, cooking and final viscosities) and cooking tests. The curves for the head rice yield show a small increase in the first six weeks (Fig. 3). The rest of the curves show no significant trend (Fig. 3).

Current and Future Analyses

Future analyses will include quantitative evaluation of the changes in rice functional properties over time. Anticipated results from the computer simulation work include recommendations for system management, based on product value and operating costs.

SIGNIFICANCE OF FINDINGS

The preliminary data in this project indicate a need to further investigate the effect of cultivar and grain type on the effectiveness of on-farm drying/aeration controllers. Pending simulations of the drying/aeration system should enable improved management recommendations, based on rice quality, economics and system effectiveness in maintaining moisture content.

ACKNOWLEDGMENTS

This project is partially supported by funds from the Arkansas Rice Research and Promotion Board.

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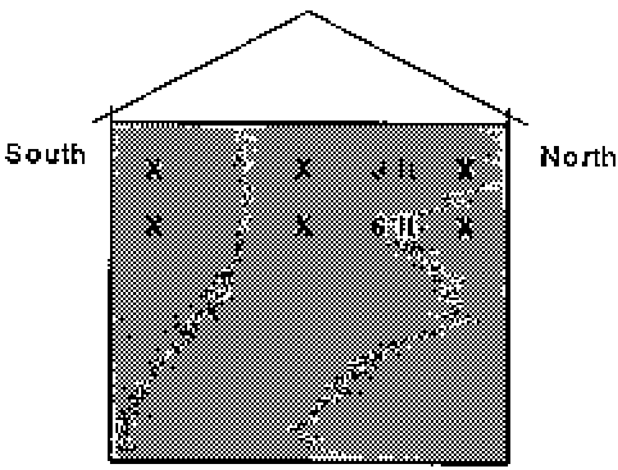

Fig. 1. Locations in bins where samples are being collected.

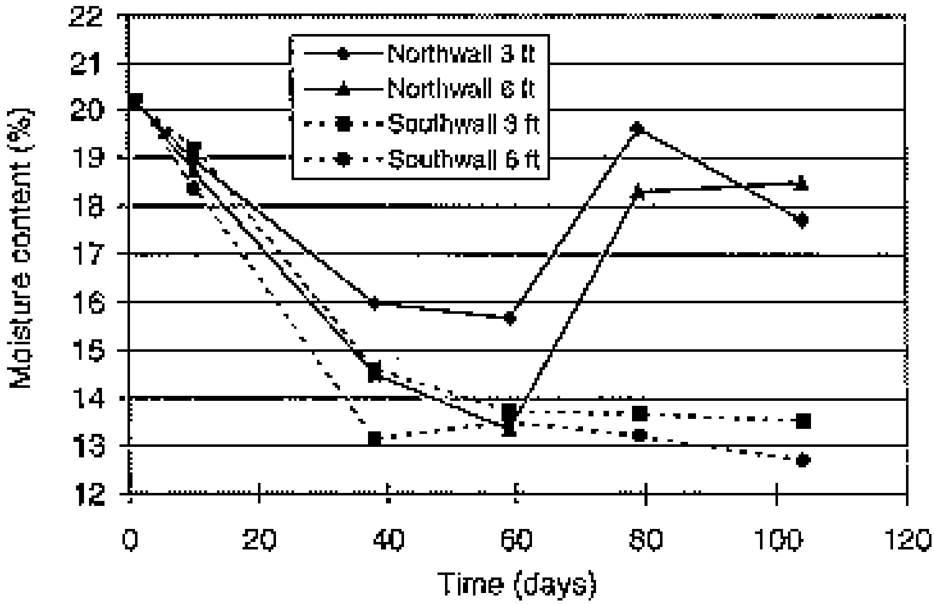

Fig. 2. Moisture content at four locations in Bin 1 during the first 100 days of storage (cv. Bengal).

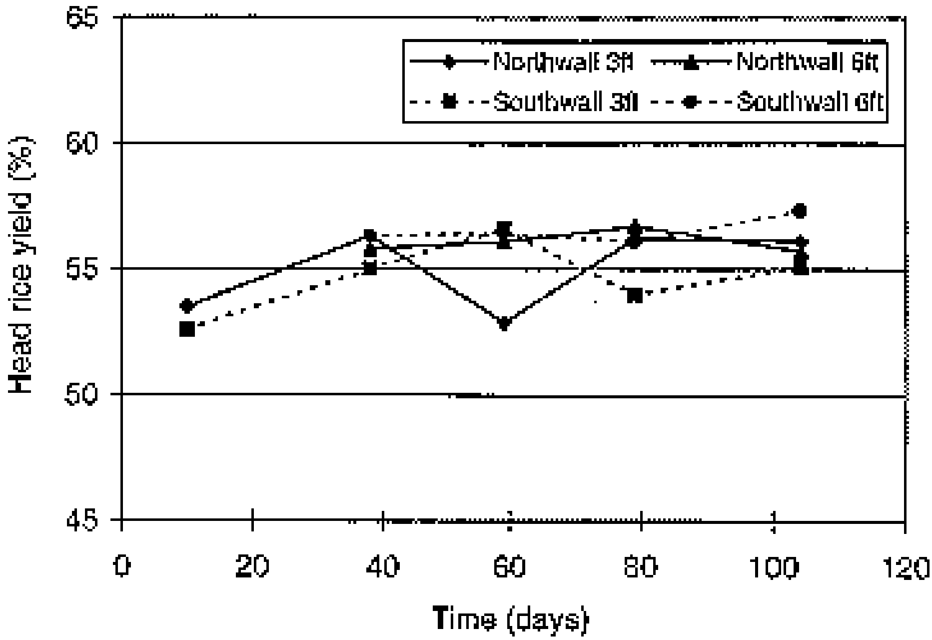

Fig. 3. Head rice yields from four locations in Bin 1 during the first 100 days of storage (cv. Bengal).

EFFECTS OF RICE STORAGE HISTORY ON THE END-USE QUALITY OF LONG-GRAIN RICE

M.J. Daniels, B.P. Marks, J.F. Meullenet, T.J. Siebenmorgen

ABSTRACT

Rough rice from two harvest seasons (1995 and 1996) was harvested, dried and stored in laboratory-scale storage studies. The experimental variables included several pre-drying conditions, drying treatments and storage moisture contents, temperatures and durations. Results from the 1995 study showed that temporary wet storage of the rice cultivar, 'Cypress', prior to drying had a significant effect on the cooking properties and sensory characteristics of the cooked rice. The drying treatments significantly affected head rice yield, cooking properties and several sensory attributes. Additionally, storage temperature signficantly affected several of the sensory attributes. Samples from the 1996 harvest season for cultivars Cypress, 'Kaybonnet' and 'Bengal' are currently in storage, and sub-samples are being periodically analyzed for the various quality characteristics. Statistical models will be developed and tested for predicting changes in quality as functions of postharvest parameters.

INTRODUCTION

Rice quality changes continuously through the entire postharvest system, from the moment it enters the tank in a combine, through transportation, drying, storage and milling and up to the moment of consumption. Some of these changes are negative, while others can be positive. This fact distinguishes rice from the other cereal grains, where most of the current research and extension information focuses only on the loss of quality during postharvest handling and storage. Consequently, there is a need for better research and extension information that is developed specifically for rice, in which both positive and negative changes in quality are evaluated during postharvest operations.

A small amount of previous research and industry experience has shown that storage history can affect both head rice yield (HRY) and cooking quality of rice (Villareal et al., 1976; Chrastil, 1990; Hamaker et al., 1993; Tamaki et al., 1993). However, various other postharvest handling parameters can also significantly affect end-use quality. These factors include duration of wet holding and drying method (Calderwood and Webb, 1969). Each of these factors can significantly affect energy consumption and/or head rice yield; however, the effects on end-use quality have not been quantified.

Because the end-use quality of rice ultimately affects its value throughout the market stream, this research seeks to develop quantitative models and recommendations for postharvest management that will enhance the quality of Arkansas rice in the market. The specific objective of the project is to evaluate the effects of cultivar, moisture content (MC), drying method and storage history (i.e., temperature, duration) on the end-use quality characteristics of rice, including head rice yield, cooking properties, starch functionality and sensory attributes.

PROCEDURES

Rice from two different harvest seasons (fall 1995 and fall 1996) was treated and stored for two separate storage studies. The rice for both studies was obtained from the University of Arkansas Rice Research and Extension Center in Stuttgart, Arkansas, or the University of Arkansas Northeast Research and Extension Center in Keiser, Arkansas. After harvest, each lot was immediately (unless otherwise noted) dried in small-scale laboratory dryers to mimic large-scale drying conditions and then slowly equilibrated to the target storage moisture content. All rice was placed in sealed containers, to prevent changes in moisture, and then placed in respective storage chambers. Sub-samples were periodically removed and subjected to a battery of physicochemical analyses.

Fall 1995 Treatments and Sampling Times

The 1995 study included one long-grain cultivar, Cypress, with a harvest MC of 20%. The postharvest treatments were 1) immediate vs. delayed drying (i.e., held 80 h at harvest MC prior to drying), 2) low-temperature (33°C, 67.8% RH, 30 min) vs. high-temperature (54.3°C, 21.7% RH, 30 min) drying and 3) storage temperatures of 4, 21 and 38°C. The combination of treatments resulted in 12 distinct lots of rice. Sampling times were scheduled at 0, 3, 6, 10, 15, 18 and 36 weeks. Sensory evaluation occurred only at 0, 6, 18 and 36 weeks.

Fall 1996 Treatments and Sampling Times

The 1996 experimental design included two long-grain cultivars (Kaybonnet and Cypress) and one medium-grain cultivar (Bengal). The comparison of immediate and delayed drying was omitted from the 1996 study; all three 1996 cultivars were dried immediately after harvest. In a full-factorial design, the 1996 experimental treatments were: 1) low-temperature (43.3°C, 16.9% RH, 75 min) and high-temperature (60°C, 16.9% RH, 20 min) drying, 2) three storage MC (10, 12 and 14%) and 3) three storage temperatures (4, 21 and

38°C). Sampling times were scheduled at 0, 3, 6, 9, 12, 16, 24, 36, 50 and 75 weeks, with sensory analysis at 0, 6, 12 and 36 weeks.

Head Rice Yield

Head rice yield was determined in triplicate by the following method. Starting with 150 g of rough rice, the rice was hulled, and the brown rice was milled in a McGill #2 mill, to a target degree of milling (DOM) of 90 on a Satake MM-1B Milling Degree Meter. Head rice was separated from brokens in a shaker table. The HRY is reported as the percentage of the original rough rice weight (150 g) remaining as head rice after milling.

Water Absorption and Volume Expansion

Twenty grams of raw head rice were placed in a pre-weighed wire basket (7 cm tall and 3.5-cm diameter), and the height of the uncooked rice was measured. The wire basket was placed into a 250-ml beaker filled with 200 ml of near-boiling water, and the beaker was placed in a kettle of boiling water. After 20 min, the sample was removed, and the rice was allowed to drain before measuring the final weight. The water absorption was calculated as

$$[\mathbf{W}_{(wb + cr)} - \mathbf{W}_{(wb + rr)}] / \mathbf{W}_{rr}$$

where $\mathbf{W}_{(wb + cr)}$ was the weight of the wire basket and the cooked rice, $\mathbf{W}_{(wb + rr)}$ was the weight of the wire basket and the raw rice, and W_{rr} was the weight of the raw rice. The volume expansion was computed as $\mathbf{H}_{cr}/\mathbf{H}_{rr}$, where $\mathbf{H}_{cr}$ was the height of the cooked rice, and the $\mathbf{H}_{rr}$ was the height of the raw rice.

Amylography

Sixty grams of head rice were ground in a UDY Cyclotec mill with a 0.5-mm screen. The flour obtained was used to produce an 8% slurry (dry basis). In a Brabender Viscoamylograph, the slurry was initially heated from 30 to 95°C at a rate of 3°C/min; the temperature remained at 95°C for 10 min and then was cooled to 50°C, at a rate of -3°C/min.

Sensory Methodology

Eight professionally trained panelists collectively developed a sensory profile for rice. Three flavor and seven texture attributes were identified by the panel as adequately describing the sensory profile of cooked rice. Intensities of overall sensory impact, grain flavor note, sulfur flavor note, clumpiness, roughness, hardness, gluiness, moisture absorption, cohesiveness of mass and geometry of slurry were evaluated on a 15-cm scale. Flavor note intensities were evaluated by comparison with the references of the universal scale (Spectrum method). The intensities for texture attributes were assessed by comparison with carefully chosen references.

RESULTS AND DISCUSSION

1995 Storage Study

There are two remaining sampling times for the 1995 storage study. The data presented here represent the first five months of the study.

Head Rice Yield

For all treatments, HRY increased during the first 18 weeks of storage, and the effect of time was statistically significant ($P < 0.001$). HRY for the low-temperature dried rice was significantly ($P < 0.02$) higher than the HRY for the high-temperature dried rice, but there were no noticeable differences between the HRY of the immediately-dried and the delayed-dried rice. Figure 1 shows the HRY range for the low and high temperature dried rice.

Cooking Properties: Water Absorption and Volume Expansion

The low-temperature dried rice had a significantly ($P < 0.001$) greater water absorption and volume expansion than did the high-temperature dried rice for all storage temperatures and sampling times. The pre-drying conditions also affected the cooking properties of the rice; the delayed drying conditions, particularly for the low-temperature dried samples, resulted in significantly lower water absorption ($P < 0.001$) and volume expansion ($P < 0.0005$) when compared to the samples that were dried immediately after harvest.

Amylography

Samples from all storage temperatures and times have increased in peak and final viscosity. The low-temperature dried rice, most specifically the delayed low-temperature dried rice, displayed a greater increase in peak and final viscosity when compared to the samples that were dried at high-temperature.

Sensory Analysis

Effect of wet-holding conditions. Samples dried immediately after harvest were found to have a significantly lower ($P < 0.05$) overall sensory impact. Samples held before drying exhibited lower hardness and a less gritty geometry of slurry. No other significant differences ($P < 0.05$) were found between samples dried immediately after harvest and samples held wet for 80 h prior to drying.

Effect of drying conditions. Samples dried under the high-temperature conditions were found to exhibit a significantly higher ($P < 0.05$) overall sensory impact and grain flavor note. Samples dried under low-temperature conditions were found to be rougher and harder ($P < 0.05$) and exhibited a lower cohesiveness of mass ($P < 0.05$). No significant differences ($P < 0.05$) were found between samples for the stale grain flavor note, sulfur flavor note, clumpiness, gluiness, moisture absorption and geometry of slurry.

Effect of storage temperature. Samples stored at 38°C exhibited a significantly ($P < 0.05$) lower sulfur flavor note, a higher hardness, a lower cohesiveness of mass and a grittier slurry than did samples stored at 4 and 20°C. No significant differences ($P < 0.05$) were found between samples stored at 4 and 20°C.

1996 Storage Study

Seven sampling times have been completed (0, 3, 6, 9, 12, 16 and 24 wks), and three more sampling times will take place at 36, 50 and 75 wks, with three of the sampling times (12, 24 and 36 weeks) also including sensory evaluation. Statistical analyses have not been completed, and only preliminary results can be reported. The changes between the initial samples and the 12-week samples are consistent with results from the 1995 study (i.e., increase in head rice yield for all subsequent samples and greater volume expansion, water absorption and final viscosity for the low-temperature dried rice). The 1996 rice also shows an initial trend of the medium storage moisture content (12%) having the greatest HRY for the long-grain cultivars Kaybonnet and Cypress. The highest storage MC (14%) resulted in the greatest HRY for the medium-grain cultivar Bengal.

SIGNIFICANCE OF FINDINGS

The results from the 1995 samples have shown that all postharvest processes, to varying degrees, significantly affect specific end-use quality factors in rice. This is the first step toward developing quantitative models for predicting quality changes as functions of the various postharvest parameters. Ultimately, this will allow for improved recommendations to optimize the design and management of postharvest systems, with respect to rice quality and value.

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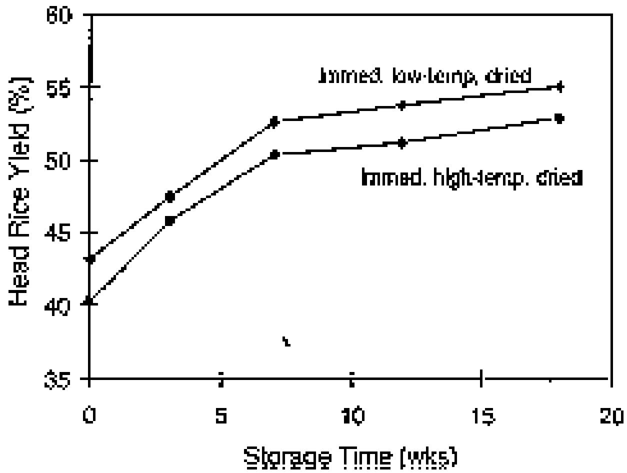

Figure 1. Head rice yield vs. storage duration and drying method for 1995 'Cypress' stored at 38°C.

ONGOING STUDIES
RICE QUALITY

DRYING CONDITIONS IN RELATION TO HEAD RICE YIELD REDUCTION

J. Fan, T. J. Siebenmorgen, J. Reid, and B. P. Marks

ABSTRACT

Improper drying can create kernel fissuring, which results in a significant reduction in head rice yield. This research is investigating the effects of drying rate and drying duration on head rice yield reduction. The rice cultivars used for drying tests in 1996 were 'Bengal' (medium grain), 'Kaybonnet' and 'Cypress' (long grain), harvested from Stuttgart and Keiser, Arkansas. The rough rice was dried under three conditions: A (110°F, 38.2%RH), B (125°F, 24.9%RH) and C (140°F, 16.9%RH). The effect of high moisture content storage before drying is also being investigated for rough rice stored in a cooler (35°F) and a freezer (20°F) for a period of two and four months. A classic grain drying equation, Page's model, was found to fit well for most drying trials. Drying condition, rice cultivar and harvest moisture content had significant effects on drying rate. Evaluations of milling quality of dried rice are underway. A quantitative relation between head rice yield and drying rate will be developed upon the completion of milling tests.

INTRODUCTION

It is a common practice to dry newly harvested rough rice to a certain safe moisture content (MC) prior to storage and milling. The rate of water removal from rice kernels during drying depends on drying air temperature, relative humidity, rice grain type and its physical and chemical characteristics. The changes in MC of rice during thin-layer drying can normally be described by using Page's equation, which is expressed as in the following (ASAE, 1995):

$$\frac{MC - EMC}{IMC - EMC} = exp(-k \times t^n) \qquad (1)$$

where IMC = initial moisture content (%, d.b.)
EMC = equilibrium moisture content (%, d.b.)
MC = moisture content (%, d.b.) after drying duration t (min)
k and n = drying rate constants.

The drying rate constant, k, has previously been related to the drying temperature and air relative humidity (Henderson and Pabis, 1961; Allen, 1960). In a recent investigation of kernel drying of long-grain types, Banaszek and Siebenmorgen (1993) found that the drying constant is a function of initial moisture content and the ratio of kernel width to thickness.

Drying is a critical factor affecting head rice yield and, thus, the economic value of rice. Drying creates moisture and temperature gradients in rice kernels that have a potential for the development of kernel fissures (Sharma and Kunze, 1982). Improper drying operations induce significant stress inside the kernels, producing extensive kernel fissuring and cracking (Arora et al., 1973). Recent rice studies conducted in our laboratory have shown that drying rate constant and drying duration have a great effect on head rice yield (Chen et al. 1997).

The objectives of this research are to determine the drying behavior of long- and medium-grain rice cultivars harvested at various MCs and locations and to quantify the relationship between drying rate constants and head rice yield reduction.

PROCEDURE

The rice used in this study was harvested at Stuttgart and Keiser, Arkansas, in the fall of 1996 with harvest moisture contents ranging from approximately 16.5 to 26%(w.b.). The rice cultivars included 'Kaybonnet' and 'Cypress' long-grain and 'Bengal' medium-grain. The freshly harvested rough rice was normally bagged in paper bags and then transported to the University of Arkansas Rice Processing Lab on the day of harvest.

After foreign matter was removed using a Carter Dockage machine, drying was conducted for rough rice using three relative humidity and temperature control units (Parameter Generation and control 300 CFM Climate-Lab-AA). Each control unit supplied air to a drying chamber. The control units were separately set to drying condition A (110°F, 38.2% RH), condition B (125°F, 24.9% RH), or condition C (140°F, 16.9%RH). Figure 1 is the psychrometric representation of the drying air conditions. Each drying chamber consisted of sixteen 6x10-in. screen trays. For each drying run, about 500 g of rough rice was spread uniformly onto each screen tray. The drying duration for each drying condition was allocated as follows: 0, 10, 20, 30, 60, 90, 120, 180 min for condition A and 0, 10, 20, 30, 45, 60, 90, 120 min for conditions B and C. Upon removal from the drier after a given duration, the samples were immediately transferred to a conditioning chamber held at 21°C, 50%RH, which corresponds to a rice equilibrium MC of ~12.5%. The equilibrated samples were then placed in sealed plastic bags and are being held (at the time of this writing) in a cold storage room at a temperature of 1°C for at least three months prior to milling.

Two 150-g subsamples for each aged sample will be hulled using a hulling machine (McGill sample huller) and the brown rice milled for 30 sec using a laboratory mill (McGill #2). The milling quality of the dried rice will be evaluated in terms of head rice yield, which is defined as the percentage of head rice mass remaining from the original 150-g rough rice sample. Degree of milling (DOM) of the head rice will be measured using a milling meter (Satake MM-1B).

To investigate the effect of high MC storage before drying, harvested rice was stored in a cooler (35°F) and a freezer (20°F) for a period of two and four months, respectively. The drying trials were conducted with the same conditions and procedures as was done for the freshly harvested rough rice.

RESULTS AND DISCUSSION

From the measurements of rice weight loss in a drying tray at the given drying durations, the drying curves for all rice cultivars and harvest MCs used in this study have been obtained. Figure 2 shows the drying curves for Bengal harvested at 22.5% (w.b.), at Stuttgart. It is apparent that the drying air conditions have a significant effect on drying rate.

Nonlinear least squares procedures (SAS, 1987) were employed to obtain the drying constants, k and n, in equation 1 for each drying run. The solid lines in Fig. 2 represent the predicted drying curves using Page's model. It is shown that Page's equation gives a reasonably good fit to the drying data for condition B but that there are some deviations observed for conditions A and C.

Figure 3 shows the experimental drying data for Cypress harvested at 17.4% from Keiser. Except in the early drying of condition A, Page's model well describes most of the rice drying process.

Table 1 summarizes the drying rate constants obtained from the nonlinear regression procedures for each rice variety, harvest MC and location. It is expected that as drying condition becomes more severe from condition A to condition C, the k value increases whereas the n value generally decreases. The 'gentle' drying condition A produced a value of n close to 1.0. This suggests that the Newton model, in which n is equal to 1.0, could be more suitable to describe the less severe drying condition.

The effect of harvest MC appears inconsistent. For conditions A and B, a decrease in harvest MC normally gives a decrease in k value and an increase in n value; however, the trend is opposite for the more severe condition C. It appears that location and cultivar have a small effect on the drying rate compared to the effect of drying condition and harvest MC.

A CTR-800 individual kernel moisture tester was also used to determine the individual kernel MC distribution for freshly harvested rice and rice subjected to 20, 30 and 60 min of drying. This data analysis, as well as drying tests for high MC storage in refrigerated and frozen temperature, and milling of the dried rice are ongoing; these results will be reported in the next series.

SIGNIFICANCE OF FINDINGS

Previous studies have shown that fissures or cracks in rice kernels can develop during heated-air drying. Damaged kernels break readily in subsequent milling, resulting in a significant reduction in head rice yield. Because of the great economic value of head rice, drying conditions should be carefully considered to minimize the head rice yield reduction. This research focuses on the drying behavior of Bengal, Cypress and Kaybonnet, which were the primary cultivars produced in Arkansas in 1996. Increase in head rice yield, even by 1%, will bring significant value to the Arkansas rice industry. This research is directed at quantifying the relationship between drying rate and head rice yield reduction. Furthermore, the results from this study may provide useful information on the effect of harvest MC on drying and milling behavior.

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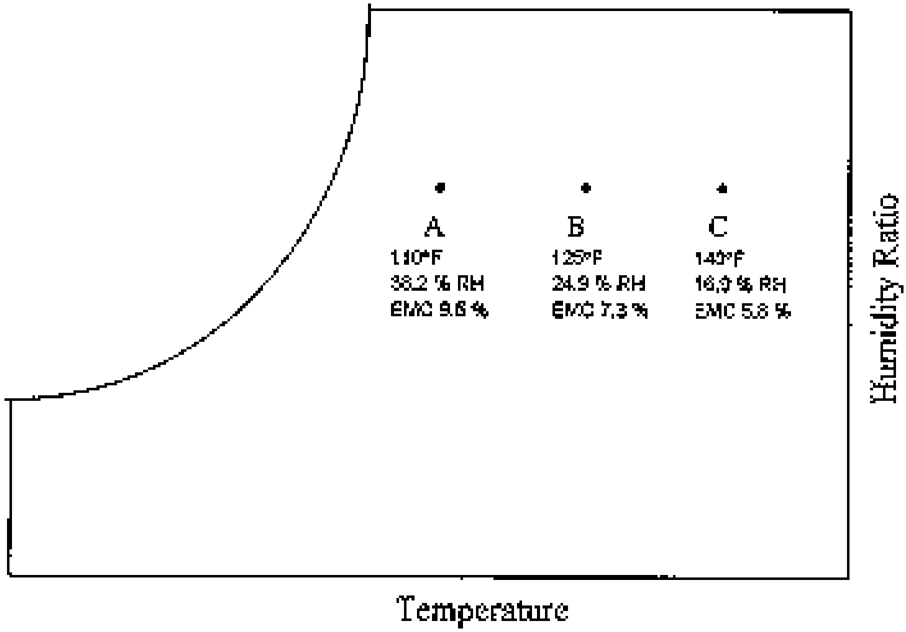

Fig. 1. A psychrometric chart showing the three drying conditions along with the associated rough rice equilibrium moisture content (EMC).

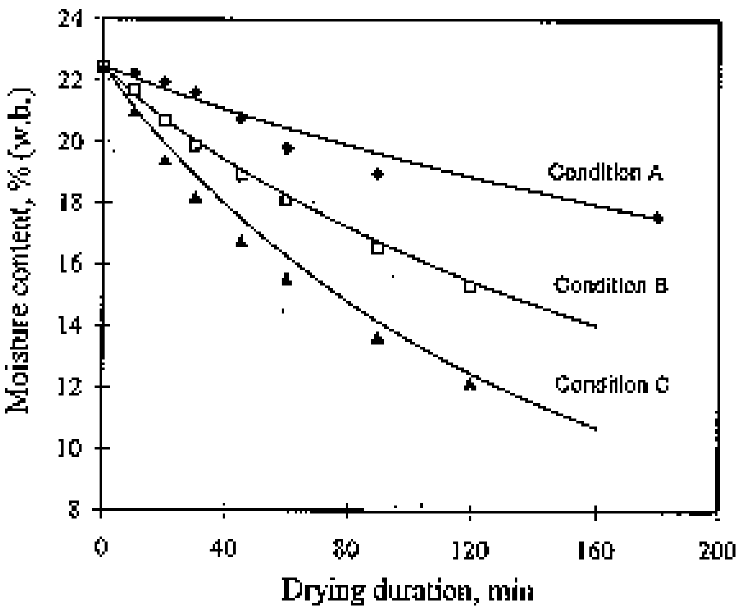

Fig. 2. Drying curves of 'Bengal' (harvested at 22.5% MC, Stuttgart, Arkansas) under the different drying conditions defined in Fig. 1. Solid lines are the predicted results using the Page model.

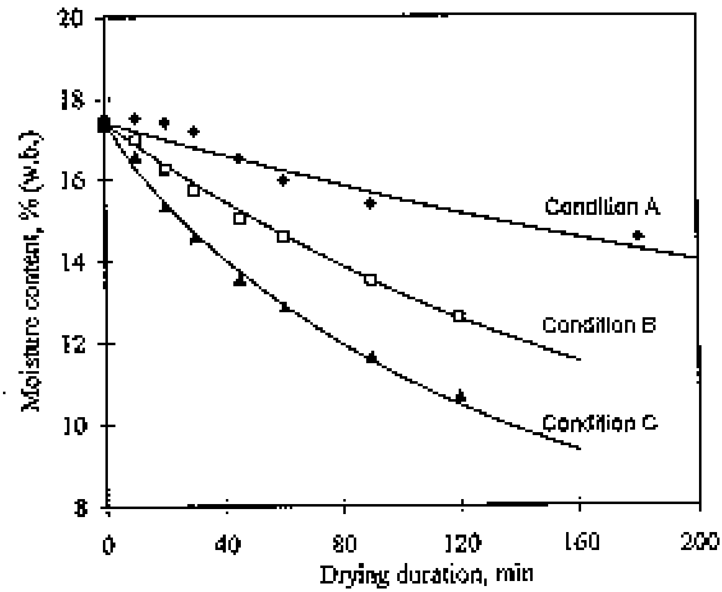

Fig. 3. Drying curves of 'Cypress' (harvested at 17.4% MC, Keiser, Arkansas) under the different drying conditions defined in Fig. 1. Solid lines are the predicted results using the Page model.

Table 1. Drying rate constants, k and n, from the Page model (Equation 1) for each rice classification and drying condition defined in Fig. 1 for two locations in Arkansas.

Harvest location	Cultivar	Harvest MC % w.b.	Drying condition A k	Drying condition A n	Drying condition B k	Drying condition B n	Drying condition C k	Drying condition C n
Stuttgart	Bengal	25.9	- *	-	0.0080	0.92	0.0134	0.92
		22.5	0.0041	0.92	0.0099	0.88	0.0123	0.92
		17.4	0.0027	1.00	0.0064	0.97	0.0163	0.85
	Cypress	24.6	-	-	0.0095	0.99	0.0125	0.90
		19.8	0.0063	0.89	0.0111	0.85	0.0164	0.87
		16.5	0.0035	0.94	0.0078	0.93	0.0187	0.82
	Kaybonnet	19.1	-	-	0.0129	0.89	0.0201	0.87
Keiser	Bengal	22.4	0.0048	0.90	0.0101	0.87	0.0169	0.84
		21.5	0.0026	0.99	0.0093	0.89	0.0143	0.87
	Cypress	20.9	0.0041	0.92	0.0099	0.88	0.0123	0.92
		17.4	0.0027	1.00	0.0064	0.97	0.0163	0.85
	Kaybonnet	19.5	0.0040	0.96	0.0074	0.95	0.0130	0.91

*Data not available due to control chamber malfunction.

THERMAL PROPERTIES OF MILLED RICE AND THEIR EFFECTS ON BREAKAGE

Z.T. Nehus, T.J. Siebenmorgen and A.A. Perdon

ABSTRACT

Milled, long-grain rice of six cultivars was conditioned to a range of moisture contents (MCs) and analyzed in a differential scanning calorimeter (DSC). Glass transition temperature (T_g) and starch melting temperature (T_m) were measured. A comparison of the T_g with the temperatures of the rice as it exited the milling machine revealed that rice approaches the T_g within the mill. These results are being used to help explain trends in milled rice breakage observed in previous experiments.

INTRODUCTION

Extensive financial loss occurs in the rice industry each year due to fissuring of kernels during post-milling operations. The term *residual breakage* has been used to describe the process in which milled rice kernels will fissure sufficiently to break apart during subsequent handling and processing operations. Residual breakage is a major source of quality reduction in the rice milling industry, affecting both rice millers and end users of rice in value-added operations.

Siebenmorgen et al. (1996) developed an experimental procedure that simulated the residual breakage process. Exposure air temperature and relative humidity (RH), kernel moisture content (MC) and cultivar were all shown to affect residual breakage. They also showed that milled rice kernel temperature produced an interesting trend in the level of residual breakage. Rice exposed to a fissuring environment immediately after milling ("hot") showed a lower amount of brokens than rice that was allowed to cool for a day ("cold") before exposure.

An investigation of the thermal properties of the rice starch may help to identify any effects that kernel temperature might have on the level of breakage. Rice starch is a semicrystalline polymer containing both crystalline (amylopectin molecules) and amorphous (amylose molecules) regions. T_g and T_m are two thermal properties of starch that can be measured with a DSC. T_g is the temperature at which the amorphous region of the starch polymer is transformed from a glassy, immobile state into a rubbery, visco-elastic substance. Melting of the crystalline portions of starch occur at T_m.

Previous work (e.g., Normand and Marshall, 1989; Champagne et al., 1990) involving the thermal properties of rice have been related mainly to the cooking quality of rice, i.e., gelatinization temperature (T_{gel}). T_{gel} is a water-mediated T_m of the rice starch. The purpose of this study was to identify the T_g of several cultivars of rice over a range of moisture contents and in a native, non-water-mediated state. These T_gs could then be compared to the temperatures at which the rice exits the mill in order to determine whether the kernels were in the "glassy" or "rubbery" phase. A hypothesis could then be proposed about whether or not residual breakage is affected by the thermal state of the rice kernels.

PROCEDURE

A review of the procedures used in previous work (Biliaderis et al., 1986; Zeleznak and Hoseney, 1987) indicates that the researchers performed their analyses on purified rice starches rather than on the original product. Since the goal of this study was to analyze the thermal properties of raw, milled rice, the procedures used herein vary slightly from other works.

Sample Preparation

Six long-grain rice cultivars, 'Cypress', 'Lemont', 'Newbonnet', 'Kaybonnet', 'Lagrue' and 'Katy', were used. The rough rice was hulled using a commercial-scale Satake husker with paddy separator (Model APS30 CXM). The resulting brown rice was milled to a certain degree in a single pass through a Satake BA-7 pearler. Degree of milling (DOM) was measured using a Satake MM-1B milling meter. A thermocouple probe was fitted inside the milling chamber, and the temperature of the rice was recorded as it exited the mill.

The milled head rice was then conditioned to various MCs by equilibrating small subsamples in ten different constant-humidity environments. Subsamples of each cultivar/conditioned MC combination were then ground in a Thomas-Wiley (Model 3383-L10) intermediate mill using a 20-mesh screen. The MC of the resulting powder was determined by drying duplicate 5-g samples in a convection oven at 130°C for 1 hour. MCs ranged from 7 to 20%, dry basis. Amylose content for each cultivar was determined using the method outlined by Juliano (1971).

Thermal Analysis

Duplicate powder subsamples of 20 to 30 mg were hermetically sealed in stainless steel high-pressure cells with gold-plated seals. A Perkin-Elmer Pyris 1 DSC equipped with an intracooler was used to measure the thermal properties. The DSC routine consisted of cooling the sample to -50°C and holding for 5 min. The sample was then heated to 150°C at 10°C/minute, cooled to 0°C at

10°C/minute, held at 0°C for 5 minutes and finally reheated to 220°C at 10°C/ minute. An empty sample cell was used as a reference.

RESULTS AND DISCUSSION

All samples were milled to a DOM of about 90, and the kernel temperatures of the rice as it was removed from the mill ranged from 35°C to 52°C. Table 1 shows the six cultivars with their respective DOM, kernel temperature exiting the mill and amylose content.

Thermograms generated by the DSC consistently showed a T_g of approximately 50°C for all cultivars. A sample scan is presented in Fig. 1. The large peak at the high-end temperature represents the T_m of the starch. A glass transition is shown at the mid-range temperatures and the characteristic change in slope is evident. The midpoint of this second-order transition is reported as the T_g.

Figures 2 and 3 illustrate the effects of moisture content upon T_g and T_m. The trends represented in Figs. 2 and 3 were similar for all six cultivars. Water has been shown to have a plasticizing effect (depression of T_g and T_m) on the amorphous phase of semicrystalline starch polymers. Biliaderis et al. (1986) showed that T_g remained constant in rice starch for MCs higher than 30%, wet basis (w.b.), but sharp increases were observed in T_g and T_m at lower MCs (about 50°C increase in going from 20% to 10% w.b. MC). Zeleznak and Hoseney (1987) observed the same trend in the T_g of wheat starch. The graphs in Figs. 2 and 3 show no change in T_g as a function of MC over the 7 to 20%, d.b., range. However, the T_ms show a distinct increase as the MC decreases, but not as dramatic as was reported in the previously mentioned studies.

A possible explanation for these differences may be in the materials used. Both Biliaderis et al. (1986) and Zeleznak and Hoseney (1987) worked with purified starch. Raw, milled rice was analyzed in this study. Therefore, the lipids, proteins and other chemical constituents of the rice kernel were present in testing. The presence of these components may affect the thermal analysis of the starch.

Most of the T_gs fell between 50°C and 60°C for all cultivars. This non-dependence on the cultivar used seems reasonable since the T_g is related to the amorphous region in the starch and the amylose (amorphous) contents of all cultivars were similar (Table 1). Thus, the glass transition of each, likewise, would be expected to be similar.

When the milled rice kernel temperatures in Table 1 are compared to the T_gs, it is evident that milling of several cultivars generated kernel temperatures close to the T_g of the starch. The rice starch is in a more viscous state at these higher temperatures, possibly allowing the starch granules to better withstand the stresses caused by moisture transfer within the rice kernel. A kernel with a temperature below the T_g would behave more as an immobile material that would be more susceptible to fissuring due to these stresses. If this is the case, it is postulated that rice exposed to a fissuring environment immediately after milling (when the kernel temperature was at or above the T_g) would develop fewer fissures than rice that was cooled before exposure to the same environment. This coincides with the findings reported by Siebenmorgen et al. (1996) mentioned earlier.

SIGNIFICANCE OF FINDINGS

The results of the thermal analyses provide a better understanding of the process of post-milling fissuring. The DSC data provide an indication that rice kernels were in a more pliable state immediately after milling than kernels that were cooled to room temperature. This could provide insight into better understanding and minimizing residual breakage in milling and in subsequent end-use processing operations.

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Table 1. Degree of milling (DOM, as measured using a Satake MM-1B milling meter), temperature of the rice as it exited the mill and amylose content of the six rice cultivars analyzed.

Cultivar	DOM	Kernel Temperature (^oC)	Amylose Content (%, w.b.)
Cypress	86	52	29.8
Lemont	90	48	30.0
Newbonnet	89	47	28.0
Kaybonnet	86	39	26.9
Lagrue	93	35	27.1
Katy	90	48	28.0

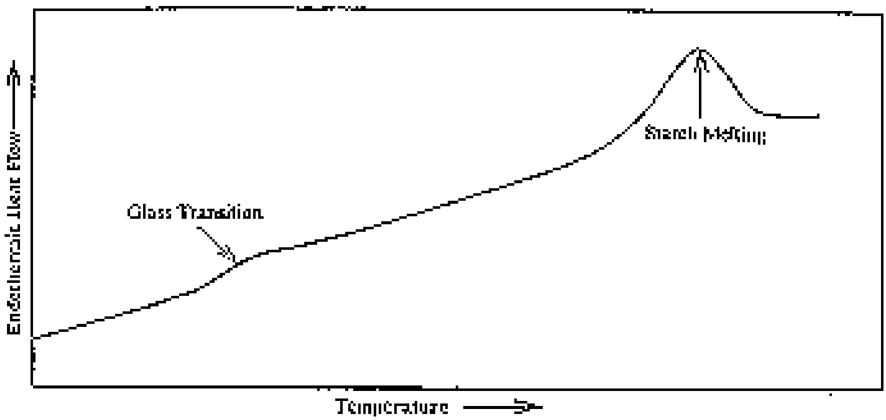

Fig. 1. Example of a thermogram obtained with a differential scanning calorimeter.

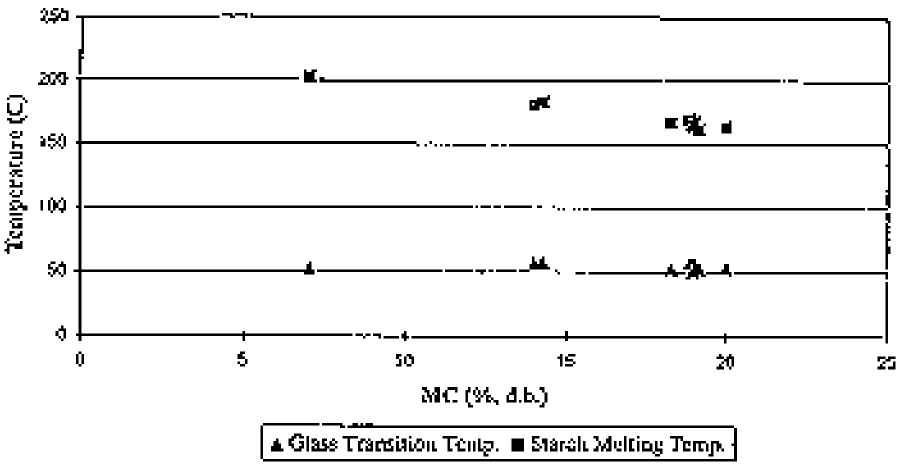

Fig. 2. Glass transition temperature (T_g) and starch melting temperature (T_m) at various moisture content (MC) levels for 'Cypress' milled rice.

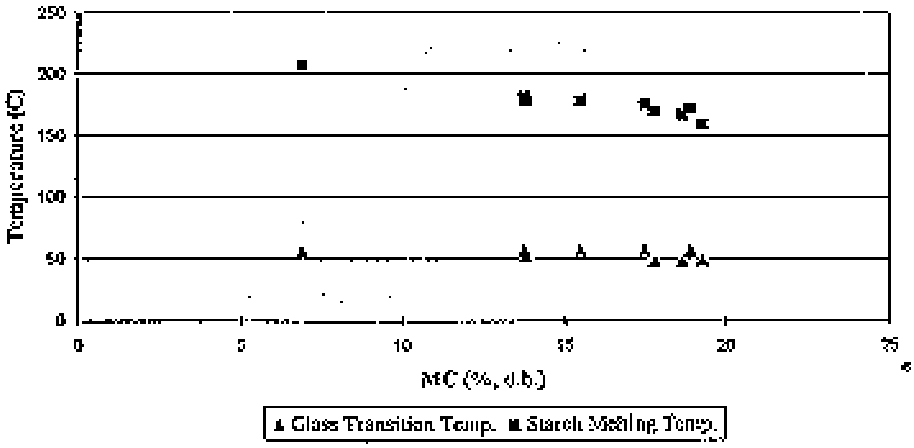

Fig. 3. Glass transition temperature (T_g) and starch melting temperature (T_m) at various moisture content (MC) levels for 'Newbonnet' milled rice.

EFFECTS OF STORAGE CONDITIONS ON THE AMYLOGRAPH AND COOKING PROPERTIES OF MEDIUM-GRAIN (VAR. BENGAL) RICE

A.A. Perdon, B.P. Marks, T.J. Siebenmorgen and N.B. Reid

ABSTRACT

Rough rice (var. Bengal) was stored at four moisture contents (8.8, 10.7, 12.9 and 13.6%) and three temperatures (3°, 20° and 37°C) for up to five months. Changes in the amylograph and cooking properties of the rice occurred during storage. Increases in the paste viscosity and the water absorption of rice during cooking were most apparent in the rice that was stored at 37°C. A statistical model is being developed to predict the changes in viscosity and water absorption as a function of storage time, temperature and moisture content.

INTRODUCTION

Previous research has shown that the functionality of rice changes during storage. As rice is aged, head rice yield increases (Villareal et al., 1976), the water absorption during cooking increases, and the cooked rice texture becomes fluffier and harder (Chrastil, 1990, 1992; Indudhara Swamy et al., 1978, Villareal et al., 1976). One of the most sensitive indexes of the aging process in rice is the change in the pasting property as measured by the amylograph. The overall viscosity of the rice paste increases dramatically during storage. These changes have been shown to be dependent on storage temperatures and durations. Viscosity increases at higher temperatures during the first three months of storage and tends to level off afterwards (Hamaker et al., 1993; Indudhara Swamy et al., 1978, Villareal et al., 1976). However, an extended 48-month-storage study showed that the viscosity started to decrease after 24 months (Indudhara Swamy et al., 1978).

This project is part of an overall research program aimed at quantitatively modeling changes in the physicochemical properties of rice as functions of storage history. The specific objective of this particular on-going study is to evaluate the effects of storage temperature and duration on the amylograph and cooking properties of Bengal, a medium-grain rice variety.

PROCEDURES

Materials

Rough rice (var. Bengal) was harvested from the University of Arkansas Rice Research and Extension Center in Stuttgart, Arkansas, in September 1995. The rough rice samples were cleaned with a Carter-Day Dockage Tester and air-dried at room temperature. Samples were taken at different drying durations to give rough rice with the following wet-basis moisture contents (MC's) - 8.8, 10.7, 12.9 and 13.6% w.b. These samples will be referred to as A, B, C and D, respectively. Each lot of dried rice was split into three 10-kg portions using a Boerner divider and placed in sealed plastic buckets. The storage lots were then held at -10°C for four months prior to the beginning of the storage study.

Storage Conditions

One rough rice lot at each MC was stored at 3°C, 20°C and 37°C, for a total of 12 lots. Subsamples were removed from each lot at 0, 1, 2, 3, 4 and 5 months. Each of the samples was allowed to equilibrate to room temperature prior to milling and analyses.

Analytical Methods

The moisture contents of the rough rice samples were analyzed by the air oven method with duplicates at 130°C for 24 h (Jindal and Siebenmorgen, 1987), prior to milling. A 150-g portion of the rough rice was dehulled with a McGill sample sheller. The resulting brown rice was milled in a McGill #2 mill operated with a 1.5-kg weight at 15 cm from the mill saddle. Because the moisture content of the rice affects the degree of milling, milling time to yield milled rice with 0.75% total lipids was determined for each lot. The milling times were A - 100 s; B - 75 s; C - 35 s; and D - 35 s. Head rice was separated from the brokens using a Seedburo sizer fitted with two 10/64 sizing plates. The head rice was used for subsequent analyses.

Amylography, using a Brabender Viscograph-E, was conducted in duplicate according to a modified AACC Method 61-01 for milled rice (AACC, 1996). The head rice was ground in a UDY Cyclotec with 0.5-mm screen. The moisture content of the ground rice was measured (AACC, 1996). A 500-g slurry containing 8% dry matter in water was used for the amylography. The slurry was heated from 30°C to 95°C at 3°C/min, kept at 95°C for 10 min, and then cooled to 50°C at -3°C/min. The peak and final viscosity data from each sample were recorded and analyzed.

For cooking properties, the water absorption and volume expansion ratio of the rice when cooked in excess water were measured in duplicate (Bhattacharya and Sowbhagya, 1971). A wire basket (4.3 cm i.d. x 7 cm) containing 20 g of milled rice was placed in a 250-ml beaker filled with 150 ml of deionized water. The beaker was then placed in a cooker filled with boiling water for 20 min. After removal of the basket from the cooker, the excess water was drained for 10 min prior to weighing. Water absorption was computed as the increase in mass of the cooked rice divided by the initial mass of the raw rice. Volume expansion ratio was computed as the ratio of the cooked rice height to raw rice height in the basket.

Data Analyses

Multiple linear and quadratic regression models were tested, via SAS (1993), for predicting the amylograph and cooking properties as functions of storage time, temperature and moisture content.

RESULTS AND DISCUSSION

Changes in the Amylograph and Cooking Properties

As noted in previous research, the amylograph properties of rice changed with rough rice storage time and temperature. The rice stored at 8.8% MC (Set A) had a peak viscosity (PV) of 620 Brabender Units (BU) at the start of the storage study (Fig. 1). PV increased to 805 BU after one month of rough rice storage at 37°C and reached a maximum of 890 BU after three months. It started to decrease after the rough rice had been stored more than three months before milling. At 20°C, PV increased from 620 BU initially to 770 BU for rice stored at two months and started decreasing after being stored more than two months. At 3°C storage temperature, PV increased from 620 BU to 760 BU for rice stored one month, then decreased and leveled off to approximately 680 BU. The same trend was observed in Set B, where the MC of Bengal rough rice was 10.7% MC. At this time, the decrease in PV of the rice milled after three months of storage at 20°C and 37°C cannot be explained. Consequently, future work will seek to explain the fundamental cause of this phenomenon.

With set C (12.9% MC), the PV increased with storage time and temperature, and leveled off after two months of storage (Fig. 1). At 37°C, PV was initially 550 BU and increased to approximately 750 BU after two months. The change in the PV at 20°C was less, increasing from 550 BU to 600 BU in the same period. The same trend was observed for set D (13.6% MC).

A similar increase in final viscosity was observed in all the rough rice samples stored at 37°C (Fig. 2). With set A, the final viscosity increased from 640 BU at 0 month to 855 BU at three months and leveled off after that. No appreciable change was observed in the samples stored at 20°C and 3°C, except perhaps in set D.

During cooking in excess water, all the rice stored at 37°C showed an increase in water absorption during storage (Fig. 3). At 20°C, the change in water absorption for all the samples was not much different from the samples stored at 3°C. There was no definite trend observed for the volume expansion ratio of the stored rice.

Numerical Model for Rice Storage

Initial statistical analysis shows that a parabolic model can best predict changes in rice properties as a function of time. However, the observed changes in the amylograph and cooking properties suggest that temperature may be the most important variable influencing the change in rice properties during storage. We are currently building a parabolic model that will incorporate the moisture content of the rice, storage time and storage temperature as variables in predicting the changes in rice cooking and processing properties (i.e. functionalities).

SIGNIFICANCE OF FINDINGS

Changes in rice functionalities during storage are affected by storage time and temperature. Models for these properties will allow for predictions of changes, given various storage scenarios. Our ultimate goal is to enable rice producers, processors and end-users to optimize their rice storage systems for ensuring desirable end-use characteristics.

ACKNOWLEDGMENTS

This research was supported by funds and equipment contributed by the Kellogg Company and funds from the University of Arkansas Center for Food Processing and Engineering.

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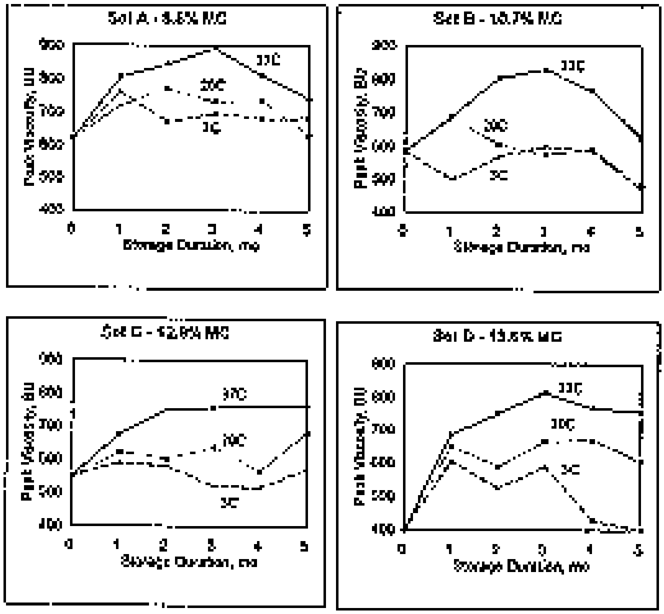

Fig. 1. Effect of storage duration, temperature and moisture content on amylograph peak viscosity of 'Bengal' milled rice.

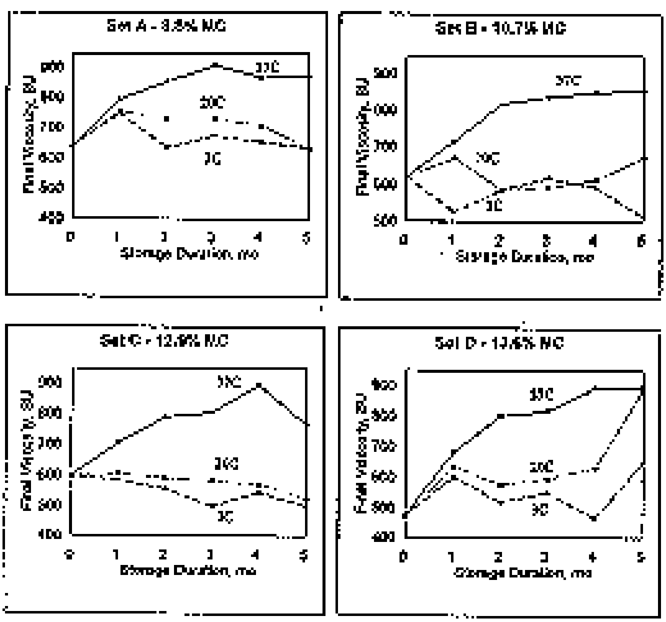

Fig. 2. Effect of storage duration, temperature and moisture content on amylograph final viscosity of 'Bengal' milled rice.

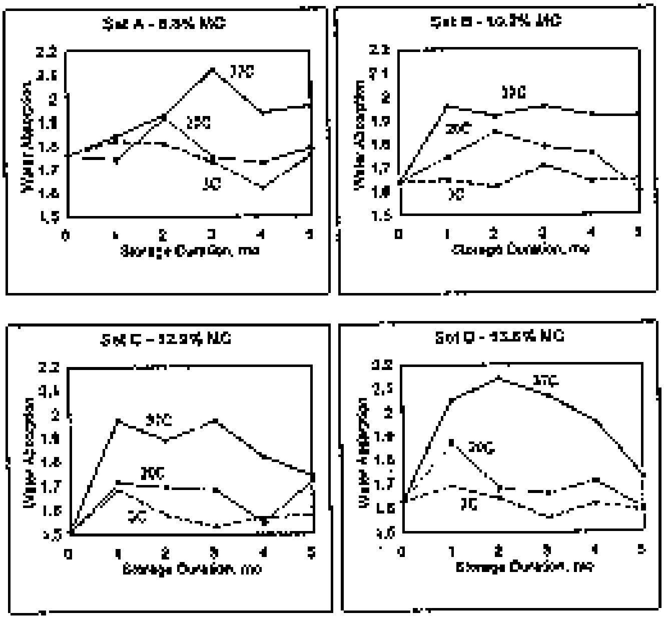

Fig. 3. Effect of storage duration, temperature and moisture content on water absorption ratio during cooking of 'Bengal' milled rice.

EFFECT OF TEMPORARY HIGH MOISTURE CONTENT STORAGE ON RICE FUNCTIONALITIES

Alicia A. Perdon, Terry J. Siebenmorgen and Bradley P. Marks

ABSTRACT

Rough rice, variety 'Bengal', was stored in plastic bags at three moisture content levels (17.5, 15.5 and 13.5% w.b.) and under four different atmospheric conditions (sealed with 0.001% CO_2, sealed under N_2, sealed airtight and partially sealed to allow air exchange). Each of the treatments was stored at two storage temperatures, 20 and 35°C, and sampled after 2, 4, 8 and 16 weeks of storage. There was no apparent change in the head rice yield of the stored rough rice after correcting for the degree of milling. The amylograph peak and final viscosities increased during storage, and the increase was greatest for the rice treatments in partially sealed bags stored at 35°C. Water absorption and volume expansion ratios during cooking of milled rice also increased. The change in the functional properties of rice samples stored under modified atmospheres was less than in the partially sealed bags. These results indicate that modified atmosphere may slow down the changes brought about by storage.

INTRODUCTION

Several factors, including increased harvesting rates, have led to a compression of the rice harvest season. However, the drying capability of rice processors is limited, and questions have been raised as to whether rice can be *temporarily* stored at high moisture content (MC) levels prior to drying without quality degradation. There are limited studies on the different methods of storing high-moisture-content rice, including airtight and modified atmosphere storage. Of these, most studies focused on the identification of the microbiological changes and only a few addressed the issue of the effect of these methods on the processing quality of rice (Wills et al., 1983).

This research was initiated to assess the feasibility of delayed drying through temporary storage of freshly harvested rice at relatively high MCs. The effects of the harvest MC level, storage atmosphere and storage temperature on the milling, physicochemical and functional properties of rice will be determined.

PROCEDURE

Bengal rough rice was harvested in September 1995 at 19.0% MC. The rice was placed in double-lined paper seed bags. The seed bags were placed in plastic bags, sealed with duct tape and stored in a cooler set at 3°C for three months prior to testing. At the start of the storage study, the rice was taken out of the cooler and allowed to equilibrate to room temperature. The rice was air-dried at an air temperature of 21°C and relative humidity (RH) of 31% to three different MC levels: 17.5%, 15.5% and 13.5% MC. Each lot was divided into 32 sub-samples (800 g each) and placed in individual 1-gal sealable plastic bags. The treatments applied to these sub-samples followed the experimental design shown in Table 1, which included four storage atmosphere conditions, two storage temperatures and four storage durations.

For the nitrogen atmosphere, the bag was purged with N_2 and sealed. For CO_2, dry ice was placed in the bag (0.8 g per 800-g sub-sample) and sealed. For the airtight atmosphere, the bag was sealed with no additional treatment. Each sealed bag was individually placed in ~ half-gallon tin cans, covered and sealed with duct tape. The "open to air" treatment consisted of placing the rice in a partially sealed plastic bag that allowed air exchange. Half of the samples were stored at 20°C and the other half at 35°C. The control sample consisted of the original Bengal rice that had been stored in double-lined paper seed bags at 3°C at 17.5% MC.

The treatments were sampled after 2, 4, 8 and 16 weeks of storage. The CO_2 concentration in each sampled bag, at each sampling duration, was measured using a Gastek CO_2 tube analyzer. The water activity (Aw) at 25°C of a 2- to 3-g portion of each sample at each sampling interval was measured using a Rotronic Aw meter. The MCs of these samples were determined by drying at 130°C for 24 h (Jindal and Siebenmorgen, 1987). The remaining rough rice was conditioned to 12.5% MC using a controlled temperature and RH chamber set at 37°C and 54% RH. After conditioning, the rice was divided into two portions. The first portion was used to determine milling quality while the other was used for Brabender amylography.

The milling quality was analyzed by dehulling three 150-g subsamples with a McGill sheller and milling the resulting brown rice for 15, 30 and 60 sec using a McGill #2 mill. Head rice was separated from broken kernels using a Seedburo sizer fitted with two 10/64 sizing plates. Head rice yield (HRY) is reported as the mass percentage head rice from the original 150 g of rough rice. The degree of milling (DOM) was measured using a Satake milling meter (MM-1B).

Brown rice was used for amylography to eliminate the effect of the degree of milling on paste viscosity. The conditioned rice was dehulled and manually cleaned. It was immediately ground in a UDY Cyclotec mill with a 0.5-mm screen. The MC of the ground sample was determined by drying for 1 h at 130°C (Juliano et al., 1985). The amylography of an 8% solid suspension (dry basis) of the ground brown rice was performed by heating the slurry from 30°C to 95°C at 3°C/min, isothermal cooking at 95°C for 10 min and cooling to 50°C at -3°C/min.

Cooking tests were conducted in excess water using some of the rice that had been milled for 30 sec (Bhattacharya and Sowbhagya, 1971). A 20-g portion of milled rice was placed in a wire basket and the height of the raw milled rice measured with a vernier caliper. The basket was placed in a 250-ml beaker and 150 ml of deionized water added. The beaker was placed in a kettle with boiling water (400°F setting for the first 10 min and 300°F for the next 10 min). After cooking, the basket was removed from the beaker, and the excess water was drained for 10 min prior to weighing. The amount of water absorbed by the rice and the volume expansion ratio after cooking was measured. Water absorption was computed as the increase in mass of the cooked rice divided by the mass of the raw milled rice. Volume expansion ratio was computed as the ratio of the cooked rice height to the raw rice height.

RESULTS AND DISCUSSION

No appreciable changes in the appearance and odor of any of the rough rice samples were observed during the first four weeks of storage. However, after eight weeks, a "musty" smell was noted in the 17.5% and 15.5% MC samples stored both at 20°C and 35°C. Also, the presence of some smutty grains was observed in the same samples. After 16 weeks, these samples showed extensive mold growth at both temperatures.

There was no measurable change in the level of CO_2 within two weeks of storage in any storage environment. However, after four weeks, an increase in CO_2 was noted in the samples at 17.5% MC stored at 35°C under CO_2 and N_2 (Fig. 1). The same increase occurred in the 15.5% and 13.5% MC samples after eight weeks of storage under CO_2 and N_2. The increase in the CO_2 may be attributed to the increased respiratory activity of the grain and/or the micro-organisms present in the samples. At 16 weeks, the amount of CO_2 decreased in all samples except the samples at 17.5% MC that were stored in partially sealed plastic bags. The decrease may be caused by slower respiration rates and/or air leakage into the plastic bags.

No appreciable change in the MC was observed in all the samples stored under CO_2, N_2 and airtight atmospheres. As expected, a decrease in the MC was observed for the samples stored in partially sealed plastic bags. The changes observed in the Aw's of the samples did not always correlate with the respective MCs. An increase in the Aw was noted in the samples at 17.5% MC at both temperatures. This, along with the increase in the CO_2 level, suggests an increase in the respiratory activity of the grain.

Head rice yields of the samples during the storage period did not have a definite trend. This may be due to misleading DOM readings possibly caused by some observed yellowing of the rice as it aged. The amount of surface lipids on the head rice may be a better indicator of the DOM of "aged" rice than Satake milling meter readings. This procedure will be carried out with the storage studies for Bengal and 'Cypress' rice harvested in 1996.

The amylography results are shown in Fig. 2 and 3. As shown before, the peak viscosity (PV) of rice increases with storage. The increase was greatest on samples with high MCs at higher temperatures. The storage atmosphere seemed to play a minor role. Rough rice stored in partially sealed plastic bags showed a slightly faster rate of increase. The water absorption and volume expansion ratio of the head rice during cooking increased with storage duration and temperature (Fig. 4). As with the amylography results, samples stored in partially sealed plastic bags showed the greatest increase. When the storage atmosphere was modified with CO_2 or N_2 purging, oxygen concentration decreased. This slowed down the metabolic activities in the rice grain, thus slowing down the aging process. The observed changes in the amylograph and cooking properties of rice during storage are consistent with the results of previous research on rice storage under normal conditions, i.e., without atmosphere modifications (Chrastil, 1994; Hamaker et al., 1993; Indudhara Swamy et al., 1978; Villareal et al., 1976).

Observations from all of the treatments indicate that most of the changes occurring during high MC storage affects the smell of the rice. Head rice yield was not drastically affected. The changes in the amylograph and cooking properties of the rice are consistent with the changes that occur in rice stored at normal MCs (10-12%). At the MC levels tested, storage atmosphere seemed to play a minor role compared to the sample MC and storage temperature.

SIGNIFICANCE OF THE FINDINGS

The preliminary results obtained thus far in this study suggest that rice at 17.5% MC can be stored for four weeks without decreasing its milling and processing qualities. This could be potentially important to rice processors with limited drying capabilities. During the peak harvest period, a significant percentage of the rice is harvested at 16-18%. This study is investigating the feasibility of deferring the drying of rice within this MC range while immediately drying the "early harvest rice," whose MCs are around 20%. We are confirming the findings reported herein with freshly harvested Bengal and Cypress rice from the 1996 crop. Additionally, changes in the microbial populations of rough rice during storage at high moisture contents need to be evaluated.

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Table 1. Experimental design for the high moisture content storage of 'Bengal' rough rice at different atmospheres and temperatures.

	Storage temperature							
	20°C				35°C			
Moisture content /	Storage duration				Storage duration			
storage atmosphere	2 wk	4 wk	8 wk	16 wk	2 wk	4 wk	8 wk	16 wk
17.5% Moisture Content								
Partially sealed bags								
Airtight								
Nitrogen (N_2)								
Carbon Dioxide (CO_2)								
15.5% Moisture Content								
Same as in 17.5% MC								
13.5% Moisture Content								
Same as in 17.5% MC								

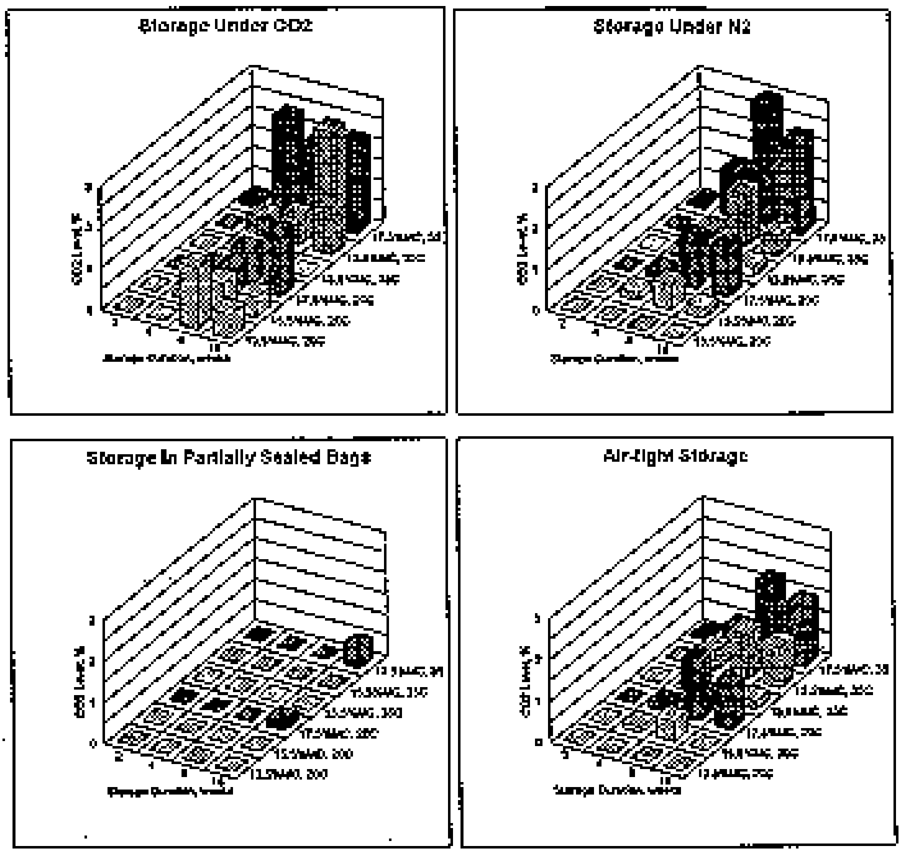

Fig. 1. Effect of high moisture content storage of rough rice on headspace carbon dioxide level.

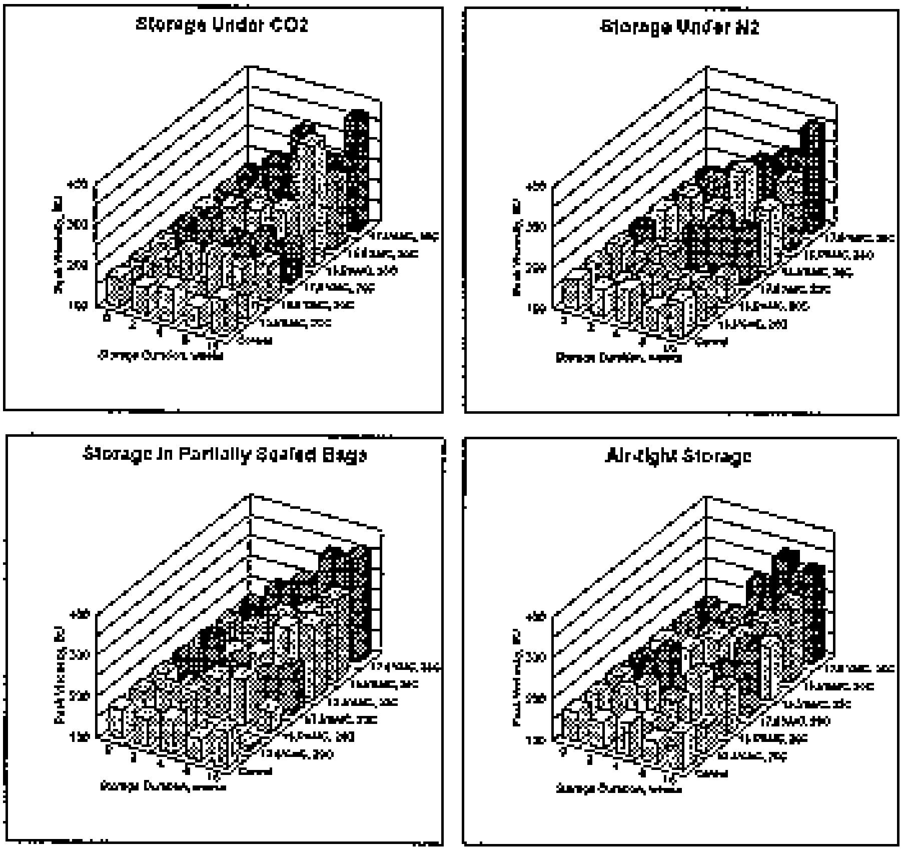

Fig. 2. Changes in peak viscosity of 'Bengal' brown rice during storage.

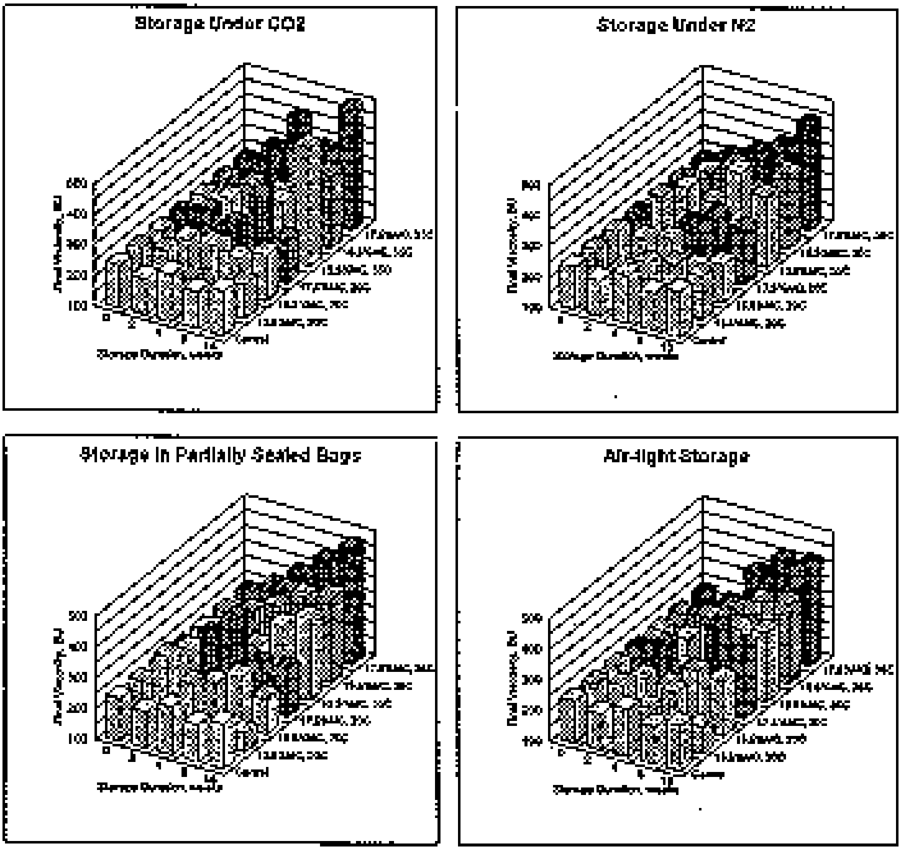

Fig. 3. Changes in final viscosity of 'Bengal' brown rice during storage.

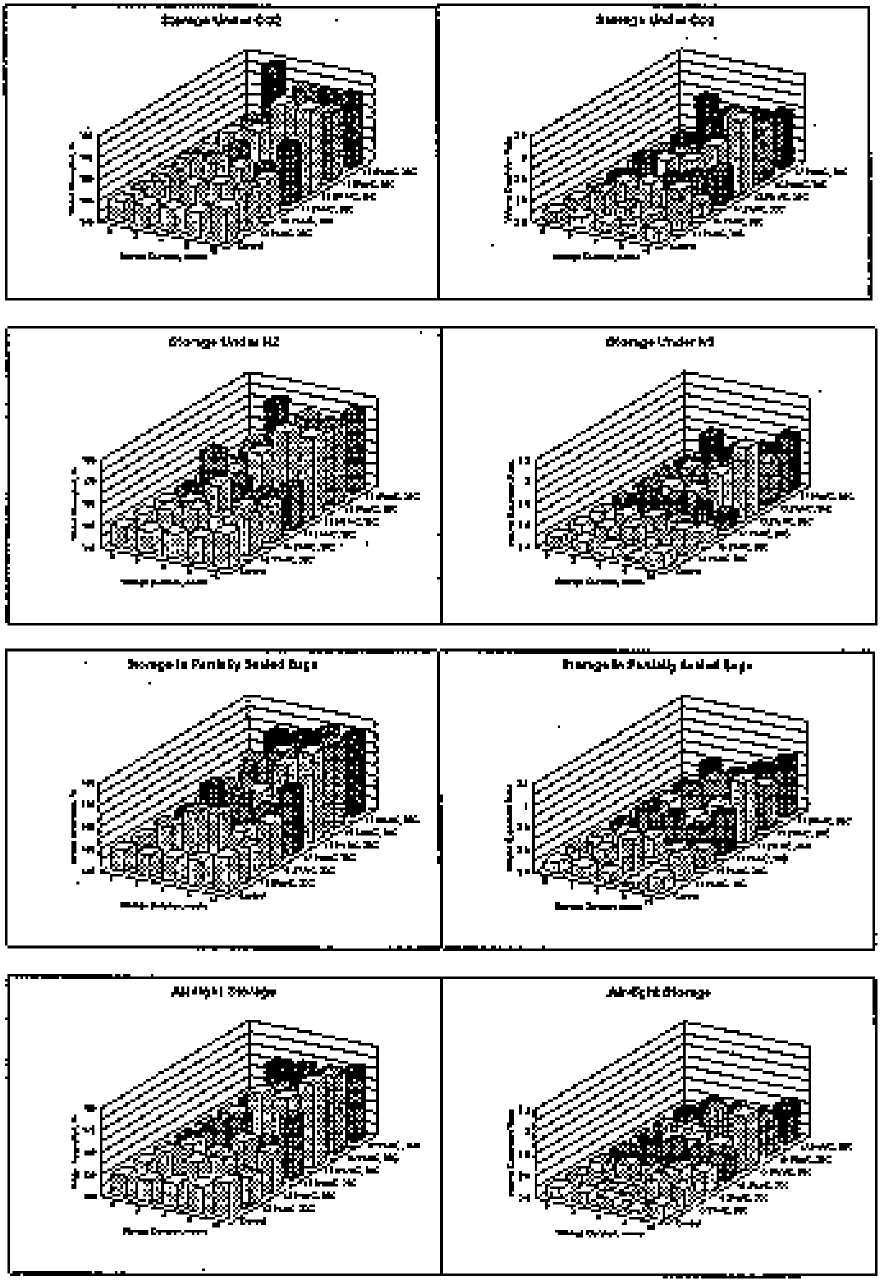

Fig. 4. Changes in water absorption and volume expansion of 'Bengal' milled rice during cooking.

COMPARISON OF THERMOCOUPLE AND INFRARED SURFACE TEMPERATURE MEASUREMENT OF ROUGH RICE DURING DRYING

J.D. Reid, T.J. Siebenmorgen, B.P. Marks and D.R. Gardisser

ABSTRACT

Currently, thermocouples are used almost exclusively for surface temperature measurement during rice processing. Infrared temperature measurement is a practical alternative to thermocouples in many scenarios. In this study, thermocouples (TC) are being compared to infrared (IR) thermometers during thin-layer drying. Response characteristics are quantified in terms of time constants and compared for several drying tests.

INTRODUCTION

Kernel temperature frequently serves as a process indicator during rice processing. Standard practice dictates the use of TCs for this kernel temperature measurement. During storage, high rice temperature warns of potential spoilage problems. During bin and column drying, constraints of maximum kernel temperatures protect the grain from drying damage. During some milling operations, the kernel temperature at the mill outlet (Archer and Siebenmorgen, 1995) is used, along with other measures, to determine whether or not rice is being over- or under-milled. In each of these applications, a TC is being used to measure the bulk surface temperature of rough or milled rice.

Since the drying operation involves both heat and mass transfer, validation of theoretical drying models requires surface temperature measurement. The general drying model (Haghighi et al., 1990) can be summarized as a system of two conservation equations, the conservation of energy and the conservation of mass. With these equations, boundary conditions and material parameters, the temperature and moisture content of a kernel can be predicted under a variety of conditions. One aspect of validating these models is comparing the measured surface temperature to the surface temperature predicted by the model (Sokhansanj and Bruce, 1986, 1987).

Thermocouples have been in use for over a century. Their relatively low cost, simple operation and diversity have contributed to their popularity in a variety of applications. However, in rice processing operations, some disadvantages exist. A disadvantage of TCs during the milling operation is fouling of the TC sheath. This fouling is due to the build-up of bran on the sheath surface, which reduces the measurement reliability. In laboratory thin-layer drying, fouling is not a problem; however, proper placement of the TC within the rice bed can sometimes be difficult. Also, with smaller sample sizes, corruption of the temperature by the TC sensor is also a concern. As an alternative, IR temperature measurement addresses these concerns.

Commercially available IR temperature sensors operate on the assumption that the temperature of a given surface of known emissivity can be determined based on the measured thermal radiation. For a commercial IR sensor, once the material emissivity is known, the optics can be chosen and arranged to measure the average temperature over a specific target projection area (Fig. 1). This non-contact method allows the measurement device to be isolated from the production environment while making a non-invasive temperature measurement.

PROCEDURES

One of the focus areas for the fall 1996 drying trials was rough rice surface temperature measurement during thin-layer drying. New drying cabinets were designed and fabricated during the summer to decrease variability in temperature and relative humidity while considering the engineering requirements for surface temperature measurement with TC and IR thermometers. During each drying run, TCs and IR sensors were used to measure surface temperature on a representative sample.

Since another focus of this year's drying research was the effect of cultivar, harvest location and harvest moisture content, rice was harvested from both the Rice Research and Extension Center, Stuttgart, Arkansas, and the Northeast Research and Extension Center, Keiser, Arkansas. The harvest included two long-grain cultivars ('Kaybonnet' and 'Cypress') and one medium-grain ('Bengal') cultivar. Each cultivar at each harvest location was harvested at 'high' and 'medium' moisture content levels. During the fall 1996 trials, 12 harvest location/harvest MC/cultivar combinations were processed.

Immediately after harvest, foreign matter was removed using a Carter-Day Dockage Tester. The rice was dried the day of or the day following harvest. The fall 1996 drying tests included three drying conditions. These drying conditions (A: 110.5°F, 38.2% RH; B: 125°F, 24.9% RH; C: 140°F, 16.9% RH) lay along a constant humidity ratio line on the psychrometric chart (Fig. 2). Conditioned air was supplied to each of three drying chambers by one of three 300 CFM Parameter Generation and Control temperature and relative humidity control units.

Each of the drying chambers had two rows of eight drawers. The dimensions of each drawer were 5.5 x 10 x 2.5 in. During drying tests, each drawer contained approximately 300 g of rough rice, corresponding to a rice bed thickness of approximately 0.4 in.

During each drying run, TC and IR thermometers measured rough rice surface temperature. A standard location in the drying cabinet was chosen for the IR measurement while the TC measurements were made in random drawers within the cabinet.

The TC probes were T-type (copper-constantan) with a 2.5-in.-long, 0.017-in.-diameter 316 stainless steel sheath. TC temperatures were measured from the center, front panel of each drawer as depicted in Fig. 3. Within the bed of rough rice, the TC probe was placed 0.25 ± 0.125 in. from the bottom of the tray. Since the drying was idealized as thin-layer, rough rice temperature was not assumed to be a function of bed thickness.

The IR thermometers provided a J-type (iron-constantan) output. The IR unit chosen for this application had a 7:1 focus. The IR sensing head was positioned 14.5 in. above the rice bed, creating a 3.15-in.-diameter target projection area (Fig. 3). In the drying sample drawer selected for IR measurement, the measurement area was centered along the width of the drawer and 4 in. along the length, measured from the face plate, as shown in Fig. 3.

RESULTS AND DISCUSSION

The temperature data from all drying trials are currently being analyzed. A typical plot (Fig. 4) of the surface temperature response during a drying run shows that the TC and IR sensors exhibited similar behavior. Each TC and IR temperature response will be modeled as a dimensionless number exponentially approaching an asymptotic value. From the equation

$$\frac{T - T_f}{T_i - T_f} = e^{-\frac{1}{\tau}t} \tag{1}$$

where T = surface temperature (°F), Tf = final surface temperature (°F), Ti = initial surface temperature (°F), t = drying duration (sec) and τ = time constant (/sec). The time constant, τ, will be used to compare the TC versus the IR surface temperature measurement.

SIGNIFICANCE OF FINDINGS

For surface temperature measurement, IR temperature measurement is a valuable alternative to the TC. In thin-layer drying, a non-contact surface temperature measurement offers several advantages. By increasing the measurement target projection area, a more representative sample offers a more accurate average kernel surface temperature. Since the IR probe can be placed remotely, the noncontact surface temperature assists in measuring surface temperatures during experimental runs. In industrial settings, remotely sensing surface temperature not only could improve accuracy, but also could reduce the maintenance required for temperature sensors.

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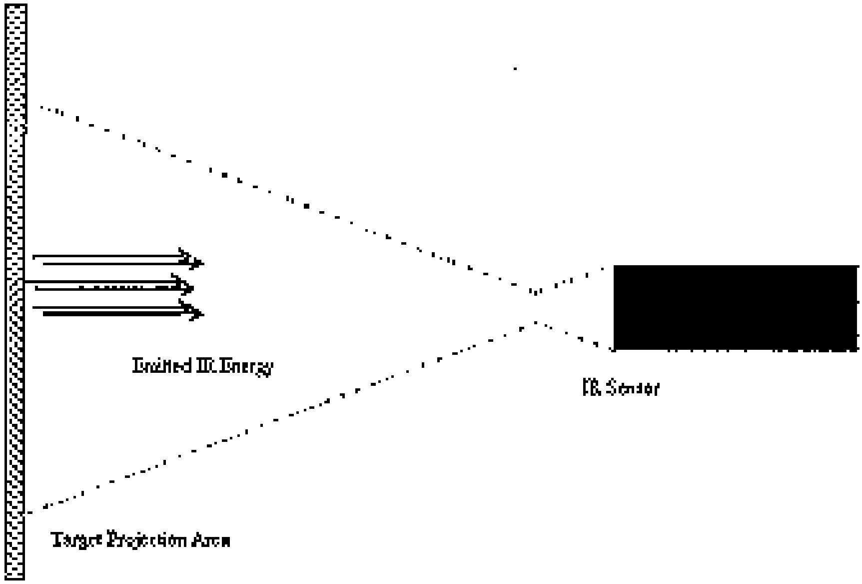

Fig. 1 The average temperature of the target projection area, for a material of known emissivity, is measured as a function of the emitted IR energy. The target projection area depends on the distance of the target from the IR sensor.

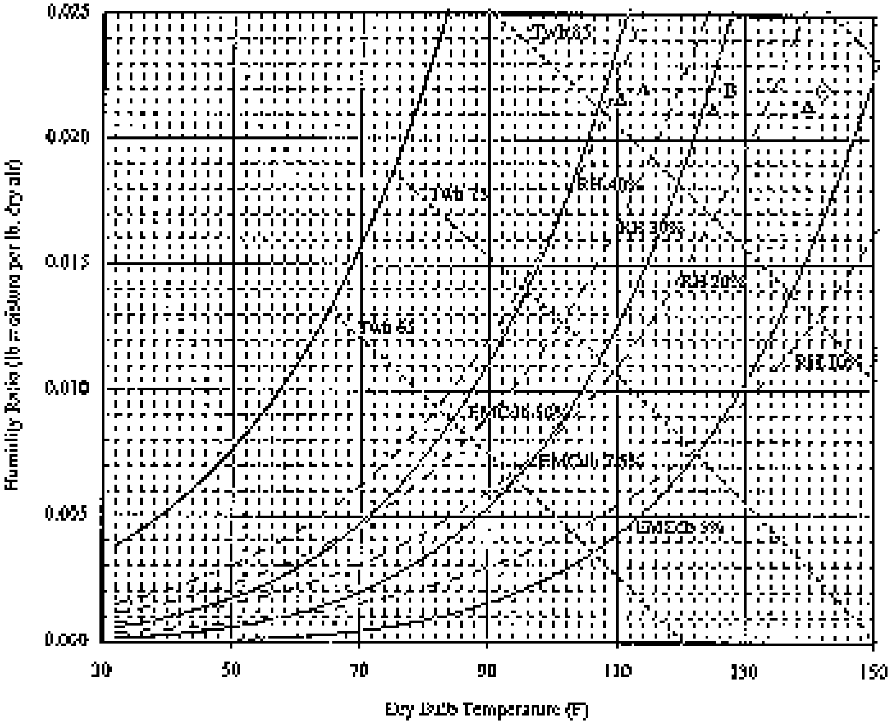

Fig. 2. Psychrometric chart, depicting the three drying air conditions used in this study. The equilibrium moisture content (EMC) lines were calculated using the Chung Equation (ASAE, 1990). Wet bulb temperature (Twb) and relative humidity (RH) lines are included.

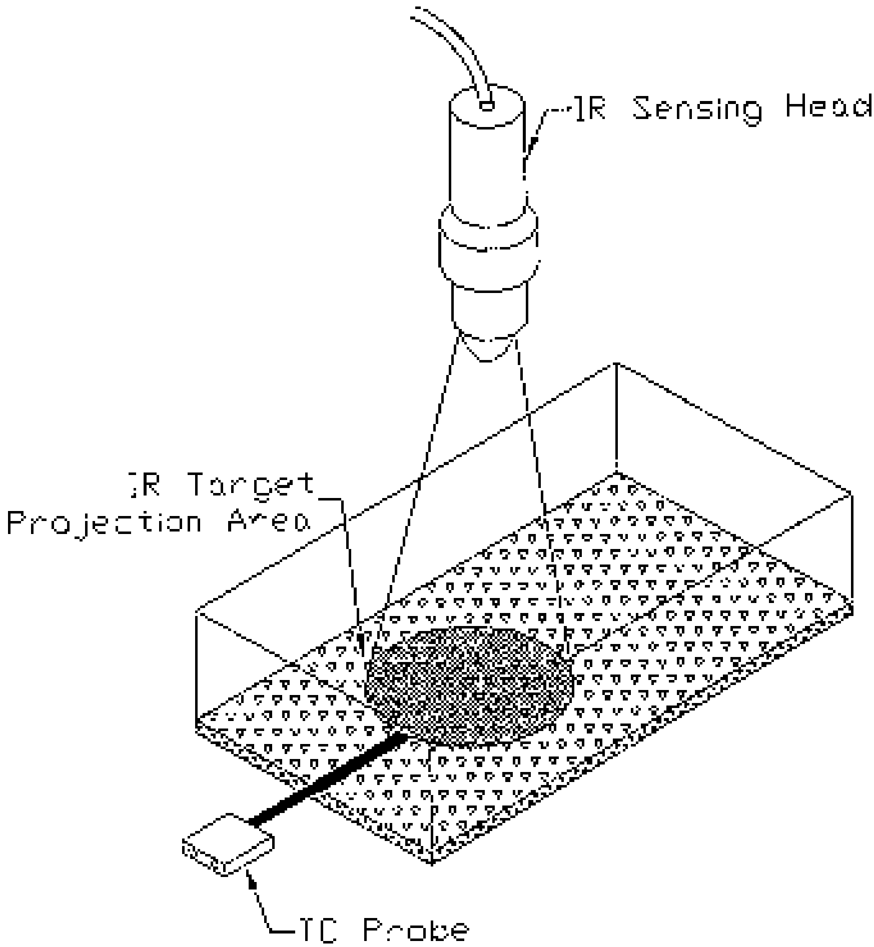

Fig. 3. One-half-scale drawing of a drying chamber drawer, showing the temperature measurement locations. The thermocouple (TC) was placed in the rice bed, approximately 0.25 in. from the bottom of the rice bed. The infrared (IR) sensing head was located 15 in. above the drawer bottom.

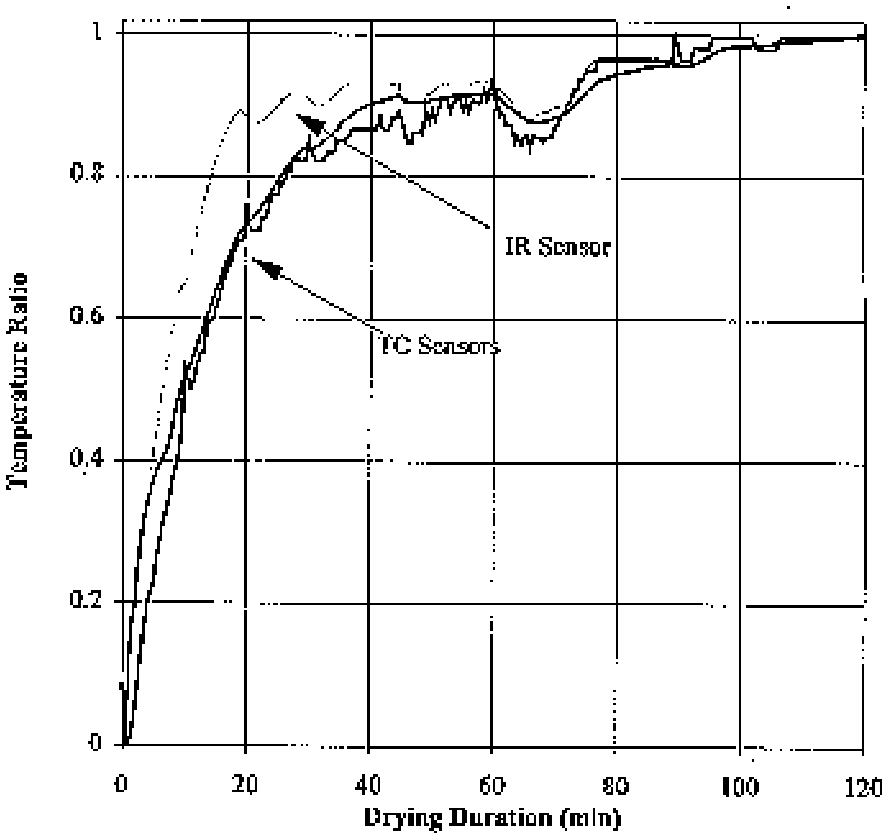

Fig. 4. The rough rice surface temperature, when dried at condition C (140°F, 16.9% RH), increases from ambient to the drying air conditions in approximately 20 min.The response characteristics of the thermocouple (TC) and infrared (IR) sensors are currently being compared. Temperature ratio is defined in equation 1.

EFFECT OF HARVEST AND CONDITIONED MOISTURE CONTENTS ON BULK DENSITY OF LONG- AND MEDIUM-GRAIN RICE CULTIVARS

T.J. Siebenmorgen, J. Fan and T.R. Gartman

ABSTRACT

The effect of harvest and conditioned moisture contents on bulk density of long- and medium-grain rice cultivars was studied. Harvest moisture content significantly affected the bulk density of rough rice at a given conditioned moisture content. There was a strong linear relationship between rough rice bulk density and conditioned moisture content. Unlike rough rice, bulk densities of brown and milled rice increased as the conditioned moisture content decreased (only kernels three-quarters or more of the original kernel length for both brown and milled rice were tested). However, the change in bulk density with conditioned moisture content changes for brown and milled rice was relatively small compared to the change of rough rice bulk density with conditioned moisture content.

INTRODUCTION

Bulk density (BD) is an important physical property of rough and milled rices. It is generally known that the BD of rice is dependent on grain type (long, medium or short grain) and other physical properties. Wratten et al. (1969) studied the individual kernel dimensions and bulk density of long- and medium-grain rice at various moisture contents (MCs). Morita and Singh (1979) observed that the length, width, thickness and BD increased linearly with MC from 11% to 21% in their studies of short-grain rough rice. Arora (1991) also reported an increase in rough rice dimensions (length, width and thickness), volume and BD with an increased MC.

The MC at which rice is harvested (HMC) is important to rice producers since it can affect the harvested rice quality and the associated economic return (Kocher et al., 1990). Research has shown that rice properties, particularly kernel MC distribution, change with HMC. Kocher et al. (1990) and Siebenmorgen et al. (1992) showed that the kernel MC variability greatly increased as the HMC increased. No information was found that quantifies how BD is affected by HMC.

The objective of this study was to determine the BD of rough, brown and milled rice of various long- and medium-grain cultivars harvested from Arkansas locations over a range of HMCs and dried to a range of conditioned MCs.

PROCEDURE

Rice was harvested from the Rice Research and Extension Center at Stuttgart, Arkansas, and the Northeast Research and Extension Center at Keiser, Arkansas, in the fall of 1995. Long-grain varieties 'Cypress', 'Kaybonnet' and 'Newbonnet' and medium-grain varieties 'Bengal' and 'Orion' were harvested from production scale fields with plot combines.

The harvest procedure consisted of harveting approximately 400 lb of each cultivar with a plot combine and bagging in paper bags. The rice was then transported to the University of Arkansas Rice Processing Lab and cleaned using a Carter Dockage Tester. Cleaned rice from each cultivar harvested at a given MC was then spread on a tarp in a lab maintained at 21°C to allow slow and uniform drying.

Once the rice on the tarp reached approximately 16% MC (wet basis) 10-lb samples of rough rice were selected at declining one-percentage-point moisture intervals from which BD measurements (wet basis) of rough, brown, and white rice were made. This procedure was repeated until the conditioned MC reached approximately 11%.

The BD of rough, brown and milled rice was measured using a Seedburo BD apparatus (Seedburo Equipment Co.). The apparatus consisted of a filling funnel with a quart cup placed beneath the funnel. From each sample of rough rice at a given MC level, a sub-sample was selected and poured into the funnel. After the valve at the bottom of the funnel was tripped, the rice flowed into the quart cup placed under the funnel. The rice was leveled off at the top of the cup using a straight edge. The BD was calculated by dividing the weight of rice in the cup by the cup volume, taken as a standard dry quart. This procedure was repeated three times from the same sub-sample to obtain an average BD for the sample.

Rough rice below 16% MC was dehulled using a Paddy Husker (Model APS-30CX, Satake). White rice was obtained by milling portions (120 g) of the brown rice samples for 30 sec using a laboratory mill (McGill #2). BD measurements on the brown and white fractions were made using only "whole" kernels (those kernels three-quarters or more of the original kernel length). BD tests were conducted on the brown and white rice samples using the same procedure described above for rough rice.

RESULTS AND DISCUSSION

The BD of freshly harvested rough rice with different HMCs and locations is given in Table 1. Figure 1 shows the changes in BD of long-grain Cypress rough rice with conditioned MC at different HMCs. It is obvious that the BD decreased linearly with decreasing conditioned moisture content. Harvest moisture content significantly affected the BD level at a given conditioned MC level. For example, at a conditioned MC of 13%, the BDs for HMCs of 29.1%, 20.6% and 14.5% at Stuttgart were 40.1 lb/bu, 42.0 lb/bu and 43.7 lb/bu, respectively. The lower BD values for rough rice harvested at high MCs can be explained by the presence of immature kernels. Immature kernels would be expected to have less mass per unit volume than fully matured kernels. The results in Fig. 1 also indicate that Cypress harvested from Keiser had a much higher BD than that from Stuttgart with a similar HMC. Major factors influencing the BD at different harvest locations could be climatic conditions, seeding times and production practices.

Figure 2 shows the conditioned MC effect on the BD of medium-grain cultivars, Bengal and Orion, with a medium HMC. There was not a great difference in BD at any given conditioned MC for these medium-grain lots. However, a statistical analysis indicated that the linear regressions for Bengal from Stuttgart and Keiser were significantly different. Thus, the harvest location difference in BDs for Bengal (a medium-grain, Fig. 2) was much less than for Cypress (a long-grain, Fig. 1). There was no significant difference in BD between Orion and Bengal harvested from Keiser.

A significant difference ($P < 0.05$) in the BD relation with conditioned MC was observed for the long-grain cultivars (i.e., Newbonnet, Cypress, Kaybonnet) harvested at medium MCs (Fig. 3). Cypress harvested at Stuttgart had a much lower BD than that from Keiser with a similar HMC. The linear regression equations representing the relationship between BD and conditioned MC for all the rice cultivars/HMC combinations used in this study are given in Table 1.

Unlike rough rice, the BD of brown and milled rices generally increased as the conditioned MC decreased (data not shown). However, the change in the BD of brown and milled rice due to conditioned MC was relatively small compared to the change in rough rice BD with conditioned MC. The medium-grain rice exhibited a higher BD for brown and milled rice than for long-grain rice cultivars over the conditioned MCs from 12% to 17%. It was also found that HMCs significantly affected the BD of brown and milled rice. Bengal harvested at 20.9% MC from Stuttgart had an average milled rice BD of 61.7 lb/bu over the conditioned MCs from 14.0% to 17.4%, whereas the same cultivar harvested at 12.9% MC from the same location had an average BD of 65.9 lb/bu.

SIGNIFICANCE OF FINDINGS

This research demonstrates the significance of conditioned MC in determining the BD of rough, brown and milled rice. Additionally, HMC appears to affect BD in that rice harvested at a higher MC gave a lower rough rice BD when corrected to a given conditioned MC. The research has also shown the changes in BD of rice cultivar and HMC as a function of conditioned MC. Results showed that the BD of rough rice is linearly related to the conditioned MC. This information is of particular value for understanding the changes in rice physical characteristics during drying where water is removed from the rice kernels

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Table 1. The dependence of bulk density (BD) of rough rice on harvest and conditioned moisture contents (MC) at two locations in Arkansas.

Harvest location	Cultivar	Harvest MC	Bulk density at harvest MC	Bulk density at 13% MC	Range of conditioned MC	Regression equations for rough rice BD[†]
		%, w.b.	lb/bu	lb/bu*	%, w.b.	
Stuttgart	Bengal	20.9	46.8	43.8	14.0-20.9	y=0.346x + 39.4 (R^2=0.94)
		12.9	44.3			NA[‡]
	Cypress	29.1	44.6	40.0	10.7-29.1	y=0.262x + 36.7 (R^2=0.94)
		20.6	44.7	42.0	12.3-20.6	y=0.369x + 37.2 (R^2=0.97)
		14.5	43.9	43.6	11.0-14.5	y=0.342x + 39.3 (R^2=0.79)
	Kaybonnet	18.9	46.9	45.3	10.8-18.9	y=0.271x + 41.9 (R^2=0.97)
		12.5	48.1			NA
Keiser	Bengal	21.7	48.0	44.1	11.0-21.7	y=0.400x + 39.0 (R^2=0.96)
	Cypress	21.0	46.9	44.1	11.6-21.0	y=0.338x + 39.8 (R^2=0.95)
	Newbonnet	21.1	47.0	44.6	11.2-21.1	y=0.279x + 41.1 (R^2=0.91)
	Orion	17.2	45.6	43.8	13.0-17.2	y=0.452x + 38.0 (R^2=0.92)

*Bulk density was calculated using the linear regression equations for rough rice BD.

[†]y is bulk density of rough rice, lb/bu, x is conditioned moisture content, % (w.b.).

[‡]Not applicable

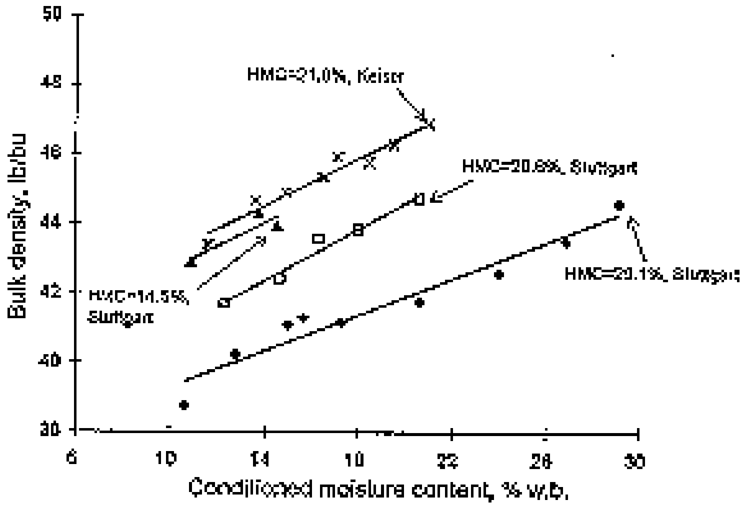

Figure 1. Dependence of rough rice bulk density on conditioned moisture content of Cypress rough rice harvested at either Keiser or Stuttgart, AR at the indicated harvest moisture content (HMCs).

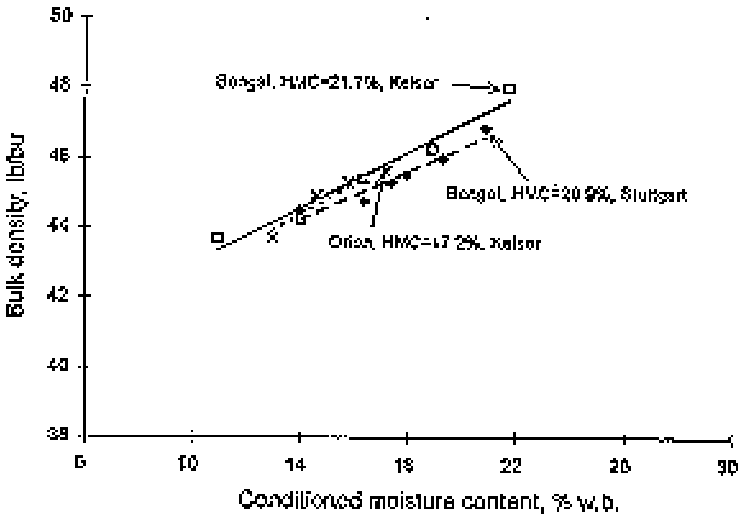

Figure 2. Dependence of rough rice bulk density on conditioned moisture content of medium-grain varieties Orion and Bengal harvested at either Stuttgart or Keiser, Arkansas, at the indicated harvest moisture contents (HMCs).

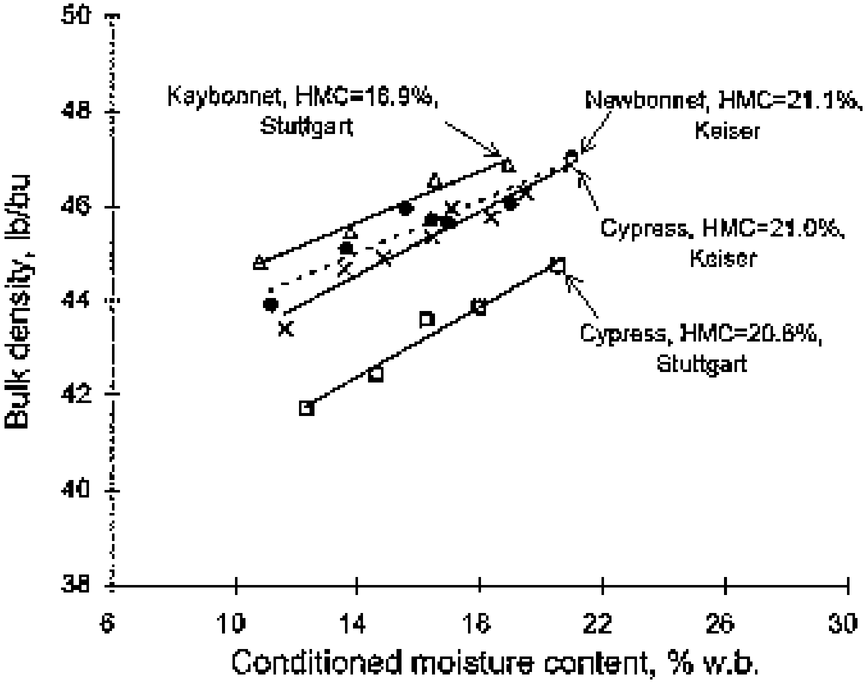

Figure 3. Dependence of rough rice bulk density on conditioned moisture content of long-grain varieties Cypress, Kaybonnet, and Newbonnet harvested at either Stuttgart or Keiser, Arkansas, at the indicated harvest moisture contents (HMCs).

IMPACT OF PARTICIPATION IN GOVERNMENT PROGRAMS ON TENANT AND LANDLORD RISK-RETURNS FOR CROP SHARED RICE

Lucas D. Parsch, Ge Cao and Shaun R. Rhoades

ABSTRACT

Under a typical 75/25 crop share, participation in the government program for rice under 1990 Farm Bill provisions (1991-1995) resulted in a $122/acre increase in expected net returns for tenants and a $37/acre increase for landlords in comparison to non-participation. The rice program also reduced risk to 70% of its market level. Without the safety net provided by government payments under the 1990 Farm Bill, the tenant would have nearly a one in two probability of incurring negative net returns under the typical 75/25 crop share arrangement.

INTRODUCTION

Ever since the 1990 Farm Bill was replaced with the new Federal Agricultural Improvement and Reform (FAIR) act in April 1996, discussion has focused on the potential economic impact of phasing out government support on crop producers. This study serves as a starting point for that discussion by quantifying the increased returns and reduced risks that producers have enjoyed under provisions of the government support program for rice, which was in effect from 1991-1995. Because the majority of Arkansas rice is grown on rented land, this study compares how crop-sharing tenants and landlords fare, both with and without participation in the government rice program under 1990 Farm Bill provisions. Simulation is used to quantify risk and returns for tenant and landlord under a typical 75/25 cropshare, the most popular cropland rental arrangement in eastern Arkansas. Because transition payments under FAIR will be entirely phased out after 2002, the "non-participation" scenarios in this study may provide insight as to how tenants and landlords share risk when government support is ultimately absent.

PROCEDURES

Monte Carlo simulation was used to estimate risk and returns for tenants and landlords by developing stochastic enterprise budgets under a typical 75/25 cropshare rental arrangement. In stochastic budgets, certain "risk" variables are allowed to vary according to historical patterns in order to reflect the risk incurred in a cropping enterprise. In developing the enterprise budgets for this grain study, yield, price of rice and government deficiency payments were modeled as random (i.e., risk) variables using Monte Carlo simulation in order to reflect the production (yield) and market (price, deficiency payment) risk faced by the Arkansas rice producer. By contrast, cost of production was assumed to be non-random. Rental arrangement terms were based on an Arkansas survey of rice producers.

Stochastic Input Distributions

Price of rice, yield and deficiency payment were modeled as a multi-variate normally distributed input distribution based on empirical estimates of the parameters (mean, standard deviation) of the marginal probability distributions and correlation matrix presented in Table 1. The estimate of input parameters for rice price was taken from a linear trend regression line fitted through a five-year (1989-1993) time series of market price received ($/cwt) by Arkansas producers indexed to 1993 dollars. Standard deviation for price was measured as root mean square error (RMSE) about the trend line. Mean price over the five-year series was measured as the trend line projected rice price for 1993. The corresponding estimate of the input parameters for deficiency payment was based on a similar regression trend line fitted through the five-year (1989-1993) time series of historical rice deficiency payments ($/cwt) paid to producers (USDA-ERS). Analogous yield estimates were taken from a regression trend line fitted through the 10-year (1984-1993) historical yield series for crop reporting districts 3, 6 and 9 of eastern Arkansas (AASS, 1994). Although none of the detrending procedures for yield, price or deficiency payment resulted in significant trends at the 0.01 level of significance, RMSE was used in order to isolate the random variability in each of the three stochastic input variables. Covariance between simulation input variables was based on correlation coefficients estimated from the five and 10-year historical data series for yield and price, respectively (Table 1).

Production Costs and Returns

Estimated cost of rice production was taken from published enterprise budgets for Arkansas (Stuart et al., 1993). These enterprise budgets show $334.98/acre in production costs for rice on silt loam soil (Table 2). Total specified cost in these published enterprise budgets includes variable costs (fertilizer, seed, chemicals, fuel, labor, etc.) and fixed cost for machinery and irrigation but excludes a charge for land, management, risk, overhead capital, and overhead labor. With a projected yield of 53.91 cwt/acre and projected price and deficiency payments of $7.74/cwt and $3.95/cwt, respectively, "mean" net returns above specified costs in Table 2 increase from $82.28/acre without government programs to $239.14/base acre under the 1990 Farm Bill program. This reflects an increase in net returns of $156.86/acre under average conditions or $1.38/bu produced due to government deficiency payments.

Cropshare Terms and Residual Claimant

The enterprise budget in Table 2 was adapted to reflect tenant-landlord crop production in Arkansas. A 1992 survey of 240 rice producers showed that a 75/25 cropshare (also called "straight" share) was the most frequently observed cropland rental arrangement for rice in eastern Arkansas. Under a 75/25 cropshare, the tenant provides the landlord with 25% of the crop and deficiency payment and pays virtually all production costs specified in the enterprise budget in Table 2. Because the producer rice survey showed that the landlord typically owns the irrigation well, pump and gearhead, the landlord was assumed to bear overhead costs associated with "underground" irrigation equipment. No other costs—including an opportunity charge for land—were levied against the landlord in this analysis. By contrast, the tenant was assumed to pay all other enterprise costs in Table 2 including those associated with the irrigation pump and irrigation fuel costs.

Because of the costing procedures described above, tenant and landlord net returns are not directly comparable. For the tenant, the residual claimant is tenant management, risk, overhead capital and overhead labor. The corresponding residual claimant for landlord returns is land, management, risk, overhead labor and overhead capital. For the landlord, land is the primary residual claimant of net returns whenever an opportunity charge for land has not been subtracted. In this study, rather than charge an opportunity cost for land, the landlord residual serves to approximate the level of risk/returns that are incurred with land ownership.

Government Program Provisions

Net return for tenant and landlord was simulated over 100 draws, with and without participation in the government rice program under the 1990 Farm Bill provisions. A $15/acre set-aside cost was charged against the 5% of idled base acres. Normal flex acreage was 15% of base acres, and optional flex acreage was assumed to be seeded to rice. ASCS program yield was set equal to the simulated mean grain yield of 53.91 cwt/acre. A simulated market price less than the loan rate ($6.50/cwt) resulted in a simulated market price equal to the loan rate to reflect the non-recourse payment of the marketing loan. Similarly, a simulated deficiency payment greater than $4.21/cwt was truncated to $4.21/cwt in order to avoid the simulation of deficiency payments greater than the target price ($10.71/cwt) minus the loan rate ($6.50/cwt).

RESULTS AND DISCUSSION

Sample statistics for simulated net returns are presented in Table 3. Because national participation rates in government farm programs for rice have exceeded 95% of base acreage in recent years (USDA), the left half of Table 3 is representative of net returns for the majority of rice produced in Arkansas while the 1990 Farm Bill was in effect. The right half of the table shows corresponding results for rice produced during the same period under a market situation, i.e., without the safety net of government programs.

Expected Returns

Simulated mean net returns in Table 3 indicate that "on average," rice production under government programs is profitable for both the tenant and the landlord. Tenant returns above specified costs are \$122/acre compared to landlord returns of \$118/acre. By contrast, non-participation in the government rice program results in dramatic decreases in expected net returns for both the tenant and the landlord. Without government programs, mean returns for the tenant are slightly negative under a 75/25 straight share and just under \$81/acre for the landlord. On average, non-participation results in a \$122/acre decrease in net returns for tenants compared to a \$37/acre decrease for landlords. This implies that tenants may have leased cropland under a 75/25 straight share—the most frequently observed rental arrangement in eastern Arkansas—primarily because government programs rendered it profitable to do so.

Risk-Return Tradeoffs

Minimum and maximum net return values in Table 3 reflect "worst-case" and "best-case" scenarios of the 100 simulated outcomes for each scenario. For example, under the government rice program, the worst-case combination of market prices, yields and deficiency payments results in net returns as low as \$65/acre for the tenant and \$99/acre for the landlord. By contrast, under the best-case scenario, both the tenant and the landlord benefit from dramatically higher returns of \$196 and \$142/acre, respectively. In "bad" years, tenant returns are lower than landlord returns, but in "good" years they are higher. The significantly larger range of possible earnings for tenants (\$131/acre) than for landlords (\$44/acre) in Table 3 is an indication that tenants are exposed to greater risk than are landlords.

Standard deviations of net returns are often used as an absolute measure of economic risk. In Table 3, standard deviations (Std. Dev.) provide quantitative documentation that the tenant bears 75% of the risk associated with a 75/25 cropshare arrangement in comparison to the landlord's 25% (e.g., \$31.53 vs. \$10.51/acre, respectively under government programs). This result is consistent with expectations because the source of risk in this analysis (yield, price and deficiency payment) directly affects gross revenues, and consequently the proportion of risk borne by the tenant is proportional to the share of gross revenues (market plus government support) that the tenant incurs.

Coefficients of variation (CV) in Table 3 quantify the income risk relative to "average" or mean earnings. For example, on average, the tenant earns $122/acre under government programs while incurring risk of $31.53/acre (measured as standard deviation). Thus, for the tenant, risk is approximately 26% of average earnings under government programs, significantly greater than the 9% relative risk that the landlord bears.

Table 3 also documents the magnitude of risk under the government rice program vs. a market (non-participation) situation. For example, the standard deviation for tenants increases from $31.53/acre with government programs to $45.45/acre under non-participation, an increase of 44%. Alternatively stated, participation in government programs under a 75/25 cropshare reduces risk to 70% of its market level.

Without participation in government programs, the range in possible earnings for the tenant and landlord increases dramatically to $233 and $78/acre, respectively. In addition, the absence of deficiency payments results in lower returns for both the tenant and the landlord under best-case and worst-case scenarios. For the tenant, it is noteworthy that under a worst-case scenario, receipts from the sale of the rice crop—after a 25% cropshare payment to the landlord—are not sufficient to cover costs of production, and hence negative returns ($-125/acre) result. Low returns of $39/acre are also encountered by the landlord under this worst case.

Cumulative Distribution Functions

Minimum and maximum values in Table 3 demonstrate how a "bad" or "good" year might affect tenant or landlord earnings, but they provide little indication of the likelihood or probability that any one of these scenarios will actually occur. Empirical cumulative distribution functions (CDF) of net returns were developed in order to provide this information (Fig. 1). Each CDF shows the probability or likelihood that net returns to tenant or landlord residual will be less than a specified dollar amount per acre. For example, although there is virtually no chance (0.00 probability) that landlord returns will be less than $100/acre under the government rice program, the likelihood of earning lower than $100 increases to 90% (i.e., 0.90 probability) for the landlord in a market situation. Likewise, although there is virtually no chance (0.00 probability) that landlord returns will be less than $100/acre under the government rice program, there is a 30% chance (0.30 probability) that tenant returns will be lower than $100/acre under the same rice program scenario. Based on the cumulative distributions, the bottom row in Table 3 documents the probability that economic returns to tenant and landlord residual will be negative. Although the CDFs for both tenant and landlord shift dramatically to the left under non-participation, negative net returns have a relatively high probability of occurring only for the tenant without government programs. For tenants, there is a one in two chance (i.e., probability of 0.47) of negative earnings without government programs under a 75/25 cropshare arrangement.

SIGNIFICANCE OF FINDINGS

This study demonstrates that the government rice program established by the 1990 Farm Bill (which was in effect between 1991 and 1995) provided an important safety net for rice producers in Arkansas. The comparison of earnings in this study provided quantitative evidence that participation in the government rice program resulted in 1) a dramatic increase in net returns and 2) a substantive reduction in economic risk for both the tenant and the landlord under the typical and popular 75/25 cropshare. Equally important, however, this study shows that when the safety net of government programs is absent, it is the tenant who bears the greater portion of the burden that results. Without government support, both the tenant and the landlord experience reduced income and increased risk, but it is the tenant who bears the greater share of this loss of income and the increased exposure to risk under a typical cropshare arrangement. In the absence of government deficiency payments, average net returns for tenants approach zero, and the probability that negative returns will be encountered is nearly 1 in 2.

It is unlikely that the non-participation scenarios that were evaluated in this study will be exactly identical to the market-oriented climate that was created when the FAIR act became law in 1996. First, there is no guarantee that market prices in the recent past will continue into the near future. Second—and perhaps more importantly—even though deficiency payments are now history, government support in the form of declining transition payments will continue through the year 2002. Although the safety net of government support continues even now under the FAIR act, the most important lesson is that it will end. For rice producers—tenants and landlords alike—the most important task that can be undertaken now is to plan how to adapt to the situation when they are finally exposed to the brunt of a true market economy after the transition payments end.

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Table 1. Estimated parameters and correlation coefficients for simulation input distributions.

	Est. Parameters		Correlation Coefficients		
Variable	Mean	Std. Dev.*	Yield	Price	Def. Pmt.
Yield	53.91†	2.78	1.00	---	---
Price	7.74‡	1.32	-0.54	1.00	---
Def. Pmt.	3.95§	0.57	-0.20	-0.41	1.00

*Root mean square error of respective trend regression.

†Projected yield from ten-year (84-93) yield trend for eastern Arkansas.

‡Projected price from five-year (89-93) trend of price received.

§Projected deficiency payment from five-year (89-93) trend of historical deficiency payments.

Table 2. Estimated enterprise costs and returns for rice production, Arkansas Delta, 1993.

Enterprise Item	Value
Yield (cwt / harvested acre)*	53.91
Price ($/cwt)†	7.74
Gross receipts ($/acre)	417.26
Non-land costs, i.e., variable costs, machinery and irrigation fixed costs ($/acre)‡	334.98
Returns above specified costs excluding land without gov't program ($/acre)	82.28
Returns above specified costs excluding land with govt program ($/base acre)§	239.14

*Projected yield based on ten-year (1984-93) yield trend for eastern Arkansas (AASS, 1994).

†Projected price based on five-year (1989-93) trend of price received, 1993 dollars (AASS, 1994).

‡Cost estimates based on Stuart *et al.* (1993).

§Assumes participation in government rice program under 1993 provision including the following: 5% idled acres with $15/acre set-aside costs; 15% flex acres; optional flex acres planted to rice; ASCS program yield equal to 53.91 cwt/ac; and, a projected deficiency payment based on a five-year (1989-93) trend of historical deficiency payments ($3.95/cwt) indexed to 1993 dollars.

Table 3. Simulated net returns for 75/25 cropshare rice, Arkansas Delta.

Simulated	Row	w/ gov't program*		w/o gov't program	
Net Returns	Unit	Tenant	Landlord	Tenant	Landlord
Mean	$/acre	121.63	117.51	-0.31	80.64
Std. Dev.	$/acre	31.53	10.51	45.45	15.15
CV	%	25.92	8.94	∞	18.78
Minimum	$/acre	65.09	98.66	-125.32	38.98
Maximum	$/acre	196.41	142.43	107.22	116.49
Range	$/acre	131.32	43.77	232.54	77.51
Prob [Net Returns $\leq$ 0]		0.00	0.00	0.47	0.00

*Participation in government rice program under 1990 Farm Bill provisions.

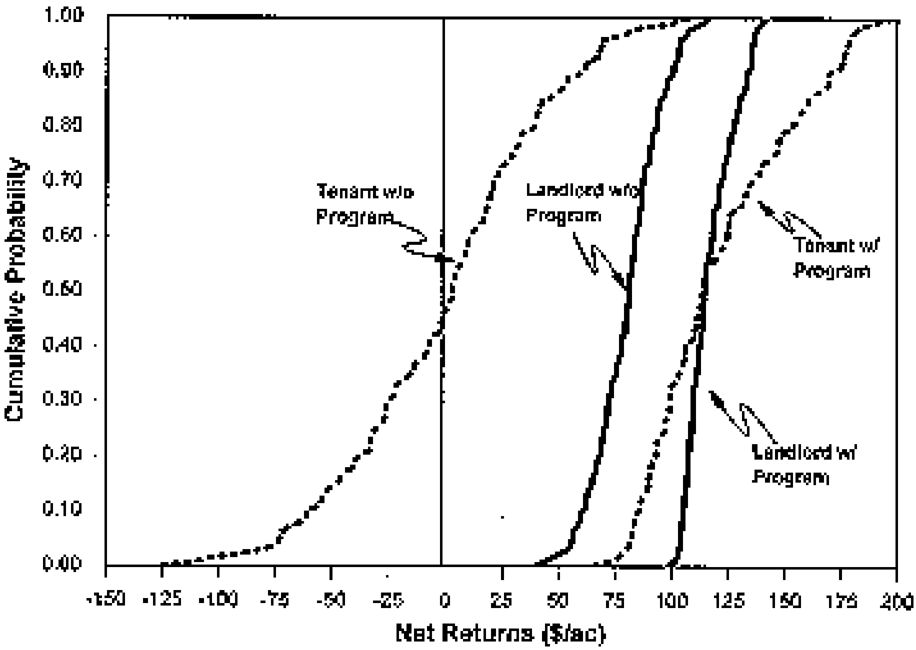

Fig. 1. Cumulative distribution functions of net returns for 75/25 cropshare rice.

COMPLETED STUDIES

OPTICAL DEGREE OF MILLING AS AFFECTED BY RICE KERNEL THICKNESS

H. Chen, T.J. Siebenmorgen and B.P. Marks

ABSTRACT

Three long-grain rice cultivars ('Newbonnet', 'Alan' and 'Katy') were milled in a commercial mill to three degree of milling (DOM) levels and separated into thickness fractions. Inverse linear relationships were established between surface fat concentration (SFC) and Satake milling meter (MM1B) optical DOM measurement values, including whiteness, transparency and DOM for the unfractionated head rice of each cultivar. The effect of kernel thickness on optical DOM measurements was investigated. Kernel thickness significantly affected whiteness and transparency readings in two of the cultivars. Within each cultivar, MM1B DOM was not significantly influenced by kernel thickness.

INTRODUCTION

Degree of milling (DOM) is a term used to describe the extent to which kernel bran has been removed in milling. Higher DOM levels are generally related to less retention of kernel bran, which is accompanied by a whiter appearance of the milled sample.

Methods, including visual examination, chemical composition analysis and optical measurements, have been developed to indicate the DOM of milled rice. Optical measurements determine the intensity of the visible or near infrared light reflected from and/or transmitted through milled rice (Stermer, 1968; Wadsworth et al., 1991). With an increasing demand for fast, reliable DOM measurements, optical methods have attracted increasing interest. Optical DOM measurement systems are currently commercially available, such as the Satake milling meter (model MM1B), which uses the amounts of reflected and permeated light to calculate DOM. Satake DOM meter readings were found to be strongly correlated to surface fat concentration (SFC) within given cultivars (Siebenmorgen and Sun, 1994).

Limited research has been conducted elucidating the effect of kernel size on optical DOM measurements. For various thickness fractions, Siebenmorgen and Sun (1994) established linear, inverse relationships between SFC and MM1B DOM measured with a Satake milling meter and found that the relationships differed across cultivars; these differences were speculated to be due ultimately to kernel size. The objectives of this research were

1) to establish general relationships of SFC versus optical values of whiteness, transparency and DOM as measured with a Satake milling meter and
2) to determine the extent to which optical DOM measurements are affected by kernel thickness.

PROCEDURES

Three long-grain rice cultivars, Alan, Newbonnet and Katy, at approximately 11-13% moisture content (MC, wet basis), were obtained from farm bins. Each one was first hulled using a commercial-scale Satake husker/paddy separator (model APS-30CX) and then milled to three DOM levels (low, medium and high) in a single pass using a commercial-scale Satake mill (model BA-7). Head rice was separated from brokens using a Satake test rice grader with a ϕ5.2mm long-grain screen. The head rice was then fractionated into five thickness fractions for Alan and Newbonnet and four thickness fractions for Katy using a Carter-Day precision sizer.

Optical DOM measurements were made using a Satake milling meter (model MM-1B). Prior to measurement, the meter was calibrated using white and brown color plates provided with the meter. A MM1B DOM of 0 corresponded to the brown plate and 199 to the white plate. MM1B measurements of whiteness, transparency and DOM were recorded as the average of readings from two subsamples of each thickness fraction and each unfractionated bulk. Whiteness was the percentage of light reflected from the sample (instrument range between 15 and 60%), while transparency was the percentage of light permeating the sample (instrument range between 0.00 and 9.99%). The MM1B DOM was calculated using both the whiteness and transparency by a factory-installed algorithm in the micro-computer of the meter.

The SFC of two subsamples from each thickness fraction and each unfractionated bulk was determined using a Soxtec System HT. Prior to extraction, a 5-g head rice sample was weighed into a cellulose extraction thimble (ϕ26 mm, length 60 mm) and dried in a convection oven at 100°C for 1 hr. Surface fat was extracted for 1 hr with 50 ml of petroleum ether (boiling point 35 to 60°C). The SFC was the surface fat expressed as a percentage of the original head rice mass (5 g).

RESULTS AND DISCUSSION

Relationships Between SFC and Optical Measurement Values for Unfractionated Samples

Figs. 1 to 3 show the relationships of whiteness, transparency and MM1B DOM versus SFC of the unfractionated samples of Alan, Newbonnet and Katy. In each curve, the data point at the highest SFC represents the unfractionated head rice at the lowest DOM level, and vice versa. Inverse relationships existed between SFC and the optical measurement values. These relationships can be described by the following linear equation:

$$\text{Optical measurement values} = A - B \cdot SFC \qquad (1)$$

where SFC is expressed as a percentage. The coefficients A and B are listed with the associated coefficients of determination (R^2) in Table 1. Good linearity existed in all cases except for the transparency of Newbonnet and Alan. Siebenmorgen and Sun (1994) reported only inverse linear relationships between SFC and MM1B DOM. The results here revealed the same trends relating whiteness and transparency to SFC.

To determine whether there were differences in the above relationships, linear regression analysis (Neter and Wasserman, 1974) was conducted; Table 2 shows calculated F values. The critical F value at the 0.05 significance level was 19. If a calculated F value is larger than the critical value, the two lines under comparison are significantly different in either the slope (B), the intercept (A), or both. Table 2 indicates that across the three cultivars, the regression lines for whiteness (Fig. 1) and MM1B DOM (Fig. 3) were significantly different, while there were no statistical differences in the regression lines for transparency (Fig. 2). This indicates that a given value of whiteness or MM1B DOM did not represent a fixed SFC across cultivars.

Effect of Thickness Fractions on Optical DOM Measurements

Fig. 4 shows the change in whiteness (a), transparency (b) and MM1B DOM (c) with SFC across thickness fractions of Alan. The corresponding relationships for the unfractionated Alan head rice from Figs. 1 to 3 are also shown in Fig. 4 for comparison. The linear relationships between optical readings and SFC as observed with the unfractionated samples (Figs. 1 to 3) remained valid for each thickness fraction. Similar linear relationships were also found to exist for Newbonnet and Katy. Compared to the unfractionated rice, the 1.52 mm fraction had higher whiteness, whereas the other four fractions had similar whiteness (Fig. 4 (a)). All fractions had lower transparency than the unfractionated head rice (Fig. 4 (b)). There was no difference between the DOM of the unfractionated rice and that of the various thickness fractions (Fig. 4(c)) in all three cultivars.

To investigate the effect of kernel thickness on optical DOM measurements, the general linear models procedure of SAS (1987) was used to analyze the data. Table 3 shows the calculated F values. Kernel thickness had significant effects on whiteness and transparency for Alan and Newbonnet, but not for Katy. Compared to whiteness, transparency was much more sensitive to kernel thickness. MM1B DOM, being calculated from whiteness and transparency, was not significantly affected by kernel thickness for any of the three types. In Fig. 4 (a), the thinnest kernel fraction (1.52 mm) of Alan had higher whiteness than the other four fractions. Linear regression analysis revealed that the regression line representing the 1.52 mm fraction was significantly different from the other four fractions, but there was no difference among the regression lines representing the other four fractions. In Fig. 4 (b), for thinner kernels (1.52 to 1.67 mm), transparency increased with increasing kernel thickness, while for thicker kernels (1.67 to 1.77 mm), transparency was not significantly affected by kernel thickness. It was apparent that the statistical significance of kernel thickness affecting whiteness and transparency (Table 3) was primarily due to the thinner kernel fractions.

SIGNIFICANCE OF FINDINGS

Satake optical measurement values, including whiteness, transparency and MM1B DOM in both unfractionated samples and thickness fractionated samples, were linearly and inversely related to surface fat concentration (SFC). The effect of thickness on whiteness and transparency was significant for Alan and Newbonnet. At given SFC levels, the thinnest kernel fraction had higher whiteness than the other four kernel fractions. Decreasing kernel thickness caused transparency to decrease in thinner kernel fractions (<1.67 mm). These findings indicate that the measurement of transparency and whiteness is dependent on cultivar but also is affected by kernel thickness, primarily the thin kernels.

Within each cultivar, MM1B DOM was not influenced by kernel thickness. However, at given SFC levels, MM1B DOM was significantly different across the three cultivars. Apparently there are factors, other than kernel thickness, that are specific to each cultivar that cause this difference. Since particle size is known to affect optical measurements, other geometric parameters such as kernel length, width or length to width ratio may explain MM1B DOM differences across cultivars at given SFC levels. Further investigation is required to elucidate these factors.

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Table 1. Coefficients of the linear regression models (Eq.1) as plotted in Figs. 1 to 3.

	MM1B whiteness			MM1B transparency			MM1B DOM		
Cultivar	A	B	R^2	A	B	R^2	A	B	R^2
Alan	45.4	17.2	1.00	4.8	1.6	0.84	132	89.1	1.00
Newbonnet	43.6	12.2	1.00	4.4	0.8	0.83	124	60.9	1.00
Katy	46.1	13.2	1.00	4.6	1.0	1.00	136	66.0	1.00

Table 2. F values calculated from regression analysis for testing the difference in the regression models plotted in Figs 1 to 3 (critical F value at 0.05 significance level is 19).

Cultivar	MM1B whiteness	MM1B transparency	MM1B DOM
Alan vs. Newbonnet	34*	3.8	64*
Alan vs. Katy	181*	2.5	120*
Newbonnet vs. Katy	36*	0.2	116*

*Significant at the 0.05 level.

Table 3. Calculated F values (F) and critical F values at the 0.05 significance level ($F_{0.05}$) resulting from the analysis of variance of optical measurements as affected by kernel thickness.

	Cultivar					
Optical	Alan		Newbonnet		Katy	
parameters	F	$F_{0.05}$	F	$F_{0.05}$	F	$F_{0.05}$
whiteness	3.8*	3.6	7.4*	3.6	0.8	4.4
transparency	59. *	3.6	24. *	3.6	1.4	4.4
DOM	0.8	3.6	1.4	3.6	0.8	4.4

*Significant at the 0.05 level.

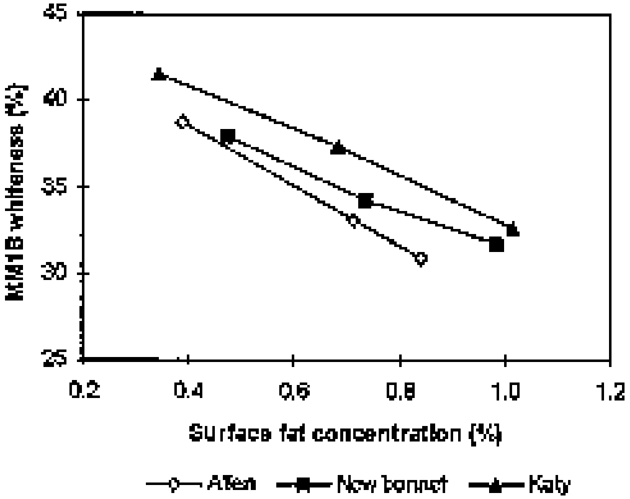

Fig. 1. Whiteness as measured by a Satake MM-1B milling meter versus surface fat concentration of unfractionated head rice for each of the indicated long-grain cultivars (each point represents an average of two measurements).

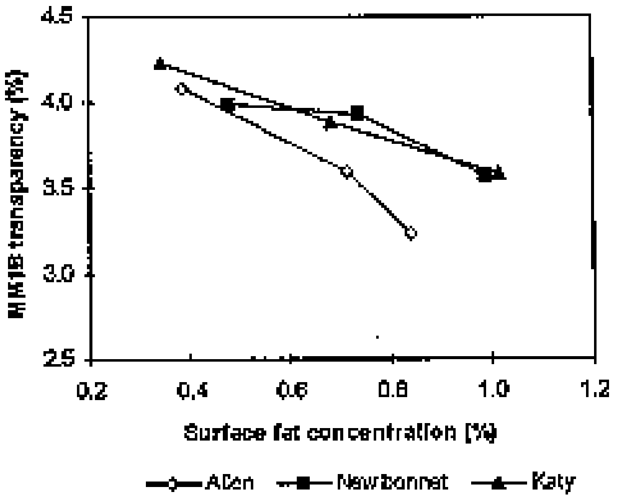

Fig. 2. Transparency as measured by a Satake MM-1B milling meter versus surface fat concentration of unfractionated head rice for each of the indicated long-grain cultivars (each point represents an average of two measurements).

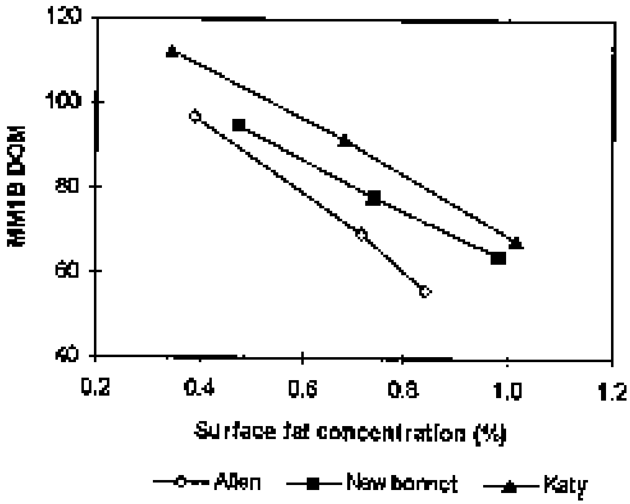

Fig. 3. Degree of milling (DOM) as measured by a Satake MM-1B milling meter versus surface fat concentration of unfractionated head rice for each of the indicated long-grain cultivars (each point represents an average of two measurements).

4a

4b

4c

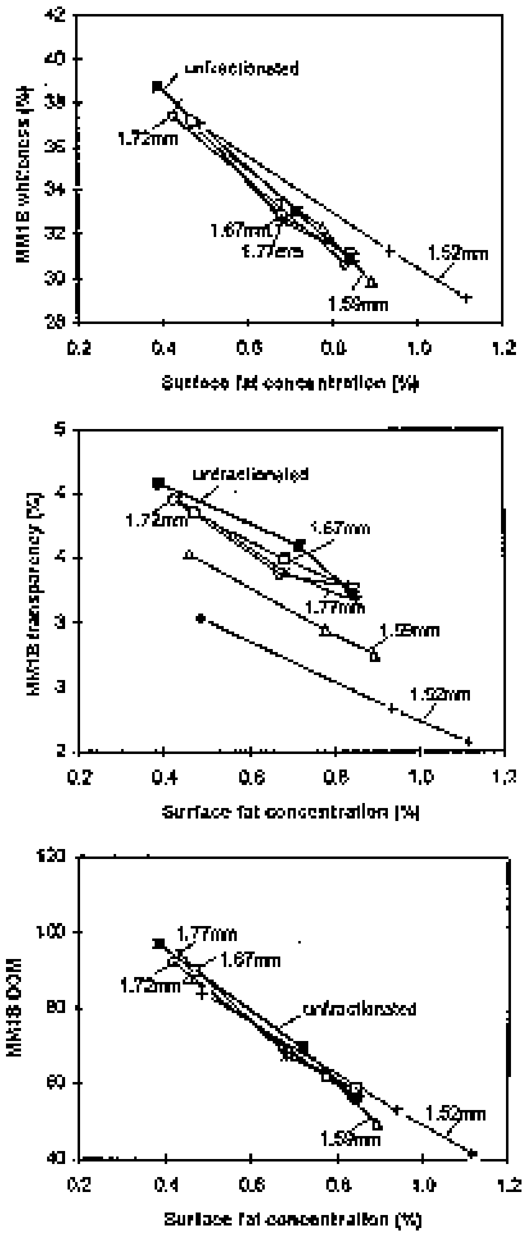

Fig. 4. Whiteness (a), transparency (b) and DOM (c) as measured by a Satake MM-1B milling meter versus surface fat concentration for unfractionated head rice and various thickness fractions of Alan cultivars (each point represents an average of two measurements).

RELATIONSHIPS BETWEEN DEGREE OF MILLING AND RICE KERNEL THICKNESS FRACTIONS FOR COMMERCIALLY MILLED RICE

H. Chen and T.J. Siebenmorgen

ABSTRACT

Three cultivars of long-grain rice were milled in a commercial mill to three degree of milling (DOM) levels and separated into thickness fractions. The effect of kernel thickness on surface fat concentration (SFC) was investigated. For a given DOM level, SFC decreased with increasing kernel thickness up to a thickness of 1.67 mm, after which it remained constant. As overall DOM level increased, the difference in DOM between thin kernels and thick kernels lessened.

INTRODUCTION

Milling is a mechanical procedure during which brown rice is subjected to abrasive and/or friction pressure to remove bran layers from the endosperm to yield white rice. This action is dependent on the surface-to-surface interaction of rice kernels. Bulk rice contains kernels of various sizes. The effect of kernel size on milling quality has been investigated (Matthews and Spadaro, 1976; Wadsworth et al., 1982; Sun and Siebenmorgen, 1993). However, in this earlier research, bulk rough rice was first separated into several thickness fractions, and each individual kernel fraction was then milled under controlled conditions. Matthews and Spadaro (1976) reported that breakage of milled rice was generally greater for thinner fractions, and the amount of bran removed in milling increased with decreases in kernel thickness for given milling durations. Wadsworth et al. (1982) found that the amount of removed bran was about the same across the thicker fractions while for thinner fractions, the amount of removed bran increased with decreasing thickness fractions. Sun and Siebenmorgen (1993) showed that head rice yield increased with increasing thickness, reached a maximum, and then decreased.

In the rice industry, rice is currently processed and milled as an unfractionated bulk. No research was found quantifying the degree of milling (DOM) of kernels with varying thicknesses milled as an unfractionated bulk. The objective of this project was to investigate the effect of kernel thickness on DOM during unfractionated milling.

PROCEDURE

Three long-grain rice cultivars, 'Alan', 'Newbonnet' and 'Katy', were used. The rice was procured from farm bins where it had been dried to approximately 11 to 13% moisture content (MC, wet basis). Each sample was first hulled using a commercial-scale Satake husker/paddy separator (model APS-30CX) and then milled in a single pass using a commercial-scale Satake mill (model BA-7). Samples were milled to low, medium and high DOM levels. Head rice was separated from brokens using a Satake test rice grader with a ϕ5.2mm long-grain screen. Using a Carter-Day precision sizer, the head rice was separated into five thickness fractions for Alan and Newbonnet and four thickness fractions for Katy.

The degree to which kernels were milled (DOM) was quantified by surface fat concentration (SFC) analyses. Surface fat of kernels from each thickness fraction, as well as from the unfractionated bulks, was extracted using a Soxtec System HT, which consisted of an extraction unit (model 1043) and a service unit (model 1044). A 5-g head rice sample was weighed into a cellulose extraction thimble (ϕ26 mm, length 60 mm) and dried in a convection oven at 100°C for 1 h. The thimble with the dried sample was then attached to magnets at the bottom of the condenser of the extraction unit. For surface extraction, the thimble was lowered to immerse the sample in 50 ml of petroleum ether (boiling point 35 to 60°C) in an extraction cup. The solvent was evaporated by circulating around the extraction cup a hot solution (mixture of 50 ml of mineral oil with 1 L of distilled water) supplied by the service unit. The vapor was condensed into the thimble to extract most of the surface fat from the head rice. This procedure was continued for 30 min. The thimble was then raised above the solvent surface and rinsed for another 30 min by the condensed solvent from the condenser to extract the remaining fat on the surface of the kernels. After rinsing, the fluid flow through the condenser was discontinued, and the solvent from the thimble was collected for 15 min. The extraction cup was dried at 100°C for 30 min to measure the amount of extracted matter, which represented the surface fat extracted. The SFC was the mass of the extracted matter expressed as a percentage of the original head rice mass (5 g). Two subsamples of each thickness fraction were measured for SFC.

RESULTS AND DISCUSSION

Figure 1 illustrates the mass distributions of the head rice for the three cultivars averaged across the three DOM levels, where thickness values represent the mean value of each thickness fraction range. Alan and Newbonnet had similar kernel thickness ranges (1.52-1.77 mm), with the major mass fraction being 1.67 mm (34.6% total mass) and 1.59 mm (48.4%), respectively. The thickness range for Katy (1.52-1.72 mm) showed the major mass fraction to be 1.59 mm (30.8%).

An analysis of variance was conducted in which thickness and DOM level were considered as two factors affecting SFC. Statistical F values related to thickness, DOM level and their interaction, as well as critical F values at the 0.05 significance level, are given in Table 1. As indicated in Table 1, thickness, DOM level and the interaction of these variables all had significant effects on SFC.

Figure 2 shows the change in SFC across thickness fraction for each of the three DOM levels for each cultivar. SFC was inversely and nonlinearly related to thickness. In general, but much more pronounced at low DOM levels, thinner kernels had higher SFC than thicker kernels. For Alan, the weighted average SFCs at the low and medium DOM levels were 0.89% and 0.74%, respectively, while the SFCs for the thinnest kernels (1.52 mm) at the corresponding DOM levels were 1.11% and 0.94%. The over-retained surface bran on the thinnest kernels may cause this fraction to behave differently in storage and/or subsequent processing operations compared to the predominant thicker kernel fractions.

SFC was also significantly influenced by the interaction between thickness and DOM level (Table 1). The change in SFC with kernel thickness was greatest at low DOM levels and least at high DOM levels (Fig. 2). For thicker kernels (>1.67 mm), SFC did not change with thickness at a given DOM level. For thinner kernels (<1.67 mm), SFC increased considerably with decreasing kernel thickness at low DOM levels. This increase diminished with increasing DOM level. It was apparent that, as the milling process progressed, thinner kernels were milled at a greater bran removal rate than thicker kernels, i.e., thinner kernels had a higher percentage of their original bran removed per unit of milling duration than the thicker kernels. By frationating bulk rice into several size fractions and milling each fraction separately for a given time period, Matthews and Sparado (1976) and Wadsworth et al. (1982) found that thicker kernels had less bran removed from the kernel surface than thinner kernels. This agreed with our findings, which were obtained by milling bulk, non-fractionated samples and then thickness fractioning the milled rice.

SIGNIFICANCE OF FINDINGS

DOM is important in determining the grade of milled rice as it may affect head rice yield, insect infestation, starch gelatinization, sensory quality and many other quality factors. This research has shown that during typical, unfractionated milling, the amount of bran left on thinner kernels can be very much higher than that left on the thicker kernels, which comprise most of the rice bulk. Thus, when rice is milled to an overall, bulk DOM, the thinner kernels may not be milled to this same level. This could have ramifications for end use processes that are affected by the DOM of kernels. This work indicates a need for further research on assessing kernel-to-kernel DOM differences in rice milled in various commercial milling systems. This research should also include an assessment of rice lots comprising a mixture of cultivars, in which a large spread in kernel size could exist.

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Table 1. Calculated F values (F) and critical F values at the 0.05 significance level ($F_{0.05}$) resulting from the analysis of variance of surface fat concentration as affected by kernel thickness and degree of milling (DOM) level.

Source of variance	Cultivar: Alan		Newbonnet		Katy	
	F	$F_{0.05}$	F	$F_{0.05}$	F	$F_{0.05}$
Thickness	55*	3.1	372*	3.1	62*	3.5
DOM level	690*	3.7	4319*	3.7	6487*	3.9
Interaction	8.7*	2.6	11*	2.6	26*	3.0

*Significant at 0.05 significance level.

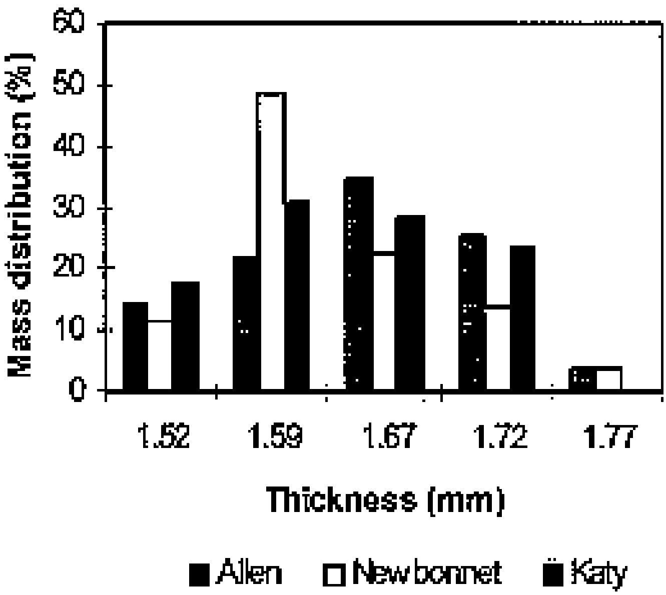

Fig. 1 Mass distribution among thickness fractions averaged across three degree of milling (DOM) levels for the indicated rice cultivars.

2 a
Alan

2b
Newbonnet

2c
Katy

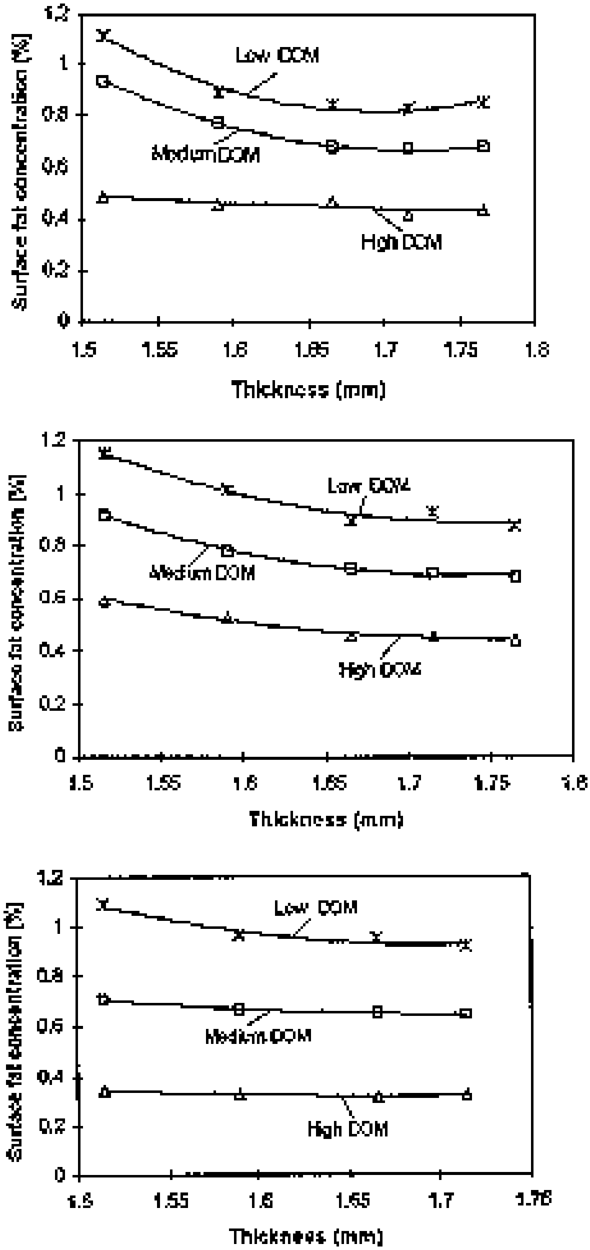

Fig. 2. Surface fat concentration of kernel thickness fractions at three degree of milling (DOM) levels for cultivars Alan (a), Newbonnet (b) and Katy (c) milled as an unfractionated bulk.

A MECHANICAL METHOD FOR DETERMINATION OF FISSURES IN MILLED RICE KERNELS

T.J. Siebenmorgen, Z.T. Nehus and T.R. Archer

ABSTRACT

A device was developed and tested for determining the extent of fissuring in milled rice samples. The device consisted of a roller mechanism that applied compressive pressure to each individual kernel, which resulted in breakage of the weaker, fissured kernels. After a sample was passed through the roller mechanism, the broken kernels were separated from the whole, unbroken kernels. In this manner, the effects of experimental treatments causing fissuring could be quantified without subjective, visual inspection of each individual kernel. Data taken from tests of the roller mechanism showed acceptably high precision, especially in tests of samples having a high percentage of fissured kernels. A second, identical mechanism was constructed in order to demonstrate the variability in performance among mechanisms. Statistical analysis of the data showed that there was not a significant difference between the two roller mechanisms.

INTRODUCTION

It is well known that rapid moisture content change, either through adsorption or desorption, will cause fissuring in rice kernels (Autrey et al., 1955). Kernel fissures typically result in kernel breakage during handling, packaging and subsequent processing. Since one of the primary quality indices in the rice industry is the percentage whole kernels, this consequence of fissuring is of foremost concern to processors. Additionally, fissures in unbroken kernels affect cooking and functionality characteristics and are, therefore, of concern to end use processors of rice as well.

The degree to which physical damage is incurred by a kernel during moisture sorption is indicated by the number and extent of fissures created in the kernel. Henderson (1954) indicated that fissured kernels do not necessarily break when milled. Thus, the presence of a fissure in a kernel is not a true measure of strength reduction.

Fissures can be "counted" by illuminating the kernel with a focused light source. Stermer (1968) employed this technique in developing an equation describing stress-crack damage as a function of change in equilibrium moisture content (due to changes in air temperature and relative humidity, RH) of milled rice kernels. This visual inspection of kernels is a slow, tedious process that lends itself to errors such as fissures that are unseen due to their small size or due to the kernel being oriented such that the light source does not illuminate the fissure.

A rapid and precise method of assessing the amount of damage incurred by experimental treatments causing fissuring was needed. The objective of this research was to develop a mechanical method to quantify the extent of fissuring damage incurred by milled rice kernels resulting from rapid moisture transfer treatments.

PROCEDURES

A 'roller' mechanism was developed and used to quantify fissuring damage incurred by milled rice after exposure to moisture adsorbing and desorbing environments. A schematic of the device is shown in Fig. 1. A single kernel feed mechanism (not shown in Fig. 1) was mounted just above the rollers and was used to meter rice kernels individually into the clearance between the rollers. The individual kernels were passed between the rollers by rotating one of the rollers using a gear motor. The compression force applied to each individual kernel while passing between the rollers resulted in breakage of the weak, fissured kernels.

The main components of the mechanism are two cylindrical rollers, each being 25 cm (9-7/8 in.) in length and 4.83 cm (2-7/8 in.) in diameter. One of the rollers was covered with a layer of neoprene rubber, 0.32 cm (1/8 in.) in thickness, with a durometer reading of 60. This covering provided a surface that would 'grip' the kernels and pull them between the two rollers. The second roller was composed of hard plastic.

Both roller axles were mounted to a frame. The bearing housing of the neoprene-covered roller axle was rigidly mounted to the frame. This roller was driven at 2.8 rpm by a 0.05-kW (1/15-hp) electric gear motor. The hard plastic roller axle was attached to slides that allowed it to move freely along the x-axis, as denoted in Fig. 1. At each end of this roller, a spring was placed against the bearing housing that secured the roller axle to the slide. Using a spring scale, each side of the "sliding" roller was adjusted (using spring compression) so that a 8.9-N (2-lb_f) force was required to displace the roller axle 0.0635 cm (0.025 in.) along the x-axis. The deflection of 0.0635 cm (0.025 in.) was chosen because trial run measurements indicated that this was a typical roller deflection when passing long-grain rice kernels between the rollers. The typical thickness of a long-grain kernel ranges from 0.1524 to 0.2032 cm (0.06 to 0.08 in.)

(Anonymous, 1995); however, kernels form a depression in the neoprene roller covering as they pass between the rollers.

Operation of the mechanism was as follows:

1) Up to 15 g of milled rice was loaded into the feed reservoir.
2) The rollers and the kernel feed mechanism were turned on.
3) Kernels were fed individually between the rollers at a rate of approximately 100 kernels per minute.
4) After the entire sample was passed through the rollers, head rice, those kernels three-fourths or more of the original kernel length, was removed from brokens.
5) The brokens percentage was calculated by dividing the mass of the broken kernels by the total sample mass and then multiplying by 100.

During this testing procedure, the mechanism was placed in an environment ranging in RH from 40 to 70%. This practice was predicated on the observation that in very low or high RHs, kernels awaiting testing in the feed reservoir would fissure due to exposure to either low- or high-RH air.

RESULTS AND DISCUSSION

Preliminary Testing

To evaluate the use of the roller mechanism as a device for indicating the extent of fissuring in milled rice, both extensively fissured and non-damaged kernels were initially tested. Milled long-grain rice ('Katy' cultivar) with no visible fissures was split into two lots; no treatment was applied to one of the lots, which represented non-damaged kernels, while the other lot was exposed to a severe moisture adsorbing environment (air at 90% RH, 30°C) that created visual fissures in all kernels inspected under a focused light source. Nine subsamples of approximately 12 g from each lots were tested in the roller mechanism.

For the samples with extensive fissuring, the average brokens percentage was 91.8% with a standard deviation of 1.47%. For the undamaged kernels, an average of 5.2% of the kernels broke with a standard deviation of 1.33%. The ideal situation would be one in which 100% of fissured kernels would be broken by the rollers, and none of the non-fissured kernels would break. Some fissured kernels may be able to withstand the force applied to them, which is supported by Henderson (1954), who indicated that fissured kernels do not always break when milled. Additionally, a bulk of rice kernels typically has a range of kernel sizes (Sun and Siebenmorgen, 1993). Even though these kernels may not have internal fissures, exposure to forces such as those applied by the rollers could break some of the immature, thinner kernels. The difference of approximately 87 percentage points to distinguish fissured rice from "good" rice was deemed acceptable to conduct further testing.

Sample-to-Sample Repeatability Tests

The repeatability of the device was subsequently tested. Two long-grain cultivars (Katy, with relatively small kernels, and 'Lemont', with relatively large kernels) were milled in a McGill No. 2 laboratory mill and then exposed to air conditions that caused various levels of fissuring in the kernels. The air conditions were a temperature of 30°C and six levels of relative humidity ranging from 29% to 55%. The samples were spread in thin layers and exposed to one of the air conditions for 20 min. Four samples from each level of fissuring were tested in the roller mechanism.

Figures 2 and 3 show the percent brokens for each of the four samples at each level of fissuring. For Katy (Fig. 2), the maximum difference in the percentage of brokens in each of the four-sample groups ranged from 2.09 to 7.26 percentage points across the six levels of fissure damage; the corresponding maximum differences for Lemont ranged from 0.64 to 10.43 percentage points. Most of the values were well within five percentage points of each other in each of the four sample groups. No trend was observed to indicate that repeatability changed dramatically across fissuring damage level. However, under very high fissuring levels, as shown in Fig. 3, there was little variability in brokens percentage. This is postulated to be due to the fact that the extreme moisture desorption environment of 30°C and 29% RH caused extensive fissuring in most all of the kernels, rendering all kernels very weak.

Mechanism-to-Mechanism Comparison Tests

In order to ascertain the uniformity of performance between mechanisms, an identical roller unit was constructed. Different levels of fissuring were produced in this instance by first gradually conditioning milled, long-grain samples of cultivars 'Newbonnet', 'Cypress' and Lemont to four moisture contents of approximately 12%, 13%, 13.5% and 14%. The samples were then exposed to an airstream at 30°C and 25% RH for 20 min. After exposure, four subsamples from each cultivar at each level of fissuring were tested in each of the two rollers, denoted as roller #1 and #2.

Figure 4 compares the two roller mechanisms using the three cultivars at each of the four fissuring levels. The top of each bar represents the average brokens percentage of the four subsamples at a given level of fissuring, as measured in each roller. As was the case in Figs. 2 and 3, the variability in brokens percentages was lowest when the extent of fissuring was very high, as indicated in Fig. 4b and 4c. A statistical analysis (α=0.05) performed on the data in Fig. 4 showed that there was no significant difference between the means of the two roller mechanisms in all 12 comparisons. Therefore, the roller mechanism appears to be reproducible.

SIGNIFICANCE OF FINDINGS

The results of this testing have indicated that the roller mechanism described herein was satisfactorily precise in indicating the extent of fissuring in long-grain milled rice kernels. The data showed that the mechanism was particularly precise when the extent of fissuring was very high. A comparison of two identically constructed roller mechanisms showed that reproductions of the unit performed similarly in measuring the extent of fissuring.

This mechanism provides a repeatable method to quantify the amount of fissuring incurred by milled long-grain rice kernels. The device is being used to evaluate the damage resulting from exposing milled rice to various environments for various durations.

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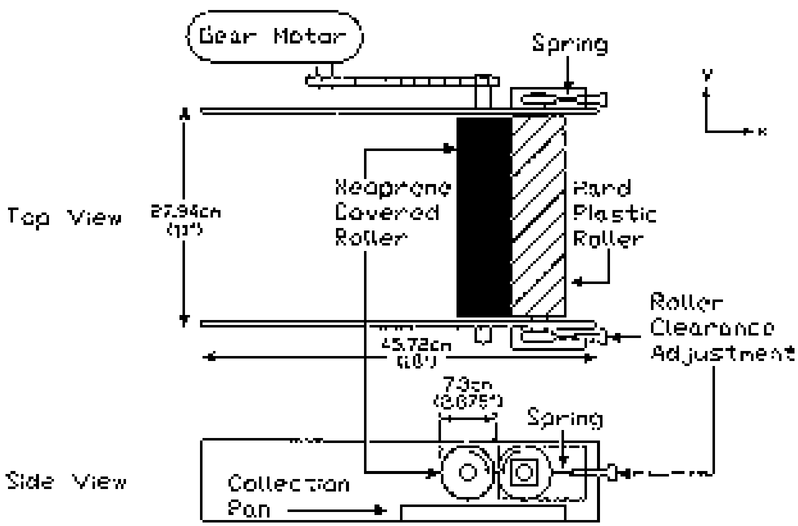

Fig. 1. Roller mechanism used for measuring the extent of fissuring in milled rice kernels.

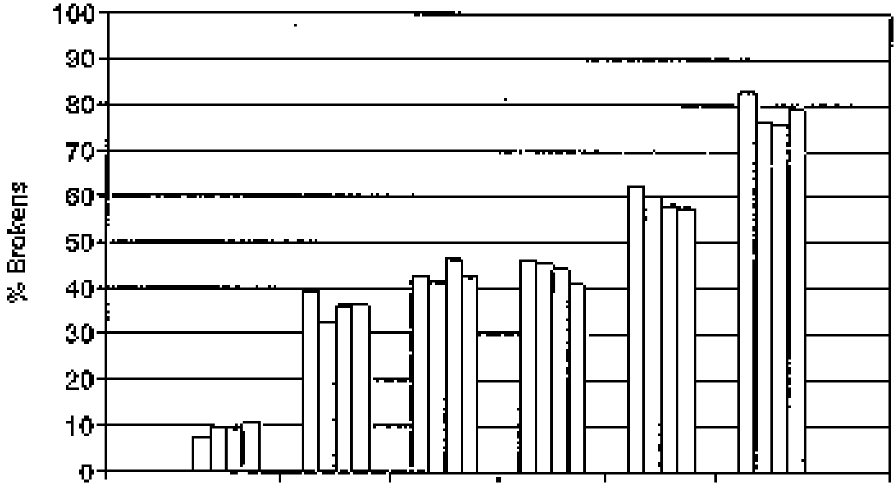

Fig. 2. Repeatability test results of a roller mechanism using 'Katy' long-grain rice at six levels of fissure damage.

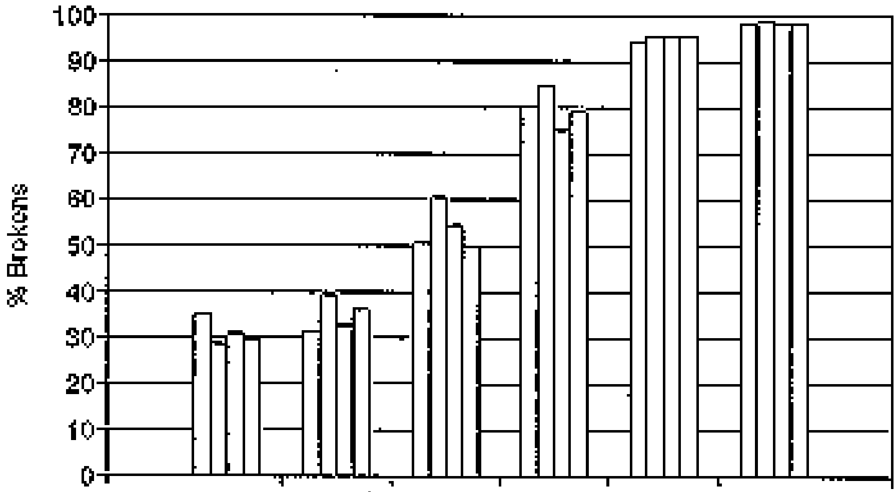

Fig. 3. Repeatablity test results of a roller mechanism using 'Lemont' long-grain rice at six levels of fissure damage.

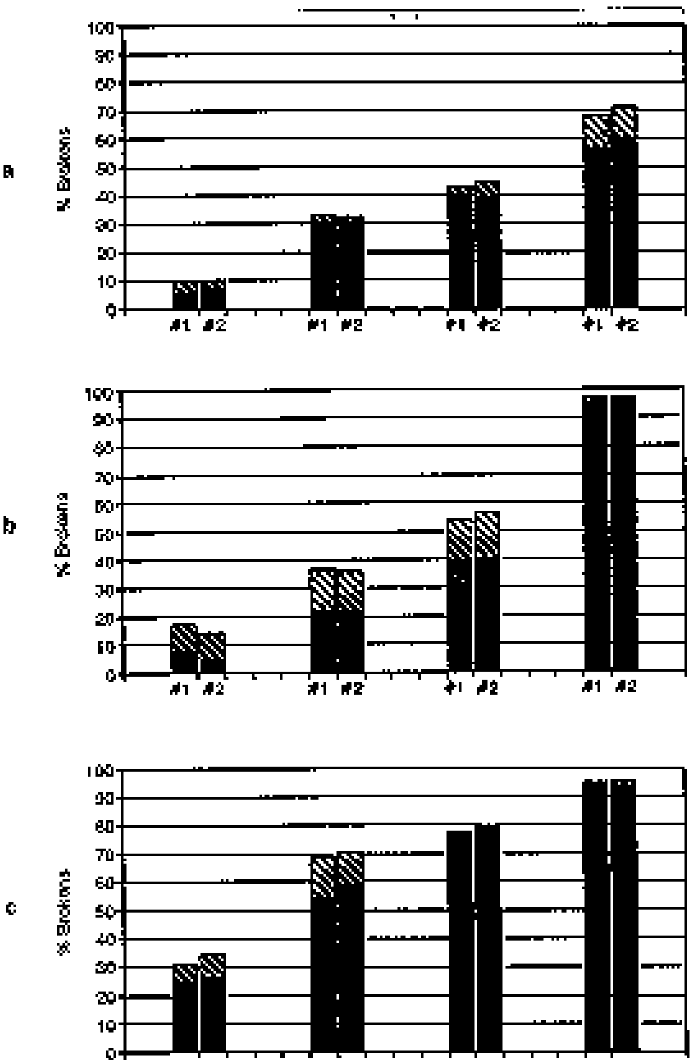

Fig. 4. Test of repeatability between roller mechanisms (#1 and #2) using: a) 'Newbonnet', b) 'Cypress' and c) 'Lemont' long-grain rice. The top of each bar represents the mean brokens percentage of four subsamples. Cross-hatching indicates the standard deviation of the mean brokens percentage level.

COMPLETED STUDIES

DISTRIBUTION OF MICROBIAL LOADS AMONG RICE KERNEL COMPONENTS

D.S. Skyrme, B.P. Marks, M.G. Johnson and T.J. Siebenmorgen

ABSTRACT

Nine lots of long-grain rice were milled, and the rice components (hulls, bran, rough, brown, broken, head and white rice) were segregated. Serial dilutions of ground samples were conducted to determine aerobic plate counts (APC) and coliform counts. The mean APCs from the hulls were significantly greater than those from all other components except rough rice, and the mean APCs from the rough rice and bran were significantly greater than those from the brokens, which were significantly greater than those in the head rice and white rice (i.e., brokens and head rice). Additionally, the mean coliform counts from the bran were significantly greater than those from all other components, and the mean coliform counts from the rough rice and hulls were significantly greater than those from the brokens, head rice and white rice.

INTRODUCTION

This research was instigated by the increasing demand for rice processors to meet tight microbial specifications for aerobic plate counts (APC) (e.g., <10,000 cfu/g) and for coliform counts (e.g., <100 cfu/g) as requested by some rice flour customers. Anecdotal evidence provided to the authors by commercial mills has indicated a consistent annual trend where bacterial counts in rice flour are typically not within the microbial specification from harvest to late spring (September through April) but are within the microbial specification during the summer months (May through August). One hypothesis for the cause of this trend was that colder weather inhibits adequate separation of bran in the process stream. An additional hypothesis was that the drop in bacterial counts during the summer months could result from bacterial senescence caused by stress from the low water activity environment of dry rice storage. The research reported here is part of an overall project directed at testing these two hypotheses.

Rice flour is manufactured from milled white rice brokens, which can typically be 15% of initial rough rice weight. Rice flour has been used in pancake and waffle mixes, in baby foods as a cereal and as a thickening agent, in extruded products as an ingredient and in refrigerated biscuit dough as a dusting or anticaking agent (James and McCaskill, 1983). Given that rice flour is typically used as an ingredient in value-added food products, rice processors are increasingly concerned with the microbial counts in this ingredient.

Previous research directed at cereal microbiology has focused on control of the microflora, mainly fungi, during storage (e.g., Cahagnier et al. 1993; Rao 1992). It is fairly well known that the main factor contributing to spoilage of high-moisture rice is fungi developing from spores inherent in the rice production and harvesting systems. Drying of rough rice below the moisture content needed for fungi to grow (i.e., ~ 13%) is the most effective and widely used method to preserve the quality of rice. However, little research has focused on other components of the microflora within stored, low-moisture cereal grains.

Ueda and Kuwabara (1988) reported on contamination levels of *Bacillus cereus*, the leading cause of bacterial food poisoning associated with rice (Beuchat, 1978), and the total viable bacteria counts for rough rice, hulls, bran, brown rice and white rice throughout the milling process. They showed significant differences in the total viable bacteria counts between rough rice and white rice as well as between brown and white rice. Currently, rice processors are interested in reducing the microbial contamination in polished rice, specifically polished broken kernels. Consequently, the specific objective of this study was to quantify the distribution of both APC and coliform counts, among all of the major components of long grain rice components (hulls, bran, rough, brown, broken, head and white rice).

PROCEDURES

Nine 23-kg lots of long-grain rice were randomly sampled from incoming trucks at a commercial rice processing facility (three trucks per week for three weeks). The rice was shipped each week to the Rice Processing Laboratory at the University of Arkansas, where it was stored at 4°C for up to three weeks to preserve the rice before testing. Each lot was allowed to equilibrate to room temperature for 24 hours before separating four 150-g sub-samples via a No. 34 Boerner divider (Seedburo Co., Chicago, Illinois).

Oven moisture content (MC), head rice yields (HRY), degree of milling (DOM) and water activity were determined for each lot. The oven tests were conducted in duplicate by drying 20- to 25-g samples at 130°C for 24 hr (Jindal and Siebenmorgen, 1987). The HRY's for each lot were determined by hulling and milling 150 g of rough rice using a laboratory huller and a McGill No. 2 laboratory mill, with the lever arm length at 15 cm and a milling time of 30 sec. HRY is the weight basis percentage of rough rice that remains as head rice after the milling process. Head rice is defined as a rice kernel that is three-quarters the original length of the whole kernel (USDA, 1979). The DOM's were measured by the Satake Milling Meter model MM-1B (Satake Inc., Houston, Texas). The Satake milling meter determines a numeric value between 0 (for brown rice) to 200 (for extremely well milled white rice) based on the transmittance and reflectance properties for a 50-g sample of rice. The water activities (a_w) were measured by a water activity meter (Rotronic Hygroskop DT, Rotronic Instrument Corp., Huntington, New York) and indicate whether microbial growth is possible on a given rice sample.

To generate the materials for the microbial assays, two 150-g subsamples from each lot were hulled in a Satake Rice Machine (laboratory huller), milled in a McGill No. 2 laboratory mill and separated into head rice and brokens by a Seedburo shaker-sizer. During the milling process, approximately 30 g of hulls, bran, brokens, brown, head, rough and white rice were separated and placed into sterile bags for microbial assays. Between each milling, the surfaces of the milling equipment and trays were cleaned by rinsing and wiping with 70% ethanol to minimize any cross contamination between the lots.

After milling and sample collection, 10 g of each component sample was mixed with 90 ml of Butterfield phosphate buffer (Speck, 1976) and mixed in a Waring blender on the high speed for 30 sec. Successive dilutions were made by transferring 10 ml of the suspension medium to 90 ml of buffer solution. Because the amount of contamination was initially unknown, the components were plated in duplicate using dilutions from 10^{-1} to 10^{-6} on Petri-Film™ (3M, Minneapolis, Minnesota) specific for APC and coliform determinations. Coliform films were counted after 24 hours, and APC films were counted after 48 hours.

Surface sterilization tests were performed on the brokens from lots 1-3. The broken samples from lots 1-3 were mixed together and subjected to a 30-sec wash in water and a 30-sec wash in NaClO solutions at concentrations of 5%, 2.5% or 1%. After samples were treated, they were plated in duplicate on Petri-Film specifically for coliform count and APC determinations as previously mentioned.

The statistical analyses of the resulting data were conducted via SAS/STAT™ (SAS Institute, Cary, North Carolina). The effects of rice component, MC, HRY, DOM and a_w on APC and coliform counts were evaluated by analysis of variance for a five-way classification. A Duncan multiple range test was used to determine any significant differences within the kernel components for both APC and coliform counts.

RESULTS AND DISCUSSION

The MC, HRY, DOM and a_w for each lot are reported in Table 1. The nine lots had typical characteristics for incoming rice at a commercial rice processing facility

Rice component was the only significant variable ($P < 0.05$) related to either APCs or coliform counts. The r^2 values for the analysis of variance were 0.84 and 0.61 for APC and coliform counts, respectively.

Table 2 shows the results of the Duncan multiple range test with corresponding means and standard deviations for APC and coliform counts. The mean APCs in hulls were significantly ($P < 0.05$) greater than in all other components expect rough rice, and the mean APCs in the rough rice, brown rice and bran were significantly ($P < 0.05$) greater than those in the brokens, which were significantly ($P < 0.05$) greater than those in the white rice and head rice. These results are consistent with Ueda and Kuwabara's (1988) findings, which showed a reduction in bacterial contamination from rough rice to brown rice to white rice. Figure 1 shows the logarithmic microbial distribution in the kernel components for APCs. The mean coliform counts in the bran were significantly ($P < 0.05$) greater than those in all other components expect hulls, and the mean coliform counts in the hulls, brown rice and rough rice were significantly ($P < 0.05$) greater than those in the brokens, head rice and white rice. Figure 2 shows the logarithmic microbial distribution in the kernel components for coliform counts.

Because the bran had more coliforms and APCs than did the other components, better separation of the bran, particularly from brokens, would promote less contaminated rice flour with respect to APC and coliform counts. However, even with sufficient bran removed from the brokens in the laboratory, none of the nine lots would have satisfied an APC specification of <10,000 cfu/g, and only seven of the lots would have satisfied a coliform specification of <100 cfu/g.

The results from the surface sterilization tests are listed in Table 3. If the bacterial contamination was entirely on the surface of the broken rice kernel, one would expect significant differences in the mean APCs between the control sample and samples rinsed in NaClO solutions. The mean APCs from the broken rice rinsed in the NaClO solution were significantly ($P < 0.05$) lower than those from the control or water rinse. However, the mean APCs from the broken rice rinsed with the NaClO solutions did not drop to met a APC specifications of <10,000 cfu/g. With respect to coliforms, both the water and NaClO washes resulted in significant ($P < 0.05$) drops in counts. Internal contamination appears to exist with respect to APCs, which will help determine the type of possible sterilization methods rice processors could test to control bacterial contamination in rice flour.

Future research should develop a means to produce rice flour that is acceptable to customers throughout the year. Also, further investigation needs to determine the effect of storage conditions on the microbial loads in rice components, which may explain the seasonal changes in observed microbial loads in rice flour.

SIGNIFICANCE OF FINDINGS

The results of this study indicate that viable bacteria are present throughout the entire rice kernel. This is particularly important information as broken rice is milled into rice flour for value-added consumer food products. In order to ensure that this market for broken rice continues to expand, and the value of broken rice subsequently increases, processors need to know how to minimize bacterial counts in order to satisfy end users of the rice flour. The information presented in the report should help in developing the means to achieve these goals.

ACKNOWLEDGMENTS

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Table 1. Moisture contents, HRYs, DOMs and water activity (a_w) measurements (means of duplicate measurements) for each of the nine lots included in the study.

Lot #	Moisture content	Head rice yield	Degree of milling	a_w
	%	%		
1	13.49	58.5	99	0.628
2	12.48	53.5	97	0.618
3	14.87	52.1	108	0.760
4	13.51	55.3	102	0.628
5	13.67	48.9	97	0.606
6	13.31	53.5	106	0.641
7	11.13	58.7	84	0.403
8	12.08	49.7	103	0.512
9	12.22	53.3	97	0.547

Table 2. Results from the Duncan multiple range test, with corresponding means and standard deviations.

	Aerobic Plate Counts, log(cfu/g)			Coliform Counts, log(cfu/g)		
N	Kernel Component	Duncan Grouping	Mean± Std. Dev.	Kernel Component	Duncan Grouping	Mean± Std. Dev.
9	Hulls	A*	8.13±0.40	Bran	A	3.85±0.78
9	Rough	A,B	7.75±0.21	Hulls	A,B	3.20±1.05
9	Bran	B	7.49±0.35	Brown	B	2.40±0.53
9	Brown	B	7.25±0.38	Rough	B	2.32±0.76
9	Broken	C	5.69±0.70	Broken	C	1.14±1.05
9	White	D	4.61±0.83	Head	C	0.93±1.31
9	Head	D	4.29±0.91	White	C	0.88±1.00

*Rice components with different Duncan grouping letters are significantly different at $\alpha = 0.05$.

Table 3. Results from the surface sterilization tests on broken rice from lots 1-3.

Sample Treatment	APC log(cfu/g) Mean ± Std. Dev.	Coliforms log(cfu/g) Mean ± Std. Dev.
Control	5.85±0.03	2.11±0.07
30s wash w/H20	5.87±0.02	0.0±0.0
30s wash w/1% NaClO	4.90±0.01	0.0±0.0
30s wash w/2.5% NaClO	5.46±0.17	0.0±0.0
30s wash w/5% NaClO	5.57±0.02	0.0±0.0

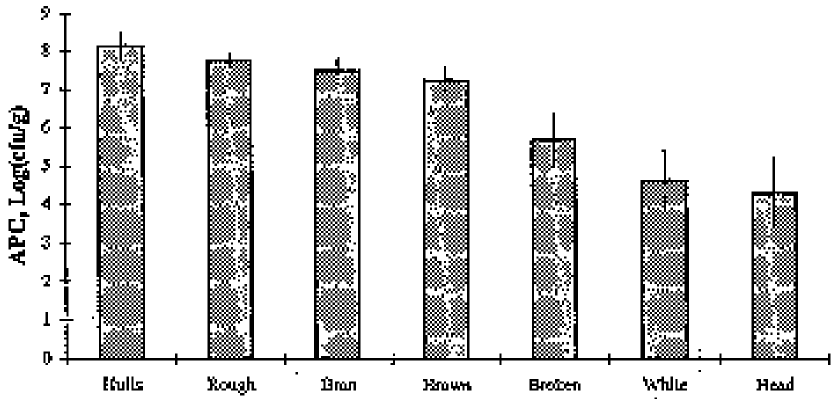

Figure 1. Total aerobic bacterial plate count (APC) distribution in long-grain rice. Bars show ± standard deviation.

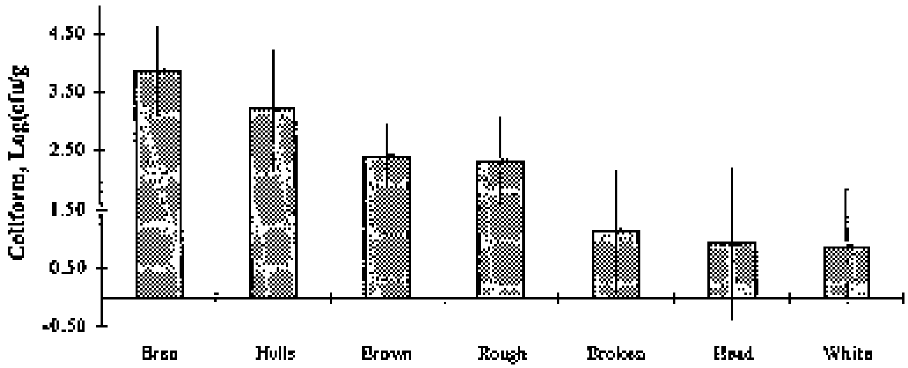

Figure 2. Coliform bacterial distribution in long-grain rice. Bars show ± standard deviation.

COMPLETED STUDIES

RICE WATER WEEVIL INFESTATION IN WATER- AND DRILL-SEEDED RICE

J.L. Bernhardt

ABSTRACT

An experiment was conducted to determine if rice water weevils responded differently to two methods of rice culture, water- and drill-seeded rice, and if current threshold recommendations for carbofuran application were adequate. Rice water weevil adult and larval infestations were different in the two seeding and rice culture methods. Infestation pattern was normal for drill-seeded rice, i.e., peak infestation about 3 weeks after permanent flood and a steady decline thereafter. Water-seeded rice had a different pattern. Rice water weevil adults located, infested and deposited eggs in water-seeded rice soon after permanent flood was established. Yet peak densities of larvae were found shortly prior to internode elongation in both rice culture methods. Grain yield was lower in the water-seeded plots. Treatment with carbofuran, when timed according to recommendations, reduced rice water weevil larvae. However, a treatment timed by the amount of adult leaf scarring reduced larvae by 50% yielded only 207 lb/acre more grain than the untreated rice. Truly puzzling was the treatment timed with larvae per core that reduced larvae by 70 to 80% yet produced only 42 lb/acre more grain than the untreated. Clearly a better understanding of an interaction among cultivars, rice water weevil infestation, economic thresholds and damage is needed.

INTRODUCTION

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is an insect pest normally found in all Arkansas rice fields. Although feeding on leaves by overwintered adults is commonly found on non-flooded rice, adults are attracted to flooded rice. Oviposition occurs only in flooded rice, where eggs are placed inside a submerged portion of the leaf sheath. Larvae must exit the leaf sheath, sink, enter the soil and find rice roots. Root-pruning results in stressed plants that are unable to receive adequate nutrients from the soil until new roots appear. As a consequence, severely stressed plants will produce less grain.

Drill-seeded rice with delayed flood allows root and vegetative growth to the four- to five-leaf stage before application of the permanent flood. In contrast, water-seeded rice provides the rice water weevil with partly submerged, small plants with a less developed root system (Beyrouty et al., 1994). Water-seeded rice has an earlier infestation of rice water weevils (Bernhardt, 1994) and likely suffers pruning to the small root system. Water-seeded rice also is attractive to rice water weevils for a longer time (~ 3 to 4 weeks). Rolston and Rouse (1964) found 3.5 and 8.5 times as many weevil larvae in water-seeded plots as in drill-seeded plots 8 and 12 weeks, respectively, after seeding rice in a Crowley silt loam. An explanation for higher numbers of rice water weevils in water-seeded rice was provided by Bang and Tugwell (1976). They found that rice water weevil adults preferred rice plants up to 30 to 40 days old for feeding and oviposition. As a result of more weevils over a longer period of time, water-seeded rice may have a lower grain yield. For example, untreated water-seeded 'Lemont' rice plots averaged 33% less grain than did drill-seeded Lemont plots (Bernhardt, 1994).

Objectives of this study were to compare the infestation levels of rice water weevils, to measure any influence on grain yield in untreated drill- and water-seeded 'Cypress' rice and to compare water weevil infestation and grain yields of untreated water-seeded rice to plots where carbofuran (Furadan 3G) was applied when currently recommended thresholds of rice water weevil larvae and leaf-scar counts had been reached or exceeded.

PROCEDURES

The comparison of rice water weevil infestation in water- and drill-seeded rice was conducted at the Rice Research and Extension Center near Stuttgart, Arkansas. The experiment had a randomized complete block design with four treatments and four replications. Plot areas for the water-seeded rice were cultivated, nitrogen (150 lb N/acre as urea) incorporated, grooved to prevent seeds from wind or wave dispersal, and treated with thiobencarb (Bolero) at 3 lb ai/acre. Pre-sprouted 'Cypress' rice (140 lb/acre) was broadcast into water over each 4.7 x 22-ft area on 30 May. After four days the water level was lowered to allow seedling establishment. Permanent flood was applied 10 June and gradually increased. A single supplemental nitrogen application of 30 lb N/acre as urea was made on 22 July to the water-seeded plots. Each plot was bound by levees. Water levels were maintained at a 5-in. depth.

Plots similar in size to water-seeded plots were drill-seeded (7-in. spacing) on 20 May with Cypress rice at a rate of 90 lb/acre. Rice emerged on 31 May. A single application of propanil (Stam, 3 lb ai/acre) and thiobencarb (Bolero, 2 lb ai/acre) in a tank mix was applied to the drill-seeded rice on 14 June. A recommended three-way split of nitrogen (90-30-30 lb N/acre as urea) was applied preflood on 24 June and during midseason on 14 and 22 July. Each plot was bound by levees. Permanent flood was applied on 24 June.

Rice water weevil larvae were monitored each sample date by removing three soil/plant cores (4-in. diameter x 4-in. depth) from each plot. Soil surrounding the roots was washed into 40-mesh sieves. The sieves were emersed in salt water, which caused the rice water weevil larvae to float. Each sample was examined for the presence and number of rice water weevil larvae and pupae. Samples in the water-seeded plots were taken on 21 June, about two weeks after rice plants emerged from the water, and continued weekly for six weeks. Samples were taken on 13 July, about three weeks after permanent flood, in the drill-seeded plots and continued weekly for four weeks.

Leaf-scar counts were taken every three to four days after permanent flood in treatment 2 of the water-seeded plots. Carbofuran was applied at a rate of 0.6 lb ai/acre on 23 June after leaf-scar counts exceeded 60% of plants with a new scar. Carbofuran was applied at a rate of 0.6 lb ai/acre to treatment 3 of the water-seeded plots on 30 June when larval counts exceeded an average of 10 larvae/core. Untreated water-seeded plots were designated treatment 1, and untreated drill-seeded plots were designated treatment 4.

Prior to harvest the number of panicles per square foot was determined in each plot. Fifteen feet of the center four rows of each drill-seeded plot and a comparable area (35 ft^2) in the water-seeded plots were harvested with a small plot combine on 10 October. Reported yields were corrected to 12% moisture.

RESULTS AND DISCUSSION

Rice Water Weevil Populations

The pattern of infestation of rice water weevils, as indicated in the untreated plots, was different in the two rice production methods (Table 1). As expected, rice water weevil adults infested water-seeded rice within one week after permanent flood was established. Rice plants had two leaves at that time. Core samples taken two weeks after permanent flood in the water-seeded plots had low densities (1/core) of larvae. Each weekly sample thereafter had a higher density until a peak density of 40 larvae/core was recorded five weeks after permanent flood. Densities declined each week thereafter. In contrast, a peak density of 24.9 larvae/core was recorded three weeks after permanent flood in the drill-seeded rice. However, for both rice culture methods, the peak density of larvae was approximately one week prior to internode elongation. At that time rice plants were about 40 days old. After that age rice plants have been reported to become less attractive and/or larval survival declines (Bang and Tugwell, 1976). Densities of larvae gradually declined after peak occurrence. Not only did rice water weevil infest water-seeded plants soon after permanent flood, but plants were exposed to above-threshold larval densities for more than seven weeks. Drill-seeded plants were exposed to rice water weevil infestation for six weeks, but plants were in the four- to five-leaf stage before infestation.

The number of panicles per square foot was 24 in the drill-seeded rice and 28 in the water-seeded rice. Yet the untreated, water-seeded plots averaged 720 lb less grain per acre than did the drill-seeded plots. Rice water weevils contributed to the yield reduction.

Carbofuran Treatments

Leaf-scar counts surpassed 60% of plants with a new scar on 22 June. At that time rice water weevil larvae found in core samples taken on 21 June, approximately two weeks after permanent flood in water-seeded rice plots, were small in size and density (Tables 1 and 2). After carbofuran application, the increase in larval densities was not as great as that in the untreated (Table 1). Average larval densities before and at peak density were 50% of those in the untreated plots. Peak infestation occurred during the same week as the untreated plots. After a peak density, larval densities began to decrease and were equivalent in size in both treated and untreated plots. An early application of carbofuran applied at the recommended leaf-scar threshold did not lower rice water weevil larvae below the current larval threshold. Yields of the untreated and treated plots differed by 208 lb of grain/acre but were not statistically different.

Larval counts surpassed the recommended treatment threshold of 10/core on 29 June. After a carbofuran application on 30 June, larval densities remained below threshold for the next five weeks. Average densities were 70-80% less than in the untreated plots for three weeks after treatment. The application of carbofuran applied at the recommended larval threshold reduced rice water weevil larvae numbers below the recommended treatment density. However, yields of the untreated and treated plots differed by only 42 lb of grain/acre and were not significantly different.

A yield difference of 720 lb between water- and drill-seeded rice was within the range established by Tugwell and Stephen (1981). In that study, a range of 140 to 540 lb/acre was lost when rice water weevil larvae numbered 10 larvae per core sample. One larva per core is then assumed to cause losses of 14 to 54 lb/acre. In this study, at peak density a difference of 15.5 larvae/core was found between the two rice cultures. The estimated yield loss would then be between 217 and 837 lb/acre. The 720-lb difference falls within the range established in the earlier study.

Using the estimates from the 1981 study, yield losses for the treated water-seeded rice should be between 281 and 1085 lb/acre for that treated two weeks after permanent flood and between 421 and 1625 lb/acre for that treated three weeks after permanent flood when using 10.3 larvae/core as the peak density. Differences between untreated and treated rice of 208 and 42 lb/acre for plots treated at two and three weeks after permanent flood, respectively, clearly do not fall within the expected difference estimates. Definite reasons for the discrepancies are unknown. A possible explanation is that Cypress could have excellent recovery from damage, such as that in the untreated plots, caused by high densities of rice water weevil larvae. Clearly more research is needed on rice cultivars that are water seeded, and perhaps revised economic thresholds and economic injury levels for rice water weevils in water-seeded rice are needed.

SIGNIFICANCE OF FINDINGS

Rice water weevil adults respond differently to drill- and water-seeded rice. Rice water weevil adults located, infested and deposited eggs in water-seeded rice soon after the plants emerged from the water. Densities in untreated rice of both culture methods peaked shortly before internode elongation when plants were at least 35 days old. Compared to that of drill-seeded rice, yield was significantly lower in water-seeded rice when neither was treated to control rice water weevils.

Treatment with carbofuran, when timed according to recommendations, reduced rice water weevil larvae. However, a treatment timed by amount of adult leaf scarring reduced larvae by 50% or more yet produced only 207 lb/acre more grain than the untreated. Truly puzzling was the treatment timed with larvae per core that reduced larvae by 70 to 80% yet yielded only 42 lb/acre more that the untreated. Clearly a better understanding of an interaction among cultivars, rice water weevil infestation, economic thresholds and damage is needed.

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Table 1. Average number of rice water weevil larvae per sample and grain yields from plots of untreated drill- and water-seeded 'Cypress' rice and water-seeded rice treated with carbofuran at Stuttgart, Arkansas, 1996.

Seeding method	Treatment	Date of Sampling 6/21	6/29	7/7	7/13	7/20*	7/28	8/3	8/11	Grain yield
										lb/acre
Drill -Seeded*†	-				24.9	23.2	16.7	8.3	6.8	6647
Water-Seeded‡	-	1.2	12.3	33.9	40.4	18.6	10.3	5.3		5927
Water-Seeded	2 wk apaf§	1.0	5.3	16.4	20.3	16.8	12.6	8.0		6134
Water-Seeded	3 wk apaf	1.2	10.3	6.7	6.7	5.7	8.9	5.5		5969
										NS¶

*0.5-in. internode elongation occurred prior to the 20 July sample date.
†permanent flood applied 24 June.
‡permanent flood applied 10 June.
§apaf = after permanent flood treated with carbofuran at 0.6 lb AI/acre.
¶NS = not significant.

Table 2. Percentage size distribution of immature rice water weevils from untreated plots of water-seeded and drill-seeded rice, Stuttgart, Arkansas, 1996.

Size or stage of rice water weevil immatures	6/21 WS*	6/29 WS	7/7 WS	7/13 WS	7/13 DS	7/20 WS	7/20 DS	7/28 WS	7/28 DS	8/3 WS	8/3 DS	8/11 DS
Very Small		18	15	13	25	15	7	7	12	15	13	0
Small	80	54	26	23	24	22	19	21	22	16	19	11
Medium	20	22	24	17	17	22	22	15	22	15	19	28
Large		6	30	35	34	16	46	55	38	52	44	59
Pupae			5	13	0.5	5	6	2	6	2	5	1

*WS = water-seeded rice, DS = drill-seeded rice.

COMPLETED STUDIES

QUANTIFYING SURFACE FAT CONCENTRATION OF MILLED RICE VIA VISIBLE/NEAR-INFRARED SPECTROSCOPY

H. Chen, B.P. Marks and T.J. Siebenmorgen

ABSTRACT

Three long-grain rice cultivars were divided into two sample sets, with 100 samples for calibration and 62 samples for prediction. Spectra in the visible (400-700 nm) and near-infrared (1500-2500 nm) ranges were the most sensitive to surface fat concentration (SFC). Optimal calibration and prediction were obtained by combining the two ranges, and using the modified partial least squares technique on the spectra pretreated by standard normal variate and first derivative. The best calibration yielded a coefficient of determination (R^2) of 0.99 and standard error of prediction of 0.04% for SFC, which was approximately 1.5 times the standard error of calibration and SFC measurement error.

INTRODUCTION

Degree of milling (DOM) is a term used to describe the extent to which rice bran has been removed from brown rice during milling. Surface fat concentration (SFC) is most frequently used as a chemical measure of DOM. Optical or spectroscopic test methods are likely to be better methods for rapid analysis of DOM. Stermer (1968) found, in the wavelength range of 500 to 1000 nm, that the greatest changes in transmittance due to milling occur at 660 nm (red color wavelength) and 850 nm (near-infrared). The ratio of light intensity transmitted at these two specified wavelengths was related to color and DOM quantified by surface fat concentration, with a correlation coefficient of 0.93 and 0.88, respectively. Because such an optical system is based merely on the information from one or two wavelengths, some relevant information hidden in other wavelengths are possibly missing. It is expected that near-infrared (NIR) spectroscopy, which uses the information from a whole wavelength range, would provide a more accurate means for measuring DOM.

A small amount of previous work has been published in the area of DOM measurement using NIR spectroscopy. It was conducted in the wavelength ranges of 1100 to 2500 nm (Wadsworth et al., 1991) and 450 to 1048 nm (Delwiche et al., 1996). By means of the partial least squares method, calibration equations were established with very high correlations (>0.9) for both the DOM expressed as percentage bran removal (Wadsworth et al., 1991) and the optical DOM measured by a Satake MM-1B milling meter (Delwiche et al., 1996).

These previous calibrations were based on physical (i.e., mass weight removed) or optical definitions of DOM. In contrast, for further processed products, a chemical definition (i.e., surface fat concentration) is more important for product functionality and value. However, no reliable NIR calibration has yet been published specifically for surface fat on rice. Consequently, the objective of this project was to develop calibration equations for evaluating surface fat concentration in milled rice.

PROCEDURES

Sample preparations

Three long-grain rice cultivars ('Alan', 'Newbonnet' and 'Katy') were acquired from a commercial processor at approximately 11 to 13% moisture content (MC, wet basis). Prior to milling tests, the grain of each cultivar was cleaned in a dockage machine, and randomly separated into two sets. In set one, Alan, Katy and Newbonnet were milled to 39, 35 and 38 different DOM levels, respectively, in either a commercial-scale Satake mill (model BA-7, for Alan and Katy) or a McGill No. 2 rice mill (for Newbonnet). Set two was milled to three DOM levels (low, medium and high) in the Satake model BA-7 mill. Head rice was separated into five thickness fractions (1.52, 1.59, 1.67, 1.72 and 1.77 mm) for Alan and Newbonnet, and four thickness fractions for Katy (1.52, 1.59, 1.67 and 1.72 mm).

Visible/Near-Infrared Testing

After milling, samples were scanned in a scanning monochrometer (NIRSystems 6500; Perstorp Analytical; Silver Springs, Maryland). For each sample, approximately 100 g of milled rice was poured into a rectangular cell, presented to the instrument in transport mode and scanned (reflectance) from 400 to 2500 nm at 2-nm intervals. Each sample was scanned 25 times, and the average spectrum was stored in a computer for calibration development.

Surface fat extraction

The SFC of 324 samples (162 rice samples x 2 replications) was determined using a Soxtec System HT. Prior to extraction, 5 g of head rice was weighed into a cellulose extraction thimble (diameter 26 mm, length 60 mm) and dried in a convection oven at 100°C for 1 hr. Surface fat was extracted for 1 hr with 50 ml of petroleum ether (boiling point 35 to 60°C). The SFC was the weight of the surface fat expressed as a percentage of the original head rice mass (5 g).

Calibration and Prediction

Commercial spectral analysis software (ISI International, 1995) was used to process spectral and SFC data. From the two sample sets, 100 samples were randomly pulled out as a calibration set, and the remaining 62 samples were used as a prediction set. In order to develop calibration equations, the spectra of the calibration set were first pretreated via scatter correction and spectral derivatives (ISI International, 1995). Three scatter correction methods, referred to as standard normal variate (SNV), Detrend and multiplicative scatter correction (MSC), were compared. First and second derivative treatments were also evaluated. Multilinear regression techniques were performed on the pretreated spectra and associated SFC and included stepwise, principal component (PCA), partial least squares (PLS) and modified partial least squares (MPLS) regression methods (ISI International, 1995). Calibration accuracy was evaluated by the coefficient of determination (R^2) and the standard error of calibration (SEC) (Marks and Workman, 1991). Once developed, the calibration equations were applied to the independent prediction set for validation. Prediction accuracy was evaluated in terms of the standard error of prediction (SEP) (Marks and Workman, 1991).

RESULTS AND DISCUSSION

Figure 1 shows an example of a visible/NIR reflectance spectra of three Alan samples milled to SFCs of 0.3%, 0.72% and 0.95%, respectively, where R denotes reflectance and log(1/R) is defined as absorbance. Major changes due to SFC occurred mainly in the wavelength ranges of 400-700 nm and 1500-2500 nm. Four wavelength ranges were compared for optimal calibration and prediction (Table 1). Of the four wavelength ranges, the visible range (400-700 nm) resulted in the highest (i.e., worst) SEC (0.04%) and SEP (0.07%). The NIR range (1500-2500 nm) improved the SEC and SEP to 0.03 and 0.05%, respectively. The best calibration and prediction were obtained by the combined visible/NIR wavelength range (400-700 nm and 1500-2500 nm). Extending the combined wavelength range to entire visible/NIR spectrum (400-2500 nm) did not improve the SEC and SEP.

Scatter correction and derivative pretreatment methods were evaluated with respect to calibration and prediction. Table 2 shows SEC, R^2 (for calibration) and SEP prior to and after three scatter correction methods (SNV, Detrend and MSC) were applied to the spectral data. Without scatter correction, the SEC and SEP were 0.026% and 0.05%, respectively. All three scatter correction methods slightly improved the SEC. SNV and MSC reduced the SEP to 0.04%, and Detrend actually increased the SEP to 0.06%. SNV and MSC were therefore selected. Table 3 shows the SEC, R^2 (for calibration) and SEP prior to and after the first and second derivative were applied to the spectral data (log(1/R)). Compared to the SEC and SEP without derivative treatment, the first derivative reduced SEC and SEP while the second derivative did not. The first derivative improved calibration and prediction for SFC.

In addition to spectral pretreatment, regression techniques were also evaluated. Table 4 shows SEC and R^2 of the calibration equations developed by means of four multilinear regression methods, including stepwise, PCR, PLS and MPLS. The corresponding SEPs from these equations are also listed in Table 4. The best calibration and prediction were obtained by using the MPLS regression technique. The resulting SEP (0.04%) was two-thirds of that resulting from stepwise and PLS regression and two-fifths of that resulting from the PCR method.

In developing calibration equation by means of PCR, PLS or MPLS techniques, the number of principal components (PCs) is another important factor affecting SEP. Figure 2 shows this effect on the SEP when MPLS was performed to develop the calibration equation. Using one PC resulted in an equation with a very large SEP (0.17%). The SEP decreased dramatically when the number of PCs was increased to three, and reached the lowest (0.04%) at five to seven PCs. The SEP tended to increase again as the number of PCs was increased past seven, due to data overfitting.

Calibration equations were developed on the basis of the above optimal conditions (i.e., spectral pretreatment: standard normal variate (SNV), first derivative; regression method: MPLS; wavelength ranges: 400-700 nm, and 1500-2500 nm; seven PCs). Predicted SFC versus measured SFC is shown in Fig. 3. The SEP (0.04%) was approximately 1.5 times the SEC and the SFC measurement error.

SIGNIFICANCE OF FINDINGS

The need for a fast reliable and accurate means to evaluate degree of milling (DOM), via a chemical basis, is continuing to increase. For value-added applications of rice, this information (i.e., surface fat concentration) is essential. This research has shown that near-infrared (NIR) spectroscopy is a highly accurate means of measuring surface fat concentration (SFC) on milled rice. The standard error of prediction (0.04%) is only 1.5 times the measurement error of the chemical method; however, the NIR method is more than twenty times faster than the chemical method (i.e., approximately 60 s vs. 120 min). This should allow for improved, more accurate evaluation of DOM, in evaluating milled lots of various cultivars for value-added markets.

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Table 1. Standard error of calibration (SEC), coefficient of determination (R^2, for calibration) and standard error of prediction (SEP) from different wavelength ranges.

Wavelength range	SEC (%SFC)	R^2	SEP (%SFC)
400-700 nm	0.04	0.97	0.07
1500-2500 nm	0.03	0.99	0.05
400-700, 1500-2500 nm	0.024	0.99	0.04
400-2500 nm	0.03	0.99	0.04

Table 2. Standard error of calibration (SEC), coefficient of determination (R^2, for calibration) and standard error of prediction (SEP) as affected by different scatter correction methods.

Scatter correction methods	SEC (%SFC)	R^2	SEP (%SFC)
None	0.026	0.99	0.05
SNV	0.024	0.99	0.04
Detrend	0.025	0.99	0.06
MSC	0.023	0.99	0.04

Table 3. Standard error of calibration (SEC), coefficient of determination (R^2, for calibration) and standard error of prediction (SEP) as affected by spectral derivative treatments.

Derivative	SEC (%SFC)	R^2	SEP (%SFC)
none	0.032	0.98	0.05
first	0.024	0.99	0.04
second	0.031	0.99	0.05

Table 4. Standard error of calibration (SEC), coefficient of determination (R^2, for calibration) and standard error of prediction (SEP) from different multiple linear regression methods.

Regression methods	SEC (%)	R^2	SEP (%)
Stepwise	0.03	0.98	0.06
PCR	0.06	0.95	0.10
PLS	0.04	0.97	0.06
MPLS	0.024	0.99	0.04

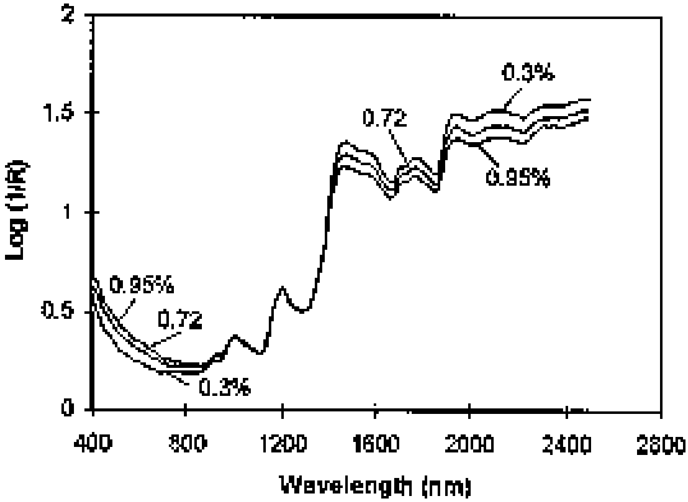

Figure 1. Reflectance spectra of 'Alan' milled to three surface fat concentrations (0.3%, 0.72%, and 0.95%).

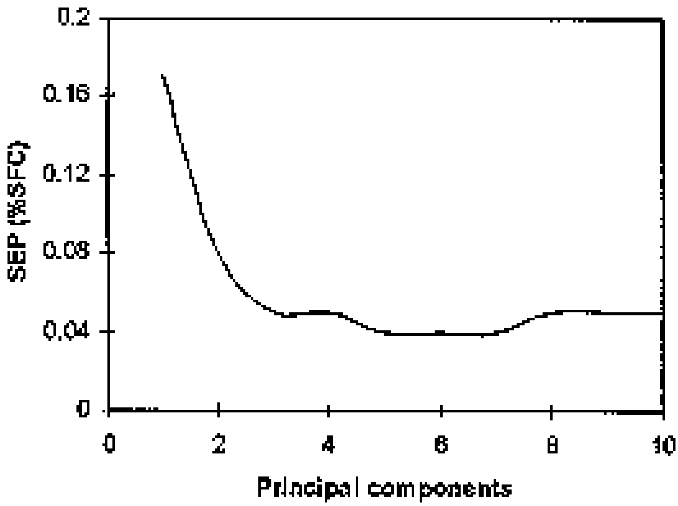

Figure 2. Effect of number of principal components on standard error of prediction (SEP) using MPLS.

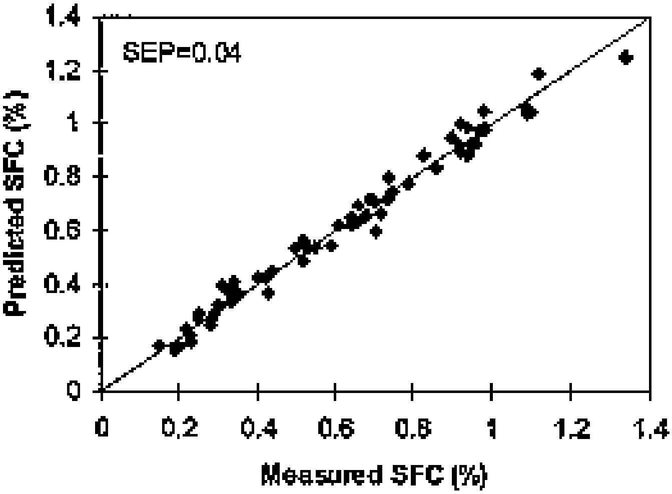

Figure 3. Predicted surface fat concentration (SFC) versus measured surface fat concentration.