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B.R. Wells Rice Research Studies 1997

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B.R. Wells
Rice Research Studies
1997

R.J. Norman and T.H. Johnston, editors

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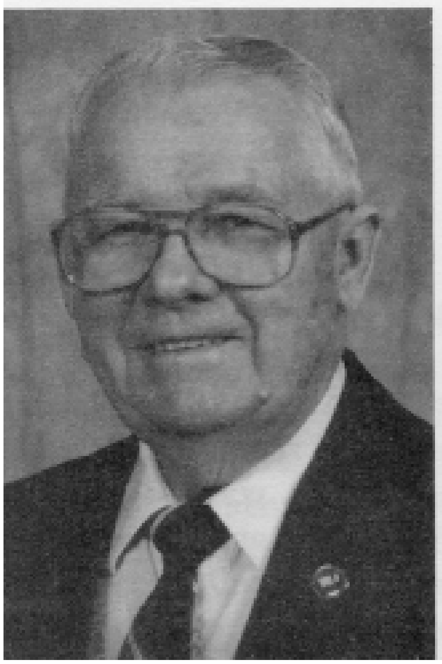
Dr. Wells was born July 30, 1934, at Wickliffe, KY. He received his B.S. in Agriculture from Murray State University in 1959, his M.S. in Agronomy from the University of Arkansas in 1961, and his Ph.D. in Soils from the University of Missouri in 1964. Dr. Wells joined the faculty of the University of Arkansas in 1966 after two years as an Assistant Professor at Murray State University. He spent his first 16 years at the U of A Rice Research and Extension Center near Stuttgart. In 1982, he moved to the U of A Department of Agronomy in Fayetteville.

Dr. Wells was a world-renowned expert on rice production with special emphasis on rice nutrition and soil fertility. He was very active in the Rice Technical Working Group (RTWG) where he served on several committees, chaired and/or moderated Rice Culture sections at the meetings and was a past Secretary and Chairman of the RTWG. He loved being a Professor and was an outstanding teacher and a mentor to numerous graduate students. Dr. Wells developed an upper-level course in rice production and taught it for many years. Dr. Wells was appointed Head of the U of A Department in Agronomy in 1993 and became *University Professor* that year in recognition of his outstanding contributions to research, service and teaching.

Among the awards he received were: the Outstanding Faculty Award from the U of A Department of Agronomy (1981), the Distinguished Rice Research and/or Education Award from the Rice Technical Working Group (1988) and the Outstanding Researcher Award from the Arkansas Association of Cooperative Extension Specialists (1992). He was named a Fellow in the American Society of Agronomy (1993) and was awarded, posthumously, the Distinguished Service Award from the RTWG (1998).



Dr. T.H. (Ted) Johnston was born on a farm in Antelope County, Nebraska, on May 3, 1917. He received his B.S. and M.S. degrees in 1940 and 1942, respectively, from the University of Nebraska, Lincoln. After three and a half years in the U.S. Army, he was discharged as a Captain and joined the faculty of Oklahoma State University at Stillwater in 1946 as an Assistant Agronomist in small grains research. While at Stillwater, he took periodic leave and completed his graduate work, receiving a Ph.D. in crop breeding from Iowa State University at Ames in 1953.

Dr. Johnston then moved to Stuttgart, Arkansas, as a Research Agronomist with the USDA/ARS to lead the UA cooperative State/ Federal rice varietal improvement project at the Rice Research and Extension Center for 30 crop years. During this time 12 improved cultivars were developed, including ‘Starbonnet’ and ‘Mars’, which added untold millions of dollars in value to the Arkansas and Southern U.S. rice crops. After retiring from the USDA, Dr. Johnston spent four years as a consultant rejuvenating the USDA World Rice Collection.

Dr. Johnston has been a member of the American Society of Agronomy since 1940 and chaired and/or served on several committees of ASA/CSSA. He has been named a Fellow by ASA, CSSA and AAAS, and he received the prestigious Superior Service Award from the USDA (1979). He represented the U.S. State Dept. and/or USDA at international rice conferences in Tokyo; Rome; Tehran, Iran; Los Banos, Philippines (IRRI - six times); Washington D.C.; and Lake Charles, Louisiana. He served six years on the seven-man International IBPGR/ IRRI Rice Advisory Committee including meeting at Cuttack and Calcutta, India; IRRI; and Washington D.C.

Dr. Johnston coordinated the cooperative State/Federal Uniform Rice Performance and Disease nurseries for 10 years. He was very active in the Rice Technical Working Group for 30 years and served as Secretary, Chair and ARS Advisor and received the Distinguished Service Award From RTWG in 1976. He was Honoree at the 1977 International Rice Festival at Crowley, Louisiana, and later at the Arkansas Rice Festival at Weiner. He was recognized by rice industry organizations for “outstanding contributions to the Arkansas and American rice industry.”

Dr. Johnston has provided technical reviews and has helped edit all of the research reports in this series since its inception in 1991.

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, 1997, Arkansas Agricultural Experiment Station Research Series 459. 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.

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

All authors are either current or former faculty, staff or students of the University of Arkansas Division of Agriculture. For further information about any author, contact Communication Services, (501) 575-5647.

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The Arkansas Rice Research and Promotion Board

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RICE PHYSIOLOGY

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

ABSTRACT

We sought to find characteristics shared among ‘Teqing’ and other Chinese rice lines in an effort to exploit a recently available random mating population of rice from a cross of ‘Lemont’ and Teqing. We compared Teqing and Lemont/Teqing F_1 hybrid to ‘Guichao2F8426-2’, Lemont and ratoon F_1 plants of Guichao2/Lemont and Lemont/Guichao2 crosses. Comparisons of sucrose synthase activity in endosperm tissue at rapid grain filling showed that the sucrose synthase activity of Teqing is more like sucrose synthase activity in U.S. types than Guichao’s activity. Comparisons made this past year suggest that the differences in sucrose synthase and other related enzymes may be greatly different among panicles within an individual plant. Specifically, the sucrose synthase activity of Guichao2 was greater in main stem panicles than in tiller panicles. Comparisons were made between U.S. and Chinese rice lines to determine susceptibility to photooxidative stress. We placed rice at boot stage into a growth chamber for five days of 62°F and high irradiance. At the end of the period, we compared control plants (plants of the same lines from the same conditions except that temperatures for five days after boot stage were no lower than 75°F) to the cool temperature treated plants. The Chinese lines were all more susceptible to the cool temperature/high light treatment than were the U.S. lines and the one U.S./China hybrid. Consequently, the Lemont/Teqing F_2 derived lines may be useful in our molecular work to determine ways plants protect themselves from photooxidative damage. With generation F_{12} plants, we can potentially move forward as soon as we have sufficient seed for a field test, which should be in 1999.

INTRODUCTION

Physiology has been called the logic of life. Through this physiology project, we hope to gain a better understanding of the rice plant. Through that increased understanding, we can more intelligently manage the rice crop and more effectively select for higher yielding types. One of the main goals of this project has been to develop physiological markers for higher grain yield. Chief in these efforts have been efforts to determine the potential for the use of sucrose synthase as a marker for higher rice yields. Sucrose synthase is one of five enzyme steps beginning with the breakdown of sucrose by sucrose synthase (in the cytoplasm of filling grain) and ending with the incorporation of sugars into new starch chains (in the plastids).

Our research on sucrose synthase has focused primarily on the Chinese rice variety, Guichao2. In a related project, we have also sought to understand the unique photoprotective characteristics of the Chinese hybrid ‘LeQi’ produced in bulk by use of a male gameticide. The Texas rice researchers have developed a nearly homozygous population (F_{12}) from selections made at the F_2 generation of a Lemont by Teqing cross. These researchers have shared their population with us, and we presently have over 150 F_{12} generation Lemont/Teqing lines that have been molecularly mapped for physical source/sink measurements. Consequently, working in concert with scientists in other states and organizations, we sought to find out how Teqing might relate to Guichao2 and ‘Qi-gui-zao’. We sought to compare Teqing to Lemont and a Lemont/Teqing F_1 hybrid for sucrose synthase and other cytoplasmic enzymes related to sucrose metabolism. We also sought to rank the varieties and lines for photooxidative stress.

PROCEDURES

Experiment I

Single rice plants were grown in the greenhouse at the Northeast Research and Extension Center at Keiser in 1997. Plants were grown in 2.5-gal undrained containers. Plants were fertilized weekly with a complete fertilizer solution produced by the Miracle Gro Company. The rice lines grown from seed were Guichao2, Teqing, Lemont and a Lemont/Teqing F_1 hybrid. In addition, plants excavated from the field included Guichao2 and F_1 hybrids of Lemont/ Guichao2 and Guichao2/ Lemont crosses. Containers were planted first with Teqing and Guichao2. Two weeks later Lemont pots were planted. One week later, the Lemont/ Teqing F_1 hybrid seed were planted. This was done to have the populations flowering roughly within the same period of time. Tillers were tagged and mapped as described in Counce et al. (1996). For the plants grown for yield, all tillers were mapped and harvested. In the plants grown for the enzyme assays, only the first 10 or so tillers were marked and mapped. Five plants from each line were grown for yield, and five plants were grown for enzyme assays.

Experiment II

Single plants of Lemont, Guichao2, Teqing, Qi-gui-zao, ‘M11-131’ (an F_2 derived line from a cross of ‘Bond’ and Lemont), ‘Newbonnet’ and the F_1 hybrid of Lemont/Qi-gui-zao were grown in the greenhouse in 1997. All plants were grown from seed, which were planted at the same time. When plants reached boot stage, they were placed in the controlled climate chamber for five days. The temperature was set at a constant 62°F. Light levels were gradually increased from 5 am to 11 am with a maximum irradiance at 11 am to 1 pm of 1200 umoles/m^{-2}/s. We actually prolonged the length of time the U.S. lines were kept in the chilling temperature/ high light conditions. We did this because the U.S. lines were so little affected by the stress treatments. At the end of the five days, plants were removed from the chamber and compared to the control plants of the same lines remaining in the greenhouse with normal temperatures. Plants were rated from 0 (no damage) to 10 (all leaves brown).

Enzyme Assays

In Experiment I, panicles were tagged on the day of beginning anthesis for the marked panicles. The panicles to be assayed for the four enzymes were collected 10 days after anthesis and immediately placed on ice.

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

Other Work/Development of Experimental Protocols

In our laboratory, we are working to determine the characteristics of the enzyme sucrose synthase. When we have purified that enzyme, we will determine the amino acid sequence and then the DNA sequence for the gene. We are continually working on the protocol for the enzyme purification scheme. This involves experimental techniques other than those used in field research. We are preparing to test our molecular probe for yield derived from the gene for greater sucrose synthase activity. We continue to bring our F_2 derived lines from the Guichao2 and Lemont crosses to homozygosity. In 1997, we received polyclonal antibodies to maize sucrose synthase courtesy of Dr. Karen Koch of the University of Florida. In 1998, as this report was being written, we received word from our colleagues in Georgia that the polyclonal antibody does cross react with rice tissue. This confirms a powerful tool in the effort to determine the role of sucrose synthase in the high yield of Guichao2.

RESULTS AND DISCUSSION

The rice lines and culms within a plant were quite different in their enzyme activities (Table 1). Guichao2 had higher sucrose synthase activity for main stem panicles than for tiller panicles. Critical to this test is the finding that sucrose synthase activity for Teqing did not appear to be as high as the high main stem sucrose synthase activity for Guichao2. One experiment is, of course, not conclusive. This initial test, however, does indicate that the Chinese rice variety Teqing does not share the high sucrose synthase activity of Guichao2. The pedigree of Teqing is quite different from that of Guichao2.

The results of the chilling temperature/high light test do indicate that Teqing is more similar to Guichao2 and Qi-gui-zao than to U.S. rice lines in susceptibility to photooxidative damage (Table 2). This indicates to us that the DNA probes of the Lemont/Qi-gui-zao F_2 derived population may be used to screen the segregated Lemont/Teqing lines. These results need to be confirmed, however. We are increasing the seed of the Lemont/Teqing population at the Rice Research and Experiment Station, Stuttgart, Arkansas. Consequently, it is possible that yield tests combined with molecular probes for protoprotective enzymes could be commenced in 1999 if the results of the chilling temperature/high light treatment can be confirmed.

SIGNIFICANCE OF FINDINGS

Pending confirmation of our results on the chilling temperature/high light experiment, it is possible that a yield test of the rice lines in the Lemont/Teqing population could be commenced in 1999 and that some of the molecular probes we have been developing in the photoprotective research effort in Georgia could be tested. After two years of results and probing of the entire population, these probes could be tested for yield by the year 2000 and put into use in 2001.

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We thank Arkansas rice farmers for their support of this research by their check-off funds administered by the Arkansas Rice Research and Promotion Board. We thank colleagues in other institutions for excellent cooperation. In particular, we thank Dr. Susana Sung of the Institute of Tree Root Biology, U.S.D.A.-F.S. in Athens, Georgia; Dr. Clanton Black of the Department of Biochemistry and Molecular Biology, University of Georgia, Athens, Georgia; Dr. Zhikang Li, International Rice Research Institute, Los Banos, Philippines; Mr. Z.P. Tu, Rice Research Institute, Guangdong Academy of Agricultural Sciences; and Dr. Shannon Pinson, U.S.D.A.-A.R.S., Beaumont, Texas. We thank Dr. Karen Koch of the Horticulture Department of University of Florida, Gainesville, Florida, for the sucrose synthase polyclonal antibody.

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Table 1. Sucrose synthase and other enzyme activities related to sucrose metabolism.

		Enzymes[†]							
	Culm	Activity per grain				Specific Activity			
Rice Line	Type[‡]	SS	PPK	UGP	NPK	SS	PPK	UGP	NPK
		------ umoles/grain/min ------				------ umoles/mg prot./min ------			
Guichao2	M	39	527	107	308	146	134	923	63
	P	13	11	113	5	112	126	990	58
	U	22	28	129	16	457	336	1612	139
G/L F_1	R	21	28	119	14	165	175	896	95
Lemont	M	25	36	126	17	526	519	2713	219
	P	33	59	115	22	312	273	1154	94
	U	33	57	105	24	269	250	887	105
L/T F_1	M	30	42	127	37	411	321	1766	228
	P	25	30	119	17	307	265	1479	137
	U	27	35	103	23	312	251	1276	188
L/G F_1	R	20	20	117	11	187	188	1103	98
Teqing	M	20	24	127	16	153	150	975	92
	P	20	23	109	11	183	183	994	84
	U	28	31	131	22	221	167	1064	99
Standard errors:		9	15	2	9	31	22	88	9

[†] The data are from an experiment conducted in the greenhouse at the Northeast Research and Extension Center in Keiser, Arkansas, in 1997. Enzymes: SS = sucrose synthase; PFK = pyrophosphate phosphofructokinase; UGP = uridine diphosphate phosphofructokinase; NPK = NTP dependent phosphofructokinase.

[‡] Culm types: M = main stem; P = primary tillers; U = unmarked tillers; R = ratoon rice (these F_1 generation plants were removed from the field and cared for in the greenhouse.

Table 2. Comparisons of photooxidative damage to U.S. and Chinese rice lines and crosses of U.S. and Chinese lines.

Rice Line	Damage Rating[†]
Guichao2	2.67
Lemont	1.00
M11-131[‡]	0.58
Newbonnet	0.83
Qi-gui-zao	1.83
Teqing	2.67
Lemont/Qi-gui-zao F_1	0.50

[†] The data are from experiments conducted in the greenhouse and growth chamber (for the period for cool temperatures and high light damage to the plants) in 1997. Ratings were made after a period of five days in the growth chamber at a constant temperature of 62°F with a maximum irradiance of approximately 1200 umoles/m^{-2}/s during the photoperiod. The ratings ranged from 0 to 10. Leaf tissue with no brown tissue was rated as zero and leaf tissue completely brown was rated as 10.

[‡] The line M11-131 was derived from a selection made in the F_2 generation from a cross of Bond and Lemont.

ONGOING PROJECT: BREEDING, GENETICS AND PHYSIOLOGY

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

**K.A.K. Moldenhauer, F.N. Lee, R.J. Norman, J.L. Bernhardt,
R.H. Dilday, M.M. Blocker and T.A. McMinn**

ABSTRACT

The Arkansas rice breeding program is an ongoing program involving the development and testing of new cultivars 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 development in this program. They are lines with improved plant type, high grain and milling yields, increased 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), 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 and still is 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’, ‘Kaybonnet’ and ‘Drew’. 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., 1994). As interest in specialty rices has increased, the program has taken on the added task of developing 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, ‘Adair’, ‘LaGrue’, Kaybonnet and Drew, developed in this program.

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, IRRI and WARDA. 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 nitrogen (N) fertilizer use efficiency, into highly productive, well-adapted lines. Early generation selections are chosen from the various crosses each year and advanced a generation at the winter nursery in Puerto Rico. As outstanding lines are selected and advanced, they are evaluated extensively for grain and milling yield, milling and cooking characteristics, including insect tolerance by the entomologist and disease resistance by the pathology group. The advanced lines are extensively evaluated for proper timing and rate on 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, 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 rice cultivar 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 cultivar performance.

RESULTS AND DISCUSSION

Drew, the newest blast-resistant, high-yielding, long-grain rice cultivar developed in this project, was grown as registered seed on 3% of the Arkansas rice acreage in 1997. It originated from the cross ‘Newbonnet’/Katy made in Stuttgart in 1986. Data were presented on Drew in the 1995 Rice Research Studies (Moldenhauer et al., 1996).

Currently there are several promising lines in the breeding program. They have come from all phases of the breeding program (short-stature or semidwarf crosses, crosses for blast resistance and recurrent selection for sheath blight, speciality crosses and those for earliness). Among these is the line RU9601053, a very high-yielding, long-grain variety originating from the cross Newbonnet/3/ ’Lebonnet’/ CI990 2//’Labelle’ made at Stuttgart in 1989. RU9601053 yielded 175 bu/acre in the 1996-1997 Arkansas Rice Performance Trials (ARPT) compared to LaGrue and ‘Bengal’ at 172 and 180 bu/acre, respectively (Table 1). Head rows of RU9601053 were grown in 1997, and a foundation seed field of

RU9601053 is planned for 1998. This line has also performed very well in the Uniform Rice Regional Nursery (URRN) 1996-1997, being either at the top or near the top of the Group III entries both years at all locations. Like LaGrue this line may be susceptible to the common blast races, but blast has not been a problem for this line in the field for the past 2 years across the Southern growing region. In 1998, RU9601053 will be included in the disease observation nurseries, the straighthead nursery, the sheath blight yield loss study, a deep flood test, a kernel smut test and a stem disease nursery, in order to obtain additional information on the disease reactions for this line.

The line RU9401188, which looked promising in 1995 and 1996, will not be released in 1998 due to blast susceptibility, which was discovered in 1997. This line did not perform well in the ARPT in 1997 and has always showed average yields in the URRN in the other Southern states. It has been dropped from the release track.

Two of the short-grain lines (RU9601096, and RU9601099) from the cross ‘Koshihikari’/‘Mars’, which performed well in 1996, were also in the ARPT (Table 2) and URRN in 1997. These lines were again high yielding, excellent milling lines with improved texture and taste for the Japanese market when compared to typical southern U.S. medium-grain rice cultivars. Initial sensory evaluation suggests that these lines are closer to the Japanese type of rice than Mars and Bengal. Currently, these lines are being re-screened for quality characteristics. A possible seed increase of RU9601099 and head rows of both RU9601096 and RU9601099 will be grown in 1998. 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.

Three other promising lines in the ARPT are RU9601087, RU9701041 and RU9701151 (Table 3). RU9601087 is a very short-season, high-yielding sister line of RU9601053. This line showed excellent sheath blight tolerance in Arkansas, Louisiana and Texas disease nurseries in 1997. RU9701041 is a semidwarf line with some sheath blight tolerance and blast resistance. Head rows of this line will be grown in 1998. Head rows will also be grown this year of the line (RU9701151), which is a high-yielding, good-milling, long-grain rice. This line has been partially derived from germplasm (PI338064) identified by Dr. Dilday to have potential allelopathic activity.

There are many lines in the Stuttgart Initial Test that are showing outstanding yield potential. Three high-yielding, large-kerneled, medium-grain lines have been identified from the Stuttgart Initial Test entries and will be advanced into the ARPT and URRN as RU9801081, RU9801093 and RU9801148 in 1998.

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 reaction to 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 second cross to agronomically acceptable material was made in 1997. F_2 material will be screened in 1998 for blast resistance. The resistant lines from this approach will be utilized as parental material, and desirable phenotypes will be included in the breeding program and evaluated for cooking quality and agronomic characteristics.

Table 4 shows the number of lines that were in the different phases of this breeding project for the 1997 growing season. These numbers reflect only half of the lines in the early generation material through the Stuttgart Initial Test that were grown by the entire rice breeding program at Stuttgart in 1997.

SIGNIFICANCE OF FINDINGS

The goal of the rice breeding program is to develop maximum yielding cultivars with 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 releases RU9601053 and a Japanese quality line, either RU9601096 or RU9601099, are examples of the continued improvement being realized through this program. Improved lines from this program will continue to be released 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 also for specialty markets as they arise.

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Table 1. Data from the 1996-1997 Arkansas Rice Performance Trials for two experimental lines and check cultivars.

Cultivar / Line	Grain Type	Yield bu/acre[†] 1996	1997	mean[a]	Height in.	Maturity 50% HD	Kernel Wt. mg	Milling HR:TOT
RU9601053	L	178	171	175	40	85	18.90	64-75
RU9401188	L	167	157	162	39	83	16.30	63-72
LaGrue	L	177	167	172	43	85	18.30	65-73
Kaybonnet	L	136	146	141	42	85	15.10	66-73
LaFitte	M	165	157	161	37	82	18.10	70-74
Bengal	M	187	171	180	36	85	20.00	69-75

[†] 1996 locations: Rice Research and Extension Center, Stuttgart, AR; Pine Tree Experiment Station, Colt, AR; Northeast Research and Extension Center, Keiser, AR; Southeast Branch Experiment Station, Rowher, AR; and Campbell, MO; 1997 consisted of Arkansas locations.

Table 2. Data from the 1996-1997 Arkansas Rice Performance Trials for two lines from Koshihikari crosses and M-202, the medium-grain check cultivar.

Cultivar / Line	Grain Type	Yield bu/acre[†] 1996	1997	mean	Height in.	Maturity 50% HD	Kernel Wt. mg	Milling HR:TOT
M202	M	151	135	144	38	74	20.90	65-73
RU9601099	S	173	160	167	39	79	18.80	68-76
RU9601096	S	169	161	165	36	78	18.70	66-75

[†] 1996 locations: Rice Research and Extension Center, Stuttgart, AR; Pine Tree Experiment Station, Colt, AR; Northeast Research and Extension Center, Keiser AR; Southeast Branch Experiment Station, Rowher, AR; and Campbell, MO; 1997 consisted of Arkansas locations.

Table 3. Data from the 1997 Arkansas Rice Performance Trials for three experimental lines and five check cultivars†.

Cultivar / Line	Grain Type	Yield bu/acre	Height in.	Maturity 50% HD	Kernel Wt. mg	Milling HR:TOT
RU9601087	L	160	42	84	17.60	62-75
RU9701041	L	155	34	95	17.90	68-73
RU9701151	L	165	44	90	19.30	66-73
Jefferson	L	150	36	83	19.80	63-74
LaGrue	L	167	45	90	18.20	65-73
Kaybonnet	L	146	44	88	15.20	64-73
Drew	L	159	45	92	16.40	66-74
Cypress	L	148	38	92	17.30	68-74

† 1997 locations: Rice Research and Extension Center, Stuttgart, AR; Pine Tree Experiment Station, Colt, AR; Northeast Research and Extension Center, Keiser, AR; and Southeast Branch Experiment Station, Rowher, AR.

Table 4. Number of lines in each phase for project ARK01387 in 1997.

Evaluation Phase	Number of Lines
Crosses	128
F_2 Space Plants	76,500
F_3 Panicle Rows Puerto Rico	4500
F_4 P Panicle Rows	5760
L & M Panicle Rows	3330
Preliminary Trials	800
Stuttgart Initial Test	256
Arkansas Rice Performance Trials	72

ONGOING STUDIES: BREEDING, GENETICS AND PHYSIOLOGY

RICE GENETICS AND GERMPLASM ENHANCEMENT

J.N. Rutger

ABSTRACT

Six semidwarf mutants in normal Arkansas cultivars were prepared for germplasm release as breeding sources for U.S. rice breeders. These six semidwarfs had height reductions from 10 to 26% of their normal parent. Four equaled the yield of the normal parent, one exceeded, and one was lower yielding than its parent.

Two dominant and three recessive genetic male steriles were identified for potential use in population improvement schemes. Tetraploid versions of experimental lines were induced by colchicine. The tetraploid lines had very large seeds, and crosses among these and other tetraploids produced hybrids with higher seed set rates than their tetraploid parents, and some hybrids approached seed set levels of diploids.

In comparisons of indica and U.S. tropical japonica cultivars, a Chinese indica cultivar, ‘ZHE 733’, was identified that had higher grain yield and was nearly two weeks earlier than U.S. tropical japonicas. Its limitation is unacceptable grain quality for U.S. markets. This cultivar will be the cornerstone for development of an indica germplasm improvement pool for the U.S.

INTRODUCTION

The present project was initiated in 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 greatly 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 normal Arkansas cultivars in order to quickly produce useful semidwarf germplasm in otherwise well-adapted cultivars. Principal long-term objectives are to develop better genetic mechanisms for producing hybrid rice and to develop an indica germplasm improvement pool.

PROCEDURES

Near-term Objective:

Develop Semidwarf Mutants from Arkansas Cultivars

Procedures for inducing mutants were previously described (Rutger, 1997).

Long-term Objective:
Better Genetic Mechanisms for Producing Hybrid Rice

Inheritance studies were conducted on several previously induced genetic male sterile mutants. In studies on apomixis, chromosome numbers of elite germplasm lines were doubled by colchicine treatment in order to see if the expression of apomixis could be enhanced by this technique, as it has been in other crops.

Long-term Objective: An Indica Germplasm Improvement Pool

Seven indica lines and seven tropical japonicas were evaluated in yield trials in 1996 and 1997 at Stuttgart, Arkansas, and Beaumont, Texas.

RESULTS AND DISCUSSION

Near-term Objective:
Develop Semidwarf Mutants from Arkansas Cultivars

Six semidwarf mutants have been prepared for germplasm release (Table 1). These six semidwarfs had height reductions from 10 to 26% of their normal parent. Significant yield differences from the normal parent were observed only for Adair 10 in 1997 (higher than parent) and LaGrue 13 in 1997 (lower than parent). In genetic studies, each of these six semidwarfs was found to have a semidwarfing gene nonallelic (different from) sd1. Thus, they provide alternative genetic sources to sd1, should alternatives be needed.

Long-term Objective:
Better Genetic Mechanisms for Producing Hybrid Rice

Two genetic male steriles were found to be inherited by single dominant genes and three by single recessive genes (Zhu and Rutger, 1998). The dominant male steriles should be more useful for population improvement than recessives, as the former are exposed in each generation, whereas the latter are exposed only every second generation. Another male sterile mutant, 96/1388, which previously had shown photosensitive genetic male sterility (pgms) behavior, gave inconclusive results in 1997. Since pgms mutants are highly desirable for hybrid rice seed production, mutant 96/1388 is being further investigated.

Apomixis, which is known to be more prevalent in polyploids than in diploids, would be extremely useful for developing true-breeding hybrid rice. A pre-developed embryo rice (PDER) from China apparently has a very low frequency of diplospory-type apomixis, but not at a level high enough for practical breeding. In the expectation that polyploidy might enhance the expression level of apomixis, PDER-2B and another line, Ce-64, were treated with colchicine, resulting in successful induction of tetraploids (4N). Crosses were made among the two induced tetraploids and two spontaneous tetraploids, 4N L-202 and 4N Jackson. As expected, seed size of the tetraploids, at 45 mg/seed, was larger than that of diploids, 28 mg/seed. The most interesting observation was that the tetraploid hybrid F_1's had seed set rates of 74.0%. This rate was markedly higher than that of the tetraploid parents, which was 44.5%, and approached that of the original diploids, which was 86.0% (Li and Rutger, 1998). Further studies on agronomic performance of these big-seeded tetraploids is planned.

Long-term Objective: An Indica Germplasm Improvement Pool

Casual observations over the past decade have indicated that indica lines have higher yielding ability, but poorer grain quality, than the tropical japonicas grown in the southern U.S. Therefore, seven recent indica cultivars, mostly from China and IRRI, were compared with seven leading tropical japonicas from the southern U.S. The cultivars with highest yields, ZHE 733, 'ZYZ 3' and 'Teqing', were all indicas from China (McClung et al., 1998). One of these, ZHE 733, headed in only 63 days, making it about two weeks earlier than the U.S. tropical japonicas. However, ZHE 733, which is widely grown in central China has milling yields too low for U.S. markets. ZHE 733 will be used as the cornerstone at the National Rice Germplasm Evaluation and Enhancement Center to develop a semidwarf indica germplasm pool for the U.S. Within this germplasm pool, selection will be practiced for high yield plus acceptable grain quality.

SIGNIFICANT FINDINGS

In near-term studies, semidwarf mutants that have been induced in normal 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.

A high-yielding, very early-maturing, indica semidwarf from China, ZHE 733, was identified as the cornerstone for development of an indica germplasm improvement pool for the U.S.

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Table 1. Characteristics of five semidwarf mutants from long grain cultivars and one semidwarf mutant from a medium grain cultivar.

Mutant No.	Grain Type	Mutant Height	Percent Height Reduction From Parent	---------- 1996 Yield ----------		---------- 1997 Yield ----------	
		cm		kg/ha	% of parent	kg/ha	% of parent
Kaybonnet 4	long	76	26	5680	94	-----	-----
Kaybonnet 5	long	79	23	5710	94	-----	-----
LaGrue 12	long	82	22	7270	103	9180	100
LaGrue 13	long	83	21	7600	108	8590	94
Adair 10	long	88	16	7360	-----†	8500	112
Orion 172	medium	83	10	7150	95	7340	94

† Parent lodged so severely (80%) compared to mutant (50%) that parent data were considered invalid.

Source: Rutger et al., 1998.

ONGOING PROJECT
PEST MANAGEMENT: WEEDS

A SUMMARY OF SELECTED 1997 RICE WEED CONTROL STUDIES

F.L. Baldwin and T.L. Dillon

ABSTRACT

Highlights from selected 1997 rice weed control studies show that weed control technology in rice is rapidly changing. Clomazone (Command®) offers tremendous potential for excellent control of the major grass weeds in rice at a reduced cost compared to available standard treatments. The potential exists for the treatment to be applied preplant incorporated (PPI) with ground equipment. When applied in this manner, prior to levee formation, additional weed control will be required on the levees. The granular formation of quinclorac (Facet®) continues to provide control equivalent to the spray formation when applied prior to grass emergence. Halosulfuron (Permit®) continues to show promise as a nutsedge herbicide in rice. Research results in 1997 were consistent with those from 1996. Halosulfuraon has been more consistent across a range of rates, timings of application and water management regimes than has the bensulfuron (Londax®) standard. Fenoxaprop (Whip®) has excellent grass control potential in rice. However, excessive crop injury has limited its use. Results from 1997 indicate that a safener supplied by Agrevo, the fenoxaprop manufacturer, can greatly reduce the injury potential from this herbicide.

CLOMAZONE

Clomazone continues to show promise as a rice herbicide. In 1997, studies with clomazone included a rate x timing study, which included comparisons with other herbicides; a levee study; and a PPI study. In the rate x timing study (Table 1), a conventional seedbed was prepared, PPI treatments were incorporated using two passes with an s-tine field cultivator with rolling baskets, 'Cypress' rice was drilled, and the preemergence (PRE) treatments were applied 7 May 1997. A rainfall of 0.4 in. occurred 2 days after seeding, and the delayed preemergence (DPRE) treatments were applied 12 May 1997. The test area was then flushed twice prior to rice seedling emergence.

Rice injury, broadleaf signalgrass control and rice yields are shown in Table 1. Excellent grass control was achieved with all rates and application timings with clomazone, quinclorac and several of the mixtures. A significant reduction in rice yield was noted at the higher rates of clomazone applied PPI. However, at the lower rates, the rice yields were comparable to those in plots treated PRE or DPRE. Thus, clomazone applied PPI probably will have greater utility and greater acceptance by growers than the other methods of application. In addition, the grass control and yields in plots where quinclorac was applied PPI were comparable to those where it was applied PRE or DPRE.

If clomazone is to be applied to rice fields prior to levee formation, there are questions regarding weed control on the levees. It is expected that the accumulation of untreated soil during levee formation would result in poor control. In the study reported here (Table 2), clomazone and quinclorac were applied before or after levee formation. In treatments 2, 3, 7 and 9 the herbicide was applied and then two cross levees were pulled through the plots and no additional herbicides were applied to the levees. In treatments 3, 5 and 8 the plots were sprayed as before, but additional herbicide was sprayed on the levee after construction. In treatment 6 and 10, the levees were constructed first and then the plots (between levees) and levees were sprayed at the same time. There were three replications in each treatment, and the levee data were averaged over the two levees per plot. As expected, the broadleaf signalgrass control on the levees was much better either where additional herbicides were applied after levee construction or where both the plot (between levees) and levees were sprayed after levee construction. Other investigators have reported more rice injury when clomazone has been applied PPI compared to when it is applied PRE or DPRE. Studies by this investigator have not shown this trend. In these studies the seedbed has been rolled prior to drilling. Perhaps a firm seedbed could be the difference. In addition, much of the early investigation with PPI treatments were at higher rates than now believed necessary and with the 4EC formulation, whereas the PRE and DPRE treatments were with the 3ME formulation. In a small study, PPI treatments of clomazone 4EC and 3ME formulations were compared to the 3ME formulation applied PRE and DPRE where the seedbed was either rolled or not rolled prior to seeding. A common rate of 0.5 lb ai/acre was used for the clomazone. This rate is higher than needed on this soil, but it was felt a higher rate would be more likely to show differences. Quinclorac + pendimethalin (Prowl®) applied DPRE was used as a standard. There were three replications. In general the PPI treatments (Table 3) resulted in higher injury over a longer period and a trend toward lower yields. There were no apparent differences due to formulation or due to rolling versus not rolling.

QUINCLORAC GRANULES

Research has continued comparing the spray formulation of quinclorac DF with the granular formulation. In the study reported here (Table 4) the two formulations were compared at several rates and times of applications. In addition, several labeled and reduced-rate standard programs were included. Each treatment was replicated four times, and data reported are broadleaf signalgrass control, rice injury and grain yield. Typical grower management practices were used on the Cypress rice, and flushing was used to activate the herbicides. The granular formulation of quinclorac continues to perform equivalent to the spray formulation when applied PRE or DPRE. When applied early post (POST) and postflood (POFL), the grass control has been less with the granular formulation. Data from this study also continue to support the MP-44 reduced rates of quinclorac + pendimethalin and quinclorac + thiobencarb (Bolero®).

YELLOW NUTSEDGE CONTROL AND RICE YIELDS WITH HALOSULFURON

Two studies were conducted with halosulfuron in 1997. One was a yellow nutsedge study conducted near Lodge Corner (Table 5), and the other was an effect on yield study (Table 6) conducted at Lonoke. In the yellow nutsedge study, all treatments provided excellent control, and differences were not as apparent as in 1996. Halosulfuron has provided more consistent control of nutsedge over a range of rates, application timings and water management practices compared to the bensulfuron standard. Yield data were not taken in this study. In the rice yield study (Table 6), halosulfuron was applied at various rates and applications timings in single and repeat applications to Cypress rice that was maintained weed free using standard herbicides applied as a blanket treatment. There were essentially no observable differences in rice injury, and there were no differences in rice yield among treatments. Halosulfuron appears to provide excellent crop safety in rice.

FENOXAPROP SAFENER

There are many situations that occur in Arkansas each year where fenoxaprop would be a good recommendation. However, there has been a history of excessive injury with this herbicide, which has severely limited its usefulness. In 1997, two formulations of fenoxaprop, Whip 360® and Bugle®, were compared with and without a safener (Hoe 122006) provided by the Agrevo Company. Single applications were made to two-leaf rice, and in one treatment a repeat application was made preflood (PREFL). The two-leaf stage is earlier than recommended for fenoxaprop. It was felt this should increase crop injury and the opportunity to study the effect of the safener. This study was somewhat complicated by an excessive rate of 2,4-D applied for broadleaf weed control at midseason. However, there was a consistent decrease in crop injury and corresponding increase in rice yields when the Hoe 122006 was added to both Whip 360 and Bugle (Table 7). If this is proved to be consistent in future research and if the product is placed on the market, it could greatly increase the utility of fenoxaprop as a rice herbicide in Arkansas. If the study is repeated in 1998, plans are to seed ‘Bengal’ rice. This cultivar is among the most susceptible to fenoxaprop injury.

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Table 1. Broadleaf signalgrass control, plant injury and grain yield in 'Cypress' rice seeded 7 May 1997 at Lonoke, Arkansas.

		Growth	Broadleaf signalgrass control			Rice injury		Rice yield
Treatment	Rate	stage	5/22	7/22	8/27	5/22	7/22	9/17
	lb ai/acre		%					bu/acre
Untreated check			0	0	0	0	0	85
Clomazone (3ME)	0.3	PPI	93	98	94	19	0	147
Clomazone (3ME)	0.4	PPI	100	100	96	28	0	125
Clomazone (3ME)	0.5	PPI	100	100	100	21	0	111
Clomazone (3ME)	0.6	PPI	100	100	99	40	0	115
Clomazone (3ME)	0.3	PRE	99	100	98	25	0	143
Clomazone (3ME)	0.4	PRE	100	100	100	43	0	134
Clomazone (3ME)	0.5	PRE	89	100	100	40	0	123
Clomazone (3ME)	0.6	PRE	100	100	100	55	0	131
Clomazone (3ME)	0.3	DPRE	63	100	100	33	0	131
Clomazone (3ME)	0.4	DPRE	86	100	100	45	0	135
Clomazone (3ME)	0.5	DPRE	93	100	100	35	0	145
Clomazone (3ME)	0.6	DPRE	90	100	100	55	0	130
Quinclorac	0.25	PPI	98	100	100	0	0	130
Quinclorac	0.375	PPI	100	100	100	0	0	143
Quinclorac	0.25	PRE	95	100	100	0	0	147
Quinclorac	0.375	PRE	100	100	100	5	0	153
Quinclorac	0.375	DPRE	100	100	100	8	0	149
Thiobencarb	4.0	DPRE	63	60	48	3	0	117
Pendimethalin	1.0	DPRE	85	58	48	0	0	122
Clomazone (3ME) + quinclorac	0.3 + 0.25	PPI	98	100	100	15	0	152
Clomazone (3ME) + quinclorac	0.3 + 0.25	PRE	93	100	99	30	0	137
Clomazone (3ME) + quinclorac	0.3 + 0.25	DPRE	90	100	98	23	0	137
Clomazone (3ME) + thiobencarb	0.3 + 2.0	DPRE	83	99	95	28	0	151
LSD (P=0.05)			9	4	8	10	0	26

Table 2. Clomazone and quinclorac for broadleaf signalgrass control on levees, Lonoke, Arkansas, 1997.

	Treatment	Rate	Growth stage	Broadleaf signalgrass control							Rice injury			
				Between levees		On levees								
				5/30	6/27	5/30	6/17	6/27	7/22	9/2	5/30	6/17	6/27	9/2
		lb ai/acre		%										
1.	Untreated check			0	0	0	0	0	0	0	0	0	0	0
2.	Clomazone (3ME) Pull Levee	0.5	PPI	90	93	57	50	23	5	33	28	28	0	0
3.	Clomazone (3ME) Pull Levee Clomazone (3ME) Spray Levee Only	0.5 0.3	PPI PRE	90	100	77	92	78	43	23	35	33	8	7
4.	Clomazone (3ME) Pull Levee	0.5	PRE	93	100	67	57	33	7	37	22	12	5	0
5.	Clomazone (3ME) Pull Levee Clomazone (3ME) Spray Levee Only	0.5 0.3	PRE PRE	92	100	78	95	77	33	37	28	25	0	0
6.	Pull Levee Clomazone (3ME) Spray Over the Levee	0.5	PRE	92	100	78	95	77	13	53	22	8	0	0
7.	Quinclorac Pull Levee	0.375	PRE	95	100	53	73	55	20	60	10	0	0	0
8.	Quinclorac Pull Levee Quinclorac Spray Levee Only	0.375 0.25	PPI PRE	93	100	87	93	78	47	60	10	0	0	0
9.	Quinclorac	0.375	PRE											

Table 3. Clomazone injury on 'Cypress' rice (rolled vs. not rolled seedbed) in a broadleaf signalgrass infestation, Lonoke, Arkansas, 1997.

Treatment	Rate	Growth stage	Broadleaf signalgrass control			Rice injury							Rice yield
			5/22	5/30	6/17	5/22	5/30	6/17	6/27	7/22	8/21	9/2	9/16
		lb ai/acre	%										bu/acre
Pendimethalin + quinclorac; rolled	1.0 + 0.25	DPRE	100	98	100	0	20	13	3	0	0	5	149
Pendiemthalin + quinclorac; not rolled	1.0 + 0.25	DPRE	100	98	100	7	13	0	3	0	0	0	149
Clomazone (4EC); rolled	0.5	PPI	100	95	100	47	35	30	17	0	0	0	133
Clomazone (4EC); not rolled	0.5	PPI	100	97	100	30	45	42	32	13	7	8	125
Clomazone (3ME); rolled	0.5	PPI	100	95	100	30	28	47	33	7	3	3	126
Clomazone (3ME); not rolled	0..5	PPI	100	95	100	37	25	35	20	2	0	0	121
Clomazone (3ME); rolled	0.5	PRE	100	93	100	40	18	17	12	0	0	0	143
Clomazone (3ME); not rolled	0..5	PRE	100	92	100	50	17	23	3	0	0	0	145
Clomazone (3ME); rolled	0.5	DPRE	100	95	100	47	17	15	5	0	0	0	126
Clomazone (3ME); not rolled	0..5	DPRE	100	95	100	47	17	10	5	0	0	0	140
LSD (P=0.05)			0	5	0	13	13	10	8	13	7	10	36

Table 4. Quinclorac granules for broadleaf signalgrass control in 'Cypress' rice, Lonoke, Arkansas, 1997.

Treatment	Rate	Growth stage	Broadleaf signalgrass control			Rice injury		Rice yield
			5/30	6/27	8/27	5/30	6/27	9/19
	lb ai/acre		%					bu/acre
Untreated check			0	0	0	0	0	93
Quinclorac (75DF)	0.25	PRE	90	98	98	10	4	147
Quinclorac (1.5GR)	0.25	PRE	84	100	99	10	0	140
Quinclorac (75DF)	0.375	PRE	90	100	100	10	5	144
Quinclorac (1.5GR)	0.375	PRE	85	93	100	10	5	145
Quinclorac (75DF)	0.5	PRE	90	99	100	13	4	143
Quinclorac (1.5GR)	0.5	PRE	89	98	100	13	11	136
Quinclorac (75DF)	0.25	DPRE	90	100	100	10	0	144
Quinclorac (1.5GR)	0.25	DPRE	84	98	100	10	1	148
Quinclorac (75DF)	0.375	DPRE	90	100	100	11	3	141
Quinclorac (1.5GR)	0.375	DPRE	89	98	100	11	0	138
Quinclorac (75DF)	0.5	DPRE	90	100	100	10	0	151
Quinclorac (1.5GR)	0.5	DPRE	88	100	98	11	5	146
Quinclorac (75DF) + Agri-Dex (1 pt/acre)	0.25	EPOST	0	100	100	0	3	144
Quinclorac (1.5GR)	0.25	EPOST	0	89	49	0	0	130
Quinclorac (75DF) + Agri-Dex (1 pt/acre)	0.375	EPOST	0	100	100	0	1	135
Quinclorac (1.5GR)	0.375	EPOST	0	70	80	0	5	123
Quinclorac (75DF) + Agri-Dex (1 pt/acre)	0.5	EPOST	0	98	100	0	3	136
Quinclorac (1.5GR)	0.5	EPOST	0	100	90	0	5	125

continued

Table 4. Continued.

Treatment	Rate	Growth stage	Broadleaf signalgrass control			Rice injury		Rice yield
			5/30	6/27	8/27	5/30	6/27	9/19
	lb ai/acre		%					bu/acre
Quinclorac (75DF) + Agri-Dex (1 pt/acre)	0.375	POFL	0	0	75	0	0	109
Quinclorac (1.5GR)	0.375	POFL	0	0	35	0	0	92
Quinclorac (75DF) + Agri-Dex (1 pt/acre)	0.5	POFL	0	48	63	0	0	121
Quinclorac (1.5GR)	0.5	POFL	0	60	76	0	0	127
Quinclorac (75DF) + thiobencarb	0.25 + 2.0	DPRE	90	100	95	10	0	135
Quincloraci (75DF) + thiobencarb	0.188 + 2.0	DPRE	86	98	100	10	1	142
Quinclorac (75DF) + pendimethalin	0.25 + 1.0	DPRE	90	98	100	10	4	138
Quinclorac (75DF) + pendimethalin	0.188 + 1.0	DPRE	90	100	100	11	4	133
Quinclorac (75DF) + thiobencarb	0.375 + 2.0	DPRE	90	100	100	10	0	147
Quinclorac (75DF) + thiobencarb	0.375 + 3.0	DPRE	90	100	100	10	0	131
Quinclorac (75DF) + pendimethalin	0.375 + 1.0	DPRE	90	100	100	10	0	144
LSD (P=0.05)			3	9	15	2	7	23

Table 5. Yellow nutsedge control in 'Cypress' rice, Lodge Corner, Arkansas, 1997.

Treatment	Rate	Growth stage[†]	Yellow nutsedge			Rice injury
			6/5	7/2	7/18	7/2
	lb ai/acre		%			
Untreated check			0	0	0	0
(Propanil + molinate) + bensulfuron fb[‡] (propanil + molinate) + bensulfuron	4.5 + 0.019 fb 4.5 + 0.019	2-3 lf fb PREFL	48	99	98	13
(Propanil + molinate) + halosulfuron fb (Propanil + molinate) + halosulfuron	4.5 + 0.031 fb 4.5 + 0.031	2-3 lf fb PREFL	60	100	100	15
Clomazone (3ME) + sulfentrazone	0.4 + 0.2	DPRE	88	93	100	26
All remaining treatments included pendimathalin, 1.0 + quinclorac, 0.25, DPRE:						
Halosulfuron + Induce (0.25%)	0.047	2-3 lf[†]	40	100	100	8
Halosulfuron + Induce (0.25%)	0.063	2-3 lf	43	98	100	9
Halosulfuron + Induce (0.25%)	0.047	2-3 lf	50	99	100	14
Halosulfuron + Induce (0.25%)	0.063	PREFLD	4	96	100	8
Halosulfuron + Induce (0.25%)	0.094	PREFLD	0	98	100	10
Halosulfuron + Induce (0.25%)	0.047	POFL	0	94	100	23
Halosulfuron + Induce (0.25%)	0.063	POFL	0	94	100	18
Halosulfuron + Induce (0.25%)	0.094	POFL	0	90	100	16
Halosulfuron + propanil (Stam -4)	0.063 + 3.0	PREFL	0	100	100	4
Halosulfuron + propanil (Super Wham) + Penetrator Plus (1 pt/acre)	0.063 + 3.0	PREFL	0	100	100	16
Halosulfuron + (propanil + molinate)	0.063 + 4.5	PREFL	0	100	100	13
Propanil (Stam M-4) + bensulfuron	3.0 + 0.038	PREFL	0	93	100	10
Propanil (Super Wham) + bensulfuron + Penetrator Plus (1 pt/acre)	3.0 + 0.038	PREFL	0	86	100	6
(Propanil + molinate) + bensulfuron	4.5 + 0.038	PREFL	0	98	100	6
(Propanil + molinate) + bensulfuron	1.5 + 0.047	POFL	0	50	64	6
F8426-2 + AG-98 (0.25%)	0.025	PREFL	0	0	0	0
LSD (P=0.05)			10	10	6	15

[†] 2-3 lf = 2- to 3-leaf rice; PREFL = preflood; POFL = postflood; DPRE = delayed preemergence.

[‡] fb = followed by.

Table 6. Halosulfuron injury screening in 'Cypress' rice, Lonoke, Arkansas, 1997.

			Rice injury			Rice yield
Treatment	Rate	Growth stage[†]	6/1	7/22	9/17	9/22
	lb ai/acre		--------	%	--------	bu/acre
All treatments included pendimathalin, 1.0 + quinclorac, 0.25, DPRE fb propanil (Stam M-4) PREFL:						
Check (DPRE + PREFL)			3	0	1	151
Halosulfuron	0.062	PRE	4	3	4	145
Halosulfuron	0.124	PRE	10	0	5	147
Halosulfuron + Induce (0.25%)	0.062	EPOST	8	0	4	159
Halosulfuron + Induce (0.25%)	0.124	EPOST	3	0	4	148
Halosulfuron + Induce (0.25%)	0.062	PREFL	3	1	6	154
Halosulfuron + Induce (0.25%)	0.124	PREFL	0	0	1	145
Halosulfuron + Induce (0.25%)	0.062	POFL	5	0	5	160
Halosulfuron + Induce (0.25%)	0.124	POFL	0	0	3	151
Halosulfuron + Induce (0.25%) fb[‡] halosulfuron + Induce (0.25%)	0.062 fb 0.047	EPOST PREFL	6	4	10	146
Halosulfuron + Induce (0.25%) fb halosulfuron + Induce (0.25%)	0.062 fb 0.062	EPOST POFL	6	3	6	154
Halosulfuron + Induce (0.25%) fb halosulfuron + Induce (0.25%)	0.062 fb 0.047	PREFL POFL	1	0	3	156
LSD (P=0.05)			12	4	8	17

[†] PRE = preemergence; EPOST = early postemergence; PREFL = preflood; POFL = postflood.

[‡] fb = followed by.

Table 7. Fenoxaprop safener study in 'Cypress' rice, Lonoke, Arkansas, 1997.

Treatment	Rate	Growth stage	Rice injury 7/3	Rice injury 8/27
	lb ai/acre		%	%
Untreated check			0	0
Fenoxaprop (Bugle)	0.057	2-lf[†]	8	5
Fenoxaprop (Bugle)	0.114	2-lf	16	25
Fenoxaprop (Bugle) + HOE 122006	0.057 + 0.057	2-lf	3	14
Fenoxaprop (Bugle) + HOE 122006	0.114 + 0.114	2-lf	3	10
Fenoxaprop (Whip 360)	0.057	2-lf	11	38
Fenoxaprop (Whip 360)	0.114	2-lf	33	43
Fenoxaprop (Whip 360) + HOE 122006	0.057 + 0.057	2-lf	3	14
Fenoxaprop (Whip 360) + HOE 122006	0.114 + 0.114	2-lf	3	10
Propanil (Super Wham) + quinclorac + Penetrator Plus (1 pt/acre)	3.0 + 0.25	2-lf	14	8
Fenoxaprop (Bugle) fb fenxoaprop (Bugle)	0.04 fb 0.057	2-lf PREFL	18	33
Fenoxaprop (Bugle) + HOE 122006 fb fenoxaprop (Bugle) + HOE 122006	0.04 + 0.04 fb 0.057 + 0.057	2-lf PREFL	11	11
LSD (P=0.05)			11	20

[†] 2-lf = 2-leaf rice; PREFL = preflood.

[‡] fb = followed by.

ONGOING PROJECT
PEST MANAGEMENT: WEEDS

ALLELOPATHIC ACTIVITIES TO BARNYARDGRASS IN RICE ANDYIELD REDUCTION DUE TO BARNYARDGRASS INFESTATION

R.H. Dilday, K.A. Moldenhauer, W.G. Yan and D.R. Gealy

ABSTRACT

Seven germplasm accessions that vary in allelopathic activity to barnyardgrass based on previous tests and two U.S. semidwarf cultivars plus one blank plot (no rice) were evaluated. Four of the germplasm accessions originated at the International Rice Research Institute (IRRI), Los Banos, Philippines (PI 338064, PI 350468, PI 366150 and PI 373026), two were from China (‘Guichao’ and ‘Teqing’), and one was from Taiwan (PI 312777). The two non-allelopathic U.S. cultivars were ‘Rexmont’ and ‘Lemont’. The average grain yield reduction in the barnyardgrass-infested plots was 3423 lb/acre or 48.9%. Two germplasm accessions from IRRI, PI 350468 and PI 338064, had the least grain yield reduction (2173 lb/acre or 36.7% and 2519 lb/acre or 37.2%, respectively). The two non-allelopathic U.S. check cultivars, Rexmont and Lemont, had the highest percent yield reduction (4609 lb/acre or 68.1% and 3815 lb/acre or 59.5%, respectively).

INTRODUCTION

More than 50 weed species infest direct-seeded rice and cause major losses in U.S. rice production (Smith et al., 1977). Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] is the most frequently reported and troublesome weed in rice fields, followed by ducksalad [*Heteranthera limosa* (Sw.) Willd.], hemp sesbania [*Sesbania exaltata* (Raf.) Rydb, ex A. W. Hill], bulrushes (*Scirpus* spp.), red rice (*Oryza sativa* L.), broadleaf signalgrass [*Brachiaria platpyhylla* (Griseb) Nash] and sprangletops (*Leptochloa* spp.)(Chandler, 1981).

Although technology of weed control in rice integrates preventive, cultural, mechanical, chemical and biological practices, herbicides are probably the most important component of weed management for rice production in the United States (Smith, 1982), since over 95% of the rice area is treated with herbicides (Smith et al., 1977). The most recent and least exploited method of weed control is biological control. Although the use of biological weed control has been limited, successful research and implementation of these methods have occurred. Attracting wild ducks to red rice-infested fields by flooding fields in the fall reduced the red rice seed remaining in the field by 96%, and this was a benefit for the subsequent rice crops (Smith and Sullivan, 1980). Water lily aphid (*Rhopalosiphum nymphaeae* L.) reduced ducksalad biomass by 58-87% and seed pods by 82%, and this did not noticeably injure rice (Oraze and Grigarick, 1992).

Allelopathy is another potential strategy of biological weed control of rice. Dilday et al. (1989a, 1989b) reported that 191 and 156 rice accessions screened from 5000 different accessions each year from the USDA, ARS world collection of rice showed allelopathic activity against ducksalad in field evaluations. The accessions had a radius of activity up to 6 in. around rice plants and a range of 82 to 90% weed control within the area of activity compared to Rexmont, a cultivar without allelopathic activity.

The objectives of this study were 1) to evaluate rice germplasm for allelopathic activity to barnyardgrass and 2) to determine grain yield reduction due to barnyardgrass infestation in allelopathic and non-allelopathic germplasm.

PROCEDURES

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. Seven germplasm accessions that vary in allelopathic activity to barnyardgrass based on previous tests and two U.S. semidwarf cultivars, Rexmont and Lemont, plus one blank plot (no rice planted) were evaluated in this experiment (Table 1). Four of the germplasm accessions originated at the International Rice Research Institute (IRRI), Los Banos, Philippines [PI 338064 (IR 782-98), PI 350468 (IR 781-92-1-2-1-2-2), PI 366150 (SH 30-21) and PI 373026 (IR 788-16-1-1-1)]; two were from China (Guichao and Teqing), and PI 312777 (T65*2/TN-1) was from Taiwan. The experiment was a randomized complete block design (two replications) with two treatments, barnyardgrass control (clean) and barnyardgrass infestation. Barnyardgrass seed harvested in 1983 was broadcast at a rate of 1.5 gallon/acre to insure a uniform infestation of barnyardgrass. The barnyardgrass seeds were incorporated with a harrow prior to seeding the rice. After seeding the rice, a second broadcast application of barnyardgrass seed (0.75 gallon/acre) was made, but these seeds were not incorporated. Eighty grams of rice (116 lb/acre) were seeded in nine-row plots 12 ft long with 8-in. row spacing on 23 May 1997 and the seedlings emerged on 30 May 1997. A 15-in.-diameter plastic cylinder was placed in the center of each plot, and the number and dry weight of barnyardgrass plants within each cylinder were recorded at maturity. Four-way split applications of fertilizer [pre-planting incorporation (30 lb N/acre as ammonia sulfate), pre-flood (60 lb N/acre as urea), 0.5-in. internode elongation (IE) (30 lb N/acre) and 7 days after 0.5-in. IE (30 lb N/acre)] were applied. Four quarts of propanil mixed with 1.5 pints of bentazon (Basagran®) were applied per acre on 2, 11 and 19 June to control barnyardgrass in the barnyardgrass control (check) plots. Two 10-ft rows in each plot were harvested for grain yield.

RESULTS AND DISCUSSION

Grain yields of the nine rice entries were taken in both barnyardgrass-infested plots and plots free of barnyardgrass. The average grain yield reduction in the barnyardgrass-infested plots was 3423 lb/acre, or 48.9%, compared to the yields from weed-free plots (Table 1). The average grain yield of the nine rice entries in the control (no barnyardgrass) plots was 6998 lb/acre compared to 3575 lb/acre from the barnyardgrass-infested plots. The two U.S. check cultivars, Rexmont and Lemont, had the greatest yield reduction (4609 lb/acre or 68.1% and 3815 lb/acre or 59.5%, respectively) when the barnyardgrass-infested plots were compared to the control plots (no barnyardgrass). Two germplasm accessions from the International Rice Research Institute (IRRI), PI 350468 and PI 338064, had the least yield reduction (2173 lb/acre or 36.7% and 2519 lb/acre or 37.2%, respectively). Also, the two IRRI accessions, PI 350468 and PI 338046, had the least barnyardgrass biomass (2.0 and 10.5 g, respectively) and the two U.S. cultivars, Rexmont and Lemont, produced large amounts of barnyardgrass biomass (29.5 and 30.5 g, respectively). The number of barnyardgrass plants observed in Guichao (5.0) from China, PI 312777 (6.5) from Taiwan and Teqing (8.5) from China were significantly less than in Rexmont (30.0) or the blank plot (41.0).

SIGNIFICANCE OF FINDINGS

These data demonstrate that rice germplasm exists in our U.S. rice germplasm collection that can reduce barnyardgrass number and partially inhibit the growth and development of barnyardgrass. Also, this natural inhibition of barnyardgrass by rice germplasm alone can account for more than a 20% increase in grain yield when compared to non-allelopathic germplasm where no herbicide is applied to control barnyardgrass. In the breeding program we have used some of the germplasm that has demonstrated allelopathic activity in crosses with U.S. cultivars. Advanced lines from some of the hybridizations made as early as 1990 are presently being evaluated in the variety development program.

ACKNOWLEDGMENTS

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Table 1. Allelopathic activities of rice accessions to barnyardgrass and yield reduction due to barnyardgrass infestation.

		Clean[†]	Barnyardgrass (BYG)[‡]				
Name	PI No.	Rice	Rice	BYG Number	BYG Weight	Rice yield reduction	
		(lb/ acre)	(lb/ acre)	(no.)	(g)	(lb/acre)	(%)
Blank-no rice				41.0	17.0		
T65*2/TN1	312777	7251	3969	6.5	15.0	3282	45.3
IR 782-98	338064	6776	4257	16.5	10.5	2519	37.2
IR 781-92-1-2-1-2-2	350468	5926	3753	11.0	2.0	2173	36.7
SH 30-21	366150	7880	4047	17.5	10.5	3833	48.6
IR 788-16-1-1-1	373026	6750	3185	23.5	30.5	3565	52.8
Lemont	475833	6413	2598	19.0	30.5	3815	59.5
Rexmont	502968	6772	2163	30.0	29.5	4609	68.1
Guichao	na[§]	8146	4408	5.0	21.5	3738	45.9
Teqing	na	7071	3793	8.5	14.5	3278	46.4
Mean		6998	3575	17.9	18.2	3423	48.9
LSD 0.05		2021	1199	20.5	38.6		

[†] Clean = barnyardgrass was controlled by herbicides.

[‡] Barnyardgrass = barnyardgrass was not controlled.

[§] na = not available.

ONGOING PROJECT
PEST MANAGEMENT: WEEDS

INITIAL WEED CONTROL RESULTS IN IMI-TOLERANT RICE

T.L. Dillon and F. L. Baldwin

ABSTRACT

The imidazolinone herbicides include imazethapyr (Pursuit®) and imazaquin (Scepter®). Development of rice cultivars tolerant to these herbicides shows great promise for weed control in rice. Based on these studies conducted in Arkansas, imazethapyr has excellent potential for broad-spectrum residual grass and red rice control in dry-seeded rice. It also has the potential to be applied at a range of application timings. Further research is needed to develop combination and sequential treatments with other herbicides for broad-spectrum weed control.

INTRODUCTION

Research has been conducted to develop “IMI-tolerant” rice lines that can survive treatment with the broad-spectrum imidazolinone herbicides imazethapyr (Pursuit®) and imazaquin (Scepter®). Imazethapyr has the potential to be applied at a wide range of application timings (Dillon et al., 1998).

An “IMI-tolerant” rice line designated ‘93AS3510’ has been developed by Dr. Tim Croughan at LSU. Its parent line ‘3510’ originated in a private breeding program but reportedly lacks the yield potential that modern producers demand (Linscombe, 1998). Line 3510 was one of hundreds of rice lines treated with different levels of the chemical mutagen EMS. Line 3510 was the only one to mutate an AHAS enzyme that is directly tolerant to imidazolinones (Croughan et al., 1992). This mutated line (93AS3510) survived field spraying with imazethapyr in tolerance studies conducted by Dr. Tim Croughan at LSU. The line is short season in maturity but has a low yield potential.

PROCEDURES

The IMI-tolerant rice line 93AS3510, a non-transgenic line described above, was used in experiments conducted at Stuttgart and Rohwer in 1997 to evaluate imazethapyr for red rice control and at Lonoke and Rohwer for broadleaf signalgrass control. The Stuttgart location was over-seeded with red rice in 1996 for a soybean demonstration. The area was reseeded with red rice in 1997 prior to conducting the IMI-tolerant rice study. The study at Rohwer was on a newly over-seeded population of red rice. Similar studies were conducted at Lonoke and Rohwer to evaluate imazethapyr for control of natural infestations of broadleaf signalgrass and barnyardgrass. Imazethapyr was applied preplant incorporated (PPI), preemergence (PRE), delayed preemergence (DPRE), early postemergence (EPOST), preflood (PREFL) and postflood (POFL) at rates from 0.063 to 0.125 lb ai/acre. In addition to these treatments, various sequential applications of imazethapyr were also evaluated. Dates of treatments are indicated in the tables.

RESULTS AND DISCUSSION

At the Stuttgart location, all single and combination treatments of imazethapyr except POFL treatments provided 100% control of red rice 71 days after seeding line 93AS3510 (Table 1). Good control of entireleaf morningglory was also achieved with the soil-applied treatments of imazethapyr. Severe injury occurred with the DPRE causing stand reduction and delayed maturity of the 93AS3510 (Table 2). It is not clearly understood at this time why this injury occurred. This study was destroyed before flowering to prevent any potential out-crossing to the red rice; thus no yields were taken. On the clay soil at Rohwer, sequential applications were required to provide red rice control comparable to single applications at Stuttgart (Webster and Baldwin, 1998).

Excellent control of broadleaf signalgrass was achieved with most treatments at the Lonoke location (Table 3). Imazethapyr gave poor control on eclipta and hemp sesbania. Imazaquin at 0.125 lb ai/acre applied PPI provided excellent broadleaf signalgrass control and was also effective on eclipta. No injury was noted from any of the treatments. By the end of the season this study was heavily infested with hemp sesbania and was not harvested.

Selection 93AS3510 is being back-crossed into LSU and U of A varieties, with the projection for possible foundation seed in the year 2001. American Cyanamid Company reports that imazethapyr will be registered for use on the rice crop about the same time.

SIGNIFICANCE OF FINDINGS

IMI-tolerant rice offers the potential for controlling red rice as well as a broad spectrum of other weeds in drill seeded rice. It also offers the potential for residual control and for the increased use of ground application in rice. It could potentially be the biggest breakthrough in rice weed control since propanil.

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Table 1. Red rice control in IMI-tolerant rice, Stuttgart, Arkansas, 1997. Seeding date 5/13/97.

Treatment (Appl. Date)	Red rice control 6/5/97	Red rice control 7/23/97	Entireleaf morningglory control 7/23/97
lb ai/acre			
Untreated check	0	0	0
Imazethapyr, 0.063, PPI[†] (5/13/97)	91	100	73
Imazethapyr, 0.063, PRE (5/13/97)	75	100	60
Imazethapyr, 0.063, DPRE (5/23/97)	81	100	83
Imazethapyr, 0.063, EPOST (6/5/97)	90	100	58
Imazethapyr, 0.063, POFL (6/25/97)	0	28	--

[†] PPI = preplant incorporated; PRE = preemergence; DPRE = delayed preemergence; EPOST = early postemergence; POFL = post flood.

Table 2. Rice injury in IMI-tolerant rice, Stuttgart, Arkansas, 1997. Seeding date 5/13/97.

Treatment	% Injury 6/5/97	% Injury 7/23/97	% Heading of 93AS3510 7/23/97
lb ai/acre			
Untreated check	0	0	40[†]
Imazethapyr, 0.063, PPI[‡]	3	0	98
Imazethapyr, 0.125, PPI	28	0	75
Imazethapyr, 0.063, PRE	0	0	100
Imazethapyr, 0.125, PRE	15	0	95
Imazethapyr, 0.063, DPRE	41	0	63
Imazethapyr, 0.125, DPRE	63	0	10

[†] Heading delay in untreated check attributed to red rice competition. Few plants of 93AS3510 survived in the untreated check.

[‡] PPI = preplant incorporated; PRE = preemergence; DPRE = delayed preemergence.

Table 3. Broadleaf signalgrass control in IMI-tolerant rice, Lonoke, Arkansas, 1997.

Treatment (Appl. Date)	Weed control on 18 June 1997: Broadleaf signalgrass	Weed control on 18 June 1997: Eclipta
lb ai/acre		
Untreated check	0	0
Imazethapyr, 0.063, PPI[†] (5/8/97)	98	0
Imazethapyr, 0.063, PRE (5/8/97)	99	24
Imazethapyr, 0.063, DPRE (5/12/97)	100	13
Imazethapyr, 0.063, EPOST (6/2/97)	100	70
Imazaquin, 0.125, PPI (5/8/97)	96	95

[†] PPI = preplant incorporated; PRE = preemergence; DPRE = delayed preemergence; EPOST = early postemergence.

ONGOING PROJECT
PEST MANAGEMENT: WEEDS

RESPONSE OF RED RICE BIOTYPES AND RICE CULTIVARS TO DIFFERENT POPULATION DENSITIES

L.E. Estorninos, Jr., D.R. Gealy and R.E. Talbert

ABSTRACT

Two field experiments were conducted at the University of Arkansas Rice Research and Extension Center at Stuttgart, Arkansas, in 1997 to evaluate the growth response of 1) Stuttgart strawhull red rice to four seeding rates of 'Kaybonnet', 'Guichao' and PI 312777 and 2) Kaybonnet to four seeding rates of 'Stuttgart strawhull', 'Katy strawhull' (KatyRR) and Louisiana (LA3) red rice biotypes. In experiment I, red rice panicle density decreased by 65% when grown together with a 45-lb/acre seeding rate of domestic rice and by 81% when grown with an 89- or 134-lb/acre seeding rate. Yields of PI 312777 and Guichao were higher than yields of Kaybonnet when in competition with red rice. When infested with red rice, grain yields of commercial rice increased when the seeding rate increased from 45 to 89 lb/acre, but seeding rates between 89 and 134 lb/acre gave no further yield increase. In Experiment II, potential contamination from red rice seed yield of LA3 red rice biotype was higher than for Stuttgart strawhull and KatyRR red rice biotypes with higher red rice seeding rates. Kaybonnet panicle density was reduced with the presence of Stuttgart strawhull (16-22%) and LA3 (20-32%) and was reduced more by increasing seeding rates of LA3 than by increased rate of KatyRR. This indicates that Kaybonnet is less competitive against LA3 and Stuttgart strawhull than against KatyRR.

INTRODUCTION

Red rice, *Oryza sativa* L., has been a major problem weed in most rice growing areas in the United States and in many other parts of the world. In the Southern Rice Belt, the percentage of acreage infested with red rice was estimated at 30 to 40% in Arkansas, 50% in Mississippi, 40 to 50% in Texas and almost 100% of the rice areas in Louisiana (Deshaies, 1996). Red rice infestation increased in Italian rice crops due to the use of contaminated seed and ineffectiveness of chemical control (Ticchiati et al., 1996). Red rice plants reduce yield and quality of domestic rice (Diarra et al., 1985) and contaminate the land with shattered grains (Smith, 1981). Grain yield was reduced from 22 to 82% when red rice density was increased from 5 to 215 plants/m^2 (Diarra et al., 1985). Despite ongoing efforts to control it, red rice continues to be the second major problem weed in rice and soybean growing areas. There is a need, therefore, to address the red rice problem with a combination of approaches, and to do so, its biology and ecology need to be more fully understood.

The objectives of these experiments were: 1) to determine the response of Stuttgart strawhull red rice to four seeding densities and different growth characteristics of three rice cultivars and 2) to determine the response of Kaybonnet rice cultivar to three bioytpes and four seeding densities of red rice.

MATERIALS AND METHODS

Two field experiments were conducted at the University of Arkansas Rice Research and Extension Center at Stuttgart, Arkansas, from May to October 1997. Each experiment was laid out in a split plot design with four replications. For experiment I, the main plots consisted of the rice cultivars, Kaybonnet (popular commercial cultivar), Guichao (Chinese cultivar with possible competitiveness against weeds), and PI 312777 (T65*2/TN1; a possible allelopathic cultivar from Taiwan). The subplots were domestic rice-seeding rates of 0, 45, 89 and 134 lb/ acre. The standard red rice biotype Stuttgart strawhull was broadcast seeded at 12 lb/acre. For Experiment II, the main plots were the red rice biotypes, Stuttgart strawhull (a prominent red rice biotype in Arkansas), Katy strawhull (KatyRR - a short-statured, suspected hybrid of Katy rice and a red rice biotype) and Louisiana red rice (LA3 - tall and awned biotype). The subplots were red rice seeding rates of 0 (domestic rice alone), 6, 12 and 18 lb/acre. The standard rice cultivar Kaybonnet was drill seeded at 89 lb/acre in rows spaced 7 in. apart in plots 20 ft in length. A roller was pulled parallel to drill rows across plots immediately after seeding to bury the seeds and compact the soil.

Growth responses of red rice and domestic rice were determined by the number of tillers from two 0.7-ft^2 quadrants/plot 7 weeks after emergence (WAE) and panicle density from two 2.7-ft^2 quadrants/plot at harvest. Domestic rice grain yield was determined by harvesting samples by hand from 15.1 ft^2 per plot. Leaf area of 10 subsample plants was measured 4, 7, 10 and 13 WAE, and dry weight was determined for growth analyses. Fifteen red rice panicles from the 15.1 ft^2 were bagged at the hard dough stage to prevent losses from shattering and to improve accuracy of red rice yield estimates. Red rice panicles were harvested by hand. Grain from panicles was weighed and was adjusted to 12% moisture. This value was multiplied by the number of panicles counted from 15.1 ft^2 domestic rice sampling area and multiplied by the constant 0.4236 to extrapolate red rice seed yield in lb/acre.

RESULTS AND DISCUSSION

Experiment I

Panicle density of Stuttgart strawhull was not significantly affected by the different rice cultivars; however, it was reduced by all seeding rates of domestic rice when compared to red rice planted alone (Table 1). Panicle density of Stuttgart strawhull was reduced by 65% when grown with 45 lb/acre domestic rice seeding rate and by 81% when grown with 89 or 134 lb/acre seeding rate. Red rice panicle density was reduced by 44% when seeding rate of domestic rice was increased from 45 to 89 lb/acre. The average number of panicles of red rice when grown alone was 26/ft^2 and only five to nine panicles/ft^2 when grown with domestic rice. Seed yield of Stuttgart strawhull was lower when seeded in competition with PI 312777 than with Kaybonnet (Table 2). The red rice seed yield appeared to be unrealistically high. This was probably due to extrapolating from a small harvest area to pounds per acre. Thus, one should not be concerned with the absolute yields but with the relative differences between treatment yields. The comparisons shown in Table 2 do indicate the relative competitive effects of rice cultivars and seeding density on red rice seed production. Yield of red rice was lower when domestic rice was present, even at the lowest seeding rate, compared to red rice alone, but was not reduced further when domestic rice seeding rate was increased. Panicle density of PI 312777 was greater than that of the other cultivars when infested with Stuttgart strawhull (Table 3). Rice panicle density increased when rice seeding rate was increased. Kaybonnet apparently was less competitive against red rice since the yield was considerably lower than that of Guichao and PI 312777 (Table 4). Rice yield at the rice seeding rate of 89 lb/acre was as high as that of 134 lb/acre, indicating that under the conditions of this experiment, optimum yield can be obtained at the 89-lb/acre seeding rate in the presence of Stuttgart strawhull red rice.

Experiment II

The general trend for all red rice biotypes was for panicle density to increase with seeding rate (Table 5). However, there were significant interactions between biotypes and red rice seeding rates. Stuttgart strawhull panicle density was greater at the highest red rice seeding rate, but KatyRR did not differ among seeding rates. LA3 had higher panicle density than KatyRR and Stuttgart strawhull at the two higher seeding rates. Seed yield of Stuttgart strawhull increased when seeding rate increased from 6 to 18 lb/acre, but KatyRR yields did not differ among seeding rates (Table 6). LA3 yielded higher at the two higher seeding rates. At the medium seeding rate, LA3 was more competitive than Stuttgart strawhull and KatyRR. At the highest seeding rate, yield of LA3 was higher compared to the other two biotypes while Stuttgart strawhull yielded higher than KatyRR.

Stuttgart strawhull and LA3 reduced the panicle density of Kaybonnet, whereas KatyRR did not (Table 7). Rice panicle density was reduced by LA3 and by higher seeding rates of Stuttgart strawhull. Grain yield of Kaybonnet was reduced by Stuttgart strawhull and LA3, but not by KatyRR (Table 8). LA3 tended to cause greater yield reduction at lower seeding rates than did Stuttgart strawhull.

SIGNIFICANCE OF FINDINGS

The Stuttgart strawhull red rice biotype seeded at 12 lb/acre reduced yields of Kaybonnet more than those of PI 312777 partly because of its greater effect on Kaybonnet panicle density. This suggests that highly competitive, and possibly allelopathic, cultivars such as PI 312777 could help reduce red rice infestations over time. The red rice biotype LA3 was more competitive than the other biotypes, indicating that management strategies of the future may need to distinguish between highly and moderately competitive red rice biotypes. The fact that KatyRR did not reduce Kaybonnet yields and produced only limited seed yields of its own suggests that small-statured offspring of crosses between red rice and domestic rice (possibly including herbicide resistant rice) may pose lowered risks to domestic rice production.

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Table 1. Red rice panicle density as influenced by cultivars and domestic rice seeding rates, Stuttgart, Arkansas, 1997.

	Domestic rice seeding rate (lb/acre)				
Cultivars	0	45	89	134	Mean
	no. red rice panicles/ft^2				
Kaybonnet	26	10	5	5	11 a
Guichao	26	7	5	6	12 a
PI 312777	25	8	4	4	11 a
Mean	26 a[†]	9 b	5 c	5 c	

[†] In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 2. Red rice seed yield as influenced by cultivars and domestic rice seeding rates, Stuttgart, Arkansas, 1997.

	Domestic rice seeding rate (lb/acre)				
Cultivars	0	45	89	134	Mean
	lb rice/acre				
Kaybonnet	11000	3930	1700	1880	4630 a
Guichao	9560	2480	1250	1600	3720 ab
PI 312777	10000	2040	1380	940	3590 b
Mean	10190 a[†]	2820 b	1470 b	1450 b	

[†] In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 3. Panicle density of rice cultivars when in competition with seeded red rice at 12 lb/acre as affected by cultivars and domestic rice seeding rate. Stuttgart, Arkansas, 1997.

Cultivars	Domestic rice seeding rate (lb/acre) 45	89	134	Mean
	no. rice panicles/ft^2			
Kaybonnet	23	32	40	32 b
Guichao	23	33	39	32 b
PI 312777	31	41	49	40 a
Mean	26 c[†]	36 b	43 a	

[†] In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 4. Rough rice yield of cultivars when grown in competition with seeded red rice at 12 lb/acre as affected by cultivars and domestic rice seeding rate. Stuttgart, Arkansas, 1997.

Cultivars	Domestic rice seeding rate (lb/acre) 45	89	134	Mean
	lb rice/acre			
Kaybonnet	1460	2850	2590	2320 b
Guichao	3300	3840	4100	3750 a
PI 312777	2940	4010	4460	3840 a
Mean	2590 b	3570 a	3660 a	

[†] In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 5. Red rice panicle density as influenced by red rice biotypes and red rice seeding rates when grown in competition with Kaybonnet. Stuttgart, Arkansas, 1997.

Red rice biotype	Red rice seeding rates (lb/acre) 6	12	18
	no. red rice panicles/ft^2		
Stuttgart strawhull	2 c[†]	4 bc	7 b
KatyRR	1 c	2 c	3 bc
LA3	5 bc	12 a	16 a

[†] In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 6. Red rice seed yield as influenced by biotypes and seeding rates when grown in competition with Kaybonnet. Stuttgart, Arkansas, 1997.

	Red rice seeding rates (lb/acre)		
Red rice biotype	6	12	18
	lb red rice/acre		
Stuttgart strawhull	738 d[†]	1630 cd	2870 bc
KatyRR	304 d	560 d	1140 d
LA3	1900 cd	4100 ab	5520 a

[†] In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 7. Panicle density of Kaybonnet rice as affected by red rice biotypes and seeding rates. Stuttgart, Arkansas, 1997.

	Red rice seeding rates (lb/acre)			
Red rice biotype	0	6	12	18
	no. rice panicles/ft^2			
Stuttgart strawhull	41 a[†]	34 cde	31 def	31 def
KatyRR	40 ab	38 abc	38 abc	35 bcd
LA3	39 abc	31 def	29 ef	27 f

[†] In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 8. Yield of Kaybonnet rice as affected by red rice biotypes and seeding rates. Stuttgart, Arkansas, 1997.

	Red rice seeding rates (lb/acre)			
Red rice biotype	0	6	12	18
	lb rice/acre			
Stuttgart strawhull	6620 a[†]	4570 bc	3230 cd	3070 de
KatyRR	6390 a	5800 ab	5390 ab	5560 ab
LA3	6690 a	3570 cd	1400 e	2150 de

[†] In a column or row, means followed by a common letter are not significantly different at the 5% level by LSD.

ONGOING PROJECT
PEST MANAGEMENT: WEEDS

ACTIVITY OF GLUFOSINATE (LIBERTY) AGAINST RED RICE BIOTYPES IN GLUFOSINATE-RESISTANT GULFMONT RICE

David R. Gealy and Howard L. Black

ABSTRACT

The most effective control of known red rice biotypes in glufosinate-resistant ‘Gulfmont’ rice was from split applications of glufosinate at the three-leaf stage and pre-flood stage, or single pre-flood applications. These treatments generally gave good control of Stuttgart strawhull (StgS) red rice at total rates of 0.75 to 1 lb/acre. Post-flood glufosinate at 0.5 lb/acre or greater gave excellent control of StgS, but yield loss due to competition can result when initial control measures are delayed this long. Texas 4 (TX4) red rice is about twice as tolerant to glufosinate as other biotypes. High temperature causes the greatest and most immediate reduction in photosynthetic productivity of red rice biotypes, and by the time plants have developed chlorosis, photosynthetic production has usually ceased. Resistant Gulfmont was highly tolerant to glufosinate at all rates and timings tested. At rates of glufosinate that killed red rice, resistant Gulfmont plants experienced only a brief period of moderate photosynthesis inhibition, and only mild visible symptoms developed.

INTRODUCTION

Red rice is one of the most troublesome weeds in the rice cropping systems of the southern United States (Deshaies, 1996). BAR-transformed glufosinate-resistant rice cultivars are being developed (Linscombe et al., 1996) that may allow farmers to control red rice (*Oryza sativa*) in the rice (*Oryza sativa*) crop. Glufosinate (Liberty®) is a nonselective herbicide that appears to be a promising candidate for these systems because of its potential to control red rice and other problem weeds (Linscombe et al., 1996; Webster et al., 1997; Wheeler et al., 1997). Different biotypes and populations of red rice may be differentially susceptible to glufosinate (Gealy and Dilday, 1997; Noldin et al., 1994), which would increase the likelihood of unintentional selection for highly tolerant biotypes of red rice and complicate control strategies.

To better understand the efficacy of red rice control with glufosinate in transgenic, glufosinate-resistant Gulfmont rice, survival, growth, chlorosis development and photosynthetic responses of several biotypes of red rice were evaluated in field and growth chamber experiments in Stuttgart, Arkansas, in 1996 and 1997.

PROCEDURES

Field Study

Experiments were conducted at Stuttgart in 1996 and 1997 to determine the effect of application rate and timing on the control, reduction of plant productivity and development of leaf chlorosis in red rice biotypes following glufosinate application in a crop of glufosinate-resistant Gulfmont rice. Henceforth, this herbicide-resistant Gulfmont will be referred to as GFMT. General procedures for 1997 are presented, and combined data for 1996 and 1997 are presented in graphs. GFMT (selection 517-1-R1) and red rice biotypes StgS, Stuttgart blackhull (StgB) and TX4 blackhull were drill-seeded 0.75 in. deep on 4 June 1997 at a seeding rate of 110 lb/acre. Plots consisted of six consecutive rows of GFMT, and one row each of the three red rice biotypes. Additionally, StgS was overseeded on the entire plot area. Plots were flushed 10 June 1996. Red rice plants emerged 10 June 1997, and GFMT emerged 13 June 1997. Plots were fertilized on 9 July 1997 with 120 lb N/acre as urea. Permanent flood was established 10 July 1997. Glufosinate was applied postemergence with a backpack sprayer at the three-leaf stage (27 June 1997), pre-flood (7 July 1997, plants 25 to 32 in. tall), three-leaf followed by pre-flood and post-flood (14 July 1997, three highest rates only, plants 31 to 41 cm tall) at rates of 0.25, 0.38, 0.5, 0.75 and 1.0 lb/acre. Total-season rates applied in the sequential treatments are double those shown above.

Tiller densities and total shoot dry weights were determined for GFMT and StgS, StgB and TX4 red rice biotypes from 26 Aug to 3 Sept 1997, prior to anthesis of either species. Leaf gas exchange parameters were measured with a portable infrared gas analysis system (CID Inc. CI301; Gealy, 1998), and relative leaf chlorosis was estimated with a silicon photodiode detector (Minolta SPAD-502) several consecutive days following a 1-lb/acre late post-flood application (10 days after flooding) of glufosinate. Experiments were conducted using a randomized complete block design with four replications. For gas exchange and chlorosis measurements, at least three and five subsamples, respectively, were taken at each date. After data were collected, the entire plot area was burned to prevent possible outcrossing between the herbicide-resistant rice and red rice plants.

Growth Chamber Study

The effect of glufosinate on gas exchange, chlorosis and visual control of StgS and TX4 red rice biotypes and GFMT was measured in growth chambers to determine glufosinate interaction with temperatures and light intensities that may be present in rice fields during spring application of herbicides. Five plants per pot were grown in Crowley silt loam in Conviron PGR15 growth chambers at 1000 uE/m^2 s, 15°C/25°C day/night temperature and 14-hour photoperiod until they reached the 3.5- to 4-leaf stage. The following four temperature x light regimes were then established:

30°C/20°C day/night and 1000 uE/m^2 s	(HiT-HiL);
30°C/20°C day/night and 250 uE/m^2 s	(HiT-LoL);
20°C/10°C day/night and 1000 uE/m^2 s	(LoT-HiL);
20°C/10°C day/night and 250 uE/m^2 s	(LoT-LoL).

The high and low light levels were about one-half and one-ehghth of full sun, respectively. After a 24-hr equilibration period, plants were sprayed twice with 0.5 lb/acre glufosinate with a pneumatic track sprayer (Allen Machine Works). Photosynthesis, relative chlorosis and plant heights were measured at ambient conditions in the respective temperature—light regimes at 2, 24, 48 and 120 hr after treatment (HAT) as described above. Subsample measurements were as described previously. The experiment was replicated three times and conducted twice.

RESULTS AND DISCUSSION

Field Study

In 1997, glufosinate activity against red rice was substantially less than in 1996 (data not shown), presumably because of the extended drought stress experienced by plants from emergence to permanent flood establishment in 1997. Consistent with previous field and greenhouse results (Gealy and Dilday, 1997), TX4 red rice (Figure 1A) was more than twice as tolerant as StgS (Figure 1B). StgS red rice was controlled more completely when it was intermixed in the GFMT rice canopy (sparse population in competition with crop canopy; Figure 1C) than when growing in separate rows (high population in open row; Figure 1B).

Overall, excellent control of StgS was obtained post-flood with 0.5 lb/acre glufosinate or greater. However, yield loss due to competition can result when control is delayed into the growing season (Smith, 1988), and some glufosinate-resistant varieties can be damaged severely by glufosinate if applied after tiller elongation. The split application and pre-flood application generally gave good control at total rates of 0.75 to 1 lb/acre. Single applications at the three-leaf stage generally were least effective, requiring rates of 1 lb/acre to achieve even moderate control.

Photosynthesis of red rice biotypes decreased rapidly beginning within the first 5 HAT (Figure 2A). Transpiration decreased within the same time frame (Figure 2B), but inhibition was less pronounced than for photosynthesis. Leaf chlorosis (as estimated by a Minolta SPAD-502) developed more slowly and was noticeable within 24 HAT (Figure 2C). It intensified over the next few days, leading to plant death. Unseasonably high temperatures during this period may have hastened herbicide damage and plant death. Glufosinate did not cause chlorosis or any other visible changes in the GFMT plants even though it initially reduced photosynthesis and transpiration of these plants to about 30 and 80% of the control levels, respectively (Figures 2A and 2B). Within 72 HAT, plants had recovered.

Growth Chamber Study

Photosynthetic productivity of untreated plants at HiT-HiL was more than double that at LoT-LoL (Figure 3A), which correlates with plant size under these conditions (data not shown). Untreated plants at LoT-HiL appeared to be slightly chlorotic compared to those at other temperature x light regimes (Figure 3B). This loss of green color is consistent with the process of photo oxidation of chlorophyll known to occur at high light intensities and low temperatures. In most treatments, 1 lb/acre glufosinate inhibited red rice photosynthesis substantially within 2 HAT (Figure 4A). At this time, the greatest inhibition was from high temperature treat ments where photosynthesis values averaged about 20% of the untreated control. The high temperatures probably increase rates of herbicide absorption and binding to the target enzyme (glutamine synthetase), which leads to elevated levels of ammonia that are responsible for inhibition of photosynthesis and membrane functions (Ahrens, 1994). The least inhibition was from low temperature treatments where photosynthesis values averaged about 55 and 65% of the untreated control, respectively, for StgB and TX4. At 24 HAT, photosynthesis values for all red rice treatments were near zero, and GFMT averaged about 60 and 80% of the untreated control, respectively, for high and low temperature treatments. GFMT plants had recovered to near control levels by 48 HAT.

Consistent with field observations, development of chlorosis (Figure 4B) was delayed compared to inhibition of photosynthesis. Chlorosis was first observed at 24 HAT in high light treatments. The Stuttgart blackhull biotype generally developed chlorosis earlier and to a greater extent than did the TX4 biotype, especially at HiT-HiL. Generally, red rice plants were slightly chlorotic under LoT-LoL, moderately chlorotic under LoT-HiL and HiT-LoL and most chlorotic under HiT-HiL. GFMT developed little or no chlorosis. The degree of visual injury from glufosinate at 120 HAT was StgB > TX4 >>> GFMT (data not shown).

SIGNIFICANCE OF FINDINGS

This research demonstrates that glufosinate can effectively control several red rice biotypes with a high degree of selectivity in a glufosinate-resistant rice crop in Arkansas. Some potential biotypes of red rice may be more tolerant to glufosinate than others, so it would be helpful for growers to learn as much as possible about the different kinds and proportions of biotypes present in fields before deciding to apply glufosinate, especially at the lower range of rates available. Environmental conditions at the time of application can alter the visible and physiological activity of glufosinate against red rice. This research suggests that high temperature and high light intensity tend to cause the most rapid and greatest damage to red rice.

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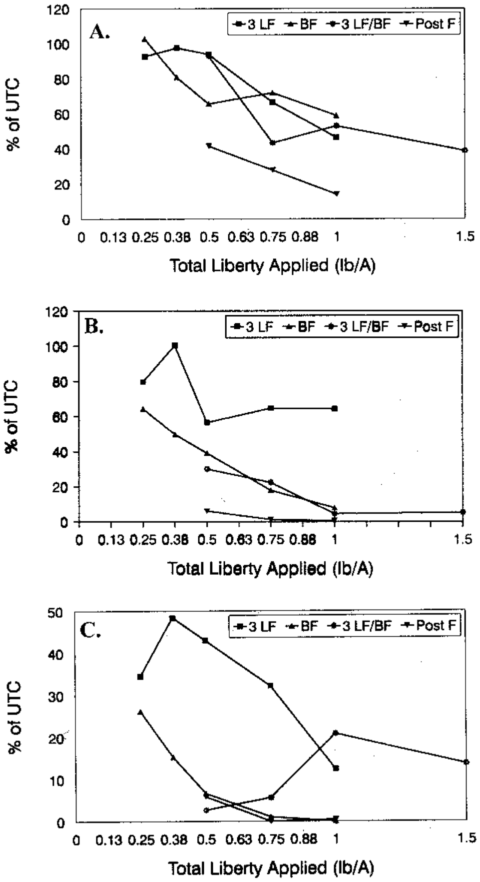

Fig. 1. Effect of total rate and timing of glufosinate (Liberty) application on dry weight of TX4 red rice (A) and StgS red rice (B) in separate drill rows, and StgS in glufosinate-resistant 'Gulfmont' plots (C) in the field. Abbreviations for application timing: 3 LF = three-leaf; BF = before flood (pre-flood); 3 LF/BF = three-leaf followed by before flood; Post F = 4 days post-flood; UTC = untreated control.

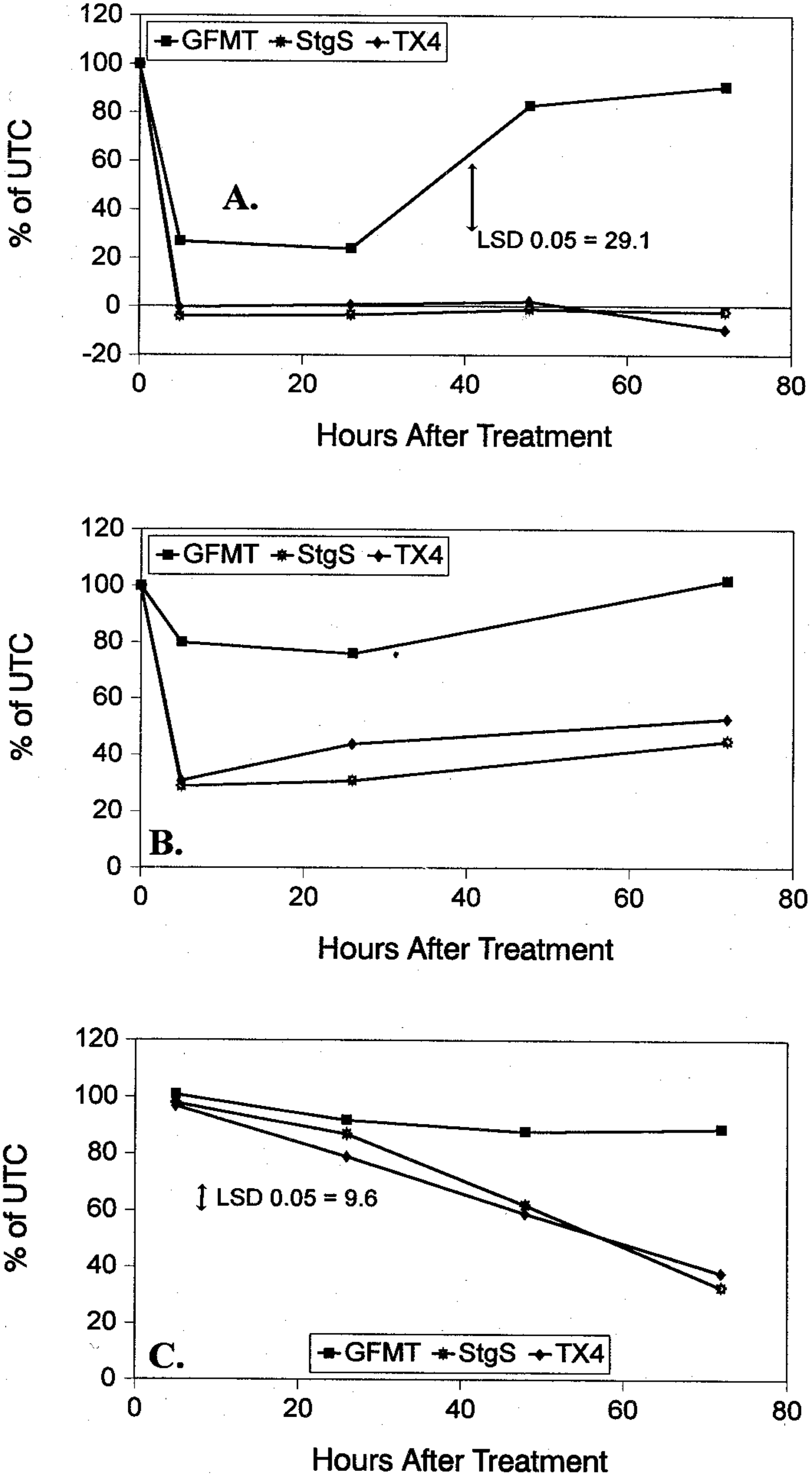

Fig. 2. Effect of 1 lb/acre glufosinate (Liberty) applied 10 days post-flood on photosynthesis(A), transpiration (B) and relative chlorophyll content (C) of StgS and TX4 red rice biotypes and glufosinate-resistant 'Gulfmont.'

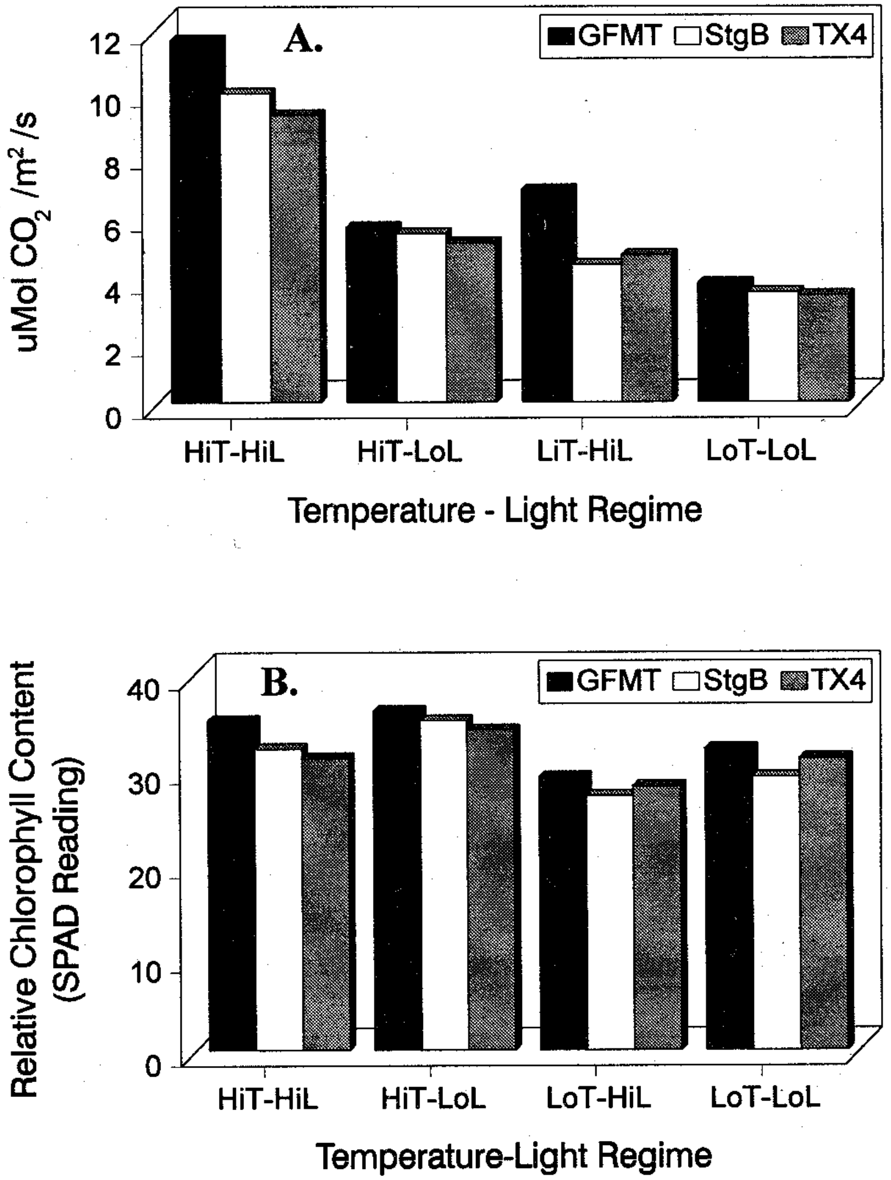

Fig. 3. Effect of temperature and light intensity combinations on leaf photosynthesis (A) and relative chlorophyll content (B) of StgB and TX4 red rice biotypes and glufosinate-resistant 'Gulfmont' in a growth chamber. Values are means of four measurement dates. Combinations are high temperature - high light (HiT-HiL), high temperature - low light (HiT-LoL), low temperature - high light (LoT-HiL) and low temperature - low light (LoT-LoL). See procedures section for actual temperatures and light intensities.

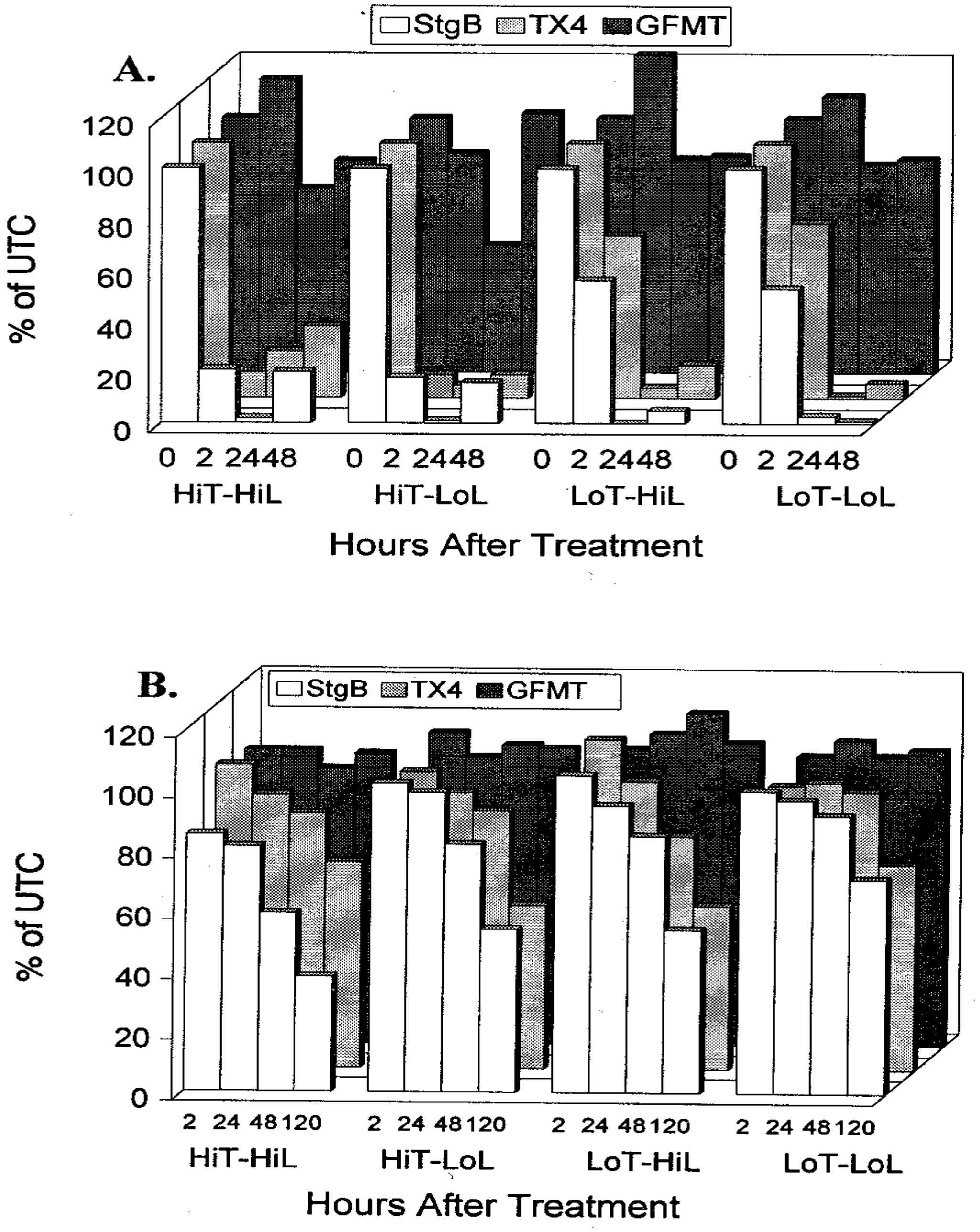

Fig. 4. Effect of 1 lb/acre glufosinate (Liberty) at four temperature - light intensity combinations on leaf photosynthesis (A) and relative chlorophyll content (B) of StgB and TX4 red rice biotypes and glufosinate-resistant 'Gulfmont' in a growth chamber. See Fig. 3 legend and Procedures section for additional explanation.

ONGOING PROJECT
PEST MANAGEMENT: WEEDS

INTERACTION OF FLUSH IRRIGATION TIMING AND SUPPRESSION OF BARNYARDGRASS WITH POTENTIALLY ALLELOPATHIC RICE LINES

D.R. Gealy, R.H. Dilday and J.N. Rutger

ABSTRACT

The ability to maintain high grain yield under heavy weed pressure is a highly desirable varietal characteristic. A rice line from Taiwan, PI 312777, dramatically reduced barnyardgrass (BYG) growth and maintained high grain yields in the absence of herbicides. PI 312777 produced nearly 70% of its weed-free yield under weedy conditions, whereas ‘Kaybonnet’ (KBNT) produced only about 35% of its weed-free yield under these conditions. Factors consistent with the PI 312777 weed suppression advantage over KBNT include more vigorous emergence from cold, wet soil, greater early tiller production, greater panicle density, greater yield and plant biomass and perhaps a greater ability to deplete soil of nutrients and moisture in the preflood stage. True allelopathic activity was not demonstrated in these studies, but it cannot be ruled out as a contributing factor. Learning more about the mechanisms of weed suppression and the cultural practices required for consistent, economical results in the field will be key to the exploitation of weed suppressive activity in varieties such as PI 312777 and their eventual incorporation into new rice varieties.

INTRODUCTION

The potential for growing rice varieties that suppress weeds naturally has received increased attention in recent years (Dilday et al., 1991; Fujii, 1992; Olofsdotter et al., 1998). The mechanisms of suppression are not well understood, but it seems most desirable to combine physical competitiveness and allelopathy where feasible (Olofsdotter et al., 1998). Maintaining consistent activity in variable environments is presently a limitation of these systems. The rice line PI 312777 from Taiwan can suppress BYG dramatically, even at greatly reduced herbicide rates or without herbicide. Cultivars such as KBNT and ‘Lemont’ suppress weeds to a much lesser degree. In field studies conducted at Stuttgart, Arkansas, in 1995, PI 312777 suppressed weeds nearly 100% when propanil was applied at one-quarter the normal use rate (Gealy et al., 1996). Suppressive activity appeared to be enhanced because initial rainfall or irrigation flushings were delayed for about a week and temperatures were high after rice seeding. Suppression was much less dramatic in 1996 studies when conditions following rice seeding were cool and relatively moist (unpublished data). Our objectives were to determine the effect of delayed irrigation flushing of PI 312777, 'Teqing' and KBNT rice cultivars on suppression of BYG in the field.

PROCEDURES

In 1997, a field experiment comparing the weed suppression activity of PI 312777, Teqing and KBNT under standard and delayed flush irrigation regimes was conducted at Stuttgart. Rice was drilled in plots 10 ft long and 9 rows wide with 7 in. row spacing on 12 May 1997 using standard agronomic practices for the area. Barnyardgrass was push-planted between rice rows immediately before flush-irrigations at 2, 7 or 11 days after planting (DAP) to synchronize BYG germination with the irrigation flushes. Propanil was applied to plots between planting and flush irrigation dates to kill BYG that had emerged before the appropriate time. No significant rainfall occurred until after 11 DAP. A weed-free control of each rice cultivar was maintained for each flush-date with propanil applications. Rice-free, weedy control plots also were established for each flush date. Nitrogen (as urea) at 100 lb/acre was applied preflood to all plots on 3 July 1997. Experimental design was a split plot with four replications. Flush irrigation dates were main plots, and rice cultivars with and without weeds were subplots.

Emergence dates, seedling leaf numbers, plant heights, tiller numbers, panicle numbers, lodging, grain weight, stem weight and total weight of rice plants were determined. Visual injury, plant density, height, photosynthesis and total biomass of weeds were determined. Plots were hand harvested from 23 October to 29 October 1997.

Soil samples were obtained preflood to a depth of 7 cm to determine cultivar effects on soil nutrient levels (including N, P and K; U of A Soil Testing Lab), soil water potential (Campbell Scientific; Tru-Psi thermocouple psychrometer) and soil moisture levels. To test for weed suppressive activity in this soil, seeds of BYG, oats and Stuttgart strawhull red rice were planted in flats and grown in chambers with 25/20°C (day/night) temperature, 14-hr photoperiod, 1000 uE/m^2 s light intensity and 70% relative humidity. Flats were observed periodically for inhibition of germination and growth. In a separate test, ducksalad seed was placed on soil, covered with water and maintained in constant light at a constant 30°C.

RESULTS

Weed suppression that was dramatically greater in PI 312777 than in KBNT plots was first observed in 11-day delayed flush plots shortly before nitrogen application and establishment of the permanent flood on 3 July 1997 (Fig. 1). Results for Teqing usually were intermediate between those for KBNT and PI 312777. Throughout the growing season, these PI 312777 plots maintained greater visual suppression of weeds. On 31 July 1997 the BYG plants in these plots were 17% shorter, 50% fewer in number and had 30% lower photosynthesis rates compared to those in KBNT plots (Table 1).

Grain yields (Figure 2A), panicle densities (Figure 2B), tiller densities, total dry weights and stem weights (data not shown) were all substantially greater for PI 312777 than for KBNT in weed-free plots. Lodging in

PI 312777 was severe, even though final plant height was less for PI 312777 than for KBNT (data not shown). Susceptibility to lodging is a serious limitation of PI 312777 and probably will prevent its being grown commercially in Arkansas and the southern U.S.

The ratios of weedy vs. weed-free yields of PI 312777 usually were more than double those of KBNT. PI 312777 produced nearly 70% as much grain under weedy as under weed-free conditions, whereas KBNT produced only about 35% as much grain under these conditions (Figure 3A). A similar trend in weedy vs. weed-free ratios occurred with rice panicle densities that averaged about 30% more for PI 312777 than for KBNT (Figure 3B). The ability to maintain high grain yield under heavy weed pressure is a highly desirable characteristic. Competitive cultivars such as PI 312777 may eventually allow growers to greatly reduce the rates and total costs of herbicides.

Although not generally statistically significant in these studies, PI 312777 appears to have a moderately greater ability than KBNT to deplete soil of water and nutrients in the seedling stage. Nitrate-nitrogen levels in PI 312777 plots (averaged over soil sampling depths to 7 cm) before establishment of the permanent flood, were about 15% lower than in KBNT plots (Table 2). All rice plots were greatly depleted of nitrate with at least 75% less soil nitrogen than in bare soil. Phosphorous and potassium levels also followed trends similar to those of nitrate (data not shown). These results suggest that nutrient depletion by the more vigorously growing PI 312777 may have been involved in its early-season weed suppression. Similarly, preflood soil water potentials were slightly, but not significantly, lower (more droughty) in the PI 312777 plots than in KBNT plots (Table 3), suggesting that PI 312777 may have a greater ability to remove moisture from the surface soil in moisture-limited soils.

Barnyardgrass seed germination and seedling growth bioassays with these soil samples revealed no consistent stunting from any soil sample and no marked differences among the rice cultivars tested (data not shown). These results suggest that allelochemicals were not primarily responsible for the early-season BYG suppression in PI 312777 plots or were undetectable under the conditions of the assays used. However, apparent allelopathic activity of PI 312777 has been demonstrated against BYG in laboratory bioassays (Steve Duke, Robert Dilday; personal communications), so the involvement of allelopathic chemicals in the present experiments cannot be ruled out, especially if very small quantities of the chemicals were produced initially and dissipated prior to soil sampling or before the bioassay was conducted. Other factors consistent with the PI 312777 advantage over KBNT include more vigorous emergence from cold, wet soil, greater early tiller production, greater panicle density and greater yield and plant biomass.

SIGNIFICANCE OF FINDINGS

The ability of PI 312777 to suppress BYG in the absence of herbicide is impressive and is far superior to that of KNBT under identical field conditions. Learning more about the mechanisms of weed suppression and cultural systems required to obtain consistent, economically viable results in laboratory assays and field tests will be keys to the further development of weed suppressive activity in PI 312777 and eventual incorporation into new rice cultivars that would allow farmers to reduce rates and total costs of herbicides. Techniques such as marker-aided selection may be helpful in transferring these traits into cultivars.

ACKNOWLEDGMENTS

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Table 1. Effect of rice cultivars on photosynthesis, plant density and height of barnyardgrass on 31 July 1997 in plots flushed 11 days after seeding.

	Photosynthesis		BYG Density		BYG Height	
Cultivar	umol CO_2/m^2s	% of KBNT	plants/m^2	% of KBNT	cm/plant	% of KBNT
Kaybonnet	10.4	---	84	---	114	---
PI 312777	7.3	70	42	50	95	83
Teqing	8.6	83	67	80	99	87
LSD 0.05	2.1		19		10	

Table 2. Effect of rice cultivar on nitrate nitrogen levels at two soil depths in weed-free plots.

	Nitrate nitrogen[†]	
Cultivar/Treatment	0 - 3 cm	3 - 7 cm
Weedy Standard	8.1	16.7
Kaybonnet	5.0	23.4
PI 312777	4.0	21.1
Teqing	3.5	22.8
LSD 0.05	2.6	5.1

[†] Samples were taken preflood, and data were averaged over flush dates 2 and 11 days after planting.

Table 3. Effect of rice cultivar on water potential at two soil depths and flush irrigation dates in weed-free plots.

Cultivar/Treatment	Flush 2 DAP[†] 0 - 3 cm	Flush 2 DAP[†] 3 - 7 cm	Flush 11 DAP 0 - 3 cm	Flush 11 DAP 3 - 7 cm
	kPa			
Bare Soil	-1320	-216	-1490	-221
Weedy Standard	-2740	-379	-2790	-406
Kaybonnet	-5120	-835	-4720	-558
PI 312777	-5480	-588	-5420	-768
Teqing	-5640	-746	-5400	-791
LSD 0.05	1150	230	1690	341

[†] DAP = days after planting.

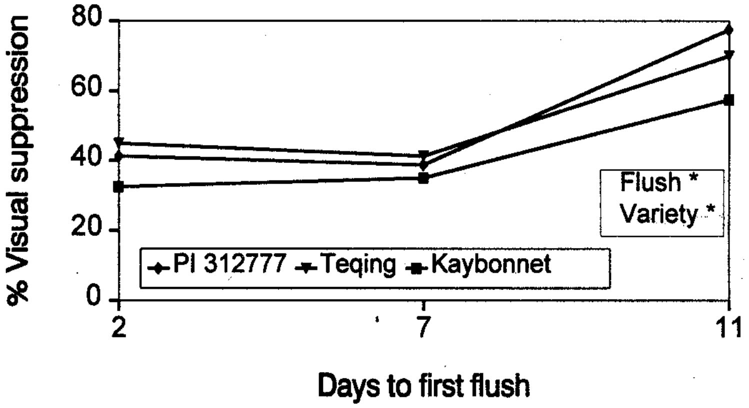
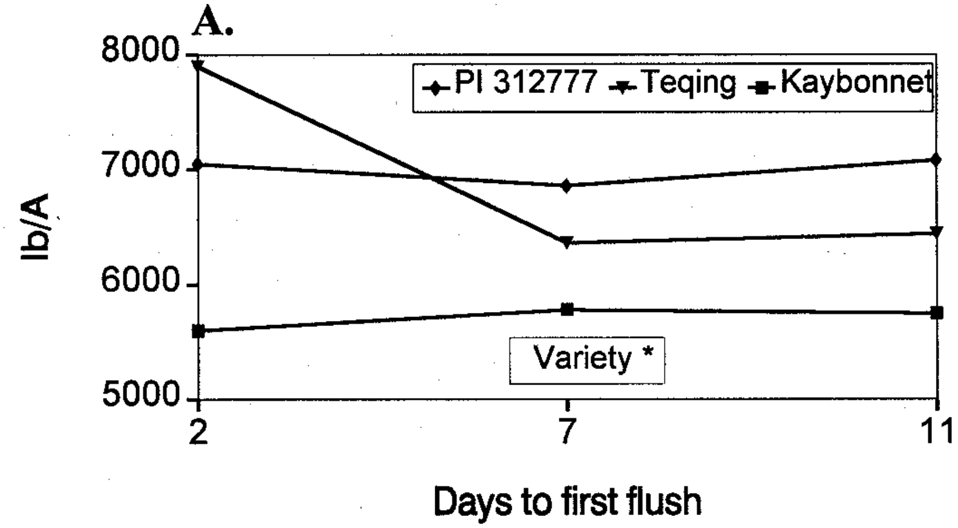


Fig. 1. Effect of flush irrigation date on visual suppression of barnyardgrass at preflood by several rice cultivars. An asterisk (*) indicates that the main effect was significant at the 0.05 level of probability.



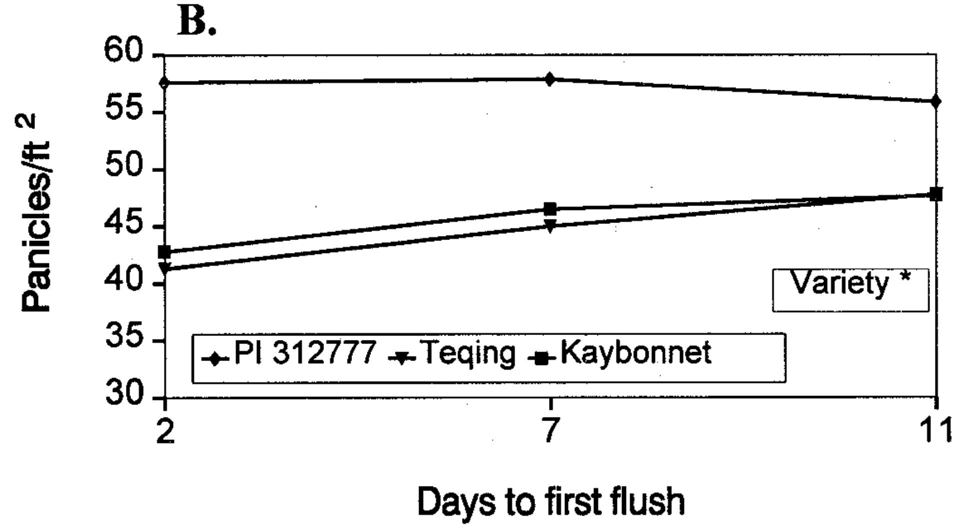


Fig. 2. Effect of flush irrigation date on rough rice yield (A) and panicle density (B) of several rice cultivars in weed-free plots. The asterisk (*) indicates that the main effect was significant at the 0.05 level of probability.

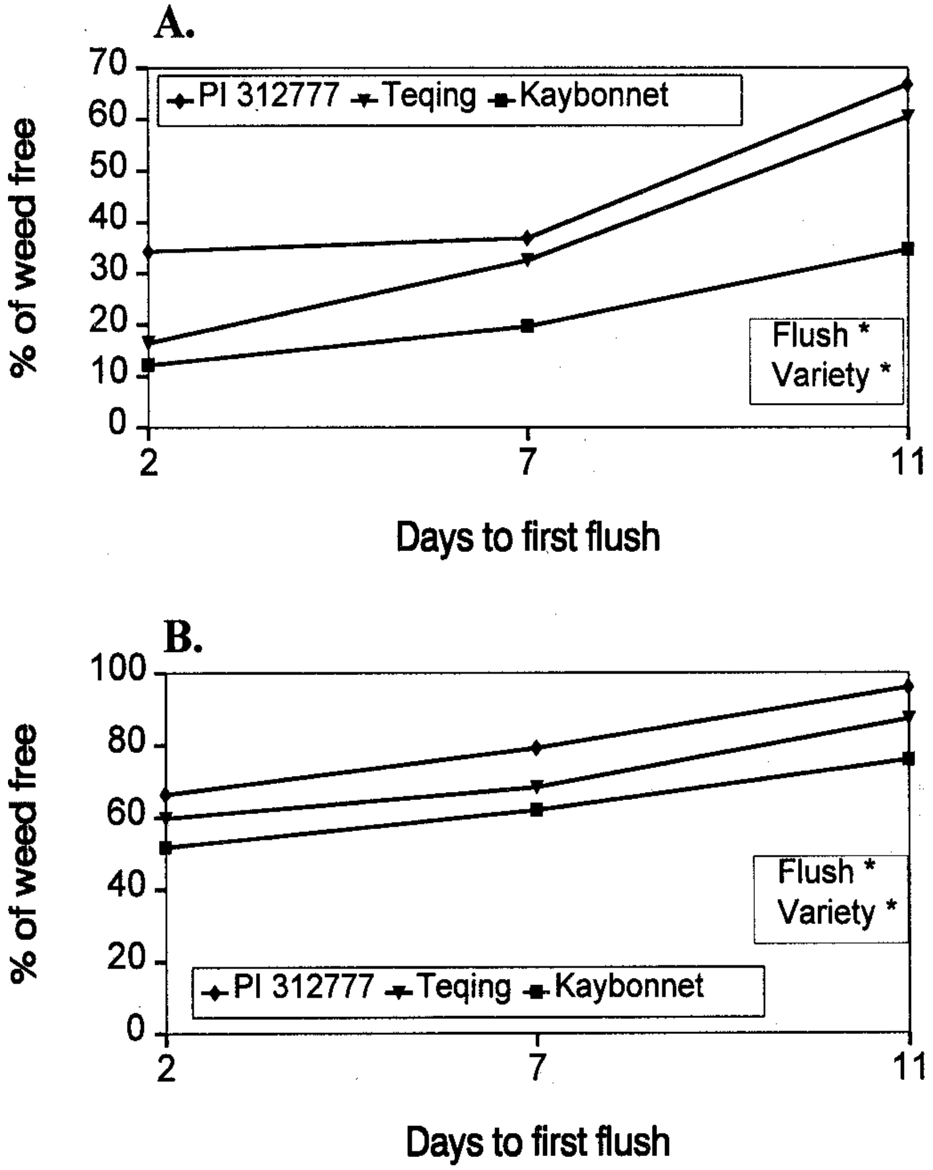


Fig. 3. Effect of flush irrigation date on rough rice yield (A) and panicle density (B) of rice cultivars in weedy plots. An asterisk (*) indicates that the main effect was significant at the 0.05 level of probability.

ONGOING PROJECT

PEST MANAGEMENT: WEEDS

INVESTIGATIONS INTO THE USE OF MICROBIAL PRODUCTS TO CONTROL WEEDS OF RICE

D.R. Gealy and S. Gurusiddaiah

ABSTRACT

In preliminary tests, weed-inhibitory metabolites were shown to be present in ethyl acetate extracts from aerobic shake culture broths of numerous fungal and bacterial isolates. Inhibitory activity of 21 of the most active of these extracts was determined against ‘Katy’, a commercial rice cultivar (*Oryza sativa*), and several weeds common in rice-soybean rotations, including straw-hull red rice (*Oryza sativa*), barnyardgrass (*Echinochloa crus-galli*), pitted morningglory (*Ipomoea lacunosa*) and hemp sesbania (*Sesbania exaltata*), in seed germination assays on paper and/or agar. Several extracts were active against weeds in the 50 ppm range. None of the extracts was superior to that of the previously tested bacterial isolate, Ps-3366. Little selectivity between Katy and weed species was observed.

INTRODUCTION

In recent years, biologically based weed control efforts have received increased attention in rice as in many other agronomic crops. Among the driving forces for these efforts are increased incidences of herbicide-resistant weeds (Carey et al., 1995) and governmental mandates requiring substantially reduced herbicide use in the future.

Inundative inoculations of fungi can be highly effective against broadleaf weeds of rice. *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *aeschynomene* is highly active against northern jointvetch (*Aeschynomene virginica*; Templeton et al., 1986), and *Colletotrichum truncatum* is active against hemp sesbania (Boyette et al., 1993; Egley and Boyette, 1995).

Ethyl acetate extracts from the rhizobacterium, *Pseudomonas syringae*-strain 3366 (Ps-3366), were shown to inhibit germination and seedling growth of several weeds of rice but had little selectivity in rice (Gealy and Gurusiddaiah, 1996). Similarly, ethyl acetate extracts from Ps-3366 have reduced weed root and shoot growth under field conditions in the Northwest (Gealy et al., 1996). Live Ps-3366 and other bacteria did not control grass weeds consistently because of the poor survival of these organisms in the harsh field environment (Skipper et al., 1991).

The objectives of this project were to determine the activity of microbially derived ethyl acetate extracts against germination and growth of weeds common in rice-soybean rotations and to determine the degree of selectivity between rice and these weed species.

PROCEDURES

For more than 20 years, S. Gurusiddaiah has been systematically isolating, culturing and fermenting microorganisms to obtain bioactive molecules such as phytotoxins (herbicidal compounds), antibiotics and compounds antagonistic to enzyme receptors. Collection sites have included agricultural soils, forests, parks and marshy areas in the continental United States. Microorganisms were obtained from infected plant parts such as leaves, stems, roots, fruits, seeds and flowers and from plant rhizospheres. Colonies were isolated from their various sources using general procedures. Soils and surface sterilized plant parts were plated out first on suitable media (such as potato dextrose agar, minimal media, actinomycetes agar, etc.) to develop distinct colonies. The colonies belonging to bacteria (including actinomycetales) and fungi were then subcultured, purified and finally stored in a suitable medium.

Of approximately 3000 such cultures, about 1500 were grown on a shaker at 24 to 26°C in a complex medium usually containing yeast extract, peptone (or malt) extract, starch and glycerol with added minerals. The culture media used for aerobic fermentation differed slightly for each species. After 4 to 6 days of growth, 100 ml of each culture broth was extracted overnight with an equal volume of ethyl acetate (Gealy and Gurusiddaiah, 1996; Gealy et al., 1996). Ten milliliter of the ethyl acetate extract from each culture was dried and resuspended in water, and 0.2 ml of this was layered on agar plates and assayed against downy brome seed as a standard. About 100 of the cultures were highly inhibitory to downy brome. In addition to the seed germination assays, extracts were routinely tested against fungal plant disease organisms, including *Rhizoctonia solani*, which causes sheath blight in rice, using paper disk agar diffusion assays (Gurusiddaiah et al., 1986).

Twenty-one of the most active of the cultures mentioned above were selected for testing against rice weeds (Table 1). Shake cultures were prepared as described above but in proportionately larger volumes to supply extract material for numerous species x concentration combinations. Following the method described previously, equal volumes of ethyl acetate and shake-culture broth were combined and allowed to mix overnight to extract the active compounds from the aqueous phase. The organic phase was saved and concentrated in a rotoevaporator. The ethyl acetate extract was resuspended in a small volume of acetone, placed in a glass vial, evaporated to dryness and stored in a freezer. Total weight of each extract was determined by weighing vials with and without the extracts. Two thousand ppm stock solutions of each extract were prepared in acetone and placed in a refrigerator.

Initial petri dish paper assays were conducted with red rice (RR), the rice cultivar Katy (Katy), barnyardgrass (BYG), downy brome (DBR), pitted morningglory (PM) and hemp sesbania (HS) at extract concentrations of 50, 100 and 200 ppm at 20°C for 7 d in the dark. Appropriate volumes of each stock solution were diluted in about 2 ml ethanol (pure acetone can cause the plastic petri dishes to crack), introduced into petri dishes and evaporated to dryness overnight. Twenty to 25 seeds of the appropriate species were then incubated in dishes moistened with 4 ml of water. Due to the large number of samples involved, experiments were conducted one replication at a time and one extract concentration at a time. Each experiment was conducted two or more times. Percent germination and total fresh weights of roots and shoots were determined. Data were expressed as percentage of the water control.

Based on the results from the above paper assays and available quantities of extracts, a subset of seven extracts and four weed species was selected for further evaluation in agar assays similar to the paper assays conducted previously. Final extract concentrations of 0, 12.5, 25, 50 and 100 ppm were prepared in acetone by serial dilution of the stock solution. In the assay, 0.8 ml of the various extract solutions was spread evenly on the surface of 20 ml of solidified 0.8% agar in the appropriate dish. Dishes prepared similarly, and treated only with acetone, were included as nontreated controls. The solvent in petri dishes was evaporated in a hood as described previously. Seeds of red rice, barnyardgrass, pitted morningglory and hemp sesbania were placed on the surface of the agar in the petri plates, and plates were sealed with parafilm. The plates were incubated in the dark for seven days at 20°C. At the end of the incubation period, germination was determined, seedlings were removed from the agar, and root and shoot lengths were measured to the nearest millimeter with a caliper. The experiment was conducted as a randomized complete block with four replications.

RESULTS AND DISCUSSION

Although a few extracts were inhibitory in the initial paper assays at 50 ppm and many were inhibitory at 200 ppm (data not shown), only the 100 ppm data are presented here (Figures 1A and 1B). Little selectivity was observed between the Katy rice cultivar and weed species. This complicates the potential future development of useful herbicide products from these extracts. In both paper assays (Figure 1B) and agar assays (Table 2), the Ps-3366 extract (Gealy et al., 1996) was among the most inhibitory to most species. Most extracts were more inhibitory to root and shoot growth than to germination and were many times more inhibitory to fungal plant disease organisms than to plant seeds and seedlings (data not shown). Neither fungi nor bacteria as a group appeared to be more inhibitory than the other to seedling growth.

In agar assays, nearly all extracts caused significant inhibition of weed seedling growth at 100 ppm, but almost none was inhibitory at 12.5 ppm (data not shown). Also, inhibition was less responsive to extract concentration and less linear than might be expected for commercial herbicides. Low water solubility of some extracts may prevent their complete expression of inhibition of seed germination and seedling growth. Results from these kinds of extract studies are further complicated because each extract probably contains numerous compounds, and we have no method to determine whether the biological activity across the range of concentrations results from the same key inhibitors.

In agar tests with the seven selected extracts (Table 2), red rice and hemp sesbania were the most inhibited and barnyardgrass and pitted morningglory the least inhibited across extracts. Across the four selected weed species, the fungus (9-7956-89A) and the bacterium (Ps-3366) tended to produce the most inhibitory extracts whereas the bacterium (8-7505) and the unknown isolate (9-7905) produced the least inhibitory extracts. Some extracts appeared to be moderately selective between weed species. For example, the isolate (9-7530F5B) was one of the two extracts most inhibitory to barnyardgrass but was among the least inhibitory to the other three species.

SIGNIFICANCE OF FINDINGS

Although activity of several of the microbial extracts was quite high, selectivity between rice and weeds appeared to be lacking. Therefore, in their present form, these extracts probably will not be suitable herbicides against rice weeds. Additional characterization and chemical optimization of the active metabolites may be necessary before further progress is possible. Because some of these extracts appear to be extremely active against plant fungal disease organisms in laboratory assays, they could prove to be useful disease suppression agents in rice and perhaps other crop species.

ACKNOWLEDGMENTS

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Table 1. Information on parent organisms and ethyl acetate extracts.

Extract code	Parent organism	Extracts active in soil†	Description	Possible phytotoxic extract ingredient
9-7868	Fungus	yes	----	penicillic acid
C-558	Fungus	no	*Cytospora sp.* collected in Colorado	pH reversible pigment: acid=red, neutral=yellow
MGF	Fungus	yes	lesions from *Convolvulus arvensis*	peptides active against *C. arvensis*
9-7727	Fungus	no	----	----
SMFSM	Fungus	yes	from die back fungus of willow (*Salix sp.*)	----
9-7956-89A	Fungus	no	----	----
CdNH	Fungus	no	*Cytospora decipiens*	heterocyclic red crystals; also yellow and white crystals
1-9005	Fungus	no	fungus from betel leaf (*Piperaceae*)	----
Cbs	Fungus	no	*Cytospora sp.-Bromus* strain	brown-black pigment
9-8033	Fungus	no	----	red, red-orange, pH reversible pigment
C-703	Fungus	yes	*Cytospora sp.*	----
9-8052	Bacterium	no	*Bacillus badius*	peptides similar to 1-9002F1B
9-7856F5A	Bacterium	no	----	----
63-Bact	Bacterium	no	----	----
9-8058	Bacterium	yes	----	----
8-7505	Bacterium	no	----	----
1-9002F1B	Bacterium	yes	----	peptides (similar to 9-8052) active against *Bromus tectorum*
Ps-3366	Bacterium	yes	*Pseudomonas syringae*-strain 3366	phenazine-1-carboxylic acid
9-7530F5B	Unknown	yes	----	----
9-7905	Unknown	no	----	----
9-7590F2A,B	Unknown	no	----	pinkish-red extract

† 'Yes' indicates at least 95% inhibition of shoot dry weight and 50% inhibition of germination of *A. fatua* or *Bromus tectorum* in soil assays conducted in Pullman, Washington. All extracts were originally screened and found highly active against *B. tectorum* in petri dish germination assays in Pullman, Washington. Dashed lines in columns indicate that information is not available for these entries.

Table 2. Inhibition of rice weeds in agar assays with selected active ethyl acetate extracts.[†]

		Total seedling length				
Extract	Source	BYG	RR	HS	PMG	Extract main effect
		% of untreated check				
SMFSM	Fungus	78	72	66	79	73
9-7956-89A	Fungus	---	---	44	66	53
9-7856F5A	Bacterium	81	57	49	69	63
8-7505	Bacterium	91	---	---	85	88
Ps-3366	Bacterium	54	41	48	65	51
9-7905	Unknown	86	---	79	79	81
9-7530F5B	Unknown	47	65	62	85	66
		Overall LSD = 20				Extract LSD = 12
Weed species main effect		73	59	59	76	
		Weed species LSD = 8				

[†] Weed species key: BYG = barnyardgrass; RR = red rice; HS = hemp sesbania; PMG = pitted morningglory. All data have been averaged over 12.5, 25, 50 and 100 ppm concentrations. Total seedling length is the sum (in mm) of total root length plus total shoot length per dish. All LSD values are at the 0.05 level.

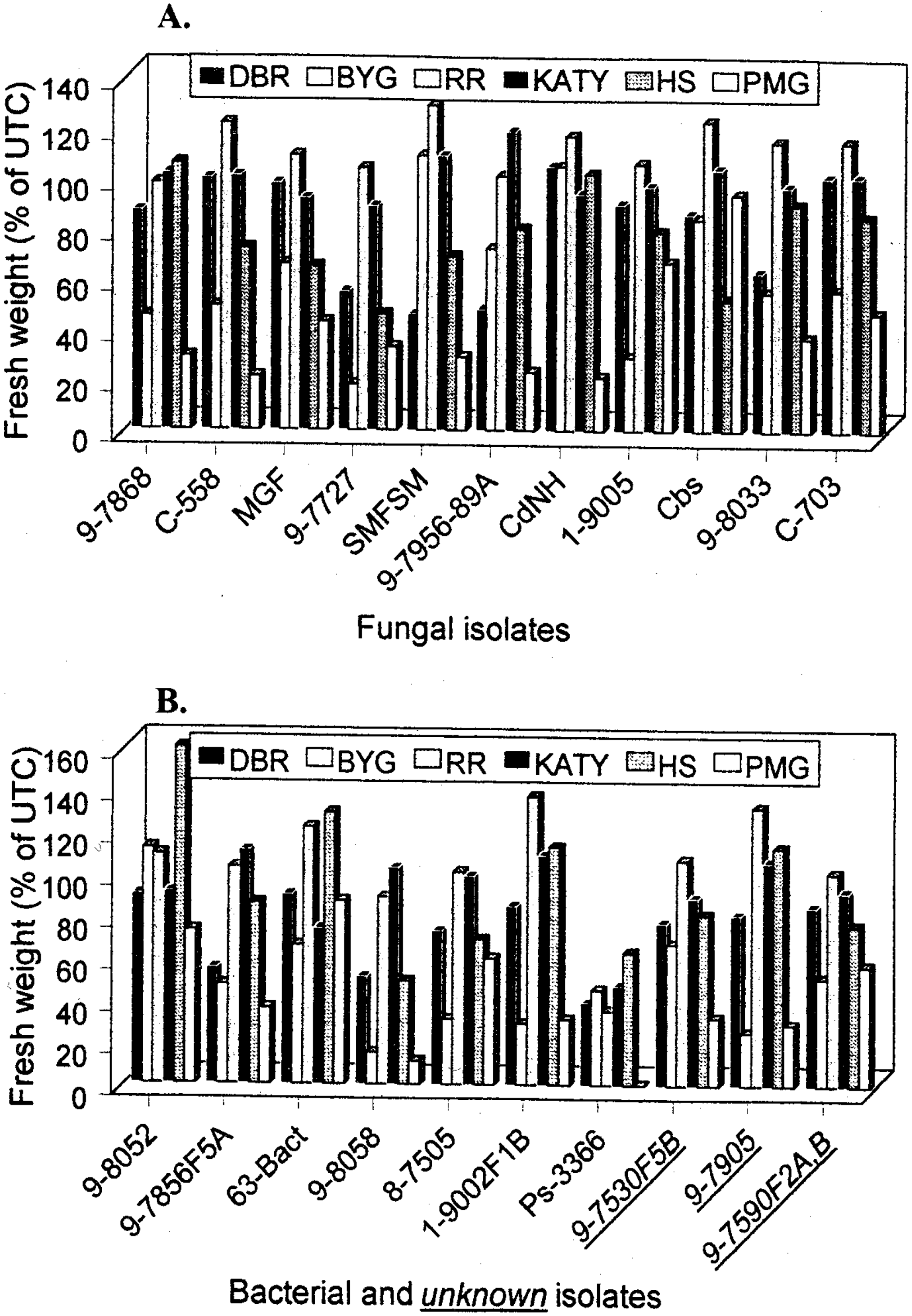

Fig. 1. Effect of 100 ppm ethyl acetate extracts from fungal isolates (A) and bacterial and unknown organism isolates (B) on fresh weight of selected weed and crop species in paper assays. The parent organisms for the three isolates to the far right of frame B are unknown. Plant species are: DBR = downy brome; BYG = barnyardgrass; RR = red rice; KATY = Katy rice; HS = hemp sesbania; and PMG = pitted morningglory. UTC = untreated check.

ENVIRONMENTAL IMPLICATIONS OF PESTICIDES IN RICE PRODUCTION - 1997

T.L. Lavy, J.D. Mattice and R.J. Norman

ABSTRACT

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

Six independent locations were monitored for 17 rice pesticides in 1997. The rivers selected for monitoring include the White, Arkansas, L'Anguille and St. Francis and two sites on the Mississippi River. Water samples were transported to the laboratory and extracted using solid phase extraction (SPE) techniques. Quantification and confirmation of pesticide residues were obtained by HPLC and GC/MS analysis. Pesticides selected for monitoring were determined after assessing state recommendations and our analytical capabilities. Pesticides included were: benomyl (Benlate®), thiobencarb (Bolero®), quinclorac (Facet®), carbofuron (Furadan®), triclopyr (Grandstand®), bensulfuron (Londax®), malathion, methyl parathion, molinate (Ordram®), pendimethalin (Prowl®), iprodione (Rovral®), carbaryl (Sevin®), propanil (Stam®), propiconazole (Tilt®), fenoxaprop (Whip®), 2,4-D and MCPA. A complementary field study was also conducted to evaluate the dissipation of 2,4-D and quinclorac under 12 different water treatments.

Pesticides were detected in surface waters flowing from rice producing areas in Arkansas. Most of these detections were at very low levels and often were not detected at the next sampling period. This suggests that water contamination was sporadic and not present throughout the rice production season. The field study showed that light is an important factor in the degradation of both 2,4-D and quinclorac. 2,4-D dissipated more rapidly and under more conditions than did quinclorac. Detectable amounts of quinclorac remained throughout the 36-day study.

INTRODUCTION

In recent years, both public awareness and concern about water quality have increased. The detection and persistence of several rice pesticides in the Sacramento River have resulted in restrictions for California rice producers (Ross and Sava, 1986). The potential for similar persistence in Arkansas is an obvious question that should be addressed. Monitoring for pesticides in water may determine which or what classes of pesticides are potential problems, thereby providing time to address any contamination problems. Examination of the environmental dissipation factors provides information about which factors are important in the degradation of the various classes of pesticides, such that management techniques might be developed that help prevent their subsequent contamination of water resources. In short, monitoring tells us which materials are potential problems while dissipation studies show when and how these materials are most effectively degraded before they become serious contaminants.

The overall objective of this research was to assess pesticide runoff into streams and tributaries from rice fields and to determine the fate of pesticides in environmental water sources. Specific goals were: 1) to monitor numerous surface water sources for rice pesticide residues and any trends associated with pesticide movement into streams and tributaries leading to the Mississippi River and 2) to evaluate the dissipation of 2,4-D and quinclorac residues from environmental water sources.

Environmental Monitoring of Selected Rivers for Rice Pesticides

Six separate locations were monitored for 17 rice pesticides in Arkansas during May-November of 1997. The sample collection sites were in Chicot, Desha, Lee and Mississippi Counties. The rivers selected for monitoring include the White, Arkansas, L'Anguille and St. Francis. Additionally, two Mississippi River sites were monitored to assess water quality as the water both entered and left the major rice growing region of the state. Each site location was selected as a point through which major watersheds flow from rice production areas.

Simulated Environmental Dissipation Studies

The majority of research to evaluate pesticide dissipation processes from paddy rice culture have been conducted in California (Ross et al., 1989) and Texas (Deuel et al., 1985). A thorough report was prepared by Crosby and Mabury (1992) that compiled previously published research on the aquatic fate, microbial degradation, sediment fate, toxicity, plant uptake and pesticide residue management of several rice pesticides. A previous greenhouse study showed that under greenhouse conditions, pesticide dissipation was less than expected due to filtering of the ultraviolet light by the greenhouse covering (Dewell, 1997). Therefore, a field study was initiated to gain a better understanding of the potential mechanisms involved in the dissipation of two pesticides commonly used in southern rice production systems. This study was designed: 1) to determine if commonly used and/or detected rice pesticides are degraded from various water systems and 2) to identify which degradation mechanism(s) are involved. Aqueous solutions of pesticides were subjected to selected environmental factors of light, sediment and water quality to determine which factors were important in the dissipation of different classes of pesticides.

PROCEDURES

Environmental Monitoring

Eight sampling periods at approximately two-week intervals were taken during the rice production season. A final post-season sampling was made in November. Samples were transported to the laboratory and extracted using solid phase extraction (SPE) techniques. Quantification and confirmation of pesticide residues were obtained by HPLC and GC/MS analysis. The lower limit of quantitation was 2 µg/L in water. Pesticides selected for monitoring were determined from state recommendations and our analytical capabilities. The selected compounds included benomyl, thiobencarb, quinclorac, carbofuran, triclopyr, bensulfuron, malathion, methyl parathion, molinate, pendimethalin, iprodione, carbaryl, propanil, propiconazole, fenoxaprop, 2,4-D and MCPA.

Simulated Dissipation

Aquatic dissipation trends of two rice pesticides were evaluated under field conditions. The pesticides examined were 2,4-D and quinclorac. The experiment was conducted in June and July of 1997. Independent water systems, prepared in 2.5-qt. Pyrex bowls, involved all combinations of water type, presence or absence of sediment and solar exposure. The bottom of every bowl, regardless of treatment, was wrapped in aluminum foil while bowls receiving no light were completely covered with aluminum foil. Light treatments were from ambient daily sunlight. Bulk supplies of reservoir sediment and water were collected from a tailwater collection pond in Arkansas County, Arkansas. Equal volumes of saturated sediment (100-mL beaker filled to the rim) were added to 12 fish bowls. To the bowls, 1.5 L of either deionized or reservoir water was then added to obtain all possible combinations of water-type, sediment factor and solar condition with two replications of each combination (24 total systems). These systems equilibrated for several days prior to pesticide treatment. Each system was treated with a stock fortification solution containing 2,4-D and quinclorac (formulated material) to obtain initial concentrations of 1.6 and 0.58 µg/L, respectively, for each compound. Water samples were collected 1 h (T_0) and 1, 2, 3, 8, 15, 22, 29 and 36 d after pesticide treatment. Samples were then extracted by the appropriate Empore^{TM} SPE disk extraction method and analyzed by HPLC.

RESULTS AND DISCUSSION

Environmental Monitoring

Presently, six of the nine sampling periods have been analyzed. Pesticides were detected 77 times from a potential 612 possible, or approximately 12.6% of the potential possible detections (Table 1). Of these 77 detections, 18.2% were in May, 44.2% were in June, and 37.7% were in July. This suggests the expected trend based on when pesticides are most commonly used during production. The most frequently detected compounds were quinclorac, iprodione, propiconazole, carbaryl and molinate, which were responsible for 15.6, 14.3, 11.7, 10.4 and 9.1% of the 77 positive detections, respectively (Table 2). Detections were observed from all sampling sites with a similar number of detections for each site with the exception of the Mississippi River, which tended to have fewer detections. To our knowledge, no detected pesticide has exceeded advisory limits.

Simulated Dissipation

Results for the simulated environmental dissipation studies carried out in the field showed that light exposure was a significant degradation factor for dissipation of quinclorac residues. Figure 1 shows the dissipation of quinclorac for all treatments. All dark treatments showed little dissipation of quinclorac. The type of water used was a significant interactive factor in the light exposed treatments. Quinclorac dissipation was enhanced when stream water was used in combination with light exposure. This suggests that the environmental water (stream water) provided either microbial or other soluble factors that are favorable to dissipation. However, the presence of sediment in the stream water/ light exposed treatment caused a reduction of quinclorac dissipation. When sediment was added to the deionized water/light treatment, no effect on dissipation was observed. The negative effect of sediment on quinclorac dissipation in stream water may be due to a reduction of available light for chemical or biological photolysis, adsorption of quinclorac to sediment or interference of sediment with dissipation factors in stream water. Since sediment showed no effect on degradation in deionized water/light treatments, the effect may be due to the latter two explanations. Dissipation of 2,4-D occurred under all treatments except the deionized water, no sediment and dark treatment. Figure 2 shows the dissipation of 2,4-D for all treatments. Dissipation occurred more quickly in the dark treatments when stream water and/or sediment was present than in those treatments exposed to light with the possible exception of the stream water, sediment and light treatment. Though the deionized water, no sediment and light treatment exhibited significant dissipation, the addition of sediment increased dissipation. Quinclorac and 2,4-D should exhibit significant dissipation under normal environmental water source conditions. Exceptionally turbid water conditions might reduce the rate at which quinclorac dissipates.

SIGNIFICANCE OF FINDINGS

Pesticides were detectable from surface waters flowing from rice production areas in Arkansas. Fortunately, most of these detections were at very low levels, transient in nature and often did not appear during the next sampling period. This suggests that water contamination was intermittent and not chronically present during the rice production season. Whether these contaminants had dissipated through degradation, downstream migration or dilution was not determined. At no time did any contaminant approach known health advisory levels.

Quinclorac dissipation is strongly influenced by exposure to light, particularly in the UV wavelengths. The combination of clear stream water and light exposure provided the greatest overall amount of dissipation while the presence of sediment tended to reduce dissipation. Detectable amounts of quinclorac remained for over 36 days. Along with excellent exposure to sunlight, it would be expected that water management and rice production methods that reduced silting of runoff water would provide enhanced degradation conditions for quicker quinclorac dissipation. Light also was an important environmental factor for 2,4-D dissipation. However, if sediment was present or stream water was used, dissipation would proceed even under dark conditions. Since one or more of these factors are generally available, 2,4-D dissipation should generally occur under rice production conditions.

ACKNOWLEDGMENTS

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Table 1. List of pesticides, sites and detections during 1997 monitoring study.

Compound	Amount	Location	Date	Repeat detection
	ppm			
fenoxaprop	0.129	Mississippi 2	1 May	Yes
propanil	0.276	Mississippi 2	1 May	No
fenoxaprop	0.103	Mississippi 2	15 May	No
benomyl	0.475	Mississippi 2	1 Jun	No
bensulfuron	0.489	Mississippi 2	1 Ju	No
carbaryl	0.084	Mississippi 2	1 Jun	Yes
propiconazole	0.197	Mississippi 2	1 Jun	No
thiobencarb	0.055	Mississippi 2	1 Jun	No
iprodione	0.3	Mississippi 2	1 Jul	No
propiconazole	1.19	Mississippi 2	1 Jul	No
carbaryl	0.038	Arkansas	15 May	No
iprodione	0.102	Arkansas	15 May	No
propanil	0.262	Arkansas	15 May	No
bensulfuron	0.591	Arkansas	1 Jun	No
thiobencarb	0.053	Arkansas	1 Jun	No
iprodione	0.14	Arkansas	15 Jun	Yes
iprodione	0.18	Arkansas	1 Jul	No
propiconazole	0.46	Arkansas	1 Jul	No
carbaryl	0.05	Arkansas	15 Jul	No
quinclorac	0.147	Arkansas	15 Jul	No
thiobencarb	0.08	Arkansas	15 Jul	No
fenoxaprop	0.125	White	1 May	No
iprodione	0.127	White	1 May	No
propiconazole	0.164	White	1 May	No

continued

Table 1. Continued.

Compound	Amount	Location	Date	Repeat detection
	ppm			
carbaryl	0.048	White	1 Jun	Yes
carbofuran	0.118	White	1 Jun	No
fenoxaprop	0.044	White	1 Jun	No
propiconazole	0.053	White	1 Jun	No
iprodione	0.125	White	15 Jun	Yes
quinclorac	0.126	White	15 Jun	Yes
iprodione	0.23	White	1 Jul	Yes
propiconazole	1.18	White	1 Jul	Yes
quinclorac	0.2	White	1 Jul	Yes
iprodione	0.23	White	15 Jul	No
propiconazole	0.84	White	15 Jul	No
quinclorac	0.307	White	15 Jul	No
thiobencarb	0.09	White	15 Jul	No
fenoxaprop	0.091	L'Anguille	15 May	No
carbaryl	0.072	L'Anguille	1 Jun	Yes
carbofuron	0.08	L'Anguille	1 Jun	No
molinate	0.277	L'Anguille	1 Jun	Yes
quinclorac	0.16	L'Anguille	1 Jun	Yes
iprodione	0.09	L'Anguille	15 Jun	No
moliante	0.09	L'Anguille	15 Jun	Yes
quinclorac	0.818	L'Anguille	15 Jun	Yes
molinate	0.29	L'Anguille	1 Jul	Yes
quinclorac	0.435	L'Anguille	1 Jul	Yes
triclopyr	0.494	L'Anguille	1 Jul	No
iprodione	0.17	L'Anguille	15 Jul	No
molinate	1.16	L'Anguille	15 Jul	No
quinclorac	0.194	L'Anguille	15 Jul	No
benomyl	0.105	St. Francis	1 May	No
carbaryl	0.25	St. Francis	1 Jun	Yes
carbofuran	0.169	St. Francis	1 Jun	No
molinate	0.124	St. Francis	1 Jun	No
propiconazole	0.536	St. Francis	1 Jun	No
quinclorac	0.043	St. Francis	1 Jun	Yes
thiobencarb	0.096	St. Francis	1 Jun	No
2,4-D	0.091	St. Francis	15 Jun	No
bensulfuron	0.063	St. Francis	15 Jun	No
iprodione	0.14	St. Francis	15 Jun	No
mcpa	0.158	St. Francis	15 Jun	No
quinclorac	0.256	St. Francis	15 Jun	No
molinate	0.59	St. Francis	1 Jul	Yes
triclopyr	0.535	St. Francis	1 Jul	No
2,4-D	0.185	St. Francis	15 Jul	No
molinate	0.94	St. Francis	15 Jul	No
quinclorac	0.462	St. Francis	15 Jul	No
thiobencarb	0.05	St. Francis	15 Jul	No
benomyl	0.279	Mississippi 1	1 May	No
bensulfuron	0.267	Mississippi 1	1 May	No

continued

Table 1. Continued.

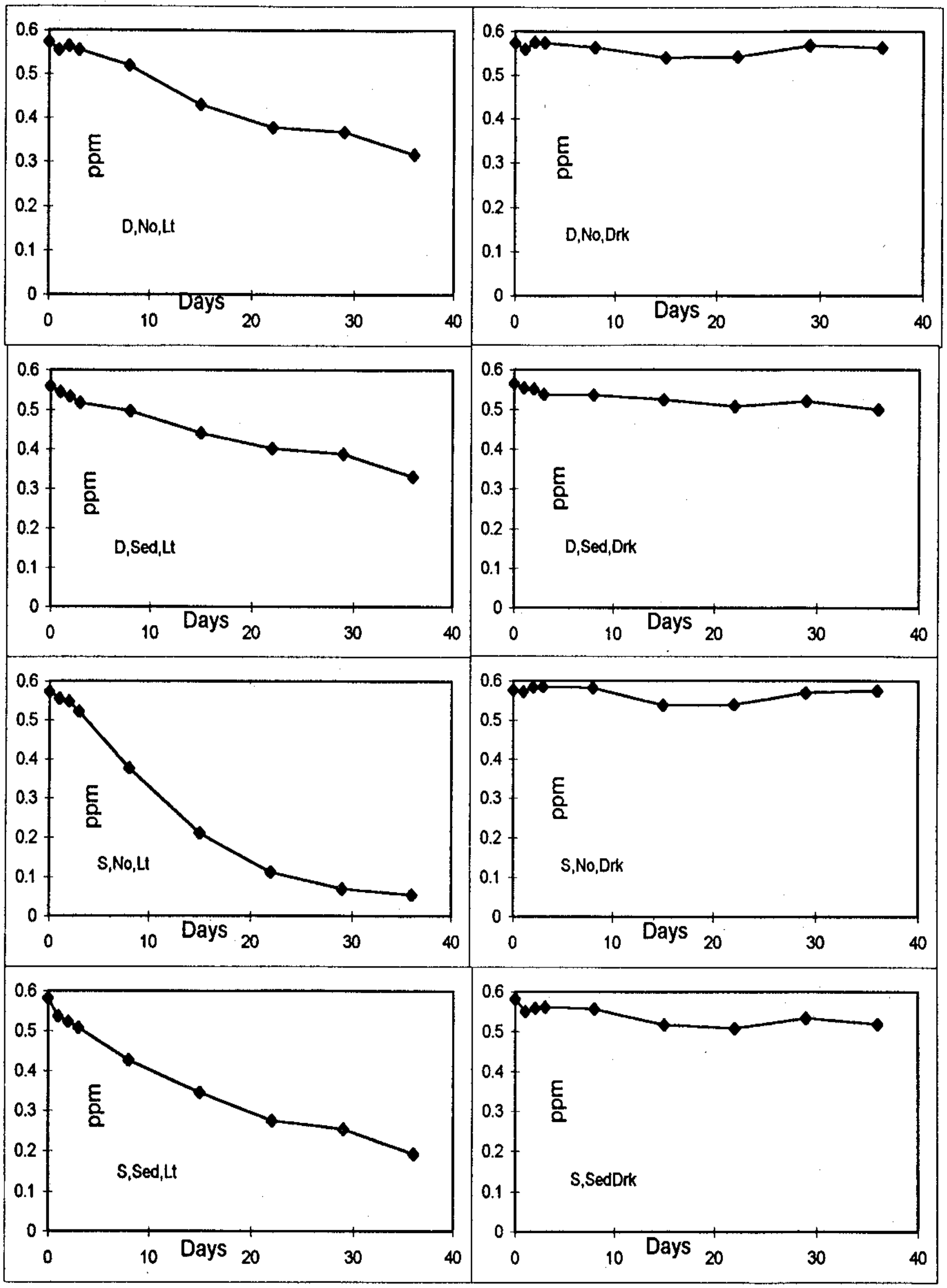
Compound	Amount	Location	Date	Repeat detection
	ppm			
carbaryl	0.1	Mississippi 1	15 May	Yes
benomyl	0.333	Mississippi 1	1 Jun	No
carbaryl	0.182	Mississippi 1	1 Jun	No
propiconazole	1.05	Mississippi 1	1 Jul	No
2,4-D	0.36	Mississippi 1	15 Jul	No
quinclorac	0.118	Mississippi 1	15 Jul	No
methyl parathion	ND[†]			
malathion	ND			
pendamethalin	ND			

[†] ND = these pesticides were never detected.

Table 2. Summary of rice pesticide detections during 1997 monitoring.

	Locations[†]							
Compound	A	B	C	D	E	F	Total	%
benomyl	1	0	0	0	1	2	4	5.19
bensulfuron	1	1	0	0	1	1	4	5.19
carbofuran	0	0	1	1	1	0	3	3.90
carbaryl	1	2	1	1	1	2	8	10.39
propanil	1	1	0	0	0	0	2	2.60
molinate	0	0	0	4	3	0	7	9.09
propiconazole	2	1	4	0	1	1	9	11.69
thiobencarb	1	2	1	0	2	0	6	7.79
iprodione	1	3	4	2	1	0	11	14.29
2,4-D	0	0	0	0	2	1	3	3.90
MCPA	0	0	0	0	1	0	1	1.30
quinclorac	0	1	3	4	3	1	12	15.58
fenoxaprop	2	0	2	1	0	0	5	6.49
triclopyr	0	0	0	1	1	0	2	2.60
methyl parathion	0	0	0	0	0	0	0	0.00
malathion	0	0	0	0	0	0	0	0.00
pendamethalin	0	0	0	0	0	0	0	0.00
Total	10	11	16	14	18	8	77	100.00

[†] Location codes: A = Mississippi River site 2; B = Arkansas River; C = White River; D = L'Anguille River; E = St. Francis River; F = Mississippi River site 1.



S = Stream water
D = Deionized water

Sed = Sediment added
No = No sediment

Lt = Light exposure
Drk = No light exposure

Fig. 1. Simulated environmental degradation of quinclorac.

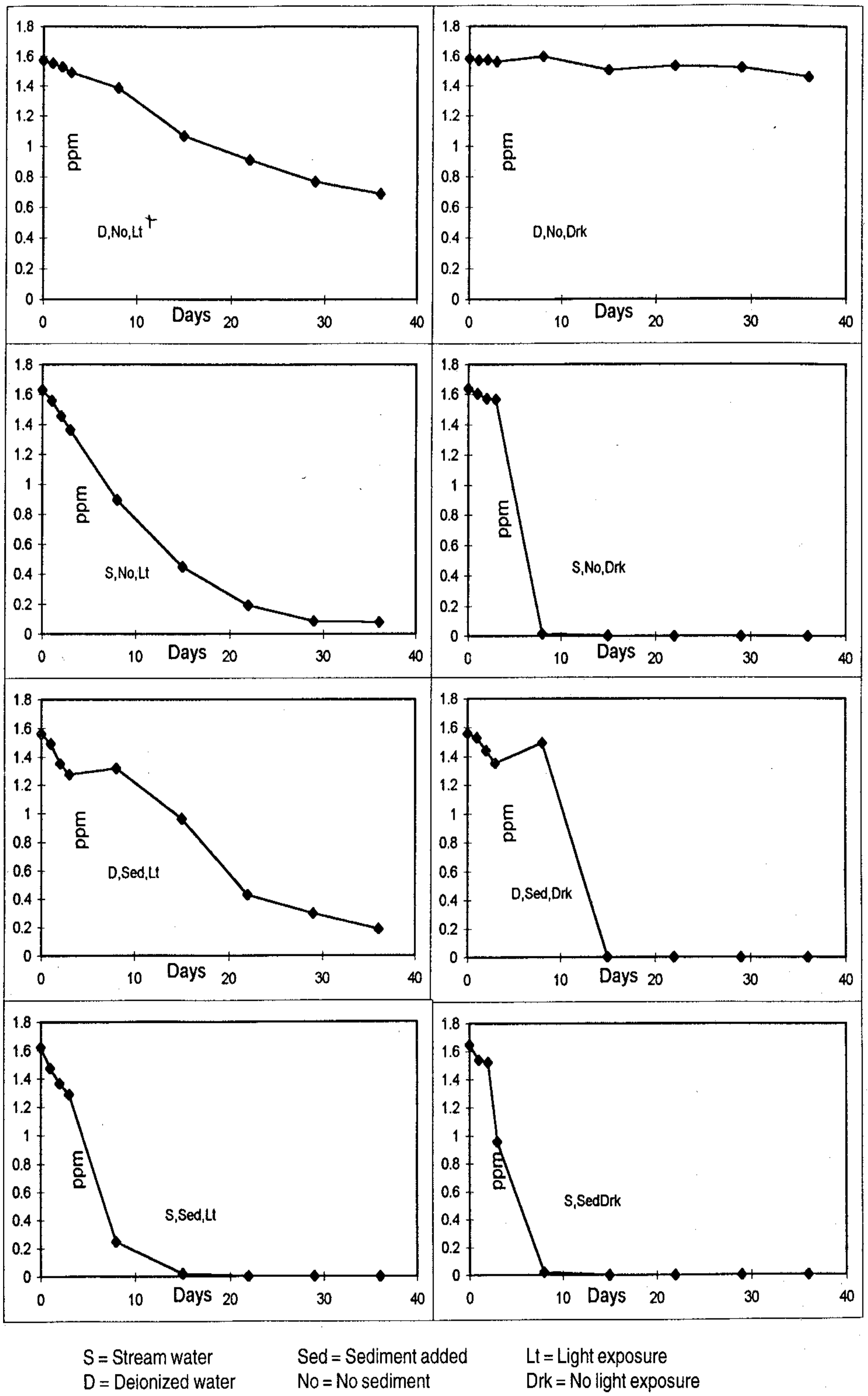


Fig. 2. Simulated environmental degradation of 2,4-D.

CHEMICAL ASPECTS OF RICE ALLELOCHEMICALS FOR WEED CONTROL

J.D. Mattice, B.W. Skulman, R.H. Dilday and T.L. Lavy

ABSTRACT

Analysis of soil in which the nonallelopathic cultivar ‘Rexmont’, allelopathic accession PI 312777 and no-rice was grown (no-rice controls) showed statistically higher amounts of some chemicals in the soil samples that had rice grown in them compared to the control, but there were no differences between soil samples that grew rice. Preliminary experiments using high performance liquid chromatography (HPLC) analysis of extracts of leaf tissue from mature rice plants showed differences in the chromatograms from allelopathic rice accession PI 312777 versus nonallelopathic Rexmont samples. Bioassays of some potential allelochemicals showed statistical differences between treatments (p-value of 0.066). Mean values for number of ducksalad plants for treatments containing both phenolic acids and straight chain acids were lower than for the controls. Values for treatments containing either straight chain or phenolic acids, but not both, were higher than for the controls.

INTRODUCTION

Some strains of rice have been shown to exude chemicals that strongly control ducksalad [*Heteranthera limosa* (Sw.) Willd]. We have been working with the strongly allelopathic rice accession PI 312777 trying to identify the chemical(s) that are responsible for this control. We have been working with ducksalad because the effect was first noticed with this species; however, we believe that this research could serve as a model for work on other weed species. For example, Hasan et al. (1996) screened 1000 rice accessions in Egypt from 1993 to 1996 and found 30 that exhibited suppression of barnyardgrass [*Echinocoa, crus-galli* (L.) Beauv.] by 50 to 90%. Kim and Shin (1996) reported four cultivars in Korea that produced 70 to 75% control of barnyardgrass.

There has been much variability in control between individual rice plants, which is not surprising since there has been no selective pressure placed on these plants to make the effect uniform. Our goals are to first identify the chemicals that are responsible for the effect and then to develop a nondestructive assay that would allow breeders to select only those plants showing the highest allelopathic potential for breeding purposes. Our approach has been to analyze soil in which allelopathic and nonallelopathic rice was grown and look for differences in the types or concentrations of compounds we find. These compounds would then be added to soil and a bioassay performed to see if they are truly the allelochemicals or are compounds that happen to be present but are not implicated in allelopathy.

PROCEDURES

Abbreviations for the compounds mentioned are listed below.

4HB	4-hydroxybenzaldehyde
3HBA	3-hydroxybenzoic acid
4HBA	4-hydroxybenzoic acid
4HCA	4-hydroxycinnamic acid
4H3MBA	4-hydroxy-3-methoxybenzoic acid
4H3MCA	4-hydroxy-3-methoxycinnamic acid
TETRA	tetradecanoic acid
HEXA	hexadecanoic acid
LEIC	linoleic acid
OLEIC	oleic acid
STEARIC	stearic acid
DHAA	dehydroabietic acid

Greenhouse Single-Plant Studies

Individual plants of allelopathic rice accession P.I. 312777 and the nonallelopathic rice cultivar Rexmont were grown for 21 and 26 days in 5 g of soil. The soil was removed from the roots, extracted and analyzed by gas chromatography mass spectrometry (GCMS). Soil in which no rice was grown, but was otherwise treated the same as the samples growing rice (no-rice controls), was also analyzed. Crowley silt loam (Typic Albaqualfs) filtered through a 2-mm mesh was used. The number of replications are given in Table 1.

Stuttgart Field Experiment

Rice was grown to approximately 15 cm in height on a Crowley silt loam in field plots at Stuttgart, Arkansas. Soil samples were removed from plots of Rexmont, PI 312777 and no-rice controls, extracted and analyzed by GCMS. Sampling was done by tracing a tongue depressor on the soil surface in two locations approximately 10 cm from the rice row and then using the tongue depressor to scoop out the outlined soil to a depth of 1.5 to 2.0 cm.

Rice Root Size as a Function of 4HBA Concentration

Evidence presented at the Workshop on Allelopathy in Rice at IRRI by Navarez and Olofsdotter (1996) indicated that 4HBA stimulated root growth of germinated rice seeds in petri dishes. To see if 4HBA would stimulate growth of rice roots over a 21-day period, newly germinated Rexmont and PI 312777 plants, 10 plants per sample, were transplanted to Hoagland nutrient solutions containing 0, 10, 50 or 100 ppm 4HBA. The solution was changed daily. Root length was measured weekly, and after 21 days root air dry weights were recorded.

Soil Extraction and Analysis

GCMS

Five grams of soil was extracted with 10 mL of 0.25 N NaOH in 1/1 methanol water on a shaker for 30 min. After centrifuging at 750 x g for 10 min, 5 mL of centrifugate was combined with 0.5 mL of concentrated HCl and 5 mL of deionized water. The solution was extracted with two 7-mL portions of ethyl acetate, shaking 1 min each time. The ethyl acetate was put through a 5-cm plug of anhydrous sodium sulfate in a disposable Pasteur type pipet into a clean, dry 150 mm x 15 mm screw cap culture tube. After evaporating to just dry under nitrogen at 33 to 38°C, 2 mL of ethyl acetate was added by pipet and mixed, and 1 µL was analyzed by GCMS. The ethyl acetate was again removed under nitrogen. The samples were then derivatized by adding 50 µL of a mixture of 99% BSTFA + 1% TMS and 116 µL of pyridine and heating in a capped culture tube at 100 to 105°C for 90 minutes for analysis of carboxylic acids, phenols and phenolic acids.

Leaf Extraction and Analysis

A brass #3 cork borer with an internal diameter of 6 mm was used to remove disks from rice leaves grown in field plots in Fayetteville, Arkansas, on 10 September 1997. The plots that were sampled contained PI 312777 and Rexmont. One leaf was removed from each of four different plants in the middle of each plot, and one near each end of the plot. Two disks were removed from each leaf, and one disk from each leaf was placed in each of two different sample vials. One vial was extracted with 1.5 mL of ethyl acetate, and one was extracted with 1.5 mL of 1/1 methanol /deionized water. From the total of six samples from each plot, three were extracted with ethyl acetate and three with methanol/water. The capped samples were placed in a refrigerator overnight.

GCMS

The samples extracted with ethyl acetate were analyzed by GCMS in the morning. The ethyl acetate was then removed and the samples derivatized as for soil samples for GCMS analysis of acidic compounds.

HPLC

The extracts from samples extracted with 1/1 methanol/deionized water were analyzed directly by HPLC.

Bioassays

Two bioassays were performed on several chemicals that were considered to be potential allelochemicals. The compounds are listed in Table 2. In the first experiment we used 50 g of the Stuttgart soil, which has a natural infestation of ducksalad, and no additional ducksalad seeds were added.

In the second experiment we used 200 g of soil, and 50 additional ducksalad seeds were added for this bioassay. The samples were flooded, and counts of ducksalad plants were taken weekly. At the end of the experiment ducksalad plants were counted as they were removed with tweezers. The plants were allowed to air dry, and weights were recorded.

RESULTS AND DISCUSSION

GCMS Analysis of Field and Greenhouse Samples

With the exception of oleic acid, the concentrations of all compounds were lower in field samples than in the single plant greenhouse study samples lending support to the idea that growing the rice plants in a minimum amount of soil will increase the concentrations of chemicals in the soil (Table 1).

There were no significant differences at a p-value of 0.05 between concentrations for any of the compounds for any treatments in the field studies, although values for 4HB (p-value of 0.09) and DHAA (p-value of 0.116) approached significance. The mean concentration of DHAA in the PI 312777 plots was more than twice the amount found in the no-rice control or in the Rexmont plots. However, due to the large variability in concentrations, this was not a significant difference.

For the 21-day greenhouse samples there were significant differences in soil concentrations between rice samples and no-rice controls for six compounds and for the 26-day samples for two compounds. The two compounds that showed significance in the 26-day samples did not show significance in the 21-day samples. The two tests were performed sequentially, not concurrently, and differences in environmental conditions such as watering may contribute to the difference in results. It is difficult to maintain a moist soil that is neither flooded nor dry when the amount of soil is only 5 g. In each of the eight cases where significance was seen in the 5-g samples, the difference was between no-rice controls and soil supporting the growth of rice. There were no differences between the two types of rice.

Rice Root Size as a Function of 4HBA Concentration

If 4HBA stimulates root growth in the concentration range of 10 to 100 µg/mL in nutrient solution, we should see an increase in either root length or root mass. The results for both Rexmont and PI 312777 were similar (Table 3). The root length was not affected by the 10 ppm concentration but was reduced for both strains in the 50 and 100 ppm solutions. However, the root mass after 21 days was not statistically different for either strain at any concentration. The results indicate that increasing concentrations of 4HBA above 10 ppm in nutrient solution may reduce overall root length but not reduce the root mass.

Rice Leaf Analysis

It may be possible to identify a marker that would correspond to allelopathic activity in the rice tissue. To try to determine this, samples were removed from mature rice plants, extracted and analyzed directly with HPLC. Figure 1 shows chromatograms from three replications each of Rexmont and PI 312777. Although the chromatograms were very similar over most of the range, there was one peak corresponding to one compound that was consistently higher in the PI 312777 samples than in the Rexmont samples.

Bioassays

The bioassay results (Table 2) for the number of ducksalad plants present were not significant at a p-value of 0.05 but were significant at a p-value of 0.1 (p-value of 0.066). It is interesting to note that treatment 4, which contained only phenolic acids, and treatment 8, which contained only straight chain acids, both had the highest mean value for the number of ducksalad plants present. The mean values for treatments 3 and 5, which contained only straight chain acids, were also higher than the mean value for the controls. Treatments 1, 2 and 6, which contained both phenolic acids and straight chain acids, had the three lowest average numbers of ducksalad plants, and these were lower than the average for the controls.

SIGNIFICANCE OF FINDINGS

The bioassay results indicate that there may be an interaction between phenolic acids and straight chain acids that is responsible for the allelopathic affect. This needs further investigation.

The GCMS analysis of the single plant greenhouse study samples revealed that soil in which the rice plants were growing had significantly higher amounts of some of the compounds that were bioassayed. The statistical significance was not reproducible between the 21- and 26-day samples. This may be reflective of the difference in allelopathic activity from plant to plant or environmental conditions such as difficulty in maintaining uniform water levels in the 5-g samples.

Higher concentrations of 4HBA did not produce more extensive roots. Larger root systems may allow more chemical to be exuded into the environment, but they probably are not larger as a result of the 4HBA.

Analysis of leaf tissue may reveal a marker that can be used to predict allelopathic activity.

ACKNOWLEDGMENT

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Table 1. GCMS analysis of soil samples supporting growth of 'Rexmont', rice accession PI 312777 and no-rice controls from field plots and from single plants grown in 5 g of soil in the greenhouse at Fayetteville, Arkansas in 1997.

	Stuttgart field				21 days - 5 gram - greenhouse				26 days - 5 gram - greenhouse			
		n=14[†]	n=15	n=15		n=7	n=7	n=8		n=13	n=14	n=14
Compound	p-value	control	Rex	312777	p-value	control	Rex	312777	p-value	control	Rex	312777
			µg/g soil				µg/g soil				µg/g soil	
4HB	0.09	0.17	0.20	0.22	0.006	1.76	2.04	2.12	0.438	0.72	0.88	0.86
3HBA	0.927	0.01	0.01	0.01	0.075	0.49	0.51	0.54	na[‡]	na	na	na
4HBA	0.741	0.16	0.16	0.17	0.014	1.42	1.49	1.48	0.425	0.68	0.58	0.64
TETRA	0.744	0.49	0.52	0.52	0.047	2.22	3.02	2.94	0.211	1.67	1.90	2.20
4HCA	0.365	0.32	0.34	0.44	0.0003	1.10	2.56	2.53	0.788	0.92	0.80	0.94
HEXA	0.404	2.79	2.87	2.50	0.274	20.6	24.5	22.1	0.004	13.7	15.6	17.4
LEIC	0.464	0.38	0.43	0.52	0.062	4.68	7.98	6.95	0.562	3.61	3.97	4.36
OLEIC	0.612	20.0	28.3	27.6	0.452	13.5	15.8	14.3	0.031	9.90	14.9	13.8
STEARIC	0.764	0.62	0.72	0.69	0.008	1.83	3.02	3.53	0.677	2.74	2.41	2.47
DHAA	0.116	0.26	0.22	0.60	na	na	na	na	na	na	na	na
4H3MBA	0.952	0.05	0.06	0.06	0.309	1.29	1.41	1.36	0.407	0.07	0.08	0.14
4H3MCA	0.539	0.29	0.28	0.38	0.0009	1.15	1.74	1.6	0.488	0.71	0.44	0.51

[†] n = number of replications.

[‡] na = not analyzed for.

Table 2. Compounds and soil concentrations of compounds added as acetone solutions plus the number of ducksalad plants and percent of control after 26 days for a ducksalad bioassay using 200 g of soil. Fayetteville, Arkansas, 1997.

			Treatment							
Compound	BNA[†]	BA[‡]	1	2	3	4	5	6	7	8
			(μg/g soil)							
TETRA			3	3	6			3	3	3
HEXA			30	30	60			30		30
4HCA			3	3		6		3	3	
4H3MCA			30			40		30	30	
LEIC			6	6			12		6	6
OLEIC			18	18			36		18	18
# ducksalad[§]	28.4	25.1	19.4	22.7	32.7	36.9	31.0	19.4	25.6	38.4
% of control	113	100	77	90	130	147	124	77	102	153

[†] BNA: blank, no acetone added

[‡] BA: blank, acetone added

[§] p-value: 0.066

Table 3. Root length and weight of 'Rexmont' and rice accession PI 312777 as a function of time spent in nutrient solution containing 0, 10, 50 and 100 ppm 4HBA.

	Rexmont			
	Root length			Root weight
ppm 4HBA	7 days	14 days	21 days	21 days
	(mm)			(mg)
0	93	104	160	22
10	81	102	168	32
50	59	69	105	26
100	66	93	108	24
p-value	0.002	0.028	9×10^{-6}	0.315

	PI 312777			
	root length			root weight
ppm 4HBA	7 days	14 days	21 days	21 days
	(mm)			(mg)
0	102	114	147	48
10	78	101	140	54
50	58	74	118	45
100	54	72	108	51
p-value	2×10^{-15}	4×10^{-10}	1×10^{-8}	0.541

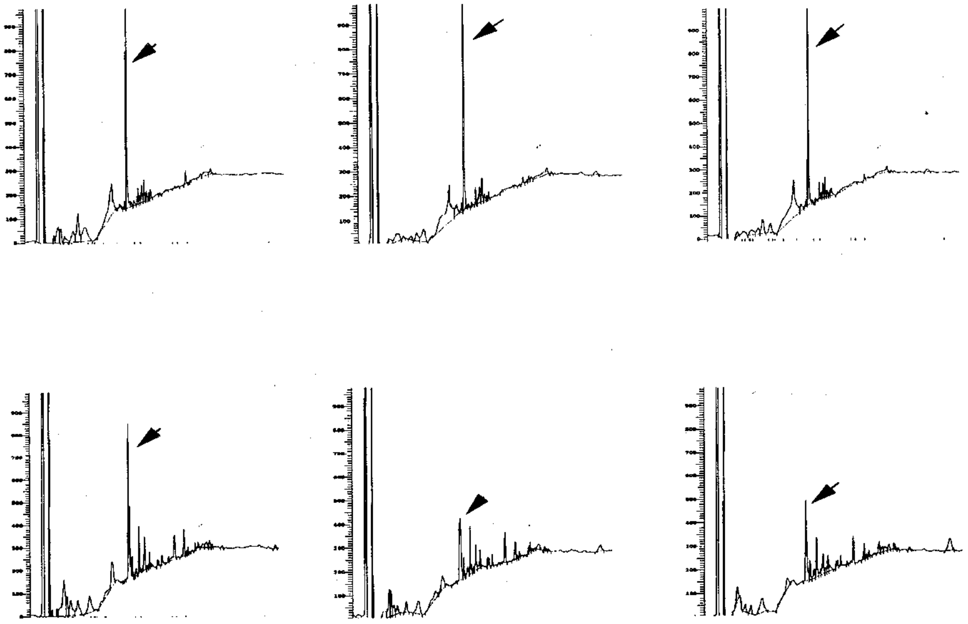

Fig. 1. HPLC chromatograms of leaf extracts of mature rice accession PI 312777 (top) and 'Rexmont' (bottom) rice plants.

ONGOING PROJECT
PEST MANAGEMENT: WEEDS

CONFIRMATION OF PROPANIL-RESISTANT BARNYARDGRASS AND STRATEGIES FOR CONTROL

R.E. Talbert, L.A. Schmidt, J.K. Norsworthy, J.S. Rutledge and W.L. Fox

ABSTRACT

Extensive use of propanil by rice (*Oryza sativa*) producers has led to the development of propanil-resistant barnyardgrass (*Echinochloa crus-galli*; R-BYG) in Arkansas. Since the initial confirmation of propanil resistance in barnyardgrass in Arkansas in 1990, propanil resistance has been confirmed in 162 populations (six new populations were added in 1997) in 18 counties. Anilophos, carbaryl, pendimethalin (Prowl®) and piperophos in combination with propanil produced synergistic effects on R-BYG by preventing propanil metabolism as determined by the chlorophyll fluorescence technique. Studies were also continued in 1997 to evaluate alternative herbicide programs for controlling R-BYG. Programs that provided excellent control of R-BYG and propanil-susceptible barnyardgrass (S-BYG) were propanil with the synergists anilophos, piperophos and carbaryl; clomazone [Command® 3G (granular) or 3ME (micro-encapsulated)] applied preemergence (PRE) or delayed-pre (DPRE); DPRE mixtures of pendimethalin or quinclorac (Facet®) applied alone or in combination with each other or thibencarb (Bolero®); quinclorac directly as a granule or the DF formulation as a spray; V-10029 or LGC-40863 applied late postemergence (LPOST); and the four formulations of propanil [M-4, 80EDF, Super Wham and propanil + molinate (Arrosolo®)] applied early postemergence (EPOST) in combinations with quinclorac, thiobencarb and pendimethalin.

INTRODUCTION

Since its introduction into Arkansas in 1962, propanil has been used extensively to control grass weeds in rice. After its introduction, rice yields in the U.S. increased 34 to 74% (Smith,1965). Propanil was one of the first herbicides to control barnyardgrass in rice and is currently used on approximately 98% of the rice acreage in Arkansas (Carey et al., 1995b). Many producers have grown rice in rotation with soybeans, with two or more sequential applications of propanil being applied when rice is grown.

In 1989, rice producers in Poinsett County began experiencing problems controlling barnyardgrass using the standard 3 to 5 lb/acre rates of propanil (Carey et al., 1995b). Seedlings grown from seed collected from Poinsett County in 1990 were tested and determined to be resistant to three times the recommended rates of propanil (Baltazar and Smith, 1994). The high selection pressure imposed from propanil application has led to the development of R-BYG.

The mechanism responsible for propanil resistance in barnyardgrass was found to be high concentrations of the aryl acylamidase enzyme,which metabolizes propanil before it can act on the photosynthesis system (Carey et al., 1995a). This mechanism is also the basis for propanil selectivity in rice.

Carbamates such as carbaryl (Sevin®) and organophosphate herbicides such as anilophos and piperophos mixed with propanil may be useful in controlling R-BYG by inhibiting the aryl acylamidase enzyme. R-BYG was controlled >90% when carbaryl at 1 lb/acre was applied one day before propanil at 4 lb/acre (Talbert et al., 1995).

Smith and Baltazar (1993) found there were alternative herbicides for controlling R-BYG. Some of these include propanil tank mixtures with thiobencarb, pendimethalin or quinclorac all applied POST; thiobencarb applied alone DPRE; quinclorac applied alone DPRE or POST, or applied POST in tank mixtures with thiobencarb or pendimethalin; propanil + molinate applied POST in tank mixtures with thiobencarb, pendimethalin or quinclorac; and fenoxaprop (Whip®). The most effective treatment involving quinclorac has caused off-target damage to tomatoes from application drift, so it is restricted in many areas, and the other treatments have been inconsistent in the control of R-BYG.

The objectives of this research were: 1) to test samples of barnyardgrass seed collected from producers for propanil resistance, 2) todetermine interactions between propanil in combination with anilophos, carbaryl, molinate (Ordram®), pendimethalin, quinclorac, thiobencarb or piperophos on photosynthesis inhibition in excised leaf segments of R-BYG and S-BYG using chlorophyll fluorescence, and 3) to evaluate efficacy for R- and S-BYG control with propanil synergists and alternative control measures.

PROCEDURES

Confirmation and Distribution of R-BYG in Arkansas

Rice growers in Arkansas have been encouraged to collect samples from problem fields since 1991 and submit them for propanil resistance testing. Seven barnyardgrass populations were collected and screened for propanil resistance. The technique used for confirming resistance in each of the samples was the chlorophyll fluorescence assay described in the following section. The results from the fluorescence assay were compared with the standard greenhouse bioassay in which the samples were grown and treated with 4 lb/acre of propanil at the two-leaf stage.

Propanil Synergists Screening with the Chlorophyll Fluorescence Assay

Chlorophyll fluorescence measurement and treatment of plant material were as described by Norsworthy et al. (1998). R- and S-BYG leaf segments were floated on 100 µM propanil, 50 µM additive or 100 µM propanil + 50 µM additive. Solutions contained methanol (0.08% by vol.) and were prepared using technical grade material. The exception was pendimethalin, which was prepared from formulated material (Prowl 3.3 EC) due to the insolubility of technical grade pendimethalin in methanol. Control segments received deionized water and methanol (0.08% by vol.). The widest portion of the youngest fully expanded leaf of barnyardgrass was harvested 28 days after planting. The excised leaf was cut into 2-cm segments and floated on the appropriate treatment solution for 2 h, adaxial side down. Segments were dark incubated in deionized water (22 h dark), allowing electron acceptors of PSII to become fully oxidized. The 22-h incubation also allowed R-BYG to alleviate photosynthetic inhibition via propanil metabolism. Chlorophyll fluorescence was then measured from the adaxial leaf surface for 90 seconds, and percentage inhibition of electron transport was calculated.

Efficacy of R-BYG Control in Rice

The following studies were conducted in 1997 at the Rice Research and Extension Center at Stuttgart, Arkansas. Experimental design for all experiments was a randomized complete block with four replications. ‘Kaybonnet’ rice was drill seeded in plots 6 by 16 ft with row spacing of 7.5 in. R- and S-BYG were planted in two separate rows perpendicular to the drilled rice in each tier of the plots. Applications were made with a three-nozzle back-pack sprayer spraying 15 GPA unless otherwise noted. Visual ratings of R- and S-BYG control and rice injury were taken after treatment with 0 = no barnyardgrass control or healthy rice and 100 = complete barnyardgrass control or dead rice. Yield was taken from the middle four rows (12-ft length) in each plot and converted to lb/acre at 12% moisture.

Field Evaluation of Propanil Synergists

Rates of the synergists with propanil were based on the preliminary studies performed in 1996. Propanil at 3 and 4 lb/acre alone and with the addition of anilophos at 0.1 and 0.2 lb/acre or piperophos at 0.22 and 0.45 lb/acre were applied at the two-leaf stage along with 3 lb/acre of propanil plus 0.1 lb/acre carbaryl for comparison. Applications at the four-leaf stage included propanil at 3 and 4 lb/acre plus anilophos at 0.33 and 0.67 lb/acre or piperophos at 0.67 and 1.34 lb/acre and 4 lb of propanil plus 0.1 lb/acre carbaryl. Plots were rated 7, 14, 28 and 56 days after treatment (DAT).

Clomazone Formulations and Application Timings

Clomazone [Command® 3ME (micro-encapsulated) and 3G (granular)] formulations were compared. Timings included PRE and DPRE. Clomazone 3ME was applied at 0.2, 0.3, 0.4 and 0.5 lb/acre, and clomazone 3G was applied at 0.4, 0.5 and 0.6 lb/acre. Clomazone granules were dispersed across the entire plot area using a shaker jar. Plot ratings were taken 7, 15 and 30 days after emergence (DAE).

Delayed-PRE Mixtures

Treatments were applied 5 days following planting and were flush irrigated the following day to insure activation. Thiobencarb at 4 lb/acre, pendimethalin at 1 lb/acre and quinclorac at 0.25 lb/acre were applied individually. Combinations of the three were thiobencarb at 2 lb/acre + pendimethalin at 1 lb/acre, pendimethalin at 1 lb/acre + quinclorac at 0.19 lb/acre, thiobencarb at 2 lb/acre + quinclorac at 0.19 lb/acre, and thiobencarb at 2 lb/acre + pendimethalin at 1 lb/acre + quinclorac at 0.19 lb/acre. Ratings were taken 14, 28 and 60 DAT.

Quinclorac Formulations

Quinclorac G was compared to quinclorac DF (dry flowable) for weed control at the PRE, DPRE and EPOST timings. The standard rate of quinclorac, 0.38 lb/acre, was compared at all three timings for both formulations. The granular formulation was dispersed across the entire plot area using a shaker jar. Ratings were taken 14, 28, 55 and 71 DAE.

Herbicides for Late Postemergence (LPOST) R-BYG Control

Studies were conducted to evaluate V-10029, an experimental herbicide from Valent, and LGC-40863, an experimental compound from the Korean-based company LG-Chem, for LPOST control of R-BYG and rice injury. V-10029 was applied at 0.3 oz/acre, and LGC-40863 was applied at 0.4 and 0.8 oz/acre. Visual rice injury and weed control ratings were taken at 7, 14 and 33 DAT.

RESULTS AND DISCUSSION

Confirmation and Distribution of R-BYG in Arkansas

Six of the seven producer barnyardgrass samples were confirmed to be resistant to propanil using the chlorophyll fluorescence assay. This brings the total of number of R-BYG confirmations in Arkansas to 162, spanning 18 counties (Figure 1). Similar results were also seen when using the greenhouse bioassay for confirmation (Table 1).

Propanil Synergists Screening with the Chlorophyll Flourescence Assay

The combinations of propanil + anilophos, propanil + carbaryl and propanil + piperophos were synergistic on R-BYG, causing >80% photosynthetic inhibition (Figure 2a-c). Insignificant inhibition resulted from propanil, carbaryl or piperophos alone. Anilophos alone inhibited R-BYG 30%. The pendimethalin + propanil treatment also caused a synergistic response on photosynthetic inhibition of R-BYG, but, to a lower extent (i.e. 55%) (Figure 2d). This response may be attributed to increased propanil uptake due to the use of formulated pendimethalin.

Propanil in combination with anilophos, carbaryl, pendimethalin and piperophos produced synergistic effects on R-BYG by preventing propanil metabolism. Molinate, thiobencarb and quinclorac did not produce synergistic effects with propanil, which may be attributed to different herbicide modes of action and/or altering of aryl acylamidase activity *in vivo*. Alternating herbicides with different modes of action for efficacious weed control should aid herbicide resistance management. Use of tank mixes of compounds with different modes of action could also prevent the development and/or spread of herbicide resistance in weeds.

Efficacy of R-BYG Control in Rice

Field Evaluation of Propanil Synergists

Outstanding treatments at the two-leaf stage included anilophos at 0.2 lb/acre plus 4 lb/acre propanil, piperophos at 0.22 or 0.45 lb/acre with either 3 or 4 lb/acre of propanil and carbaryl at 0.1 lb/acre plus 3 lb/acre of propanil (Table 2). Treatments at the four-leaf stage including anilophos at 0.33 and 0.67 lb/acre with 3 or 4 lb/acre propanil, 0.67 lb/acre piperophos with 3 lb/acre propanil and carbaryl at 0.1 lb/acre with 4 lb/acre propanil also gave promising results. Anilophos at 0.2 lb/acre plus 4 lb/acre propanil and 0.45 lb/acre piperophos with either 3 or 4 lb/acre propanil at the two-leaf stage reduced yields when compared with other treatments. Excessive injury to the rice (21 to 46%) and further yield reductions occurred with treatments of piperophos at 0.67 or 1.34 lb/acre with 4 lb/acre propanil and piperophos at 1.34 lb/acre plus 3 lb/acre of propanil.

Clomazone Formulations and Timings

All treatments of clomazone gave excellent control of propanil-resistant and -susceptible barnyardgrass (Table 2). Preemergence (PRE) treatments showed significant injury to the rice compared to the delayed preemergence (DPRE) with both formulations at the 0.4 and 0.5 lb/acre rate. Yields did not differ significantly except for the 0.5-lb/acre rate of the ME formulation at the PRE timing, which yielded significantly lower than the G formulation at 0.4 lb/acre PRE and DPRE and 0.5 lb/acre at DPRE.

Delayed-Pre Mixtures

All treatments applied DPRE provided excellent control of R-BYG and S-BYG except for thiobencarb at 4 lb/acre (Table 3). No treatments caused significant injury to rice that was evident in the yields. Results from this experiment indicate that DPRE mixtures even at reduced rates can be very effective for controlling R-BYG if adequate water is applied for continuous activation.

Quinclorac Formulations

In comparing the G and the DF formulations of quinclorac, no differences in controlling R-BYG at the PRE, DPRE and EPOST timings were observed. No significant differences were noticed in yield between the quinclorac G and DF treatments at any of the above timings as well.

Herbicides for Late Postemergence (LPOST) R-BYG Control

V-10029 at 0.2 oz/acre and LGC-40863 at 0.4 or 0.8 oz/acre provided excellent control of four- to five-leaf R- and S-BYG at 33 DAT. Both compounds injured rice initially, but by 33 DAT no injury to rice was evident. Grain yields for the treatments with the two compounds were comparable to that of the local LPOST standard of propanil + molinate at 6 lb/acre.

SIGNIFICANCE OF FINDINGS

Propanil-resistant barnyardgrass is a wide-spread and serious problem in Arkansas. Improved laboratory testing methods, such as chlorophyll fluorescence, have aided in the propanil resistance confirmation testing program being provided to the crop producers by the University of Arkansas. This technology has also provided us a method of screening for improved synergists to propanil for more selective weed control in rice. The work with the propanil synergists anilophos, piperophos and carbaryl has promise for R-BYG control in rice. Use of clomazone in rice provides an excellent new technology for R-BYG control and should be available to producers in the near future. The effective control of R-BYG with reduced rates of DPRE applications of quinclorac and/or pendimethalin plus thiobencarb indicate that with proper water management to keep the herbicide active, weed control cost in rice production may be reduced. The comparable control from quinclorac G with the quinclorac DF formulation creates an alternative means for applying quinclorac where recent restrictions have been imposed due to quinclorac drift onto vegetables. The two new compounds, V-10029 and

LGC-40863, offer promising methods to control larger R-BYG at late timings without significant injury to rice.

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Table 1. Comparison of the chlorophyll flourescence assay (CFA) and the greenhouse bioassay(GB) for confirmation of propanil-resistant barnyardgrass.

Sample #	CFA	GB	GB
	---------- % Pop. Resistant	----------	% Control (15 DAT[†])
1-96	50	75	20
2-96	50	60	30
3-96	17	18	65
4-96	83	89	28
5-96	100	94	10
6-96	33	37	88
7-96	0	10	96

[†] DAT = days after treatment.

Table 2. Propanil plus synergist treatments giving outstanding control of susceptible and resistant barnyardgrass at 56 DAT[†] in 1997.

Treatments	Rates	Timings	Barnyardgrass control		Rice	
			Susceptible	Resistant	Injury	Grain Yield
	(lb/acre)		%			(lb/acre)
Untreated	-------		0	0	0	5810
Propanil + anilophos	4 + 0.2	EPOST[‡]	95	91	0	6780
Propanil + piperophos	3 + 0.22	EPOST	95	96	0	7380
Propanil + piperophos	3 + 0.45	EPOST	96	95	0	5690
Propanil + piperophos	4 + 0.22	EPOST	95	94	0	7290
Propanil + piperophos	4 + 0.45	EPOST	95	95	5	6470
Propanil + carbaryl	3 + 0.1	EPOST	95	93	0	7090
Propanil + anilophos	3 + 0.33	MPOST	95	93	0	7600
Propanil + anilophos	3 + 0.67	MPOST	95	91	0	7710
Propanil + anilophos	4 + 0.33	MPOST	98	95	0	7370
Propanil + anilophos	4 + 0.67	MPOST	96	95	0	7870
Propanil + piperophos	3 + 0.67	MPOST	96	96	6	6660
Propanil + carbaryl	4 + 0.1	MPOST	96	96	3	6960
$LSD_{(0.05)}$			5	9	4	930

[†] DAT = days after treatment.

[‡] EPOST = early postemergence; MPOST = mid-postemergence

Table 3. Comparison of clomazone granular and microencapsulated formulations at different timings for control of propanil-resistant (R-BYG) and -susceptible barnyardgrass (S-BYG) at 30 DAE, Stuttgart, Arkansas, 1997.

Treatment	Rate	Timing	R-BYG	S-BYG	Rice Injury	Grain Yield
	lb/acre		----------------	--------%	----------------	lb/acre
Untreated Check	--		0	0	0	6210
Clomazone 3 ME[†]	0.2	PRE[‡]	94	95	6	6660
Clomazone 3 ME	0.3	PRE	95	95	9	6650
Clomazone 3 ME	0.4	PRE	95	95	9	6590
Clomazone 3 G	0.4	PRE	95	95	13	7480
Clomazone 3 ME	0.5	PRE	93	94	25	5920
Clomazone 3 G	0.5	PRE	95	95	16	6890
Clomazone 3 ME	0.2	DPRE	94	95	1	6510
Clomazone 3 ME	0.3	DPRE	95	95	1	6610
Clomazone 3 ME	0.4	DPRE	96	96	0	6660
Clomazone 3G	0.4	DPRE	96	96	1	7230
Clomazone 3 ME	0.5	DPRE	95	96	3	6710
Clomazone 3G	0.5	DPRE	95	95	1	7180
LSD $_{(0.05)}$			3	2	8	1050

[†] ME = microencapsulated; G = granular.

[‡] PRE = preemergence; DPRE = delayed preemergence.

Table 4. Control of propanil-resistant (R-BYG) and -susceptible barnyardgrass (S-BYG) and rice injury at 60 days after treatment with delayed preemergence combinations at reduced rates, Stuttgart, Arkansas, 1997.

Treatment	Rate	R-BYG	S-BYG	Rice Injury	Grain Yield
	lb/acre	----	%	----	lb/acre
Untreated Check	--	0	0	0	6590
Thiobencarb	4	63	78	0	8060
Pendimethalin	1	94	94	0	7750
Quinclorac	0.25	95	95	0	8220
Thiobencarb + pendimethalin	2 + 1	95	95	0	8410
Pendimethalin + quinclorac	1 + 0.188	95	95	0	7690
Thiobencarb + quinclorac	2 + 0.188	95	95	0	8330
Thiobencarb + pendimethalin + quinclorac	2 + 1 + 0.188	95	95	0	7700
LSD $_{(0.05)}$		2	4	NS	680

Table 5. Control of propanil-resistant (R-BYG) and -susceptible barnyardgrass (S-BYG) and rice injury at 71 days after emergence comparing quinclorac granular with quinclorac dry flowable at 0.38 lb/acre and various timings, Stuttgart, Arkansas, 1997.

Treatment	Timing	R-BYG	S-BYG	Rice Injury	Grain Yield
		----	%	----	lb/acre
Untreated Check	--	0	0	0	5800
Quinclorac G[†]	PRE[‡]	96	99	0	8060
Quinclorac DF	PRE	96	96	0	7750
Quinclorac G	DPRE	94	93	0	8220
Quinclorac DF	DPRE	99	96	0	8410
Quinclorac G	EPOST	95	96	0	7690
Quinclorac DF + COC	EPOST	99	98	0	8330
LSD $_{(0.05)}$		5	5	NS	940

[†] G = granular; DF = dry flowable.

[‡] PRE = preemergence; DPRE = delayed preemergence; and EPOST = early postemergence.

Table 6. Control of propanil-resistant (R-BYG) and -susceptible barnyardgrass (S-BYG) and rice injury at 33 days after treatment with LPOST applications of V-10029 and LGC-40863, Stuttgart, Arkansas, 1997.

Treatment	Rate/acre	Timing	R-BYG	S-BYG	Rice Injury	Grain Yield
			--------------------	%	--------------------	lb/acre
Untreated Check	--	--	0	0	0	5720
V-10029	9 g	LPOST[†]	93	93	0	7460
(Propanil + molinate)	6 lb	LPOST	98	96	0	7110
LGC-40863	12 g	LPOST	98	99	0	7050
LGC-40863	24 g	LPOST	96	95	0	7100
LSD $_{(0.05)}$			5	5	NS	730

[†] LPOST = late postemergence.

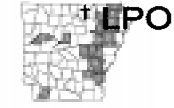

Fig. 1. Number of confirmed propanil-resistant barnyardgrass populations by county in Arkansas (199101997).

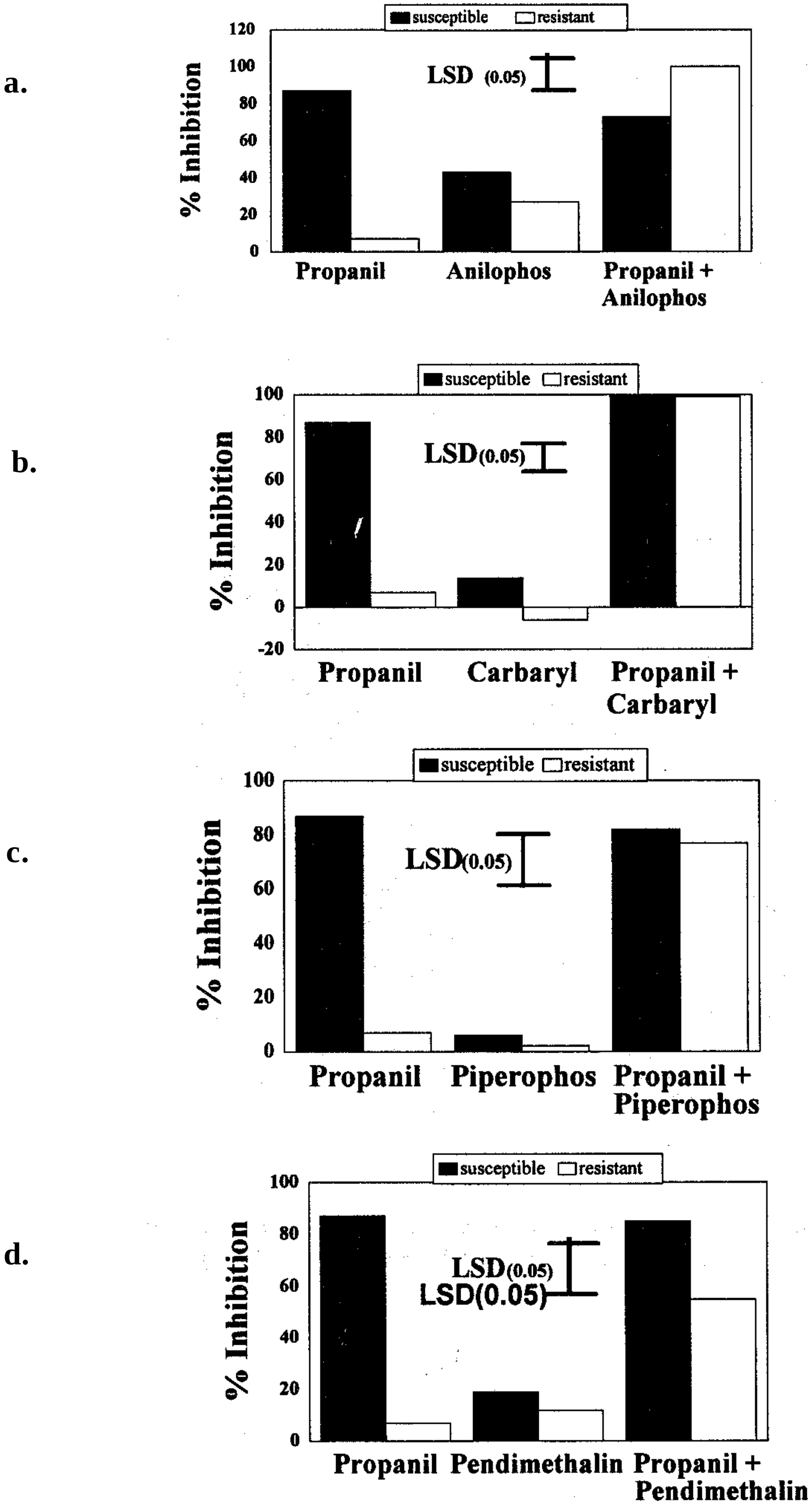

Fig. 2. Synergistic effects of anilophos, carbaryl, piperophos or pendimethalin with propanil.

ONGOING PROJECT

PEST MANAGEMENT: WEEDS

CLOMAZONE USE IN RICE

E.P. Webster and F.L. Baldwin

ABSTRACT

Clomazone (Command®) has the potential to be used as a soil-applied herbicide in a rice production system. This compound can be applied as a single application and give season-long barnyardgrass control with no reduction in yield when compared to a standard delayed preemergence (DPRE) weed control program. Research is needed to continue to determine the optimum rate and application timing for maximum weed control and grain yield and for minimum injury and off-site movement.

PROCEDURES

A field study was established at the Southeast Research and Extension Center, at Rohwer, Arkansas, in 1996 and 1997 to evaluate the potential for clomazone (Command) use in rice (cv 'Lemont'; *Orvza sativa* L.). Clomazone was applied preplant incorporated (PPI) using the 4 EC formulation of clomazone, pre-emergence (PRE), delayed PRE (DPRE) and early postemergence (EPOST) using the 3 ME formulation of clomazone. Clomazone rates were 0.4, 0.5 and 0.6 lb ai/acre at all application timings. Quinclorac (Facet®) at 0.5 lb ai/acre was applied PPI, PRE and DPRE. Pendimethalin (Prowl®) at 1.0 lb ai/acre, quinclorac at 0.38 lb/acre plus pendimethalin at 1.0 lb/acre, and quinclorac at 0.38 lb/acre plus thiobencarb (Bolero®) at 2.0 lb ai/acre were applied DPRE for comparison purposes. Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] control ratings were taken at 7, 35 and 49 days after the EPOST (DAEPOST) application timing. Crop injury was evaluated, and rice yield was determined. Data were subjected to ANOVA and separated using Fisher's protected LSD at the 5% level of significance. An interaction occurred between treatments, and data were averaged across years.

RESULTS AND DISCUSSION

At 7 DAEPOST, barnyardgrass control ranged from 86 to 98% with clomazone at all rates applied PPI, PRE and DPRE (Table 1). However, clomazone applied EPOST at any rate showed less than 60% control of barnyardgrass. Clomazone DPRE at 0.6 lb/acre gave 98% control of barnyardgrass, and this control was higher than for a single DPRE application of quinclorac. No other differences were observed.

At 35 DAEPOST, a standard DPRE application of quinclorac plus pendimethalin gave 90% control of barnyardgrass. All clomazone application timings and rates showed equal control, except clomazone EPOST at 0.4 lb/acre gave 79% control of barnyardgrass. No other differences were observed.

At 49 DAEPOST, the standard DPRE application of quinclorac plus pendimethalin gave 88% control of barnyardgrass. Clomazone DPRE at 0.5 lb/acre, PPI and DPRE at 0.6 lb/acre, and a single application of quinclorac DPRE at 0.5 lb/acre showed less control of barnyardgrass than the standard quinclorac plus pendimethalin DPRE. All other clomazone treatments controlled barnyardgrass from 83 to 93%.

Rice injury ratings were taken throughout the season. At 7 days after emergence, rice injury ranged from 8 to 18% for all soil-applied clomazone treatments (Table 2). The EPOST clomazone treatments had not been applied at the time of evaluation. Clomazone at all rates applied PPI caused 14 to 18% injury, and this was higher than any treatment added for comparison purposes. Quinclorac plus pendimethalin or thiobencarb gave less than 10% rice injury. At 7 DAEPOST, rice injury was less than 10% for all treatments. At 35 DAEPOST, no injury was noted.

Quinclorac plus pendimethalin DPRE produced the highest numerical yield of 5259 lb/acre. Clomazone at 0.4 lb/acre DPRE and EPOST, 0.5 lb/acre PRE and DPRE, 0.6 lb/acre EPOST, quinclorac plus thiobencarb DPRE, quinclorac DPRE and pendimethalin DPRE resulted in less yield than quinclorac plus pendimethalin DPRE. No other differences occurred.

SIGNIFICANCE OF FINDINGS

Clomazone has the potential to offer excellent control of barnyardgrass, propanil-resistant barnyardgrass, broadleaf signalgrass and sprangletop at a greatly reduced cost compared to available standards. It also has potential to increase the use of ground applications in rice.

ACKNOWLEDGMENT

Funding provided by Rice Research and Promotion Board and FMC Company.

Table 1. Barnyardgrass control with clomazone at different application timings compared to standard control programs, Rohwer, Arkansas.

Herbicide and Formulation	Rate	Application Timing	Barnyardgrass Control		
			7 DAEPOST[†]	35 DAEPOST	49 DAEPOST
	lb ai/acre			%	
Clomazone (4 EC)	0.4	PPI	92	81	88
Clomazone (4 EC)	0.5	PPI	93	90	88
Clomazone (4 EC)	0.6	PPI	90	81	77
Quinclorac (75% DF)	0.5	PPI	98	83	89
Clomazone (3 ME)	0.4	PRE	90	86	83
Clomazone (3 ME)	0.5	PRE	93	85	88
Clomazone (3 ME)	0.6	PRE	91	89	90
Quinclorac (75% DF)	0.5	PRE	88	78	83
Clomazone (3 ME)	0.4	DPRE	92	84	85
Clomazone (3 ME)	0.5	DPRE	86	84	66
Clomazone (3 ME)	0.6	DPRE	98	89	69
Quinclorac (75% DF)	0.5	DPRE	78	87	60
Pendimethalin (3.3 EC)	1.0	DPRE	97	78	81
Quinclorac (75% DF) + thiobencarb (6.0 EC)	0.38 + 2.0	DPRE	95	84	86
Quinclorac (75% DF) + pendimethalin (3.3 EC)	0.38 + 1.0	DPRE	97	90	88
Clomazone (3 ME)	0.4	EPOST	53	79	84
Clomazone (3 ME)	0.5	EPOST	53	88	92
Clomazone (3 ME)	0.6	EPOST	54	86	93
Nontreated			0	0	0
LSD (0.05)			13	10	10

[†] DAEPOST = days after early postemergence; PPI = preplant incorporated; PRE = preemergence; DPRE = delayed preemergence; EPOST = early postemergence.

Table 2. Rice injury and grain yield when clomazone was applied at different timings compared to standard weed control programs, Rohwer, Arkansas in 1996 and 1997.

Herbicide and Formulation	Rate	Application Timing	Rice Injury		Rice Yield
			7 DAE[†]	7 DAEPOST	
	lb ai/acre		%		lb/acre
Clomazone (4 EC)	0.4	PPI	14	4	4812
Clomazone (4 EC)	0.5	PPI	18	8	4821
Clomazone (4 EC)	0.6	PPI	14	7	4768
Quinclorac (75% DF)	0.5	PPI	9	4	4973
Clomazone (3 ME)	0.4	PRE	9	4	4848
Clomazone (3 ME)	0.5	PRE	12	5	4616
Clomazone (3 ME)	0.6	PRE	8	4	5080
Quinclorac (75% DF)	0.5	PRE	8	3	4795
Clomazone (3 ME)	0.4	DPRE	11	4	4580
Clomazone (3 ME)	0.5	DPRE	12	4	4679
Clomazone (3 ME)	0.6	DPRE	13	2	4964
Quinclorac (75% DF)	0.5	DPRE	8	1	4536
Pendimethalin 3.3 EC	1.0	DPRE	8	4	4580
Quinclorac (75% DF) + thiobencarb (6.0 EC)	0.38 + 2.0	DPRE	8	3	4723
Quinclorac (75% DF) + pendimethalin (3.3 EC)	0.38 + 1.0	DPRE	9	4	5259
Clomazone (3 ME)	0.4	EPOST		4	4643
Clomazone (3 ME)	0.5	EPOST		5	5045
Clomazone (3 ME)	0.6	EPOST		7	4661
Nontreated			0	0	3402
LSD (0.05)			5	4	500

[†] DAE = days after emergence; DAEPOST = days after early postemergence; PPI = preplant incorporated; PRE = preemergence; DPRE = delayed preemergence; EPOST = early postemergence.

DEVELOPMENT OF AN IPM MONITORING PROGRAM FOR RICE WATER WEEVIL ADULTS

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ABSTRACT

The development of an adult rice water weevil monitoring program was initiated. Two trap designs without attractants were tested for the ability to capture adult rice water weevils. The pyramidal trap, which was placed on levees, failed to catch any weevils, and no further tests will be conducted with this design. The teepee trap was placed in flooded rice and caught weevils. This design was very encouraging in that some weevils were caught in a field with very low numbers of weevils. An improved teepee trap design will be tested in 1998. Scanning electron microscopy revealed that the majority of sensillae occur on the pedicel and club of the eight-segmented antennae. Excised rice water weevil antennae connected to an electroantennogram (EAG) produced an electrophysiological response to hexanal, a known rice plant volatile. This demonstrates that our electrophysiological techniques can be used to screen rice plant and adult weevil volatiles for responses by adult rice water weevils. The information learned from these studies will be implemented to continue the development of a monitoring program for adult rice water weevils. With the loss of carbofuran (Furadan) in 1999, a new scouting method compatible with new insecticides is needed.

INTRODUCTION

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is a pest common to all Arkansas rice fields. Feeding on leaves by adults is found on non-flooded rice but increases as adults are attracted to flooded rice. Only after rice is flooded will females place eggs in the leaf sheath. Larvae must exit the leaf sheath, sink, enter the soil and find the rice roots. Larvae prune the roots, stunting rice plants, delaying heading and reducing yield.

The only insecticide registered for control of rice water weevil, carbofuran (Furadan), will be unavailable in 1999. Two insecticides, Karate® (registered for rice in 1997) and Dimilin® (not yet registered), require application within 10 days after permanent flood. Karate® is an adulticide, and Dimilin® is an ovicide. Current post-flood scouting methods for rice water weevil are leaf scar counts and soil-core samples. Soil-core samples are used to monitor larvae and are not recommended until 14 days post flood. Rice plants with intact accompanying soil are removed from the field. Samples are then agitated in water to separate the larvae from the plants and soil. The leaf scar method is begun four days after permanent flood and discontinued by 14 days after permanent flood. The number of plants with feeding scars on the newest leaf is counted. However, the leaf scar method was not widely adopted. Furthermore, neither of these methods is adequate for any of the potential replacements for carbofuran. Therefore, a new method of scouting for the rice water weevil is urgently needed.

One untested method is the use of rice plant odors or pheromones as attractants in traps. Improved monitoring of the rice water weevil would help prevent unnecessary insecticide applications. Many insects use air-borne chemicals for communication. The cotton boll weevil produces pheromones to attract other boll weevils and mates. The pheromones (Grandlure®) have been identified and are the cornerstone of boll weevil IPM programs. Furthermore, cotton boll weevil pheromone attractiveness is enhanced by cotton plant odors. Perhaps the rice water weevil has a similar means of communication to find mates or host plants. If so, traps baited with mate or host odors could be used to monitor adult rice water weevils. Improved monitoring of adults could then be coupled with data on subsequent larval infestation to properly time insecticides applied shortly after permanent flood.

The presence of any attractive pheromones or host odors must be established, identified and correctly formulated before using these as attractants in traps. No research has been done on rice water weevil pheromone and rice plant odors. Traps have not been developed for monitoring adult rice water weevils. In the first year of developing an adult rice water weevil monitoring program, we addressed two objectives: 1) to develop a trap that could be used for monitoring rice water weevil populations with or without chemical lures and 2) to determine if electrophysiological experiments could be conducted with rice water weevil antennae.

PROCEDURES

Field Experiments

Two trap designs without attractants were tested for the ability to capture rice water weevil adults: 1) a teepee trap placed in flooded portions of fields; and 2) a modified Tedder’s trap (pyramidal trap) placed on levees. Four teepee traps (Fig. 1) were placed randomly in each of five 1-acre rice plots the day of flood on 24 June. Twenty pyramidal traps were placed on levees of the same rice plots. Traps were checked weekly until 27 July 1997.

A D-ring aquatic dip net was used to take two (1 ft by 20 ft) samples in each 1-acre plot five days after permanent flood. The net was lowered into the floodwater until almost touching the soil surface and then pulled across the plants. The contents of each sample were examined for the presence and number of adult rice water weevils. Six 4 x 4 in. (diameter x depth) soil-core samples were taken from each plot on 17 and 30 July. Soil was washed from the plant roots into a 40-mesh screen. The screen was immersed in salt water, and rice water weevil larvae were removed and counted.

Laboratory Experiments

The heads of a female and male rice water weevil were excised and placed on specimen stubs with silver conducting paint. Specimens were then sputter coated with gold. The specimens were viewed and photographed with a scanning electron microscope. The antennae were thoroughly examined for the presence, placement and arrangement of structures that could potentially be sensitive to air-borne chemicals (chemosensillae).

The physiological reaction by rice water weevil to a known chemical released by rice plants was tested using an electrophysiological technique called an electrantennogram (EAG) (Schneider 1957). The sensillae on the rice water weevil are very small and almost parallel to the surface of the antennae. Therefore, the 'surface-contact' technique of Den Otter et al. (1980) was used for EAG experiments.

The electrical response of the antenna to chemical stimulation was measured by first inserting a silver/silver chloride glass pipette electrode filled with saline (Euphrussi and Beadle, 1936) into the back of an excised weevil head and a second electrode in contact with the distal end of the antenna. The antennae were continuously flushed with a humidified air stream. Hexanal, a known component of volatiles released by rice plants (Hernandez et al., 1989), was injected into the air stream. Electrophysiological responses were recorded and stored on computer for analysis.

RESULTS AND DISCUSSION

Field Experiments

The modified Tedder's trap on the levees was not successful in capturing any rice water weevil adults and has been eliminated from any further tests. The 20 teepee traps in the flooded rice captured a total of six weevils, all on 17 July. Dip net samples indicated very low numbers of adults in the plots, 0.06/ft^2. The capture of some adults by the traps was encouraging even though densities were low. The average number of larvae per core sample was expected to be low and was 2.9 and 1.3/core, respecitvely when examined three and four weeks after flood. In addition, a problem with the traps became apparent soon after the plots were flooded. The traps used a tripod arrangement of legs to support the cage. The bottom of the cage failed to contact the water's surface. Also, the legs may have been too short to allow for a constant height of the trap in relation to plant size due to rapid plant growth. A new teepee trap design (Fig. 2) with pontoons in lieu of the legs will be tested in 1998.

Laboratory Experiments

Determining the location of chemosensillae is prerequisite for electrophysiological studies. The small size of the antennae limited the use of conventional light microscopy. Thus, scanning electron microscopy was used to locate potential chemosensillae. The antennae of the rice water weevil consist of eight segments. The second segment (pedicel) is small and rounded with a high number of sensory structures (sensillae). The eighth segment is rounded and larger than the others with the majority of the sensillae on the distal half

(Fig. 3). The function of these sensillae is unknown at this time. A substantial electrophysiological response to hexanal was recorded by the EAG (Fig. 4). Although hexanal may be only one of many air-borne chemicals that elicit a response by rice water weevils, the importance of the result is that the experimental arrangement gave a positive EAG response. When other chemicals are isolated from rice plants, soil and rice water weevils, the EAG can be used to test for responses.

SIGNIFICANCE OF FINDINGS

A trap design to capture rice water weevil adults was field tested. Results of the test indicate that the design needed to be modified, but even in low densities the teepee trap did capture adults. One hundred and fifty of the improved teepee traps will be tested in 1998. This trap may be used with attractants (pheromones, rice plant odors, etc.) in the future.

Considerable time has been devoted to assembling the EAG equipment and modifying techniques to collect and isolate plant and adult rice water weevil volatiles. Furthermore, the positive results of the EAG indicated that the necessary components of the system have been assembled, and the techniques should yield more information on responses to host odors and possibly to pheromones produced by the rice water weevil. In the next two years, rice plant and rice water weevil volatiles will be evaluated for biological activity to rice water weevil adults. These positive results are the first steps in the development of a monitoring program for rice water weevil adults.

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ONGOING PROJECT

PEST MANAGEMENT: INSECTS

SCREENING RICE LINES FOR SUSCEPTIBILITY TO DISCOLORED KERNELS

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

ABSTRACT

Rice lines were evaluated for susceptibility to causes of kernel discolorations.

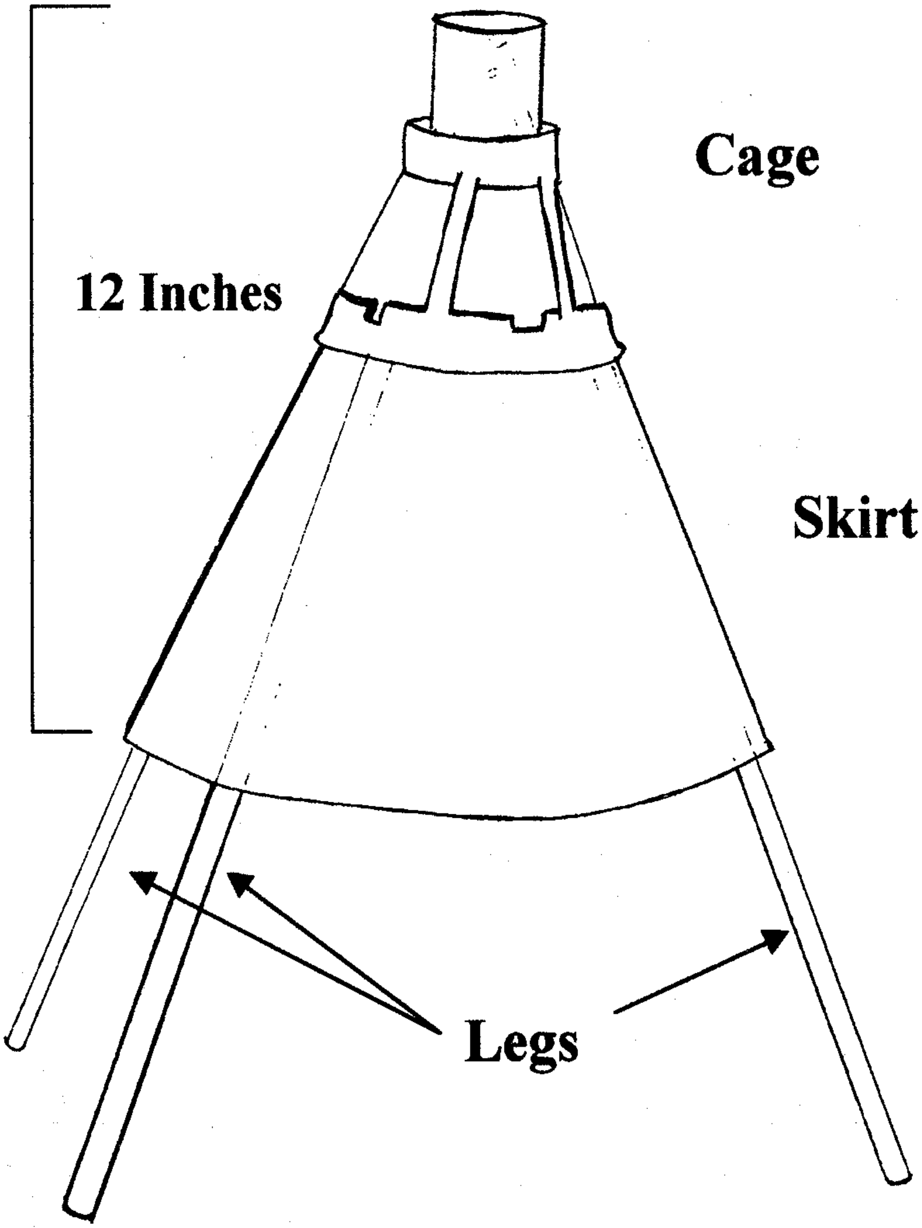

Fig. 1. Teepee trap for rice water weevil adults.

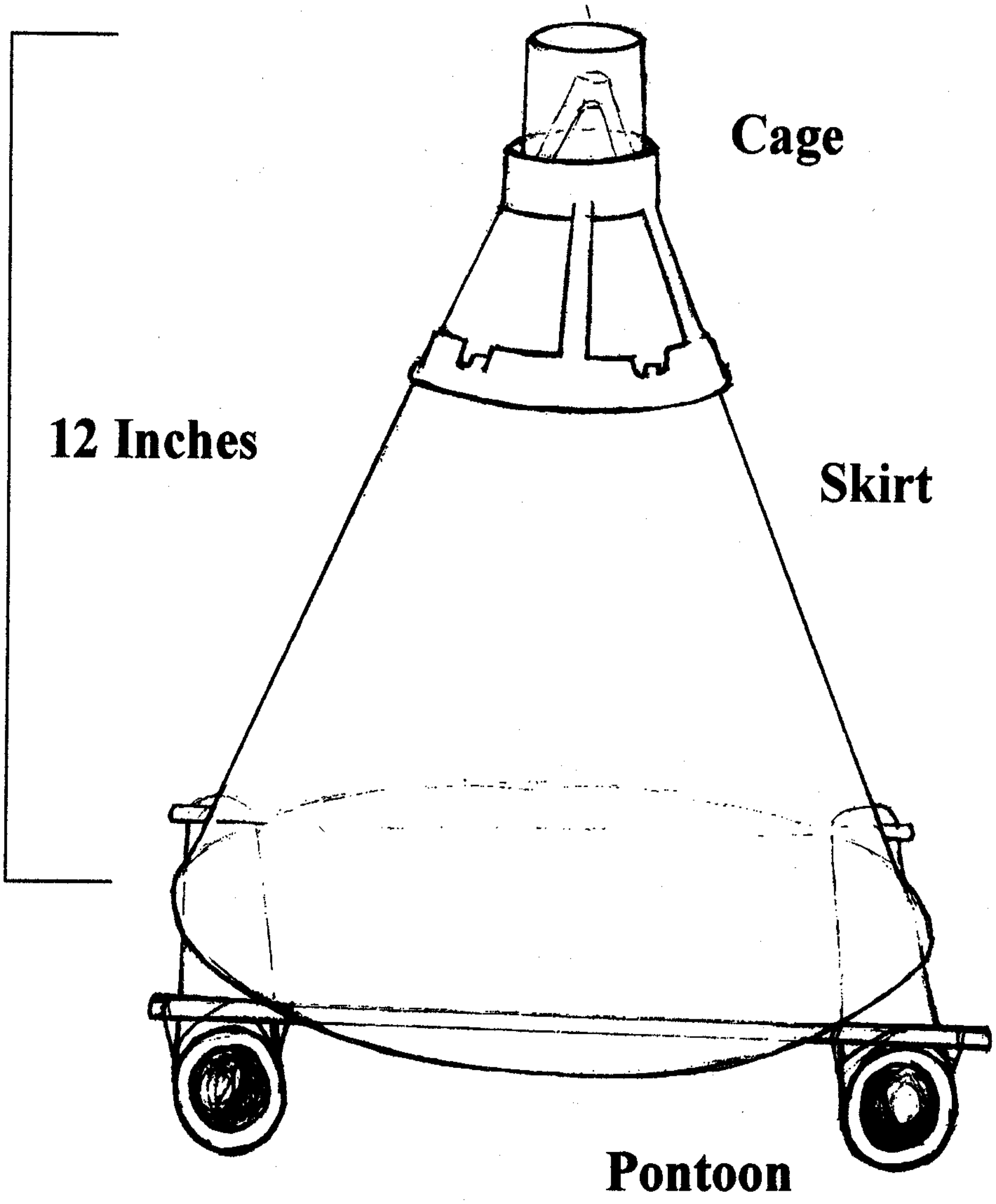

Fig. 2. Improved teepee trap for rice water weevil adults.

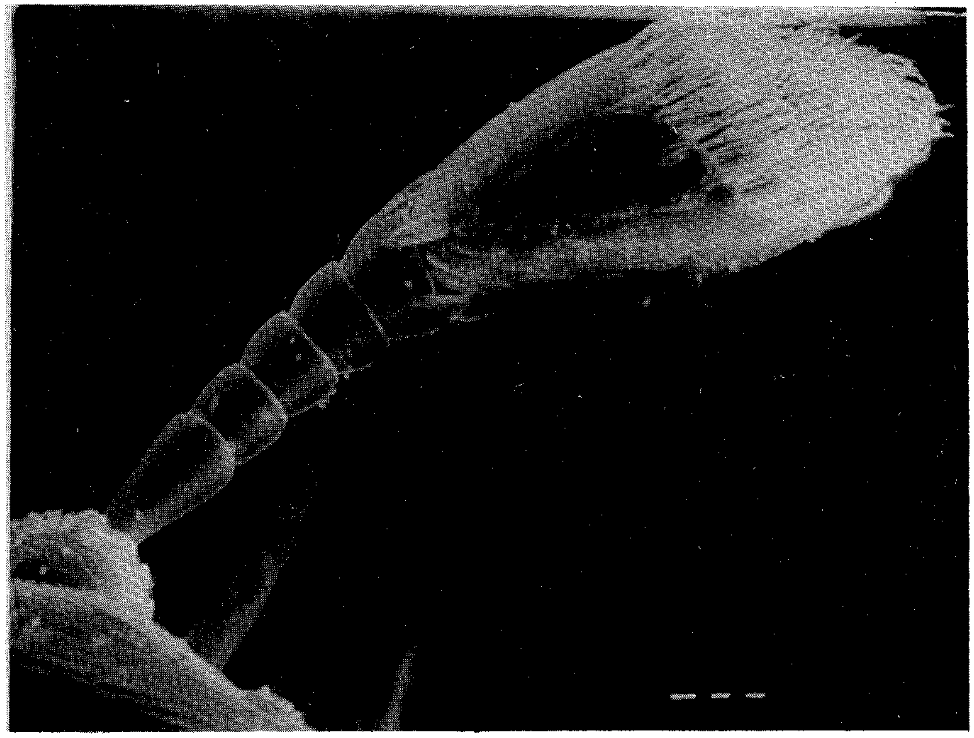

Fig. 3. Scanning electron micrograph (1500x) of adult female rice water weevil antenna.

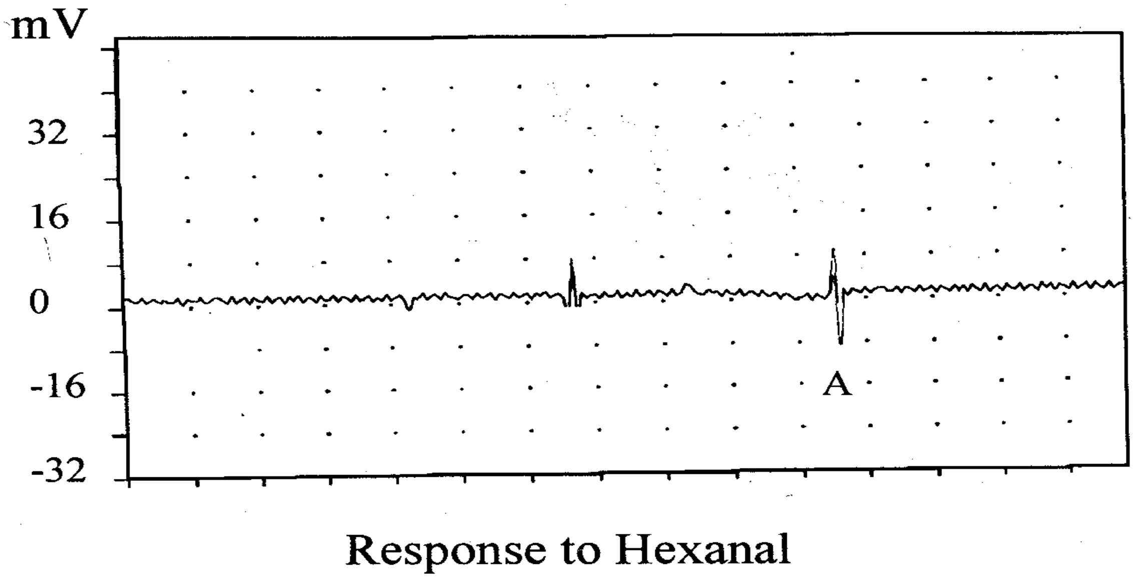

Fig. 4. Electroantennogram of rice water weevil response (A) to a rice plant volatile (mV=millivolt).

Advanced rice lines in the Arkansas Rice Performance Trials (ARPT) and the Uniform Regional Rice Nursery (URRN) were compared to check cultivars for susceptibility to feeding by rice stink bugs, kernel smut infection, other causes of bran and kernel discolorations and linear damage. In 1997, moderate levels of discolorations caused by rice stink bugs and kernel smut infection were found in the ARPT, and high levels of both types of discolorations were found in the URRN. The short grain lines RU9601096 and RU9601099 (‘Koshihikari’ / ‘Mars’ crosses) had high levels of kernel discolorations due to rice stink bug and linear damage. The three new cultivars, ‘Cocodrie’ (LA), ‘Madison’ (TX) and ‘Priscilla’ (MS), were moderately susceptible to rice stink bug, and Cocodrie and Priscilla were moderately susceptible to kernel smut. Data from yearly evaluations of rice lines and cultivars 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

Rice lines have different levels of susceptibility to organisms that discolor kernels (Bernhardt, 1992). In the field, kernel discolorations are caused by fungi alone, such as kernel smut [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] and brown spot [*Helminthosporium oryzae* Breda de Haan] or by fungi introduced by the rice stink bug, *Oebalus pugnax* (F.), and by a physiological response to adverse environmental conditions during grain fill, such as linear damage. Rice stink bugs are commonly found in all Arkansas rice fields where the adults and nymphs feed on developing rice kernels. The stage of kernel development determines the amount and type of damage. Feeding during the early stages may arrest any further development of the kernel and result in a total loss of the grain. Feeding during the later 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.

The entomology research program has placed emphasis on the development of control strategies that integrate control methods such as rice stink bug parasites, insecticides and resistant rice lines. This portion of the program evaluates 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 from all breeding programs that exist at the present time and to evaluate the rice germplasm for sources of resistance.

To accomplish the objectives, rice grain samples must be obtained from several sources for several years and evaluated for the amount of discolored kernels. Results from the evaluations of rice lines are compared and conclusions made on the relative susceptibility of rice lines to discoloration. 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 rice cultivars and lines from the following sources and years were evaluated: (1) the rice breeding program of the University of Arkansas entries in the Arkansas Rice Performance Trials (ARPT) (1988-1997); (2) breeding programs of other universities and private seed companies in the ARPT (1988 - 1997); and (3) advanced lines in the Uniform Regional Rice Nursery (URRN) (1993-1997). Locations of the ARPT were the Rice Research and Extension Center, Stuttgart, Arkansas (RREC, Arkansas Co.); Jackson County near Tupelo, Arkansas; Pine Tree Branch Experiment Station, Colt, Arkansas (PTBES, St. Francis Co.) and the Southeast Branch Experiment Station, Rohwer, Arkansas (SEBES, Desha Co.). Locations of the URRN were RREC in Arkansas (1993-1997); Rice Research Station, Crowley, Louisiana (1994-1996); Texas Agricultural Experiment Station, Beaumont, Texas (1994-1997); and Delta Research and Extension Center, Stoneville, Mississippi (1995-1997). Among the entries in the ARPT and URRN, check cultivars are used for comparisons. Data from check cultivars and advanced rice lines in the ARPT from 1992 through 1997 and data from the URRN in 1995 through 1997 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 out discolored kernels. The discolored kernels were examined with magnification to determine the cause of the discoloration. The categories of discolored kernels were: (a) kernels discolored by rice stink bug feeding, (b) kernels infected with kernel smut, (c) all other discolorations of which most had the discoloration confined to the bran layer and (d) 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, 1943). 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 1997 infestations of the rice stink bug were moderate, and overall amounts of damage were high but not as high as those recorded in 1996 (Table 1). General trends that were noted in other years of the ARPT and other varietal studies (Bernhardt, 1992) remained the same. For example, the amount of discolored kernels in the medium-grain types ‘Bengal’ and ‘M202’ was more than that in the long-grain cultivars. Also, long-grain cultivars that routinely have less damage from rice stink bug, such as ‘Katy’, ‘Jefferson’ and ‘LaGrue’, had the lowest amounts of damage in all the long-grain entries tested in 1997.

The only cultivar new to the ARPT in 1997 was the long-grain Cocodrie, which was released from Louisiana in 1997. It was evaluated with the very-short-season ARPT entries and had susceptibility to rice stink bugs similar to that of ‘Alan’ and ‘Millie’.

Five advanced lines in the 1997 ARPT have been chosen for larger plot testing in 1998. RU9601087, a long-grain line in the very-short-season group, was moderately susceptible to rice stink bug damage. RU9601096 and RU9601099 are selections from several Mars and Koshihikari crosses. Both were in the very-short-season group and were very susceptible to rice stink bug damage. RU9601053 and RU9701151 were in the short-season maturity group, and both lines were more susceptible to rice stink bug damage than LaGrue and 'Kaybonnet' in 1997.

Kernel Smut

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 methods of sample preparation removes that type of infected kernels but often detects kernels that have been only partially consumed by a kernel smut infection. The incidence of partially consumed kernels in samples from the 1997 ARPT was less than that of 1996 (Table 2) but susceptible cultivars such as 'Cypress', LaGrue, M202, Alan and 'Newbonnet' had more kernel smut than the others. RU9601053 and RU9601087 were moderately susceptible to kernel smut. The short grains RU9601096 and RU9601099 showed only a trace of kernel smut.

Other Discolored Kernels

Our method of evaluation of rice also detects kernels discolored by something other than rice stink bugs, kernel smut or linear damage. These kernels are placed in a category called "other damage." The discoloration is most often confined 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 oryzae* Breda de Haan) on the hull. Other discolorations appear to be common to a variety or caused by an interaction between variety and weather conditions. The amount of kernels in this category varies from year to year even within an entry (Table 3). However, certain entries appear to be more susceptible than others. For example, the medium-grain cultivar M202 had a higher level of bran discoloration in 1996 and 1997. The short grains RU9601096 and RU9601099 also had moderate levels of bran discolorations in 1997.

Linear Discolorations

This type of discoloration was described by Douglas and Tullis in 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 weak at the cut and frequently break during milling procedures. The discoloration is not limited to the bran, and milling does not eliminate the discoloration. Between 1988 and 1994 only one cultivar, 'Mercury', had levels of linear damage that were much higher than other entries (data not shown). 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. It is suspected that high temperatures such as those of 1995 during grain fill or maturation cause more linear damage in the susceptible types. Results of 1997 ARPT evaluations show that conditions were not very favorable for linear damage (Table 3), but M202 and the two short-grain lines (RU9601096 and RU9601099) that have Koshihikari as one parent had moderate levels of linear damage.

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 advanced lines 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 it has more advantages than other available cultivars. Prior knowledge of the susceptibility of any new cultivars to rice stink bug damage and other kernel discolorations could be used by Arkansas farmers to make informed decisions on the choice of cultivars to plant.

In addition to Cocodrie, two other long grain cultivars were released in 1997. Madison and Priscilla were released by Texas and Mississippi, respectively. Evaluation of samples from the URRN indicates that both had a susceptibility to damage by rice stink bugs similar to that of Cypress (Table 4). Susceptibility to kernel smut in the new releases was as follows: Priscilla was slightly less susceptible than Cypress, Cocodrie was slightly more susceptible than Alan, and Madison was about as susceptible as Kaybonnet. None of the new cultivars was susceptible to linear damage but Priscilla.

SIGNIFICANCE OF FINDINGS

Evaluations of cultivars and advanced rice lines provides rice breeders with information on susceptibility to rice stink bug damage and other causes of discolored kernels. Breeders can then use the information in the selection of lines for further tests and eliminate lines that are clearly more susceptible to damage than presently grown types. Rice growers can use the information to choose cultivars and use management practices that will reduce quality reductions due to discolored kernels. For example, most medium-grain and a few long-grain rice cultivars are susceptible to rice stink bug damage and other types of kernel discolorations. Careful scouting and use of insecticides for rice stink bug, when necessary, would prevent excessive discounts due to discolored kernels.

Often a cultivar is released from another state without extensive information on how susceptible it 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, possibly, before a line is released. Valuable information is made available to Arkansas rice growers to use when making cultivar choices.

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Table 1. Average percentage, by weight, of kernels discolored by rice stink bugs in brown rice samples of entries in the Arkansas Rice Performance Trials (ARPT).

Maturity Group and Cultivar / Line	Grain Type	Kernels discolored by stink bugs					
		1992	1993	1994	1995	1996	1997
		%					
Mid-Season							
Cypress	L	0.44	1.30	0.59	0.99	1.62	0.53
Newbonnet	L	0.44	1.50	0.64	1.02	1.40	0.67
Lemont	L	0.30	1.14	0.43	0.74	1.40	0.70
Katy	L	0.21	0.98	0.41	0.51	0.85	0.36
Drew	L	0.27	0.82	0.48	0.67	1.26	0.55
Short-Season							
Bengal	M	1.24	2.36	1.42	1.69	2.18	1.09
Kaybonnet	L	0.31	0.92	0.28	0.48	0.93	0.39
LaGrue	L	0.3	0.78	0.31	0.51	0.71	0.42
RU9601053	L	-	-	-	-	0.60	0.88
RU9701151	L	-	-	-	-	-	0.89
Very-Short-Season							
Millie	L	0.36	1.15	0.54	0.35	1.26	0.64
Adair	L	0.50	0.70	0.67	0.39	1.33	-
Alan	L	0.56	1.65	0.84	0.66	1.49	0.72
Jefferson	L	-	-	-	-	0.87	0.47
M202	M	-	-	-	-	2.41	1.44
Cocodrie	L	-	-	-	-	-	0.76
RU9601096	S	-	-	-	-	1.40	1.02
RU9601099	S	-	-	-	-	1.32	1.16
RU9601087	L	-	-	-	-	1.03	0.69

Table 2. Average percentage, by weight, of kernels discolored by kernel smut in brown rice samples of entries in the Arkansas Rice Performance Trials (ARPT).

Maturity Group and Cultivar / Line	Grain Type	Kernels discolored by kernel smut					
		1992	1993	1994	1995	1996	1997
		%					
Mid-Season							
Cypress	L	0.023	0.075	0	0.006	0.202	0.066
Newbonnet	L	0.031	0.123	0	0.008	0.132	0.037
Lemont	L	0.013	0.035	0.006	0.003	0.053	0.073
Katy	L	0.009	0.007	0.030	0.002	0.038	0.004
Drew	L	0.010	0.025	0.042	0.005	0.058	0.015
Short-Season							
Bengal	M	0.006	0.016	0	0.002	0.033	0.010
Kaybonnet	L	0.006	0.021	0	0.001	0.056	0.008
LaGrue	L	0.035	0.09	0	0.011	0.471	0.063
RU9601053	L	-	-	-	-	0.072	0.021
RU9701151	L	-	-	-	-	-	0.018
Very-Short-Season							
Millie	L	0.013	0.081	0.136	0.005	0.351	0.016
Adair	L	0.011	0.062	0.078	0.001	0.074	-
Alan	L	0.010	0.034	0.171	0.006	0.316	0.029
Jefferson	L	-	-	-	-	0.254	0.016
M202	M	-	-	-	-	0.397	0.068
Cocodrie	L	-	-	-	-	-	0.014
RU9601096	S	-	-	-	-	0.003	0.001
RU9601099	S	-	-	-	-	0.004	0.001
RU9601087	L	-	-	-	-	0.056	0.017

Table 3. Average percentage, 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 and	Grain	Other discolored kernels				Linear Damage	
Cultivar / Line	Type	1994	1995	1996	1997	1996	1997
		%					
Mid-Season							
Cypress	L	0.55	0.83	2.00	0.44	0.007	0.002
Newbonnet	L	0.52	0.80	1.36	0.26	0.085	0.011
Lemont	L	0.75	0.68	1.66	0.43	0.008	0
Katy	L	0.28	0.41	1.07	0.16	0.019	0.002
Drew	L	0.17	0.27	0.69	0.17	0.014	0.005
Short-Season							
Bengal	M	0.95	1.43	2.49	0.48	0.119	0.076
Kaybonnet	L	0.15	0.29	0.64	0.16	0.018	0.013
LaGrue	L	0.23	0.41	0.83	0.44	0.016	0.012
RU9601053	L	-	-	0.60	0.25	0.016	0.010
RU9701151	L	-	-	-	0.44	-	0.040
Very-Short-Season							
Millie	L	0.54	0.47	1.11	0.35	0.075	0.011
Adair	L	0.64	0.73	2.08	-	0.047	-
Alan	L	0.64	0.73	2.08	0.51	0.047	0.027
Jefferson	L	-	-	1.42	0.43	0.061	0.007
M202	M	-	-	6.69	1.56	0.261	0.141
Cocodrie	L	-	-	-	0.42	-	0.014
RU9601096	S	-	-	1.39	0.72	0.694	0.266
RU9601099	S	-	-	1.88	0.71	0.360	0.271
RU9601087	L	-	-	0.45	0.27	0.030	0.011

Table 4. Average percentage, by weight, of discolored kernels in brown rice samples of new cultivars / lines in the Uniform Regional Rice Nursery (URRN) grown in Arkansas.

		Cause of Kernel Discoloration											
		Rice Stink Bug			Kernel Smut			Other Discolored			Linear Damage		
Cultivar (state released)	Grain Type	1995	1996	1997	1995	1996	1997	1995	1996	1997	1995	1996	1997
		%											
Cocodrie (LA)	L	0.97	0.88	1.07	0.01	0.32	0.31	1.99	1.28	0.35	0.01	0.01	0
Alan (AR)	L	0.76	1.19	1.01	0.01	0.13	0.21	0.38	2.08	0.32	0.02	0.01	0
Jefferson (TX)	L	0.51	0.86	0.50	0.02	0.16	0.18	1.04	0.84	0.46	0.01	0.02	0
Jackson (MS)	L	0.63	1.10	0.76	0.02	0.22	0.55	0.45	1.51	0.39	0.01	0.06	0
RU9601096	S	-	-	0.80	-	-	0.01	-	-	0.36	-	-	0.16
RU9601099	S	-	-	1.04	-	-	0.004	-	-	0.36	-	-	0.05
RU9601053	L	-	1.46	1.64	-	0.12	0.67	-	0.49	0.32	-	0.01	0
Priscilla (MS)	L	0.66	1.26	1.25	0.04	0.32	0.67	0.86	0.61	0.80	0.04	0.01	0
Madison (TX)	L	0.78	1.35	1.12	0.01	0.07	0.07	0.43	0.7	0.42	0.02	0.01	0
Kaybonnet (AR)	L	1.68	1.06	1.03	0.01	0.08	0.07	0.30	0.31	0.40	0.04	0.03	0
Lemont (TX)	L	1.16	1.33	1.28	0.03	0.06	0.14	0.81	0.65	1.10	0.02	0	0
Cypress (LA)	L	1.15	1.35	1.33	0.03	0.91	0.77	0.70	1.23	0.90	0.04	0.01	0
Drew (AR)	L	1.53	0.91	1.31	0.04	0.16	0.19	0.55	0.24	0.32	0.31	0.02	0

ONGOING PROJECT
PEST MANAGEMENT: INSECTS

HIGH-RESOLUTION MACHINE VISION FOR NON-DESTRUCTIVE INTERNAL INSPECTION OF INSECT-DAMAGED RICE GRAINS

Y. Tao, A. Cardarelli, J. Bernhardt, F. Lee and T. Siebenmorgen

ABSTRACT

Rice kernels damaged by rice stink bugs and diseases such as smut lead to underdeveloped, discolored rice kernels, which significantly affect quality and market value. An automated inspection system was developed to detect and separate damaged from undamaged kernels as well as provide size distributions. The system uses a charge-couple device (CCD) camera combined with a back-lighting method to allow light beams to penetrate through each kernel for internal damage inspection. The kernel length and width will automatically be measured, and the kernel will be inspected from both sides. This system will provide scientists and breeders a new means of quantifying processes that are currently evaluated by hand and therefore lack consistency and objectivity. The data provided by this system will help accelerate variety development of rice and may be adapted to other grains as well.

INTRODUCTION

Rice kernels damaged by rice stink bugs and diseases such as smut lead to poor-quality rice. Damaged rice kernels are often under-developed and have undesirable discoloration, which significantly affects quality and market value. Although insecticide or fungicide applications can reduce the amount of certain pests, proper timing is essential, and it is only a short-term solution. For a long-term solution, scientists and breeders have been working for several years to develop resistant cultivars. Resistant cultivars offer a practical and economical means of pest control. These cultivars will be beneficial to producers by enhancing crop quality and lowering production costs and to the environment by reducing chemical use.

In order to develop a resistant type, it is necessary to identify resistance at various breeding stages. Early identification of resistant breeding lines will enhance the selection process and accelerate variety development. Accurate evaluation processes will ensure that only resistant rice lines are selected while eliminating any susceptible types.

Technological advances in many areas present greater opportunities than before. Scientific research today needs advanced scientific tools. In rice research, however, most current evaluation processes are still done by hand. These methods, using human observation, are not only less accurate, but also are subjective and vary from person to person. Plus, human errors are involved. The evaluation based on “good/bad/maybe” non-quantitative involved. The evaluation based on “good/bad/maybe” non-quantitative human judgment makes accurate quantitative data seem out of reach.

Technology of machine vision provides a great potential for accurate high-resolution inspection and evaluation of rice grain for damage. By using camera and image analysis, the system can provide high-resolution inspection and produce consistent objective results. The dot pixels in a digital image can provide analysis in great detail to discriminate kernel differences. This will allow scientists to have quantitative data for accurate scientific analysis that has not been available before. With quantitative data including degree of damage, size, ratio, distribution, discoloration shades and many other parameters, scientists can obtain more comprehensive information from the data, which may introduce important new findings. It not only gives more reliable analysis, but it is also a step forward in the technological development for the rice research programs. Therefore, the objectives of the study were (1) to develop a high-resolution machine vision system for accurate inspection of diseased and insect-damaged rice kernels and (2) to provide a sensitive scientific tool for the rice breeding program. In this paper, the first stage results on the imaging detection of internal damage will be presented.

PROCEDURES

A high-resolution vision system for identifying and analyzing internal damage in rough rice grains caused by stink bugs and disease was set up as shown in Fig. 1. The digital imaging system consisted of a CCD camera, a digital imaging processing system in a PC, a transparent filter plate for holding samples and a lighting system for back-light illumination. The rice samples were placed on the plates, the signal from the CCD camera was generated, converted into digital form and stored in memory for digital image processing and analysis.

The system was specially configured using back-lighting techniques to capture rough rice images. The back-lighting approach enabled imaging of internal kernel details with light beams penetrating through the kernels. This differentiates from the available systems using front lighting for surface blemish inspections of grains such as wheat and corn. To eliminate background noise caused by grain particles or dust, a thin film filter was used to filter out the noise, as seen in Fig. 2.

For data extraction, a Windows-like menu-driven software program was also developed using our existing proprietary software code for extracting the damaged areas with clicks of mouse-buttons. Algorithms, based on kernel light penetration intensities, were developed to identify damaged spots in rice. For internally damaged grains, the low-intensity segments were extracted using gray-level thresholding. Sizes and intensities were calculated based on the total number of pixels of the damaged area. The size of each pixel was obtained by camera calibrations using a known-sized object in the image for ensured accuracy.

RESULTS AND DISCUSSION

Through test and analyses of rice samples from the Rice Research and Extension Center (RREC), Stuttgart, Arkansas, the system was able to detect and measure internally damaged grains from highly accurate images and distinguish them from the healthy grains without destruction. The vision system has shown the capability of identifying the internal damage caused by insects and disease and the severity of the damage with a high-resolution of 0.0017 mm^2/pixel. An example image captured by the vision system is given in Fig. 3.

Fig. 4 shows the typical results for each sample in the image from the automated inspection, including size of damage, ratio of damaged area in a kernel, severity of damage and characteristic distribution of the damage in kernels. With back-lighting imaging, it was found that the vision unit yielded superior inspection quality when compared to humans. The system offered more clarity, detail and, most importantly, quantitative results with much higher speed (0.01 second of processing time per plate).

The intensity distribution of each kernel was also obtained through its histogram in RGB image frames as shown in Fig. 5. The distribution and skewsness of the histogram indicates the level and amount of the damage. Currently, the information has not been processed but can be used for later characteristic analyses.

SIGNIFICANCE OF FINDINGS

The quantitative data obtained by using non-destructive digital imaging analysis eliminates the “good/bad/maybe” form of human evaluation process and provides accurate results for rice sink bug and smut damage analysis. The machine vision technique provides not only rapid sample analysis with time and labor savings, but also the quantitative information about the damage for further analysis. Rice image database can also be easily established and stored for future research and data retrieval. It will be a step forward in technology for entomology and pathology research and the genetic and breeding programs.

ACKNOWLEDGMENT

Authors wish to thank Arkansas Rice Research and Promotion Board for the funding support of the research project.

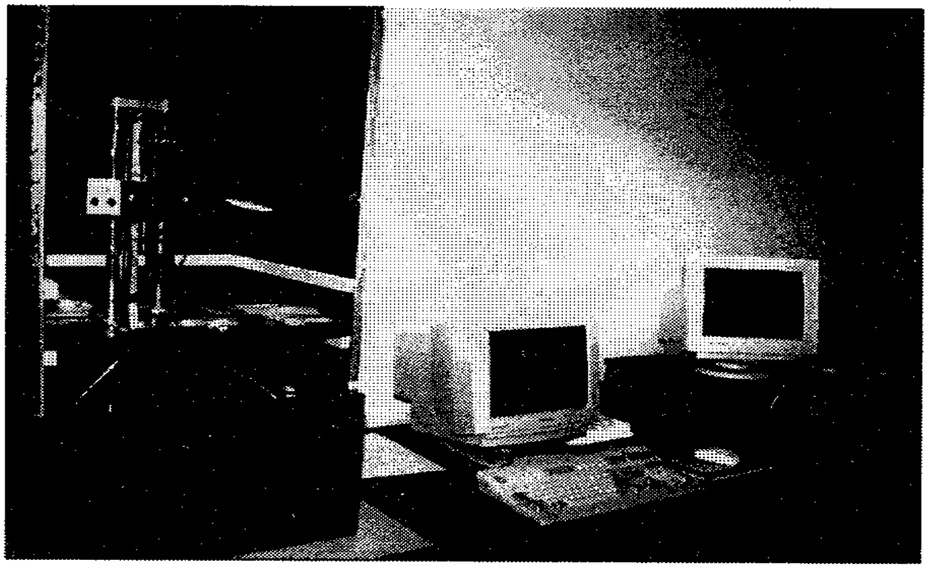


Fig. 1. The vision system for evaluating internally bug and disease-damaged rough rice grains. (Equipment was provided by the Bioimaging Lab of the Biological & Agricultural Engineering Department at the University of Arkansas.)

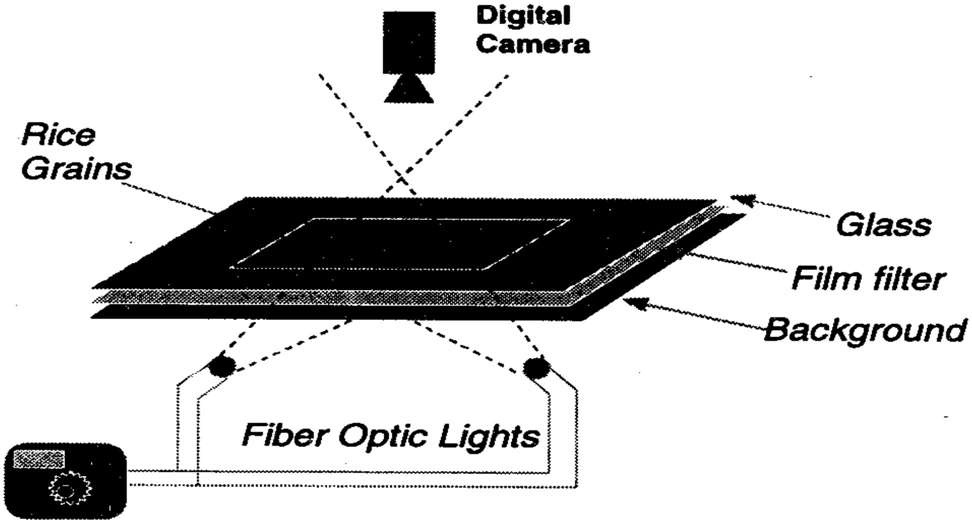
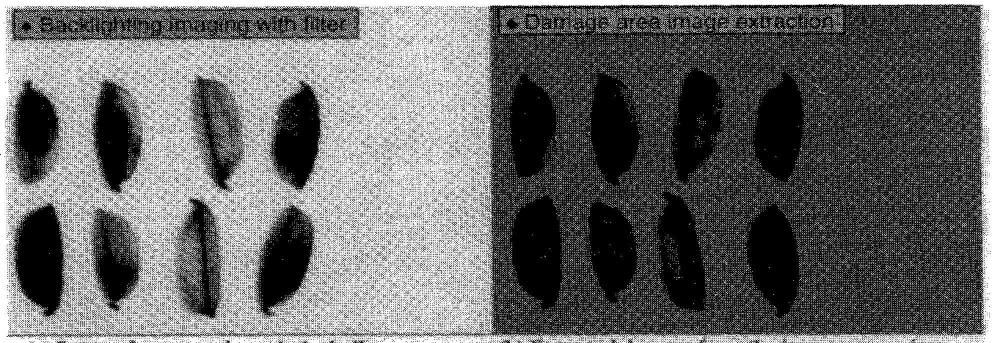
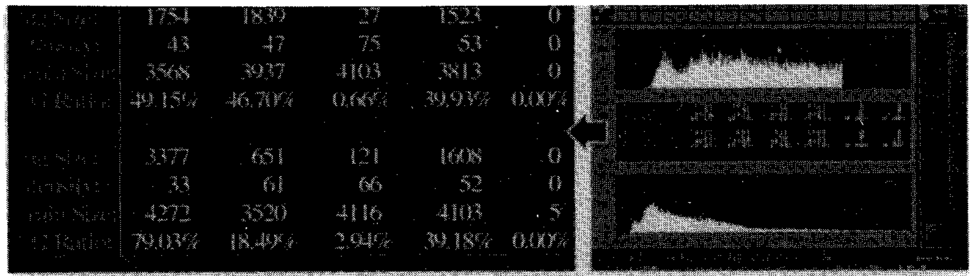


Fig. 2. The special back-lighting and filter setups for non-destructive internal imaging.



(a) **Internal** textures through the hulls. (b) Extracted damage from the image processing.

Fig. 3. The images captured showing the internal grain damage.



[illegible]	1754	1839	27	1523	0
[illegible]	43	47	75	53	0
[illegible]	3568	3937	4103	3813	0
[illegible]	49.15%	46.70%	0.66%	39.93%	0.00%
[illegible]	3377	651	121	1608	0
[illegible]	33	61	66	52	0
[illegible]	4272	3520	4116	4103	5
[illegible]	79.03%	18.49%	2.94%	39.18%	0.00%

(a) The sample results of the grains in Fig.3. (b) A sample screen of the software.

Fig. 4. The digital imaging analysis of internally damaged rough rice.

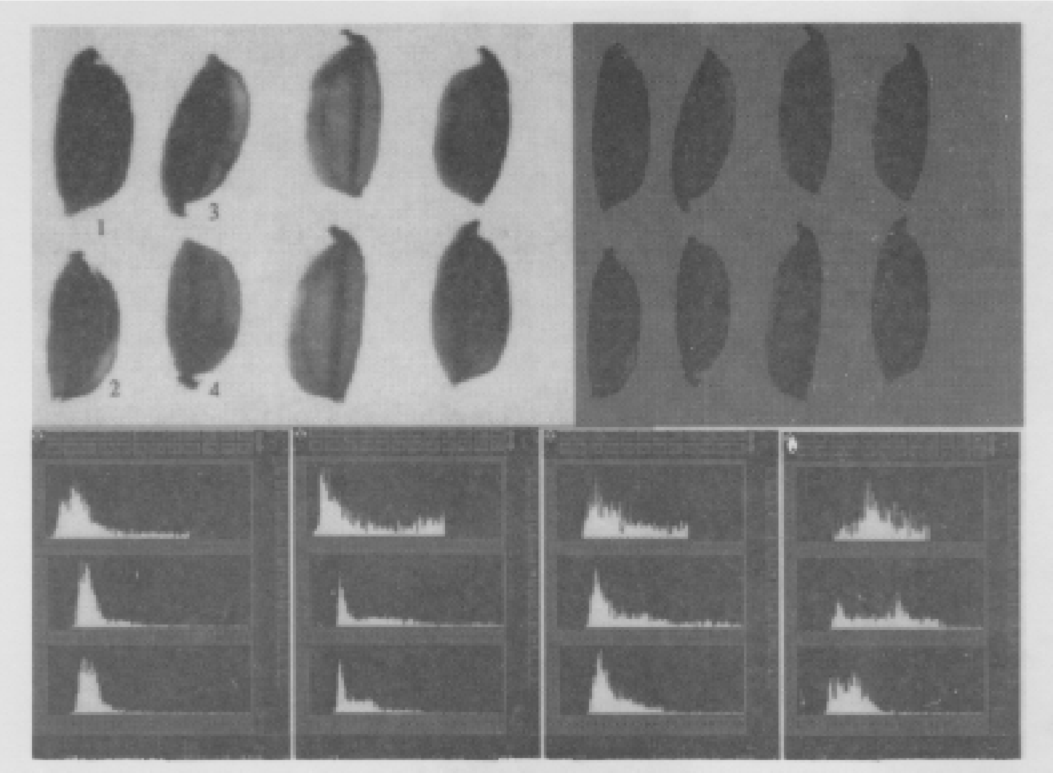


Fig. 5. The intensity distributions of rice kernels. The information can be used for further characteristic analyses of damaged kernels.

ONGOING PROJECT
PEST MANAGEMENT: DISEASE

RICE DISEASE MONITORING AND ON-FARM RICE CULTIVAR EVALUATION IN ARKANSAS

R.D. Cartwright, C.E. Parsons, W.J. Ross, F.N. Lee and G.E. Templeton

ABSTRACT

The Arkansas rice disease monitoring project was continued in 1997 to determine the identity, distribution and severity of rice diseases in the state and to evaluate new and previously released cultivars under on-farm conditions. Monitoring plots consisted of 19 rice cultivars/lines planted in four replications at 11 locations. Sheath blight again was the most widespread and severe disease statewide, especially on the highly susceptible and widely grown cultivar 'Cypress'. Blast was less severe in the state but did damage a few isolated 'LaGrue' fields. Stem rot was again observed in potassium-deficient 'Bengal' fields but on a limited basis. Kernel smut was very severe during 1997 on Cypress and LaGrue, probably encouraged by rainy weather during heading and overuse of nitrogen fertilizer. False smut of rice was observed for the first time in Arkansas, primarily in northeastern counties.

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 have also been reported (Webster and Gunnell, 1992). In addition, there remain several diseases of yet unknown cause that have been recently noted.

In Arkansas, many fungal diseases and straighthead are common, and this project continues to define them and their relative severity (Cartwright et al., 1994; Cartwright et al., 1995).

Monitoring of plant diseases is critical to better understand the spectrum of disease problems on a particular crop and their potential for change over time. Monitoring must be yearly, long-term and consistent to be of maximum value. Monitoring information guides research and suggests potential disease control options. Monitoring also serves as the first line of defense in the ongoing battle with rice diseases and can provide early warning of new 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 19 rice cultivars/lines with varying susceptibility to rice diseases was seeded in grower fields in Clay, Craighead, Cross, Lafayette, Lawrence, Lonoke, Poinsett, Randolph, White and Woodruff Counties in Arkansas and on the Pine Tree Station at Colt, Arkansas. Grower fields were selected by cooperating extension agents based on disease history, cultural practices and previous observations. Cultivars were seeded in 7-row x 25-ft plots 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 entry. Plots were harvested and yields adjusted to 12% moisture.

RESULTS AND DISCUSSION

Only one location (Lafayette) was lost and not harvested during 1997, due to uncontrollable soil factors. Of the 10 remaining sites, yields varied considerably among locations with certain cultivars being more stable than others. We have previously defined this stability in yield as “risk” and use the coefficient of variation (C.V.) for 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 1997 from a low of 27 bu/acre at Pine Tree where it showed severe blast damage to 175 bu/acre at the Lawrence County location where blast disease was minimal (Table 1). This instability resulted in a “risk” value of 45, the highest of all cultivars tested. In contrast, ‘Drew’ had a “risk” value of only 12, with yields varying from 120 bu/acre in Cross County to 181 bu/acre at the Lawrence County site. Low yields at the Cross County location were due to difficulties in stand establishment and harsh soil conditions (salt, low K). This on-farm yield performance supplements the Arkansas Rice Performance Trial data, where conditions are not as harsh as the disease monitoring sites tend to be. Reliable yield across environments is a more vital characteristic for a cultivar since rice farmers have very little margin for error in today’s economic climate. Data from this and the breeding program should continue to provide a very reliable way of selecting an appropriate rice cultivar for almost any farm. Table 2 lists the combined and summarized yield and risk information from 1994-1997.

Numerous diseases were observed in the monitoring plots, depending on location and cultivar (Table 3). Lodging was noted as well. Of the major diseases, sheath blight was most severe at the Clay and Poinsett County locations. Sheath blight incidence and severity were highest on semidwarf cultivars and lower on other types (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 50 to 70% of tiller height on semidwarf cultivars such as Cypress and 30 to 50% on others (Table 3).

Neck blast was noted primarily at the Randolph County location. M202, LaGrue and 'Newbonnet' were most heavily damaged with 'Katy', 'Kaybonnet', Drew and others suffering little to no damage at this site. Neck blast was again noted on 'Jefferson', the new cultivar from Texas that is highly resistant to certain (but not all) races of blast. We continue to recommend that Arkansas growers treat Jefferson as susceptible to blast under our conditions until we have more experience growing it in the state. Early seeding, optimum nitrogen fertilization and maintaining a 4-in.-deep flood all help reduce blast severity on susceptible cultivars.

Kernel smut was observed at most sites in 1997. It was most severe on Newbonnet, LaGrue, Cypress, 'Jodon', 'Litton' and 'Lafitte' while Kaybonnet and Drew had noticeable levels of smutted panicles as well (Table 3). Smut was at lower levels on 'Lacassine', 'Lemont', Katy and RU9601053 (Table 3).

False smut of rice, caused by the fungus *Ustilaginoidea virens*, was observed on Drew, Kaybonnet, Litton, Lemont and Cypress fields in Craighead, Cross, Jackson and Lawrence Counties. Spore balls forming on rice panicles were olive to dark brown and up to 0.5 in. in diameter. Mills and seed dealers were advised to clean the spore balls from contaminated grain lots and destroy them. Only 17 total fields were found with the disease, and incidence ranged from < 1 to 6%. Weather and plant stress that delayed panicle maturity were thought to have contributed to disease severity. Since this disease is endemic at low levels in other states, it is doubtful that it will become a significant problem here.

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) for the disease resistance research program (Table 4), 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/lines 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.

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Table 1. Rice disease monitoring plot yields for 1997 - sorted by cultivar/variety (yield in bu/acre 12% moisture).

Cultivar/Variety	Location										Mean Yield by Cultivar	CV[†]
	Clay	Craighead	Cross	Lawrence	Lonoke	Pine Tree	Poinsett	Randolph	White	Woodruff		
AB647	179	170	114	163	169	146	130	161	111	135	148	16
Bengal	154	161	113	190	186	165	157	185	152	158	162	14
Cypress	136	146	110	157	162	135	114	136	128	135	136	12
Drew	159	159	120	181	177	148	135	153	135	156	152	12
Jefferson	135	130	79	144	143	129	139	136	118	134	129	15
Jodon	147	138	89	169	171	139	123	148	134	153	141	17
Katy	139	120	112	145	157	137	123	117	123	144	132	11
Kaybonnet	144	135	123	175	161	135	144	135	129	148	143	11
Koshihikari	141	119	86	163	152	137	117	137	139	139	133	16
Lacassine	149	122	86	182	169	134	137	136	143	153	141	18
Lafitte	156	132	111	181	179	157	146	163	139	146	151	14
LaGrue	156	157	110	190	187	151	165	154	142	165	158	14
Lemont	150	136	104	170	162	133	133	123	120	146	138	14
Litton	142	129	121	164	162	138	141	138	130	140	140	10
M202	161	53	134	175	146	27	131	58	102	158	114	45
M204	157	135	145	168	173	80	142	147	122	169	144	19
Newbonnet	137	147	110	157	178	111	124	119	125	145	135	16
Priscilla	150	146	114	182	165	139	148	156	117	135	145	14
RU9601053	155	152	122	182	176	139	153	151	127	151	151	12
Mean Yield by Location	150	137	110	171	167	132	138	141	129	148		

[†] 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 rice disease monitoring plots.

	Sorted by mean yield (high to low)						Sorted by mean CV (low to high)†				
	Yield				Mean Yield		CV				Mean CV
Cultivar/Variety	1994	1995	1996	1997	1994-1997	Cultivar/Variety	1994	1995	1996	1997	1994-1997
Bengal	181	164	171	162	170	Drew	11	10	5	12	10
LaGrue	167	146	181	158	163	Kaybonnet	13	12	5	11	10
Lafitte			172	151	162	Litton				10	10
Drew	165	144	172	152	158	Lafitte			7	14	11
Kaybonnet	165	138	165	143	153	RU9601053				12	12
RU9601053				151	151	Katy	16	15	8	11	13
AB647				148	148	Cypress	26	9	8	12	14
Jodon	157	132	156	141	147	LaGrue	19	11	10	14	14
Priscilla				145	145	Priscilla				14	14
Lacassine	160	112	165	141	145	Jefferson				15	15
M204				144	144	AB647				16	16
Litton				140	140	Koshi-hikari				16	16
Lemont	147	126	149	138	140	Lacassine	20	18	9	18	16
Cypress	140	127	155	136	140	Bengal	24	16	12	14	17
Katy	149	128	150	132	140	Jodon	19	10	22	17	17
Newbonnet	141	118	162	135	139	Lemont	24	20	13	14	18
Jefferson			142	129	136	M204				19	19
Koshihikari				133	133	Newbonnet	28	34	12	16	23
M202			149	114	132	M202				45	45
Mean	157	134	161	142							

† CV = coefficient of variation for yield across locations. A higher CV indicates less stable yield across environments.

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

Cultivar/ Variety	SHBI †				SHB-HT				NB				KS			
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997
ABb647				100				22				0				60
Bengal	54	71	35	100	50	50	40	42	1	44	18	4	10	12	4	80
Cypress	46	100	64	100	60	70	60	57	6	10	2	0	38	100	68	100
Drew	48	78	28	100	30	50	40	43		0	0	0	33	41	34	50
Jefferson			54	100			50	59			12	6			40	50
Jodon	44	100	78	100	70	70	60	63	9	50	20	12	41	100	50	70
Katy	47	100	37	100	40	60	40	48		0	0	0	8	4	12	40
Kaybonnet	33	100	41	100	50	60	50	45	1	1?	0	0	24	32	30	60
Koshihikari				100				36				0				60
Lacassine	47	100	50	100	60	70	60	60	3	55	24	10	6	8	4	30
Lafitte			60	100			40	44			0	0			24	100
LaGrue	37	100	55	100	40	60	40	48	4	35	36	18	67	83	72	100
Lemont	43	100	52	100	60	70	60	59	1	70	16	2	7	10	6	24
Litton				100				36				0				100
Mars	33	67	34		30	40	30		9	35	8		15	24	6	
M202			42	100			40	43			100	52			36	100
Newbonnet	42	87	33	100	30	55	30	41	10	100	40	22	64	51	38	100
Priscilla				100				46				4				40
RU9601053				100				38				1				32

continued

Table 3. Continued.

Cultivar/ Variety	SR-DI				BS				BSHR			
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997
ABb647				1.4				40				10
Bengal	1.5	2.5	1.6	2.0	45	20	16	100	40	2	4	6
Cypress	2.1	2.2	1.6	1.4	2	6	6	44	35	26	8	18
Drew	2.4	1.9	1.6	1.4	16	39	100	100	22	11	2	4
Jefferson			1.2	1.4			6	20			8	2
Jodon	1.6	2.4	2.2	1.8	14	10	8	28	50	40	6	6
Katy	1.4	2.3	1.1	1.6	36	50	60	100	40	20	2	4
Kaybonnet	1.9	2.5	1.4	1.8	55	100	100	100	60	30	2	4
Koshihikari				1.4				16				2
Lacassine	1.4	1.8	1.6	1.8	27	60	22	80	100	14	2	6
Lafitte			1.6	1.6			80	100			6	8
LaGrue	2.1	2.3	2.4	1.6	6	14	16	40	20	24	2	4
Lemont	1.5	1.8	1.2	1.8	3	30	14	100	55	68	6	12
Litton				1.4				60				6
Mars	1.5	1.5	1.4	1.4	28	60	20		24	30	2	
M202			1.4	1.6			12	100			2	2
Newbonnet	1.8	2.4	1.8	1.8	13	30	40	100	4	6	4	2
Priscilla				1.6				60				16
RU9601053				1.4				100				4

continued

Table 3. Continued.

Cultivar/ Variety	FSHR				NBLS				SCAB			
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997
ABb647				0				0				8
Bengal	2	24	2	2		0	0	0	26	6	20	10
Cypress		10	0	0		2	0	0	6	2	12	4
Drew		1	0	0		100	100	100	33		2	0
Jefferson			0	0			2	0			2	0
Jodon		4	0	0	100	36	12	6	28	16	10	4
Katy		6	0	0	82	100	100	100	2	12	6	4
Kaybonnet		1	0	0	95	100	100	100	2	1	2	0
Koshihikari				0				0				0
Lacassine		2	0	0		2	4	2	2	2	2	4
Lafitte			0	0			20	8			12	4
LaGrue		4	2	0	47	20	10	4	19	2	6	2
Lemont		2	0	0	40	12	8	4	2	2	2	0
Litton				0				0				0
Mars	1	1	0			0	2		31	1	8	6
M202			6	2			2	2			26	14
Newbonnet		2	0	0	84	100	100	100	17	2	2	0
Priscilla				0				4				2
RU9601053				0								0

continued

Table 3. Continued.

Cultivar/ Variety	LS				SCLD				LODG			
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997
ABb647				0				0				2
Bengal	9	1	2	2	4		0	0			6	0
Cypress	46	24	40	32	8	2	0	0			16	2
Drew	42	83	46	10		1	0	0	5	5	12	2
Jefferson			6	10			0	0			0	0
Jodon	48	36	36	8		8	0	0			10	2
Katy	34	50	24	4		4	0	0	10	80	100	10
Kaybonnet	51	40	20	16	22	8	0	0	13	100	100	10
Koshihikari				4				0				00
Lacassine	26	18	20	24	60	4	0	0			2	0
Lafitte			12	8			0	0			50	20
LaGrue	25	24	12	4		8	0	0	10	4	20	0
Lemont	25	48	24	8			0	0			0	0
Litton				8				0	25	60		0
Mars	40	20	20				0				100	
M202			12	4			0	0	13	12	20	40
Newbonnet	36	12	32	4		2	0	0			24	5
Priscilla				2				0				0
RU9601053				2				0				0

[†] Notes: SHBI = average sheath blight incidence (% infected tillers); SHB-HT = severity of sheath blight as ratio of disease symptom height/infected tiller height (e.g. 50 = symptoms up 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).

Table 4. Disease reactions for U.S. rice cultivars/lines that have been included in the monitoring/on-farm evaluation program (1994-1997).

Cultivar	Sheath Blight	Blast	Stem Rot	Kernel Smut	Brown Spot	Straighthead
AB647	MS[†]	R	MS	S	R	VS
Adair	MS	S	S	S	R	MS
Alan	MS	S	MS	S	R	MS
Bengal	MS	MS	VS	MS	VS	VS
Cypress	VS	MR	MS	VS	R	MR
Dellmont	VS	MR	MS	R	R	MR
Dellrose	VS	MR	MS		MS	MR
Dixiebelle	VS	MR			R	MS
Drew	MS	R	MS	MS	S	MR
Gulfmont	VS	S	MS	R	R	MR
Jackson	MS	S	S	S	R	MR
Jefferson	S	S	MS	MS	R	MR
Jodon	VS	S	S	MS	R	VS
Katy	MS	R	MS	R	R	S
Kaybonnet	MS	R	MS	MS	S	MS
Koshihikari	MS	MR	S	R	MR	--
L-204	S	VS	MS	S	MS	S
Lacassine	VS	S	MS	R	S	MS
Lafitte	MS	MR	MS	S	MS	VS
LaGrue	S	S	MS	VS	R	MS
Lemont	VS	MR	MS	R	R	MR
Litton	S	MS	MS	S	R	MS
M-202	MS	VS	MS	VS	S	S
M-204	MS	VS	MS	VS	S	S
Mars	MS	MS	MS	R	S	VS
Maybelle	VS	S	S	S	R	MR
Millie	MS	MS	MS	MR	R	S
Newbonnet	MS	VS	S	VS	R	MR
Orion	MS	MR	VS	R	R	VS
Priscilla	S	S	MS	MS	R	
RT-7015	VS	VS	MS	S	R	MR
RU9601053	MS	S	MS	R	R	

[†] MS = moderately susceptible; VS = very susceptible; S = susceptible; R = resistant; MR = moderately resistant; VR = very resistant.

ROLE OF INFESTED SEED IN THE EPIDEMIOLOGY AND CONTROL OF RICE BLAST DISEASE

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ABSTRACT

Rice blast, caused by *Pyricularia grisea*, is one of the major fungal diseases of rice in Arkansas. Recent research has shown that the disease is present each year and can reach epidemic proportions on susceptible cultivars. This study was conducted to determine and quantify the incidence of seed infection by the fungus on seed collected from various sources in Arkansas. Rice blast sporulation on rice seeds and seedlings was detected by using a filter paper technique. Results show that the incidence of *P. grisea* on rice seed collected from 15 field sources ranged from 0 to 3.5% and from 0 to 1% on rice seedlings. This research, though preliminary, suggests that the rice blast fungus is present on some seed produced in Arkansas.

INTRODUCTION

Rice grain grown in Arkansas is used as seed for replanting or for human consumption. Rice blast is one of the most serious rice diseases in Arkansas on many of the high-yielding cultivars. Losses due to blast are significant due to its high epidemic potential, especially when grown under conditions of low night temperatures and high humidity where rice is grown in dry soil (Anonymous, 1994).

Reducing the amount of disease early in the season may be an important and necessary step in reducing the severity of the disease but requires identifying and quantifying the sources of inoculum. A substantial connection appears to be the case between early onset of disease at harvest, despite a mid-season period in which plants appear to be disease-free (TeBeest et al., 1994). The important question is: what are the important inoculum sources that initiate disease after seedling emergence? The overwintering sources of inoculum are infected plant debris, alternate hosts or rice seed (Chung and Lee, 1983). Rice seed infected by *P. grisea* can be a source of primary inoculum for seedlings grown from infected seed (Chung and Lee, 1983; Lamey, 1970); however, none of these studies quantitatively related seed infection to subsequent disease levels in the field.

Inoculum thresholds are fundamental to disease management, but they are difficult to establish and have been established only for a few seedborne pathogens (Kuan, 1988; Lee, 1994). The objectives of this research are to quantify the extent to which rice seed grown in Arkansas is infected with *Pyricularia grisea* and to investigate the quantitative relationship of seed infection to the seedling disease.

MATERIALS AND METHODS

To assess the level of seed infection, 33 samples from several sources in Arkansas were collected, and 15 lots have been examined to date. Seed lots were tested in a randomized order in a blind assay.

Blast Detection on Rice Seed

Two samples of 200 seeds from each lot were incubated for 4 days on moistened filter paper in petri dishes at 24°C with a 12-hour l:d photoperiod. Each seed was examined microscopically for visible growth of the rice blast fungus (Agarwal et al., 1989), and percentage of seed infection was calculated (Table 1). Final percentage of infection was determined as an average of two replicates.

Seedling Blast Development From Rice Seed

Two hundred seeds from each lot were rolled onto the surface of autoclaved field soil and grown in a 28°C greenhouse. After 10 days, 100 seedlings were harvested from a random mark and divided into seedlings with visible lesions, seedlings without lesions, non-germinated seeds and dead seedlings. Samples were incubated on moistened filter paper in Petri dishes at 24°C with a 12-hour l:d photoperiod. After 4 and 10 days, each seedling and seed was examined microscopically for visible growth of the rice blast fungus. The percentage of rice blast was calculated for each seed lot (Table 2).

RESULTS AND DISCUSSION

The fungus causing rice blast has been detected on seeds and seedlings after incubation among the 15 seed lots tested. The fungus was found in low incidence in the seed assays and at a lower incidence on the seedlings. The percentage of rice seed infected with rice blast (Table 1) ranged from 0 to 3.5%, that is similar to a previous report which found the range of infection from 1 to 4% (Anonymous, 1994). Out of the rice cultivars tested for seed infection, ‘LaGrue’ and ‘Bengal’ were consistently infected with rice blast.

The percentage of rice seedlings infected with blast (Table 2) ranged from 0 to 1%. The seed lot with the 3.5% (highest) seed infection is the one that had the 1% seedling infection. No seedling infection was found on the other 14 lots.

SIGNIFICANCE OF FINDINGS

Seed has been and continues to be an important mechanism for transmitting plant pathogens. Accurate estimates of pathogen levels in seed sources are essential to establishing inoculum thresholds, which are critical to effective management of seedborne pathogens (Kuan, 1988). The inoculum thresholds for rice blast have not been established.

This study will, upon completion, quantify rice blast infection of rice seed produced in Arkansas. It will document development of blast from infected seed to the seedling and will evaluate whether seed are an overwintering source of inoculum. However, further research is required to determine the extent to which seed is a significant source of primary inoculum. It is necessary to further investigate disease development from seeds to seedlings, test additional seed sources and verify whether laboratory results can estimate a useable inoculum threshold in the field.

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Table 1. Percentage of rice seed infected by rice blast fungus.

		Average of seeds infected†	
Lot	Cultivar	Number	Percent
A	Alan	0.50	0.25%
B	Bengal	0.00	0.00%
C	Cypress	0.00	0.00%
D	Drew	0.00	0.00%
E	Kaybonnet	0.00	0.00%
F	LaGrue	1.50	0.75%
G	RU 9401188	0.00	0.00%
H	Alan	0.00	0.00%
I	Bengal	1.50	0.75%
J	LaGrue	1.00	0.50%
K	Kaybonnet	0.00	0.00%
L	LaGrue	7.00	3.50%
M	Bengal	2.00	1.00%
N	LaGrue	1.00	0.25%
O	LaGrue	1.00	0.25%

† Two samples of 200 seeds from each of the 15 seed lots were examined after incubation for 4 days at 24°C under 12-hour light/dark photoperiod.

Table 2. Percentage of rice seedlings infected by rice blast fungus.

		Seedlings infected[†]	
Lot	Cultivar	Number	Percent
A	Alan	0	0.00%
B	Bengal	0	0.00%
C	Cypress	0	0.00%
D	Drew	0	0.00%
E	Kaybonnet	0	0.00%
F	LaGrue	0	0.00%
G	RU 9401188	0	0.00%
H	Alan	0	0.00%
I	Bengal	0	0.00%
J	LaGrue	0	0.00%
K	Kaybonnet	0	0.00%
L	LaGrue	1	1.00%
M	Bengal	0	0.00%
N	LaGrue	0	0.00%
O	LaGrue	0	0.00%

[†] One hundred seedlings from each of the 15 seed lots were examined after incubation for 4 days at 24°C under 12-hour light/dark photoperiod.

ONGOING PROJECT
RICE CULTURE

THE EVALUATION OF RICE HULL ASH AS A SILICON SOIL AMENDMENT TO REDUCE RICE DISEASES

Fleet N. Lee, Richard J. Norman and Lawrence E. Datnoff

ABSTRACT

Rice requires large amounts of plant-available silicon (Si) from the soil. Silicon soil amendments have reduced disease severity in rice growing on several soils deficient in Si. Rice hull ash, a locally available rice processing by-product known to contain large amounts of Si, was evaluated as a preplant incorporated (PPI) soil amendment to reduce rice diseases. In 1996, rice plant Si content was increased from 2.30 % in untreated plots to 4.68 % in plots treated with 8.9 tons/acre rice hull ash containing 61% Si. However, rice blast severity was not reduced in the 1996 test where an extremely high blast disease pressure caused an almost total crop loss in the 'Lacassine' cultivar. In 1997, rice hull ash having 91% Si applied at the rates of 4.5, 8.9 and 17.8 tons/acre increased rough rice yields, but rice blast was reduced only at the 17.8-ton rate with an accompanying 50% or greater reduction in rotten neck and panicle blast in the 'LaGrue' cultivar under a moderately low, limited blast disease pressure. It is unclear if the yield increase and blast control resulted from Si in the rice hull ash or from low levels of plant nutrients present in the ash. In summary, rice hull ash appears to be limited as a means of reducing rice diseases in Arkansas.

INTRODUCTION

Rice plants require large amounts of Si for healthy growth and development. Silicon absorption depends on the amount of plant-available Si in the soil solution. Substantial rough rice yield increases have been reported following Si applications in some rice production areas (Savant et al., 1997). For example, Si is considered an agronomically essential element in Japan where it is routinely added to easily leached rice field soils. In other rice production areas, such as Arkansas, rice is grown on mineral soils that normally provide enough available Si for the rice plant to grow and achieve its maximum yield potential. In previous Arkansas tests, minimal response to calcium silicate slag soil amendments supports the general conclusion additional Si is unnecessary for rice in our soils.

There is a need for additional research on the use of Si as a means to reduce rice diseases in Arkansas, however. In field trials conducted on Si-deficient organic Histosols of Florida, calcium silicate slag applications increased Si content in plant tissue from approximately 1.5% to as much as 5.6% and higher with a resulting reduction in rice blast incidence from 30 to 17% and brown spot incidence from 32 to 15% in the 'Lemont' cultivar (Datnoff et al., 1991). Significant disease control was also realized in subsequent rice plantings. These results are being confirmed by reports of enhanced rice disease control for several diseases following applications of calcium silicate slag to various soil types, including the Crowley soils of Louisiana. Recent research indicates there is a need to better understand the role Si plays in blast “field” resistance and in flood depth-induced blast resistance in the plant. In addition, Arkansas growers have changed to very high-yielding rice cultivars that may respond to an increased plant-available Si with a reduction in disease severity.

Field tests were established to determine if rice disease control could be enhanced in Arkansas through Si soil amendments. Rice hull ash was selected as the Si source because it is available locally and because previous research reports (Kumbhar et al., 1995) indicated applications of 4.5 tons/acre reduced seedling blast by 50% or greater in seed beds. Our test results are reported here.

PROCEDURES

In 1996, rice hull ash (RHA) containing 61% amorphous Si was applied PPI at rates of 0, 4.5 and 8.9 tons/acre in replicated 7-ft by 20-ft plots. Plots located at the Pine Tree Experiment Station (PTES), Colt, Arkansas, were seeded in 7-in. rows with Lacassine rice on 19 June. Plots on the Rice Research and Extension Center (RREC), Stuttgart, Arkansas, were seeded 13 June. The total number of leaf lesions per plant were recorded for four plants each from three sampling sites in the plot at the late boot growth stage in the PTES test. On 3 October, visual blast severity ratings were made at these sampling sites using the standard scale of 0 = no blast and 9 = very severe blast. Plant tissue was collected for a Si content assay. The PTES plots were harvested 11 October. The RREC plots were sampled for the Si assay only and were not harvested.

In 1997, a single test was conducted at PTES where rice hull ash containing 93% amorphous Si was applied PPI at rates of 0, 4.5, 8.9 and 17.8 tons/acre. Plot size was increased to 20 ft x 20 ft. The test was drill seeded in 7-in. rows of LaGrue rice on June 9. On 1 October, the flag leaf and panicle of three to four representative plants were removed from each of six predetermined sample sites in the center of each plot, wrapped in aluminum foil and placed in a freezer until the number of the flag leaf lesions, infected flag leaf collars, neck lesions and panicle lesions per plant were recorded. The distance from the soil surface to the flag leaf tip was measured to estimate plant height. Tissue samples were collected for a Si assay and are currently being processed for analysis. Plots were harvested 15 October.

During both years, plots were grown using standard fertility and production practices with the exception that flood water application was infrequently delayed until the soil surface became exposed during tillering and early booting growth stages to promote rice blast. Plots were inoculated twice during tillering with a 5×10^5 suspension of conidia harvested from *M. grisea* growing on rice polish agar. No fungicides were applied to the plots. All plots were harvested using a plot combine and grain adjusted to 12% moisture for yield comparisons.

In addition to the 61% amorphous Si, the rice hull ash used in 1996 also contained other nutrients including calcium (Ca; 0.160%), iron (Fe; 0.018%), phosphorus (P; 0.170%) and potassium (K; 0.370%). The rice hull ash used in

1997 contained 93% amorphous Si, Ca (0.252%), Fe (0.029%), P (0.148%) and K (0.789%). Thus, approximately 33,108 lb Si, 40.6 lb Ca, 10.2 lb Fe, 52.8 lb P and 281 lb K per acre were applied in the 17.8 tons RHA/acre in 1997.

RESULTS AND DISCUSSION

During 1996, much like the catastrophic situation sometimes observed in susceptible cultivars in grower fields, very severe rice blast developed in the PTES plots with many leaves having three to four large lesions throughout the growing season. At maturity, plants had few filled rice grain because of 100% neck and panicle blast. Blast pressure, although substantial in some plots, was not uniformly distributed throughout the RREC test. Plant tissue Si content increased in RHA-amended plots at both locations (Table 1). Although plant tissue Si content increased from 2.3% in untreated plots to 4.68% with 8.9 tons/acre, rice blast severity was essentially unaffected by the RHA treatments in the PTES test. Plots treated with the 8.9 tons/acre of RHA had only slightly fewer leaf lesions during the growing season, and all amended plots had a slightly better visual appearance at maturity. Relatively small rough rice yield differences were not statistically significant and showed no relation to RHA treatments.

In the 1997 test, rice blast disease pressure was characterized as being light to very moderate and may not have noticeably reduced rough rice yields. All RHA soil amendments impacted plant height and rough rice yield (Table 2), but only the 17.8- ton rate affected blast incidence with a 50% or greater reduction in the number of neck, panicle and total infections per plant. Rough rice yield increased with RHA amendment up through 8.9 tons/acre, but not beyond. The blast disease control resulting from 17.8 tons/acre did not translate into additional yield over that of 8.9 tons.

The data collected to date are unclear as to the value of using Si soil amendments as a means to reduce diseases in Arkansas rice production. In our tests, RHA soil amendments increased tissue Si content to near the suggested 5% level but apparently did not result in decreased disease incidence. However, RHA treatments did increase yield in the 1997 test, but it could not be determined if these increases resulted from application of Si or from the significant quantities of plant nutrients such as K and P that may have been abnormally low in the native soil of the test area. Rice hull ash appears not to be an efficient source of Si and might be compared with wood ash, which contains substanital quanities of Si but limited amounts of Si are immediately available to the rice plant (Snyder and Ulloa, 1998).

Future plans are to continue this line of research. The 1997 test area will be planted to rice again in 1998 to monitor carryover Si levels from breakdown of the amorphous Si in the rice hull ash. Calcium silicate slag will be utilized, and other variables such as rice cultivar and soil type will be considered.

SIGNIFICANCE OF ACCOMPLISHMENTS

It is standard practice to seed blast disease nurseries late in the growing season to insure maximum disease pressure for testing experimental breeding lines and to avoid initiating early blast epidemics that could inadvertently spread into grower fields. Thus, the data presented here are not necessarily applicable to commercial rice production fields but do form the base of information from which to plan future investigations into the use of soil Si amendments for reducing the severity of rice diseases in Arkansas.

Many Arkansas rice growers are aware of the Si research data from rice research programs in other states, and some have expressed interest in immediately adapting those practices as a means to limit rice diseases. To do so without scientific test data about Si absorption from their soil types and cultivars could prove to be an unnecessary production expense. Our results confirm Si absorption and utilization by the rice plant is a poorly understood process with source being one of many variables in a complex interaction between cultivar and other available plant nutrients in a specific soil type and the nature of the diseases involved.

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Table 1. Mean silicon (Si) content, total leaf lesions per plant and rough rice yield from inoculated 1996 plots with different rates of preplant incorporated rice hull ash containing 61% amorphous Si.

	Si content		Rice blast at PTES		
Rice hull ash	RREC[†]	PTES[‡]	Lesions per plant	Rating	Rough rice yield
tons/acre	----------- % -----------			0-9	lb/acre
0.0	2.58	23.0	11.3 a[§]	9.0 a	675 a
4.5	3.55	4.02	12.0 a	8.5 b	825 a
8.9	3.78	4.68	8.8 a	8.6 b	498 a

[†] RREC = Rice Research and Extension Center, Stuttgart, Arkansas; cultivar 'LaGrue'.

[‡] PTES = Pine Tree Experiment Station, Colt, Arkansas; cultivar 'Lacassine'.

[§] Means followed by the same letter do not significantly differ (P=0.05, Duncan's MRT).

Table 2. Mean of blast symptoms per plant, plant height and rough rice yield of 'LaGrue' from inoculated plots with different rates of preplant incorporated rice hull ash containing 93% amorphous SI at Pine Tree Experiment Station, Colt, Arkansas, in 1997.

	Mean no. of blast symptoms per plant						
Rice hull ash	Flag leaf	Collar	Neck	Panicle	Total	Plant height	Rough rice yield
tons/acre						in.	lb/acre
0.0	0.31 a[†]	0.25 a	0.25 a	1.78 a	2.60 a	34.1 a	4352.4 a
4.5	0.19 a	0.21 a	0.23 a	1.87 a	2.50 a	34.9 ab	5076.5 b
8.9	0.30 a	0.25 a	0.24 a	1.97 a	2.80 a	36.1 b	5183.6b
17.8	0.11 a	0.13 a	0.06 b	0.57 b	0.84 b	36.3 b	5145.1 b

[†] Means followed by the same letter do not significantly differ (P=0.05, Duncan's MRT).

1997 RICE RESEARCH VERIFICATION TRIALS

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

ABSTRACT

Ten rice fields in 10 Arkansas Counties were enrolled in the 1997 Rice Research Verification Trials (RRVT). The counties participating in the 1997 RRVT were Arkansas, Crittenden, Desha, Jackson, Jefferson, Lincoln, Prairie, St. Francis, White and Woodruff. Yield data from Jefferson County will not be available. The 10 production fields totaled 647 acres with an average of 65 acres/field. Yield, reported at 12% moisture, averaged 141.3 bu/acre with a range of 116 to 168 bu/acre. Three rice cultivars (‘Bengal’, ‘Cypress’ and ‘Kaybonnet’) were grown. Six fields were established with a conventional till and drill system, one with a conventional till and airflow system, one with a conventional till water-seeded system, one with a stale seedbed drill system and one with a no-till water-seeded system. Returns were calculated using a $4.46/bu selling price, a 25% crop share rent and specified operating and ownership costs associated with production. Net returns of the nine fields averaged $129.87/acre with a range of $46.72 to $204.97/acre.

INTRODUCTION

The RRVT were initiated in 1983 and to date have had 147 commercial rice fields enrolled in the program. The RRVT is 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 data base for rice production, assist in technology transfer and provide training to county 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 the 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 researcher as needed.

Ten RRVT fields were established during 1997 on a total of 647 acres. Counties participating in the 1997 RRVT included Arkansas, Crittenden, Desha, Jackson, Jefferson, Lincoln, Prairie, St. Francis, White and Woodruff.

The cultivars seeded included Kaybonnet, Bengal and Cypress, and these three cultivars accounted for 81% of the 1997 Arkansas rice acreage. Six fields were established with a conventional till and drill system, one with a conventional till and airflow system, one with a conventional till water-seeded system, one with a stale seedbed drill system and one with a no-till water-seeded system. The county acreage, soil series, previous crop, grain and milling 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 the management of the 1997 RRVT (Table 3). All fields received herbicide applications with most programs utilizing a residual compound. One field received a fungicide application, and one field received an insecticide treatment.

RESULTS AND DISCUSSION

Grain yield in the 1997 RRVT averaged 141 bu/acre with a range of 116 to 168 bu/acre (Table 1). This yield was 15 bu/acre higher than the reported state average yield of 125.6 bu/acre. The Prairie County field of Kaybonnet produced the lowest yield at 116 bu/acre. This was a large field with a high number of levees. Levee construction was conducted conditions that were wetter than ideal with further deterioration from heavy rains early in the season. The end result was that water management was extremely difficult and, therefore, less than ideal.

The Lincoln County field of cypress produced the highest yield in the 1997 RRVT at 168 bu/acre. This field was the earliest seeded field in the program. The cool spring made weed control difficult with some spots of broadleaf signal grass not controlled. Quinclorac (Facet®) could not be used in this field due to tomato production in the area. Additionally, the field needed to be treated for yellow nutsedge, but bensulfuron (Londax®) was unavailable at the time.

The Arkansas County field of Bengal also produced very good yields at 165 bu/acre. Weed control was accomplished with only one herbicide application. The blast fungus was found in this field about 2 weeks after midseason. The field was subsequently treated, but some rotten neck blast was found late in the season.

The St. Francis County field of Bengal was a large field of 152 acres that produced 156 bu/acre. In this field barnyardgrass was a problem. Quinclorac could not be used because wheat was to be planted in the fall. The barnyardgrass was not controlled until after flooding. To maximize water management in this field, the top 80 acres was fertilized at the preflood stage and flooded. Four days later the rest of the field received fertilizer and the subsequent flood. This field showed numerous sick plants at 10 to 14 days after flooding. This field had an average pH of 6.7 to 6.9 with no known zinc deficiencies. About 10 acres of the field appeared to be affected by high pH with about 3 to 5 acres severely affected. Soil samples in the severely affected area pulled after harvest showed a pH of 7.6 compared to 7.0 in a healthy area.

The Desha County field of Kaybonnet was established using a no-till water-seeded system. The field produced a very good yield in this system (148 bu/acre) with minimum inputs. This field was flooded over the winter, and the seed was broadcast into the winter flood. The field was drained and dried for peg-down.

The field was sprayed and fertilized with a ground rig. Nitrogen fertilizer was applied with the intention of utilizing a single application. However, the time required to flood was longer than anticipated, and an additional application was necessary according to the plant area board test at midseason.

The Jackson County field of Kaybonnet was produced using a more conventional water-seeded approach, which resulted in 138 bu/acre. This field was not allowed to dry at peg-down for red rice control; subsequently, larva of the rice water weevil met economic thresholds. The field was treated with carbofuran (Furadan®), an insecticide. Only two applications of nitrogen were used in this field.

The Crittenden County field of Cypress was seeded with an airflow truck and produced 130 bu/acre. This field had high levels of kernel smut in about half of the field. In this field yield potential appeared to have been lowered by wet conditions at the preflood nitrogen application. However, high amounts of nitrogen were placed on this field because of the heavy clay soil and poor stand in places.

The Woodruff County field of Kaybonnet was the last field seeded and produced 128 bu/acre. This field was heavily infested with sprangletop, which went uncontrolled early. The sprangletop was later controlled with an application of fenoxaprop (Whip®). Additionally, water management in this field was a limiting factor in that the well was only marginal to begin with and eventually had to be replaced. All in all this field produced much better than anticipated.

The White County field of Kaybonnet was drilled into a stale seedbed and produced 123 bu/acre. Red rice in this field was much heavier than anticipated and lowered grain yields considerably. Weed control otherwise was very efficient. This field also appeared to be short of nitrogen after the preflood application.

The Jefferson County field of Cypress was seeded following cotton and had major problems on about 5 acres with norflurazon (Zorial) carryover. The cooperating farmer in this RRVT field harvested the field without informing any Extension personnel. He is no longer associated with this farm, the profession, or the area due to a personal family matter. Therefore, the yield of this field could not be obtained.

ECONOMIC ANALYSIS

The net returns associated with the 1997 RRVT ranged from $46.72 to $204.97/acre with an average of $129.87/acre (Table 4). These returns account for specified operating and ownership costs associated with production and a 25% crop share rent, while assuming a selling price of $4.46/bu. The breakeven price with land cost ranged from $2.61 to $3.95/bu. The selling price is based on a preliminary estimate of 1997 rice prices made by the Arkansas Agricultural Statistics Service as of February 1998. These numbers reflect that different farmers and even different fields require vastly different prices to breakeven.

SIGNIFICANCE OF FINDINGS

1. The 1997 RRVT yielded on average 141 bu/acre. This yield was 15 bu/acre higher than the state average, which indicates that more yield potential is available to Arkansas rice growers with higher levels of management.

2. Recommended disease thresholds utilized in the 1997 RRVT proved to be effective where only 40 acres in the program were sprayed with a fungicide while good yields were maintained.
3. The net returns ($129.87/acre) associated with the 1997 RRVT show that rice can be profitable without government payments as long as prices remain good.
4. The 1997 RRVT demonstrated that there is a tremendous amount of variability when looking at returns in rice. Growers must be aware of where their break-even points are for their specific situations.

Table 1. County, acreage, soil series, previous crop, yield and cultivar of the 1997 Rice Research Verification Trials.

County	Acres	Soil Series	Previous Crop	Yield†		Cultivar
				Grain	Milling	
Arkansas	40	Stuttgart silt loam	Soybean	165	60/70	Bengal
Crittenden	60	Sharkey clay	Soybean	130	59/70	Cypress
Desha	40	Sharkey clay	Soybean	148	59/69	Kaybonnet
Jackson	80	Jackport silty clay loam	Soybean	138	63/70	Kaybonnet
Jefferson	60	McGehee silt loam	Cotton	----	----	Cypress
Lincoln	40	McGehee silt loam	Soybean	168	---	Cypress
Prairie	92	Calhoun and Calloway silt loam	Soybean	116	62/69	Kaybonnet
St. Francis	152	Calloway silt loam	Soybean	156	60/70	Bengal
White	35	Crowley silt loam	Soybean	123	60/70	Kaybonnet
Woodruff	48	Jackport silty clay loam	Fallow	128		Kaybonnet
Average	65	-----	-----	141	-----	-----

† Grain yields are reported at 12% moisture; milling yield = whole kernel/total percentages.

Table 2. Stand density, seeding rate, fertilizer rates and important dates during the 1997 Rice Research Verification Trails.

County	Stand density	Seeding rate	Nitrogen rate urea (45%)	Fertilization $N\text{-}P_2O_5\text{-}K_2O_5$	Seeding date	Emerge date	Harvest date
	plant/ft^2	------------------------lb/acre	---------------------------		--------------------month/day	---------------------	
Arkansas	18	113	200-70-70	153-40-60	5/6	5/15	9/12
Crittenden	12	135	277-100-70	201-0-0	4/22	5/5	9/15
Desha	21	90	300-100	180-0-0	5/3	5/15	9/15
Jackson	17	105	230-70	135-0-0	5/14	5/23	10/3
Jefferson	22	90	200-70-70	156-40-40	4/10	4/26	-
Lincoln	18	90	261-65-65	176-0-0	4/1	4/25	9/9
Prairie	22	103	170-75-70	142-36-72	4/24	5/12	9/12
St. Francis	15	110	225-70-70	164-40-60	5/6	5/17	9/26
White	22	91	165-70-70	137-54-0	5/12	5/23	10/6
Woodruff	20	90	165-100-75	153-0-0	5/14	5/28	10/15

Table 3. Pesticide treatment rate/acre and dates of application on the 1997 Rice Research Verification Fields.

County	Pesticide, Rate/Acre and Date of Application[†]
Arkansas	Propanil (Stam) 4 qt + pendimethalin 2 pt (5/19), benomyl (Benlate®) 1 lb (8/1)
Crittenden	Propanil (Stam) 4 qt (6/4), molinate (Ordram 15G) 27 lb (7/15); 35 acres
Desha	Triclopyr (Grandstand®) 0.67 pt + propanil 4 qt (5/27)
Jackson	Thiobencarb (Bolero®) 4 pt (5/7), bensulfuron 1 oz (6/16), propanil 1 qt + triclopyr 0.67 pt (7/1); 15 acres; carbofuron (Furadan®) 20 lb (7/1), 2,4-D 2 pt on levees (7/17)
Jefferson	Propanil 4 qt + propanil 2 pt ( ), bensulfuron 0.75 ( )
Lincoln	Propanil + molinate (Arrosolo®) 4 qt + pendimethalin 2 pt (4/23), propanil 4 qt (5/17), propanil 1 qt + triclopyr 0.67 pt on levees ( )
Prairie	Quinclorac (Facet®) 0.33 lb (5/14), propanil 4 qt (5/29), 2,4-D 2 pt (7/2)
St. Francis	Propanil 5 qt (5/29), molinate 15G 30 lb (6/19)
White	Glyphosate (Roundup®) 1.5 pt (5/12), propanil + molinate 3 qt + quinclorac 0.25 lb (5/22), propanil + molinate 3 qt + quinclorac 0.17 lb (6/20), 2,4-D 2 pt (7/10)
Woodruff	Propanil + molinate 3 qt (6/16), propanil 4 qt (6/10), fenoxaprop 9 oz (7/14), aciflurofen 0.5 pt (7/22)

[†] Dates of treatments are in (). If only a portion of a field was treated, the acreage is given; otherwise assume that the entire field was treated.

Table 4. Selected economic information for the 1997 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		$/bu		$/acre
Arkansas	300.72	66.53	2.23	2.97	184.06
Crittenden	274.86	59.37	2.57	3.43	100.13
Desha	240.44	49.10	1.96	2.61	204.97
Jackson	277.18	66.22	2.49	3.32	117.69
Lincoln	295.20	62.92	2.13	2.85	202.54
Prairie	264.79	60.31	2.80	3.74	62.49
St. Francis	310.07	59.09	2.37	3.16	152.08
White	301.39	62.86	2.96	3.95	46.72
Woodruff	272.69	56.83	2.57	3.43	98.16
Average	281.93	60.36	2.45	3.27	129.87

[†] 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/bushel required by the farmer to equal total operating and ownership cost.

[¶] Breakeven price/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 $4.46 selling price was assumed. No cost sharing was assumed.

ONGOING PROJECT
RICE CULTURE

DEVELOPMENT OF THE DD50 DATABASE FOR NEW RICE CULTIVARS

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

ABSTRACT

To be effective, the DD50 computer program 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 1997 the study, conducted on a Crowley silt loam at the University of Arkansas Rice Research and Extension Center, Stuttgart, Arkansas, included two seeding methods (drill and water), two seeding dates and three replicates. The drill-seeded study had 10 cultivars/varieties; the water-seeded study contained five of the most commonly grown rice cultivars and an experimental rice variety. Data from this study will be combined with data from previous years to formulate updated threshold values for the 1998 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. 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 seedling 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 rice 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 seeding method (i.e., dry and water) on DD50 accumulations.

MATERIALS AND METHODS

The 1997 study was conducted at the University of Arkansas Rice Research and Extension Center (RREC) on a Crowley silt loam soil. Ten rice cultivars / varieties were seeded in the drill-seeded portion of the study on 14 April and 2 June. The rice was drill-seeded at a rate of 100 lb/acre in nine-row plots (7-in. spacing) 15 ft in length. Six cultivars/varieties were seeded on 16 April and 4 June in the water-seeded study. Rice for water-seeding was soaked in water for 24 hours and allowed to drain for 24 hours prior to being broadcast into a 2- to 4-in. flood at a rate of 120 lb/acre (dry basis). In the water-seeded portion of the study, a nine- row groover (7-in. spacing) was rolled over each plot (15 ft in length) to form grooves in the soil for the soaked seed to fall into when broadcast. 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 3-day intervals beginning 35 days after seeding emergence, date of beginning internode elongation, date of 0.5-in. internode elongation, date of 50% heading and date of physiological maturity. The temperature data were then converted into DD50 accumulations from seedling emergence until the development 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 second seeding date (2 June) of the water-seeded portion of the study was abandoned because of seed movement between plots from high winds shortly after seeding. In general, all of the cultivars/varieties required more DD50 accumulations from emergence to 0.5-in. internode elongation or from emergence to 50% heading when drill-seeded in April compared to June. The cultivar/varieties that required similar or more DD50 accumulations when seeded in June compared to April to reach the designated growth stages were: i) ‘RU9401188’ from emergence to 0.5-in. internode elongation; and ii) ‘Lafitte’, ‘Litton’ and RU9401188 from emergence to 50% heading. Although there are similarities among many of the cultivars/varieties in the DD50 accumulations required to reach the designated growth stages, there is still some diversity in the DD50 accumulations among the cultivars/ varieties studied in 1997.

Five of the named cultivars and the experimental variety RU9401188 were water-seeded in 1997. Water-seeding in April enabled the cultivars to reach the two critical growth stages with fewer DD50 accumulations compared to when they were drill-seeded in April. This has been observed in previous years for the April seeding. However, in the past, most cultivars seeded in May or June have shown a similar number of DD50 accumulations required to reach the two critical growth stages when water-seeded compared to drill-seeded. Thus, only when seeded in April do some of the cultivars need different DD50 thresholds when water-seeded compared to drill-seeded.

SIGNIFICANCE OF FINDINGS

The data from 1997 will be used to refine the DD50 thresholds for ‘Drew’, ‘Kaybonnet’, ‘Jefferson’, Lafitte and Litton, to establish thresholds for ‘AB647’, ‘AS3510’ and some of the experimental varieties and to differentiate thresholds between drill- and water-seeded rice.

ACKNOWLEDGMENTS

This research was supported in part by the Arkansas Rice Research and Promotion Board.

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, 1997.

	Drill-Seeded		Water-Seeded
Cultivar/Varieties	14 April[†]	2 June	16 April
	--DD50--		
Drew	1380	1154	1236
Kaybonnet	1272	1182	1208
Jefferson	1277	1130	1118
Lafitte	1258	1174	1208
Litton	1380	1304	1350
RU9401188	1228	1270	1180
RU9502008	1148	1028	----
RU9601053	1327	1226	----
AB647[‡]	1258	1186	----
AS3510[§]	1028	940	----

[†] Emergence dates.
[‡] Anheuser Busch cultivar 647.
[§] Alexander Seed cultivar 3510.

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, 1997.

	Drill-Seeded		Water-Seeded
Cultivar/Varieties	14 April[†]	2 June	16 April
	--DD50--		
Drew	2184	2036	1926
Kaybonnet	2104	2064	1862
Jefferson	1921	1856	1672
Lafitte	1934	1960	1800
Litton	2216	2235	2118
RU9401188	1966	1960	1832
RU9502008	2063	2004	----
RU9601053	2067	2012	----
AB647[‡]	2392	2225	----
AS3510[§]	1520	1386	----

[†] Emergence dates.
[‡] Anheuser Busch cultivar 647.
[§] Alexander Seed cultivar 3510.

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

R.J. Norman, C.E. Wilson, Jr., N.A. Slaton 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. ‘Jefferson’, ‘Lafitte’ and ‘Litton’ were the new rice cultivars studied in 1997. All three of them responded equally or better in terms of grain yield when the N fertilizer was applied in a single preflood application compared to split applications. In addition, all of the cultivars required more N fertilizer to reach full yield potential on the clay soils compared to the silt loam soils.

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 rice varieties from breeding programs in Arkansas, California, Louisiana, Mississippi and Texas are entered into this study. The Louisiana program has the new semidwarf medium-grain cultivar Lafitte in the study for the second year. The Mississippi and Texas programs have the new long-grain cultivars Litton and Jefferson, respectively, in the study for the first time.

PROCEDURES

Locations where the cultivar x N rate study were conducted and corresponding soil type are as follows: Northeast Research and Extension Center (NEREC), Keiser, Arkansas, Sharkey clay (Vertic Haplaquept); Pine Tree Experiment Station (PTES), Colt, Arkansas, Calloway silt loam (Glossaquic Fragiudalf); Rice Research and Extension Center (RREC), Stuttgart, Arkansas, Crowley silt loam (Typic Albaqualf); 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 the recommended single preflood (SPF) and the two-way split (2WS) application methods. The 2WS application method has most of the N fertilizer applied preflood and one-half or 60 lb N/acre (whichever is less) applied between beginning internode movement and 0.5-in. internode elongation. 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

Jefferson, the new semidwarf, long-grain cultivar from Texas, responded similarly when the N fertilizer was applied SPF compared to a 2WS application on the clay soils at NEREC and SEBES (Tables 1 and 2). However, there was a trend at these two locations towards higher yields when the N fertilizer was applied in a SPF application (Table 1). Jefferson appeared to respond better when the N fertilizer was applied in a SPF application compared to a 2WS application on the silt loam soils at PTES and RREC (Table 3). Jefferson reached numerically highest grain yields at PTES and RREC when 120 lb N/acre was applied in a SPF application and when 150 to 180 lb N/acre was applied in a 2WS application. Grain yields did not seem to actually peak on the clay soils at NEREC and SEBES when up to 180 lb N/acre was applied in a SPF or a 2WS application.

Lafitte, the new semidwarf, medium-grain cultivar from Louisiana, responded similarly when the N fertilizer was applied in a SPF compared to a 2WS application at PTES and SEBES (Tables 4 and 5). Lafitte responded better when the N fertilizer was applied in a SPF application compared to a 2WS application at NEREC and RREC (Table 6). Lafitte grain yields showed no significant increases at PTES when more than 60 lb N/acre was applied and when more than 120 to 150 lb N/acre was applied at SEBES (Table 5). At NEREC, Lafitte had higher grain yields when the N fertilizer was applied in a SPF and showed no significant grain yield increases when more than 150 lb N/acre was applied (Table 6). At RREC, no significant yield increases were found when more than 90 lb N/acre was applied in a SPF and when more than 150 lb N/acre was applied in a 2WS application. These data are quite similar to how Lafitte responded to the N fertilizer in 1996 (Norman et al., 1997).

Litton, the new long-grain type released by Mississippi, responded similarly when the N fertilizer was applied in a SPF application compared to a 2WS application at NEREC, PTES and SEBES (Table 7). Litton showed no significant grain yield increases when more than 150 lb N/acre was applied on the clay soils at NEREC and SEBES and when more than 90 lb N/acre was applied on the silt loam soil at PTES (Table 8). At RREC, Litton responded better when the N fertilizer was applied in a SPF application compared to a 2WS application (Table 9). Litton displayed no significant grain yield increases when more than 120 lb N/acre was applied in a SPF application and when more than 150 lb N/acre was applied in a 2WS application at the RREC.

Rice grown on the clay soils at NEREC and SEBES almost always requires more N fertilizer to reach peak grain yields than when grown on silt loam soils.

This is because the native N released is less on the clay soils compared to the silt loam soils, as indicated by the lower yields when no N fertilizer is applied.

SIGNIFICANCE OF FINDINGS

Jefferson and Lafitte showed no significant grain yield differences when the N fertilizer was applied in split applications compared to a SPF application at two locations and responded better when the N fertilizer was applied in a SPF application at the two other locations. Litton displayed no significant grain yield differences between the two N application methods at three of the four locations. At RREC, Litton had peak grain yields when 120 lb N/acre was applied in a SPF application and when 150 lb N/acre was applied in split applications. All of the cultivars required more N fertilizer to reach full yield potential on the clay soils compared to the silt loam soils.

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Table 1. Influence of nitrogen (N) fertilizer application method and location on grain yields of 'Jefferson' rice in 1997.

	Grain yields	
Application method	NEREC[†]	SEBES
SPF[‡]	5779	3960
2WS	5162	3178
$LSD_{(0.05)}$	ns[§]	ns

[†] NEREC = Northeast Research and Extension Center, Keiser, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.
[‡] SPF = Single preflood; 2WS = Two-way split.
[§] ns = not significant.

Table 2. Influence of nitrogen (N) fertilizer rate and location on grain yields of 'Jefferson' rice in 1997.

Application rate	Grain yields	
	NEREC[†]	SEBES
lb N/acre	----------lb/acre----------	
0	2393	1880
60	4299	2977
90	5634	3032
120	6156	3680
150	6690	4469
180	7654	5151
$LSD_{(0.05)}$	559	1151

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

Table 3. Influenced by nitrogen (N) fertilizer rate, application method and location on grain yields of 'Jefferson' rice in 1997.

Application rate	Grain yields			
	PTES[†]		RREC	
	SPF[‡]	2WS	SPF	2WS
lb N/acre	---------- lb/acre ----------			
0	3908		2039	
60	5973	5312	5725	5274
90	6010	5372	6854	5987
120	6422	5829	7617	6495
150	6012	6466	7404	7143
180	5811	6490	7465	7478
$LSD_{(0.05)}$ within N methods	726		966	
$LSD_{(0.05)}$ between N methods	939		969	

[†] PTES = Pine Tree Experiment Station, Colt, Arkansas; RREC = Rice Research and Extension Center, Stuttgart, Arkansas.

[‡] SPF = Single preflood; 2WS = Two-way split.

Table 4. Influence of nitrogen (N) fertilizer application method and location on grain yields of 'Lafitte' rice in 1997.

Application method	Grain yields	
	PTES[†]	SEBES
	----------lb/acre----------	
SPF[‡]	6089	5496
2WS	5962	4913
$LSD_{(0.05)}$	ns[§]	ns

[†] PTES = Pine Tree Experiment Station, Colt, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.

[‡] SPF = Single preflood; 2WS = Two-way split.

[§] ns = not significant.

Table 5. Influence of nitrogen (N) fertilizer rate and location on grain yields of 'Lafitte' rice in 1997.

Application rate	Grain yields	
	PTES[†]	SEBES
lb N/acre	----lb/acre----	
0	4687	2710
60	6354	4588
90	6474	4790
120	6491	5873
150	6237	6353
180	5998	6565
$LSD_{(0.05)}$	508	771

[†] PTES = Pine Tree Experiment Station, Colt, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.

Table 6. Influence of nitrogen (N) fertilizer rate, application method and location on grain yields of 'Lafitte' rice in 1997.

Application rate	Grain yields			
	NEREC[†]		RREC	
	SPF[‡]	2WS	SPF	2WS
lb N/acre	---- lb/acre ----			
0	2470		1615	
60	5287	4016	7015	4833
90	6248	4583	8073	6269
120	6925	6137	8166	6614
150	7606	6858	8057	8044
180	7775	7036	8211	8528
$LSD_{(0.05)}$ within N methods	563		1023	
$LSD_{(0.05)}$ between N methods	535		1038	

[†] NEREC = Northeast Research and Extension Center, Keiser, Arkansas; RREC = Rice Research and Extension Center, Stuttgart, Arkansas.

[‡] SPF = Single preflood; 2WS = Two-way split.

Table 7. Influence of nitrogen (N) fertilizer application method and location on grain yields of 'Litton' rice in 1997.

Application method	Grain yields		
	NEREC[†]	PTES	SEBES
	----	lb/acre	----
SPF[‡]	4491	5711	4222
2WS	4254	5546	3722
$LSD_{(0.05)}$	ns[§]	ns	ns

[†] NEREC = Northeast Research and Extension Center, Keiser Arkansas; PTES = Pine Tree Experiment Station, Colt, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.

[‡] SPF = Single preflood; 2WS = Two-way split.

[§] ns= not significant.

Table 8. Influence of nitrogen (N) fertilizer rate and location on grain yields of 'Litton' rice in 1997.

	Grain yields		
Application rate	NEREC[†]	PTES	SEBES
lb N/acre	----	lb/acre	----
0	2698	4465	2855
60	3868	4998	3382
90	4632	5951	3984
120	4776	6056	4192
150	5178	6167	4889
180	5086	5136	4979
$LSD_{(0.05)}$	352	863	679

[†] NEREC = Northeast Research and Extension Center; PTES = Pine Tree Experiment Station, Colt, Arkansas; SEBES = Southeast Branch Experiment Station, Rohwer, Arkansas.

Table 9. Influence of nitrogen (N) fertilizer rate and application method on grain yields of 'Litton' rice at the Rice Research and Extension Center, Stuttgart, in 1997.

	Grain yields	
Application rate	SPF[†]	2WS
lb N/acre	lb/acre	
0	1628	
60	5882	4910
90	6228	5543
120	6814	5694
150	5661	6264
180	5861	6023
$LSD_{(0.05)}$	558	

[†]SPF = Single preflood; 2WS = Two-way split.

ONGOING PROJECT

RICE CULTURE

EFFECTS OF LIME, PHOSPHORUS AND ZINC ON RICE AND SOYBEAN IN ROTATION ON A CROWLEY SILT LOAM

S. Ntamatungiro, N.A. Slaton, M. Daniels, C.E. Wilson, Jr., J.R. Robinson, L. Ashlock and T. Windham

ABSTRACT

Growers are reluctant to lime fields that include both soybean (*Glycine max* L.) and rice (*Oryza sativa* L.) in rotation because it may induce nutrient deficiencies in the rice crop. The objectives of the study were: (1) to determine the response to lime by soybean and rice grown in rotation and (2) to measure the effect of phosphorus (P) and zinc (Zn) fertilization, with lime, on yields and nutrient uptake by rice and soybean in rotation. Lime rates (0, 1, 2 and 4 ton/acre), P rates (0 and 40 lb P_2O_5/acre) and Zn rates (0 and 10 lb Zn/acre) were main plot, sub-plot and sub-sub-plot factors, respectively. Cultivars of rice (‘Bengal’, ‘Cypress’, ‘Drew’ and ‘Kaybonnet’) and soybean (‘Delsoy 5500’ and ‘Holladay’) were randomly planted in strips across the main plot. Soil pH increased from 4.7 to 7.1 with 4 ton/acre of lime applied. A significant yield response to lime by both rice and soybean occurred in 1996. A trend for increased soybean yield in 1997 was observed. Dry matter production of soybean in 1997 increased from the 4-ton lime/acre application. Liming decreased P and Zn concentration for rice and soybean. Application of Zn fertilizer increased Zn concentration at both the vegetative and reproductive growth stages for rice and soybean. Liming of acid soils may benefit both rice and soybean. However, care should be taken to ensure uniform application of recommended rates when rice is in the rotation. Data suggest that over liming may result in Zn deficiencies in both crops and possible P deficiencies in rice.

INTRODUCTION

The use of poor-quality subsurface water for irrigation of rice (*Oryza sativa* L.) and soybean (*Glycine max* L.) results in deposition of lime in the upper levees and in the main water flow path. Consequently, a pH gradient is established across most fields. The bottom half of the field may become acidic compared to the top half, which may have an alkaline soil pH.

Soil pH greater than 7.0 may induce nutrient deficiencies in the rice crop, resulting in higher production costs, difficult water management and reduced yields. Soybean grown in rotation with rice produces higher yields on soils having pH greater than 6.0 in Arkansas (Muir and Sabbe, 1991). Farmers are reluctant to lime fields that include a soybean-rice rotation for fear of inducing zinc (Zn) or phosphorus (P) deficiencies in seedling rice. Recent research has demonstrated that rice yield increases from P fertilization are likely on alkaline silt loams but seldom occur on acidic silt loams. Due to years of Zn application to rice, rice yield increases to Zn fertilization are less common than 25 years ago; however, it is not known if soybean will respond to Zn application on alkaline soils.

The objectives of this experiment were to:

1. Determine the growth, nutrient uptake and yield response of both soybean and rice, grown in rotation, to lime, P and Zn applications.
2. Monitor soil pH and soil test values as affected by lime, P and Zn application.

MATERIALS AND METHODS

An experimental site with a low soil pH was selected at the Rice Research and Extension Center, Stuttgart, Arkansas. Four lime (calcium carbonate, 38-40% Ca) rates (0, 1, 2 and 4 ton/acre), two P rates (0 and 40 lb P_2O_5/acre/year as triple super phosphate) and two soil-applied Zn rates (0 and 10 lb Zn/acre/year as CoZinco Zn sulfate) were tested. Lime was applied and mechanically incorporated in the fall of 1995. Field tests were initiated during 1996 to include two rotations including rice (1996), soybean (1997), rice (1998) and soybean (1996), rice (1997), soybean (1998). The tests were conducted during each year with each crop to overcome the year-to-year variation in weather. To prevent P deficiency, 40 lb P_2O_5/acre was applied to all plots in 1995. Plots received 60 lb K_2O/acre of potassium chloride in 1995 and 1996 before seeding. Soil samples taken before planting in 1997 revealed very high soil K levels; thus, K fertilizer was not applied in 1997. Each year P and Zn fertilizers were incorporated before planting.

The experimental design was a split-split-split plot with four replications. The main plots were the four rates of lime. The subplots were the two rates of P. The sub-subplots were the two rates of Zn. The cultivars were randomly superimposed on the fertilizer treatments and planted side by side in strips. Four rice cultivars (Bengal, Cypress, Drew and Kaybonnet) and two soybean cultivars (Delsoy 5500 and Holladay) were used. Row spacing was 7 in. for rice and 32 in. for soybean. Main plots were 108 ft long and 37 ft wide. Subplots were 54 ft long and 37 ft wide. Sub-subplots were 27 ft long and 37 ft wide.

In 1996, rice and soybean were planted on 14 June; in 1997, planting was 7 May for rice and 16 May for soybean. Rice weed control was with a tank mixture of thiobencarb (Bolero®) (2 lb/acre) and quinclorac (Facet®) (0.2 lb/acre) at the rice three-leaf growth stage. Soybean received a preplant application of 1.4 oz/acre of imazaquin (Scepter®) and 1.5 pt/acre of trifluralin (Treflan®). A second application of 10 oz of clethodim (Select®) and 2 pt/acre of bentazon (Basagran®) was required during the vegetative stage of soybean to control tall grass and broadleaf weeds.

Rice and soybean responses to lime, P and Zn were measured from dry matter accumulation and nutrient uptake at different growth stages and grain yield at maturity. Dry matter was determined from above-ground plant material collected from 3 ft of row outside the non-harvest rows at midtillering (MT) and at 50% heading for rice (HDG), and at vegetative (V_8) and reproductive (R_2) growth stages for soybean. Plant material was oven-dried to a constant weight, weighed and ground. A sub-sample of ground plant material was digested with concentrated HNO_3 and 30% H_2O_2 for nutrient analysis. Harvesting was done by cutting the four middle rows for rice and two middle rows of soybean in each sub-subplot. The harvested area was 37.3 ft^2 for rice and 85.3 ft^2 for soybean for each sub-subplot. Grain yield was expressed in bushels per acre at 12% moisture for rice and 13% moisture for soybean.

Data were submitted to an analysis of variance with SAS and means separated at the 5% level of probability with the least significant difference. Data analyzed include grain yield and dry matter production for 1996 and 1997.

RESULTS

Grain Yield

Relatively low yields were obtained in 1996 as a result of late planting. There was a significant yield increase due to lime application for both rice and soybean in 1996 and a trend for yields to increase for soybean in 1997 (Table 1). Significant differences in yield were not observed among the 1-, 2- and 4-ton/acre lime rates. Phosphorus and Zn application did not result in significant yield change for rice or soybean. Kaybonnet produced higher grain yields than Bengal, Cypress and Drew with late planting in 1996 (Table 2). In 1997, Bengal produced higher yields than all other rice cultivars. For soybean, Holladay had significantly higher yields than Delsoy 5500 in both years. In1997, soybean yields increased by 17 to 19 bu/acre for both cultivars.

Dry Matter

No visual growth differences were observed among the lime treatments during the growing season among cultivars or treatments. Dry matter response was relatively higher in 1996 than in 1997 at both growth stages of rice and soybean (Table 1). Faster growth due to warmer temperatures at the later planting dates was likely responsible for higher dry matter production during 1996. Dry matter did not respond to lime application at either growth stage or year for rice or for soybean in 1996. In 1997, a significant increase in soybean dry matter at vegetative and reproductive stages was obtained with 4 ton lime/acre. A trend for increased dry matter occurred with increasing lime rate for the V_8 and R_2 growth stages in 1997.

Phosphorus and Zn application did not result in significant dry matter increases for rice or soybean during any year. Significant differences in dry matter were found among soybean cultivars only in 1996 and among rice cultivars only in 1997 (Table 2). Holladay had significantly higher dry matter than Delsoy 5500 at both growth stages in 1996. Kaybonnet produced the highest dry matter at MT and Cypress the lowest dry matter at HDG.

Soil Tests Levels Before Planting

Previous crop affected soil test results (Table 3). The soil pH at the beginning of this experiment, before lime application, in 1995 was 4.7. In spring 1997, soil pH increased to 5.5, 6.5 and 7.1 with lime rates of 1, 2 and 4 ton/acre, respectively. Soil test P significantly increased for the 2- and 4-ton/acre lime rates within each crop. Soil test P was higher for each lime rate following soybean in rotation. Liming significantly increased soil test levels for Ca and decreased magnesium (Mg), sodium (Na), iron (Fe) and manganese (Mn) soil test levels. Regardless of lime rate, nitrate levels, organic matter content and electrical conductivity were higher after rice.

Nutrient Concentration

Phosphorus concentration in the rice plant decreased with increasing lime rate at MT and HDG (Table 4). However, P concentration in soybean at V_8 and R_2 tended to increase with increasing lime rate. The decreased P availability to rice may be due to formation of Ca phosphates from lime application. Iron phosphates, which are the predominant P pool in acidic soils, are the most important P fraction for flood-irrigated rice. Lime application likely results in an increase in Ca phosphates and a decline in Fe and aluminum phosphates. Increasing lime rate increased tissue Ca concentration but also decreased tissue Zn concentrations for both crops and all growth stages.

Tissue K concentrations of rice at MT were significantly increased from 3.12 to 3.21% from application of 0 and 40 lb P_2O_5/acre, respectively. A significant lime rate x Zn rate interaction suggests that lime rate is the most important factor controlling tissue Zn concentration in this study (Table 5). Application of 4 ton lime/acre without Zn fertilizer decreased Zn concentration below the established critical limit for rice (20 ppm) during vegetative growth. Zinc application increased tissue Zn concentration within each lime rate, but tissue concentration continued to decrease with increasing lime rate. Rice tissue Zn concentration at MT increased from Zn fertilization. However, Zn application decreased P concentration at MT (Table 6). Zinc fertilizer application appears to antagonize P uptake by rice during vegetative growth. Zinc concentrations of soybean at V_8 and R_2 growth stages were increased by application of 10 lb Zn/acre (Table 6). But Zn content for the control plants (with no Zn applied) decreased between V_8 and R_2, while Zn concentration with applied Zn remained constant (63.7 and 65.0 ppm) even with an increase in dry matter production.

Nutrient analysis showed that rice and soybean cultivars differed in nutrient composition for several elements (Table 7). Rice cultivars having the highest Zn concentrations during vegetative growth also tended to have the lowest P concentrations. By HDG, cultivars having the highest Zn concentration also had the highest tissue P. Bengal had the numerically lowest tissue K concentration at MT, but the level was significantly greater than for other cultivars by HDG. Soybean cultivars did not differ in P or K concentrations at V_8. At R_2, they did not differ with respect to P, K, Ca, Mg and Fe concentration. Holladay tended to contain higher concentrations of divalent cations at the V_8 growth stage than did Delsoy 5500.

Increasing lime rate decreased Zn concentration in soybean tissue (Table 8). Soybean Zn concentrations declined sharply beginning with the 2-ton lime/acre treatment, especially when 10 lb Zn/acre was supplied. Soybean dry matter production increased for the 2- and 4-ton/acre lime rates. Lower tissue Zn concentration may be attributed to dilution from increased growth.

SIGNIFICANCE OF FINDINGS

The highest lime rate increased soil pH to 7.1 compared to 5.1 with no lime applied. Most essential plant nutrients are considered at optimum availability at pH values between 6.0 and 7.0. Data from this study suggest that soil pH values between 5.0 and 7.0 are not detrimental to rice yields. However, for soybean, soil pH should be above 6.0 for maximum yield potential. The lack of a yield response from Zn fertilization suggests that deficiencies were not induced by liming despite decreasing Zn concentration with lime application for both crops. The lack of response to P application for both crops indicates that for this soil, P soil test levels in combination with the range of soil pH values represented were adequate to provide sufficient nutrition for high soybean and rice yields. It should be noted that application of lime increased soybean P concentration but decreased rice P concentration, implying that these two crops use different pools of soil P.

LITERATURE CITED

Muir, J.H. and W.E. Sabbe. 1991. Nutrition of soybean on acid soils. Arkansas Soil Fertility Studies 1990. W.E. Sabbe (ed.). Arkansas Agricultural Experiment Station, University of Arkansas, Research Series 411:87-89.

Table 1. Rice and soybean yield and dry matter responses to lime application at the Rice Research and Extension Center, Stuttgart, Arkansas.

	Grain Yield			
	Rice		Soybean	
Lime Rate	1996	1997	1996	1997
ton/acre	bu/acre			
0	107.4	147.6	39.1	54.9
1	120.1	149.8	43.9	57.3
2	118.2	145.5	48.3	58.7
4	115.6	153.7	47.5	59.6
LSD(0.05)	8.3	6.9	5.1	6.2

	Dry Matter Production							
	Rice				Soybean			
	1996		1997		1996		1997	
Lime Rate	MT[†]	HDG[‡]	MT	HDG	V_8[§]	R_2[¶]	V_8	R_2
Ton/acre	lb/acre							
0	2399	14941	2185	11299	1477	3262	812	2096
1	2761	15791	2224	11512	1378	3414	862	2279
2	2566	15224	2112	12230	1394	3322	970	2677
4	2670	14479	2077	11785	1169	3202	1084	2859
LSD(0.05)	726	2377	414	1230	314	823	244	437

[†] MT = Midtillering

[‡] HDG = 50% Heading

[§] V_8 = Vegetative stage 8

[¶] R_2 = Reproductive stage 2

Table 4. Selected economic information for the 1997 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 ----------------------------		------------------- $/bu -------------------		---- $/acre ----
Arkansas	300.72	66.53	2.23	2.97	184.06
Crittenden	274.86	59.37	2.57	3.43	100.13
Desha	240.44	49.10	1.96	2.61	204.97
Jackson	277.18	66.22	2.49	3.32	117.69
Lincoln	295.20	62.92	2.13	2.85	202.54
Prairie	264.79	60.31	2.80	3.74	62.49
St. Francis	310.07	59.09	2.37	3.16	152.08
White	301.39	62.86	2.96	3.95	46.72
Woodruff	272.69	56.83	2.57	3.43	98.16
Average	281.93	60.36	2.45	3.27	129.87

[†] 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/bushel required by the farmer to equal total operating and ownership cost.

[¶] Breakeven price/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 $4.46 selling price was assumed. No cost sharing was assumed.

Table 3. Soil test nutrient levels before planting rice and soybean in 1997 as influenced by lime application on the previous crop in the rotation at the Rice Research and Extension Center, Stuttgart, Arkansas.

Crop & Lime Rate	EC[†]	pH	P	K	Ca	Mg	SO_4-S	Na	Fe	Mn	Zn	Cu	NO_3	OM
ton/acre			lbs /acre											%
After Soybean														
0	58.3	5.1	23.4	347	1551	240	36.4	157	661	295	12.5	1.3	1.5	1.47
1	63.0	5.5	24.4	325	2166	212	29.1	145	587	197	13.1	1.4	3.1	1.61
2	63.0	6.5	40.9	370	3269	187	24.5	136	496	118	10.1	1.7	3.5	1.43
4	75.6	7.1	41.9	319	4271	170	24.2	133	505	112	12.9	2.1	2.9	1.41
After Rice														
0	64.7	5.1	21.0	357	1645	241	40.4	154	735	334	12.7	1.2	5.1	1.67
1	65.8	5.4	21.0	319	2219	217	36.2	149	703	246	13.1	1.4	5.9	1.61
2	68.3	6.4	32.2	372	3145	200	31.4	146	602	136	11.4	1.1	5.8	1.59
4	82.6	7.1	24.6	303	4271	203	30.5	144	556	122	12.3	1.4	5.3	1.55
LSD(0.05)	3.1	0.1	1.7	16	120	10	2.0	7	19	16	2.7	0.1	1.4	0.09

[†] EC = electrical conductivity in μhos/cm [1:2 (soil:water ratio)].

Table 4. Effect of lime application on nutrient concentration of rice in 1996 and soybean in 1997 at the Rice Research and Extension Center, Stuttgart, Arkansas.

Crop	Growth Stage	Lime Rate	Elemental Concentration				
		ton/acre	P	K	Ca	Mg	Zn
			--- % ---				ppm
Rice	MT[†]	0	0.37	3.18	0.24	0.142	33.3
		1	0.32	3.20	0.25	0.138	29.9
		2	0.30	3.19	0.26	0.148	25.3
		4	0.27	3.12	0.28	0.153	24.0
LSD(0.05)			0.03	0.28	0.02	0.012	2.4
Rice	HDG[‡]	0	0.24	1.56	0.21	0.143	28.2
		1	0.23	1.50	0.21	0.142	21.6
		2	0.22	1.51	0.22	0.138	24.9
		4	0.21	1.42	0.23	0.136	22.2
LSD(0.05)			0.01	0.16	0.01	0.01	5.6
Soybean	V_8[§]	0	0.32	2.23	1.15	0.40	83.9
		1	0.32	2.10	1.28	0.39	70.4
		2	0.36	2.44	1.39	0.38	40.7
		4	0.34	1.92	1.53	0.42	31.0
LSD(0.05)			0.03	0.49	0.108	0.05	20.4
Soybean	R_2[¶]	0	0.27	1.65	1.08	0.36	77.0
		1	0.28	1.50	1.16	0.36	70.4
		2	0.29	1.78	1.23	0.35	35.1
		4	0.30	1.55	1.35	0.39	27.4
LSD (0.05)			0.02	0.34	0.13	0.06	21.9

[†] MT = Midtillering.

[‡] HDG = 50% Heading.

[§] V_8 = Vegetative stage 8.

[¶] R_2 = Reproductive stage 2.

Table 5. Interaction of lime and Zn fertilizer rate on Zn concentration at midtillering of rice grown after soybean at the Rice Research and Extension Center, Stuttgart, Arkansas.

Lime Rate	Tissue Zn Concentration	
ton/acre	0 lb Zn/acre	10 lb Zn/acre
	--- ppm ---	
0	30.1	37.5
1	24.4	37.5
2	20.5	30.2
4	17.6	29.4
LSD(0.05)	1.8	

Table 6. Effect of Zn application on nutrient concentration of rice in 1996 and soybean in 1997 at the Rice Research and Extension Center, Stuttgart, Arkansas.

Crop	Growth Stage	Zinc Rate	P	K	Ca	Mg	Zn
			Elemental Concentration				
		lb Zn/acre	%				ppm
Rice	MT[†]	0	0.32	3.21	0.26	0.15	23.1
		10	0.31	3.13	0.26	0.15	33.4
LSD(0.05)			0.005	0.06	NS[#]	NS	1.3
Rice	HDG[‡]	0	0.23	1.51	0.21	0.14	23.2
		10	0.23	1.49	0.22	0.14	25.3
LSD(0.05)			NS	NS	NS	NS	3.7
Soybean	V_8[§]	0	0.34	2.16	1.32	0.39	49.4
		10	0.34	2.18	1.35	0.40	63.7
LSD(0.05)			NS	NS	0.03	0.01	3.6
Soybean	R_2[¶]	0	0.29	1.61	1.21	0.36	39.9
		10	0.29	1.63	1.20	0.36	65.0
LSD(0.05)			NS	NS	NS	NS	6.1

[†] MT = Midtillering.
[‡] HDG = 50% Heading.
[§] V_8 = Vegetative stage 8.
[¶] R_2 = Reproductive stage 2.
[#] NS = Not significant.

Table 7. Effect of cultivar on nutrient concentration of rice in 1996 and soybean in 1997 at the Rice Research and Extension Center, Stuttgart, Arkansas.

Crop & Growth Stage	Cultivar	Elemental Concentration				
		P	K	Ca	Mg	Zn
		%				ppm
Rice - MT[†]	Bengal	0.33	3.08	0.25	0.12	26.0
	Cypress	0.32	3.17	0.24	0.15	26.5
	Drew	0.31	3.22	0.27	0.15	29.9
	Kaybonnet	0.30	3.21	0.28	0.15	29.8
LSD(0.05)		0.01	0.15	0.02	0.01	1.5
Rice - HDG[‡]	Bengal	0.23	1.6	0.22	0.12	28.2
	Cypress	0.22	1.49	0.19	0.14	20.2
	Drew	0.24	1.44	0.22	0.15	30.5
	Kaybonnet	0.22	1.47	0.24	0.15	27.7
LSD(0.05)		0.01	0.07	0.02	0.01	8.0
Soybean - V_8[§]	Delsoy 5500	0.34	2.20	1.31	0.38	52.0
	Holladay	0.34	2.14	1.36	0.41	61.0
LSD(0.05)		NS[#]	NS	0.04	0.02	8.0
Soybean - R_2[¶]	Delsoy 5500	0.28	1.61	1.18	0.36	49.0
	Holladay	0.29	1.63	1.23	0.37	56.0
LSD(0.05)		0.011	NS	0.06	NS	5.0

[†] MT = Midtillering.

[‡] HDG = 50% Heading.

[§] V_8 = Vegetative stage 8.

[¶] R_2 = Reproductive stage 2.

[#] NS = Not significant.

Table 8. Interaction of lime and zinc rate on zinc concentration in soybean plants at vegetative (V_8) and reproductive stages (R_2) in 1997 at the Rice Research and Extension Center, Stuttgart, Arkansas.

	Tissue Zinc Concentration			
	V_8 Growth Stage[†]		R_2 Growth Stage[‡]	
Lime Rate	0 lb Zn	10 lb Zn	0 lb Zn	10 lb Zn
ton/acre	ppm			
0	72.4	95.4	58.7	95.3
1	60.4	80.5	49.4	91.5
2	34.7	45.6	30.1	40.0
4	28.7	33.3	21.5	33.3
LSD(0.05)	5.1		8.6	

[†] V_8 = Vegetative stage 8.

[‡] R_2 = Reproductive stage 2.

PHOSPHORUS AND POTASSIUM UPTAKE CHARACTERISTICS OF FOUR RICE CULTIVARS

H.J. Pulley and C.A. Beyrouty

ABSTRACT

A study was initiated to relate phosphorus (P) and potassium (K) uptake to root surface area (RSA) of four rice cultivars. Rice was grown for 60 days in a growth chamber. Results indicate that K uptake did not differ among cultivars. However, 'Cypress' had the highest P uptake and P uptake per unit RSA, although the cultivars did not differ in total RSA. Thus, RSA is not the only determinative parameter influencing P and K uptake by rice.

INTRODUCTION

Phosphorus and K deficiencies in field-grown rice are becoming more prevalent in Arkansas. However, visual deficiencies do not consistently appear among all cultivars grown on the same fields. This inconsistency in susceptibility to P and K deficiencies suggests that cultivars may differ in the rate or quantity of these elements absorbed at critical times during the growing season. There is a misperception that cultivar differences in nutrient uptake can be ascribed to differences in root length. Earlier studies that we have conducted show that plant root factors other than length may contribute to differences in nutrient absorption. An understanding of nutrient uptake characteristics as influenced by root systems should be useful in selecting cultivars that optimize nutrient uptake efficiency, especially on low-fertility soils. A study was initiated to determine the nutrient uptake characteristics of 'Lemont', Cypress, 'LaGrue' and 'Kaybonnet'.

PROCEDURES

Rice was grown in a growth chamber with a 16-hour day temperature of 30°C and an 8-hour night temperature of 27°C. Seeds of each cultivar 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 (Yoshida et al., 1976). This solution was changed every 4 days, and pH was maintained at 5.0. At first tiller (approximately 10 days after transplanting), the plants were grown in half-strength nutrient solution, which was changed every 2 days. Plants were transferred to full-strength solution at active tillering (20 days after transplanting). When plants were 60 days old, they were harvested, and shoots were separated from roots. Fresh root weights were determined, and root lengths were measured by the line intersect method (Tennant, 1975). Root surface area was calculated as described by Barber (1995). Dried tissue samples were digested and analyzed for P and K by inductively coupled plasma atomic emission spectroscopy.

RESULTS AND DISCUSSION

Table 1 presents RSA and P and K uptake values for each cultivar. Root surface area did not differ among cultivars. This finding was similar to that reported by Teo et al. (1995) in which they observed no differences in RSA of three field grown rice cultivars (Table 2).

No cultivar differences in K uptake per plant were found (Table 1). Though this indicates that the cultivars absorbed the same total quantity of K during the 60-day period of growth, these values do not reveal the rate at which K was absorbed. Other studies we have conducted have shown that cultivars do differ in the rate of K absorption. Thus, some cultivars may absorb K at faster rates at different stages of development. On low-K soils, the rate at which a plant takes up K could greatly influence cultivar susceptibility to K deficiencies.

Cypress had greater total P uptake than the other cultivars. When evaluated on a unit RSA basis, P uptake by Cypress was greater than uptake by LaGrue only. This differential P uptake is similar to findings by Teo et al. (1995). In a field study of the cultivars 'Katy', 'Mars' and Lemont, they found that total P uptake was higher in Lemont than in the other cultivars (Table 2).

Differences in nutrient uptake among cultivars cannot be attributed solely to differences in RSA. It appears that total uptake among cultivars may also be related to the ion absorption characteristic, I_{max}, of the root system, which is the maximum rate of nutrient influx into a root at high solution concentration. Teo et al. (1992) measured the kinetic uptake parameters of Katy, Mars, and Lemont in a growth chamber and found that the highest total P and K uptake corresponded to the largest values of I_{max} .

SIGNIFICANCE OF FINDINGS

The results of this study show that P and K uptake are not solely related to root morphology. Nutrient uptake kinetic studies are currently being conducted to quantify the rates of nutrient absorption by root systems of various cultivars. Knowledge of these uptake kinetics in conjunction with root morphology may prove useful in predicting nutrient uptake capabilities of rice and in developing more efficient fertilization management strategies.

ACKNOWLEDGMENTS

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LITERATURE CITED

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Table 1. Potassium (K) and phosphorus (P) uptake for several rice cultivars grown in nutrient solution.

Cultivar	RSA[†]	K uptake	K Uptake /RSA	P Uptake	P Uptake /RSA
	cm²/pot	g/pot	µg/cm²	g/pot	µg/cm²
LaGrue	15684 a[‡]	3.27 a	209.4 a	0.87 b	55.9 b
Cypress	13750 a	3.44 a	250.1 a	1.09 a	79.0 a
Lemont	12576 a	2.94 a	235.1 a	0.92 b	73.2 ab
Kaybonnet	13025 a	3.08 a	236.5 a	0.93 b	71.4 ab

[†] Root surface area

[‡] Means followed by the same letter are not significant at $p = 0.05$

Table 2. Potassium (K) and phosphorus (P) uptake for several field-grown rice cultivars (data from Teo et al., 1995).

Cultivar	RSA[†]	K	P
	m²/m²	------------mol/m²-----------	
Katy	27.0 a[‡]	0.174 a	0.021 b
Mars	25.6 a	0.177 a	0.022 b
Lemont	27.8 a	0.199 a	0.025 a

[†] Root surface area

[‡] Means followed by the same letter are not significant at $p = 0.05$

ONGOING PROJECT
RICE CULTURE

SIMULTANEOUS MOVEMENT OF WATER, HEAT AND SOLUTES IN AN IRRIGATED RICE FIELD OF EAST-CENTRAL ARKANSAS

F. Renaud, H.D. Scott and D.M. Miller

ABSTRACT

Soil volumetric water content and temperature were monitored on a continuous basis during the entire flooded rice growing season on a Calloway silt loam. Measurements were made at eight depth intervals in the soil profile, probes being placed within horizons and at horizon boundaries. Results from the volumetric water contents indicate that, prior to flooding, horizons below the fragipan are close to saturation. Furthermore, upon flooding, complete saturation of the horizons was achieved only after several weeks, this possibly being due to air entrapment within the profile at flood initiation. Modelling water infiltration in the soil profile is under way. Preliminary results indicate that a modified version of the logistic equation could be used for this purpose.

INTRODUCTION

The Delta and Grand Prairie regions of Arkansas are the largest U.S. rice producing area. Rice is grown under flooded conditions whereby, in most cases, ground water is pumped to the surface and spread over the fields. In some specific areas of the Delta, ground water can have relatively high concentrations of salts, such as chlorides (Baker et al., 1996), which can negatively affect rice growth and yields in the long term (Wilson et al., submitted). Three interacting factors that affect rice productivity are soil salinity, temperature and water availability. The former two are particularly influential during germination and early seedling stages, while soil water is particularly important from mid-vegetation stage onwards (CES, 1996). Water, heat and salt transport within the soil profile are simultaneous phenomena interacting with one another. It is, therefore, important to study them together. The main objective of this research is to monitor the movement of water, heat and chlorides over an entire rice-cropping season and under real farming conditions.

MATERIAL AND METHODS

The study was conducted on Mr. Darryl Schlenker's farm in Cross County, east-central Arkansas. The soil is classified as a Calloway silt loam (fine-silty, mixed thermic Glossaquic Fragiudalfs) formed in alluvium and loess (USDA, 1968). Two regions of the profile have the potential to restrict the movement of water and salts: the plow pan (13- to 15-cm depth) and a fragipan (40- to 60-cm depth). The fragipan induces a temporary perched water table during the winter and spring.

A 2-m-deep pit was dug in an area of the field where salinity/alkalinity problems were observed on rice in previous years. Probes for water content, water potential and temperature were installed horizontally at eight depth increments (5, 10, 13 [within the plow pan], 25, 38, 52 [within the fragipan], 62 cm and 1 m). Volumetric soil water content was determined every 1 to 2 hours during the growing season using time domain reflectometry (TDR), which is a technique that uses the dielectric properties of soil, air and water. Data were stored in the TDR unit and retrieved on a weekly basis. Soil water potential and soil temperature were simultaneously monitored with MC-300 probes two to three times per hour. These data were stored in a Campbell Scientific CR10X datalogger and retrieved once a week. Water potential was also monitored by reading tensiometers installed every 10 cm up to a 1-m depth. Finally, weather data, including wind speed, relative humidity, air temperature, rainfall and solar radiation, were collected every half-hour and stored in Campbell Scientific CR21 and CR10X dataloggers. Bulk and core soil samples were collected for chemical and physical characterization of the site.

RESULTS AND DISCUSSION

The soil chemical characteristics of the research site are given in Table 1. Samples were taken in late April 1997. Soil fertility at the site can be considered as fair, but what is important is the highest electrical conductivity (EC) at the surface, the increase of sodium with depth and the decrease of pH at and below the fragipan. Increase in EC is particularly striking in the fragipan, presumably due to salt accumulation and to the presence of a perched water table. The decrease in soil pH also occurs at the fragipan level. Ground water from the region west of Crowley's Ridge is relatively high in bicarbonates, which explains the high pH values in the upper soil horizon.

Soil physical parameters are given in Table 2. Here again, many physical properties are affected by the fragipan: sharp increase in the clay content and decrease in the saturated hydraulic conductivity (Ksat). The Ksat is also low in the plow pan region. The organic matter content is low below a 10-cm depth.

Results obtained thus far from the parameters measured *in situ* are the volumetric water contents during the growing season (Figure 1) and weather data, an example of which is shown in Figure 2. The TDR failed during early July due to high air temperatures and had to be sent to the manufacturer for repair. The TDR probes installed at the 1-m depth failed to give accurate results for reasons yet to be determined. However, the infiltration and drainage during the growing season phases were properly monitored.

Volumetric soil water contents were higher in the fragipan than above it during most of the season. Exceptions to this are immediately after rainfall events or flooding and just before flood removal when more water is found in the upper 5-cm of the profile. Higher water contents can be explained by the fact that the bulk density, and inversely the porosity, in the fragipan was lower than in most areas above it (Table 2) but also characterizes the presence of a perched water table. Changes in volumetric water content induced by rainfall events (events 1 and 2, Figure 1), flooding (events 3 and 5) and flood removal (events 4 and 6) are very slow when compared to shallower areas of the profile such as at 5 cm or below the plow pan. The magnitude of changes in soil water content at the 5-cm depth are much more pronounced due to the fact that it is the first monitored soil layer subjected to weather factors and irrigation practices. The volumetric soil water contents just below the plow pan are generally higher than at the 5-cm depth before flooding (except after rainfall events) since it is subjected to less evaporative demand. After the second flood was applied, volumetric soil water contents below the plow pan were less than at the 5-cm depth, which can be explained by the lower porosity found at that region of the profile.

It is also apparent in Figure 1 that, at the three depth intervals shown (and in fact for all the depth intervals monitored), complete saturation was not reached within a few days after flooding as intuition would suggest. Indeed, although there is a gap in the database, volumetric soil water contents at day 240 (a few days before flood removal) were higher than at day 196 (15 days after the second flood was applied). Two hypotheses are being considered to attempt to explain this. First, water transmission is slow, particularly at greater depths. To confirm this, more measurements are currently being made on this parameter in the laboratory. The second hypothesis is that air is entrapped and only slowly moves toward the surface. It will be important to obtain complete data sets during the second year of monitoring (starting in the spring of 1998) in order to allow a better understanding of the wetting and drying cycles of the soil under irrigated rice.

SIGNIFICANCE OF FINDINGS

Complete saturation of the soil profile is reached only several weeks after flooding. Two hypotheses are being investigated, the first one relating to the velocity of water transmission within the profile, the second dealing with air entrapment upon flooding. Modelling of water infiltration is in development, and preliminary results indicate that a slightly modified version of the logistic equation could be used for this purpose. Analysis of atmospheric and other collected data is underway.

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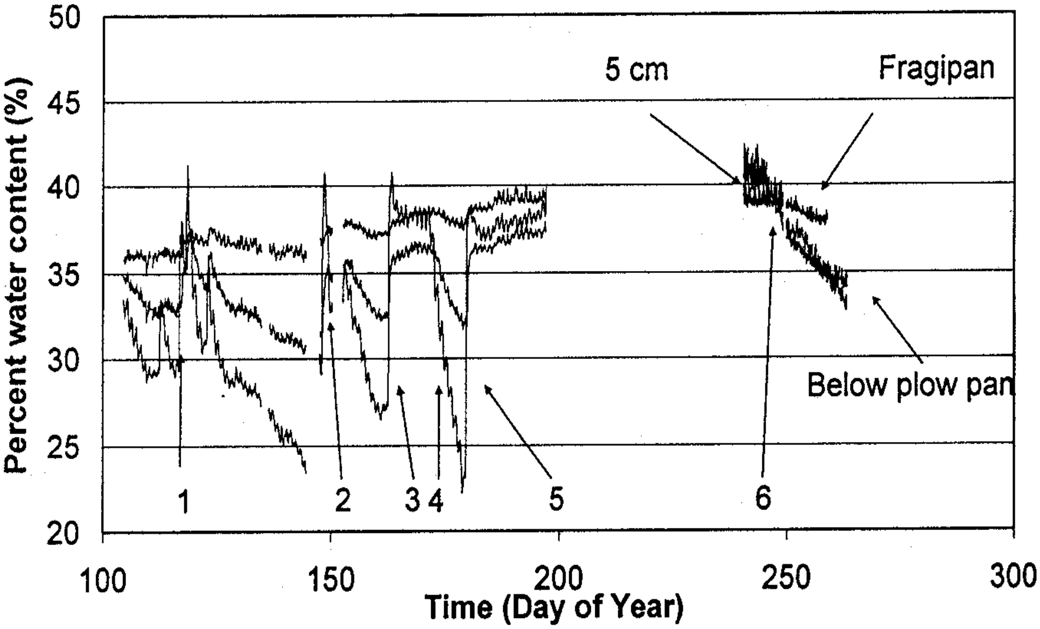
Table 1. Soil chemical characteristics.

Depth	pH	EC	P	K	Ca	Mg	Na	S	Fe	Mn	Zn	Cu	B	NO_3-N
cm		μmhos/cm						kg/ha						
0-10	7.5	448	54.9	326	6372	707	193	93	340	324	7.2	2.6	1.7	81.8
10-20	8.0	95	7.8	58	3170	567	96	32	152	318	0.7	1.6	0.3	5.7
20-30	8.0	72	4.5	54	2877	528	146	29	111	171	0.3	0.9	0.1	2.7
30-40	7.5	88	4.5	67	2014	383	262	25	109	65	0.2	0.6	0.2	3.7
40-50	5.3	127	2.2	113	1777	571	752	86	75	30	0.6	0.8	1.5	2.1
50-60	5.1	150	2.2	71	1235	556	983	101	58	41	0.4	0.8	1.8	<1.3
60-70	5.1	169	6.7	125	2281	675	1226	99	77	50	0.6	0.8	1.6	<1.3
70-80	5.2	151	5.6	143	1975	844	1584	64	104	64	0.4	1.0	1.0	<1.3
80-90	5.2	189	13.4	183	2486	959	1823	56	140	46	0.6	2.2	0.8	<1.3
90-100	5.1	232	7.8	171	2377	900	1646	48	199	75	1.1	1.7	0.7	<1.3

Table 2. Selected soil physical characteristics.

Depth	Sand	Silt	Clay	OM†	Depth	ρ_b	Ksat
cm	%				cm	Mg/m^3	cm/h
0-10	3	87	10	1.3	0-5	1.34	0.594
10-20	3	83	14	0.6	5-10	1.49	<0.001
20-30	4	81	14	0.6	10-15	1.69	0.861
30-40	5	82	13		15-20	1.65	2.899
40-50	2	63	35		25-30	1.55	4.164
50-60	2	61	37		40-45	1.41	0.002
60-70	2	65	32		65-70	1.47	0.022
70-80	2	67	31				
80-90	3	68	30				
90-100	20	56	24				

† OM is organic matter, ρ_b the bulk density, and Ksat the saturated hydraulic conductivity.



Numbers 1 and 2 denote rainfall events, 3 and 5 flooding, and 4 and 6 flood removal.

Fig. 1. Percent soil water content versus time.

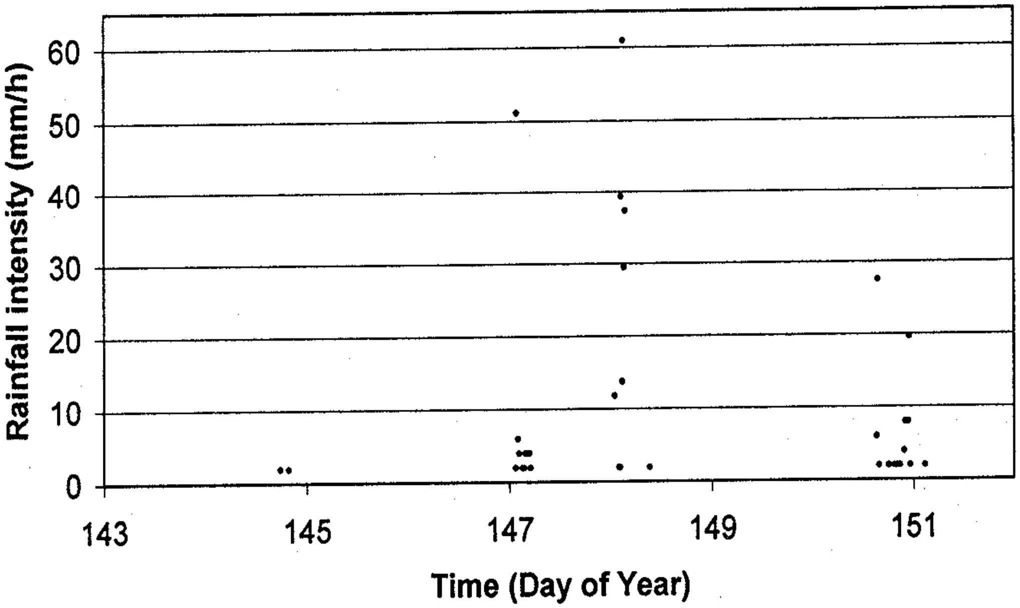


Fig. 2. Rainfall intensity versus time
(second major rainfall event).

ONGOING PROJECT
RICE CULTURE

RICE RESPONSE TO PHOSPHORUS APPLICATION TIMING IN ARKANSAS

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

ABSTRACT

Increasing frequency of phosphorus (P) deficiencies in Arkansas rice fields requires that recommendations be checked on a regular basis. Phosphorus availability declines as soil pH increases past values of 7.0. It is not known if P applied prior to planting on alkaline silt loam soils is fixed before plant use. Research was initiated on three grower fields in 1997 to evaluate P application prior to emergence, preflood, 7 days postflood and at midseason. Triple super phosphate was applied at 0, 20, 40 and 80 lb P_2O_5/acre at each timing. Rice yield responses to P application timing were obtained at the field sites having soil pH greater than 7.0. Data suggested that P application should be made during early vegetative growth, preferably before flooding, on soils where rice responds to P fertilization. Application of P fertilizer after this time may help increase grain yield in cases of deficiency, but yield potential will be lost for P applications made near midseason.

INTRODUCTION

Rice response to phosphorus (P) fertilization in Arkansas has been researched for the past 30 years with mixed results. Field studies conducted during the 1960's (Place et al., 1971) determined that P application tended to result in rice yield decreases despite significant increases in vegetative growth. Many of the tests were conducted on acid soils. Application of P to soils having pH greater than 6.5 often resulted in leaf chlorosis due to zinc (Zn) deficiency. These studies were conducted before Zn was recognized as a yield-limiting nutrient in rice production. More recent studies (Beyrouty et al., 1991) have found significant yield increases from P application in 75% of their tests. Their research was stimulated by reports of rice response to P on alkaline soils from Extension agents and rice growers in northeastern Arkansas.

Use of subsurface irrigation water high in calcium bicarbonates has created alkaline soil conditions near water inlets in many Arkansas rice fields. Rice often exhibits symptoms of bronzing on lower leaves, reduced tillering, erect leaves and, when severe, death after flooding. All of these symptoms have been attributed to either P or Zn deficiency in these high-pH areas. In many instances, application of Zn has failed to prevent or alleviate these symptoms. Reduced soil conditions created by continuous flood irrigation generally increase P availability to rice by reduction of ferric phosphates and hydroxides to their more soluble ferrous forms. The release of P from reductant soluble P and ferric phosphates is sufficient to supply rice P requirements in most rice soils. The predominant forms of P in alkaline soils are calcium phosphates. Soil reduction does not influence the solubility and subsequent availability of the calcium phosphate compounds to rice. Commonly used soil test methods, including Bray-1, Mehlich 3 and Olsen, tend to over-predict P uptake by rice and, thus, are poorly correlated with rice response to P fertilization (Teo et al., 1994). Only resin-extractable P has been found to be a good predictor of rice P response on Arkansas soils. As the frequency of P deficiency in Arkansas rice production fields increases, questions concerning application timing and rates are being asked by growers and consultants. Objectives of these tests were to evaluate rice response to P when applied at several times and rates on silt loam soils differing in Mehlich 3-extractable P and soil pH.

MATERIALS AND METHODS

Selected soil chemical properties taken from untreated check plots from each study are presented in Table 1.

Application timing studies were conducted in three grower fields during 1997. The Davis field was located in Arkansas County, Arkansas. The Brooks and Wimpy fields were located in Poinsett County, Arkansas. ‘Bengal’ was seeded at each location. Triple super phosphate was surface applied at rates of 0, 20, 40 and 80 lb P_2O_5/acre prior to rice emergence (PE), preflood (PF), 7 days postflood (POF) and at panicle differentiation or midseason (MS). Plots were managed identical to the surrounding field by cooperating producers. Total dry matter (TDM) was obtained by sampling a 3-ft row three weeks after 50% heading. Grain yield was determined by harvesting 30 ft^2 from the four middle rows of each 8 × 16-ft plot with a small plot combine. Grain moisture was measured after harvest, and yields were adjusted to 12% moisture.

RESULTS

Phosphorus rate significantly increased TDM measured three weeks after 50% heading at both the Davis and Brooks farms (Table 2). Only the 80-lb P_2O_5/acre rate increased TDM at the Brooks location. Phosphorus application rates of 20 lb P_2O_5/acre and greater significantly increased TDM at the Davis site. Application timing did not affect TDM.

Significant grain yield increases were observed for both P rate and timing of application at the Davis farm. Application of 20, 40 or 80 lb P_2O_5/acre increased grain yield compared to the untreated check (Table 3). Yields were highest when P was applied POF compared with at MS. The PE and PF applications also tended to produce higher yields than the MS application. This suggests that on soils that respond to P, fertilizer application should be made no later than the midtiller growth stage or shortly after flooding for most efficient use of fertilizer P. Data from the Wimpy farm suggests that P application at MS is not beneficial (Table 4). Although a small numerical yield increase occurred for MS applications of P, the increase was not significant. The 80-lb P_2O_5/acre rate applied PE at the Wimpy farm resulted in the greatest numerical yield of all treatments at this location (data not shown). However, the 20- and 40-lb P_2O_5/acre rates did not significantly increase yields when applied PE. Additional studies are needed to determine if fertilizer P applied early in the growing season is subject to fixation on alkaline soils before crop utilization. Lower P rates applied at PF and POF tended to increase yields, suggesting that P may be fixed when applied before emergence.

SIGNIFICANCE OF FINDINGS

Data from the P timing studies and other P fertilization projects conducted during 1997 on alkaline silt loams continue to show significant TDM and grain yield increases from P fertilization. Generally, silt loam soils with acidic pH and following soybean in rotation have not shown yield increases from P fertilization in Arkansas. Fields that have been precision graded are an exception, since they typically respond to P fertilization for several years following leveling, regardless of pH. Phosphorus timing studies conducted during 1997 indicate that P should be applied before seeding or during vegetative growth. Phosphorus applications made at MS in these field studies tended to produce lower yields than earlier applications on P-responsive soils. Data also suggest that some benefit was obtained from late P application at the Wimpy site. Additionally, yield data suggest that P applied before emergence may be subject to fixation. Phosphorus applied either PF or POF tended to produce the greatest overall yields at sites exhibiting a P response. More studies will need to be initiated to establish consistent trends among P application timings. Present and future research efforts are focused on development of more accurate P recommendations for rice.

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Table 1. Selected soil properties from phosphorus (P) application timing studies conducted during 1997 in Arkansas.

Location†	Soil pH	Soil Concentration (Mehlich 3)				
		Ca	K	Mg	P	Zn
		lb/acre				
Brooks	6.6	2870	130	418	28	20.0
Davis	7.6	3940	148	554	20	4.0
Wimpy	8.0	5660	132	698	56	40.0

† Brooks Farm located in Poinsett County, Davis Farm located in Arkansas County, Wimpy Farm located in Poinsett County.

Table 2. Influence of phosphorus (P) application rate, averaged across time of P application, on total dry matter production three weeks after 50% heading from three P timing studies conducted during 1997 in Arkansas.

	Total Dry Matter		
P Rate	Davis[†]	Brooks	Wimpy
lb P_2O_5/acre		lb/acre	
0	14852	18705	18250
20	16502	19695	17082
40	17465	20052	18090
80	16832	22960	18197
LSD(0.05)	1641	3772	NS
Pr > F	0.048	0.064	0.629
CV %	9.3	19.2	16.5

[†] Brooks Farm located in Poinsett County, Davis Farm located in Arkansas County, Wimpy Farm located in Poinsett County.

Table 3. Influence of phosphorus (P) application rate, averaged across time of P application, on rice grain yield from three P timing studies conducted during 1997 in Arkansas.

	Grain Yield		
P Rate	Davis[†]	Brooks	Wimpy
lb P_2O_5/acre		bu/acre	
0	110	191	143
20	145	182	148
40	153	171	155
80	142	178	156
LSD(0.05)	23	NS	NS
Pr > F	0.025	0.586	0.207
CV %	15.4	14.6	9.3

[†] Brooks Farm located in Poinsett County, Davis Farm located in Arkansas County, Wimpy Farm located in Poinsett County.

Table 4. Influence of phosphorus (P) fertilizer application timing, averaged across P application rate, on rice grain yield from three P timing studies conducted during 1997 in Arkansas.

	Grain Yield		
P Timing	Davis[†]	Brooks[‡]	Wimpy[§]
		bu/acre	
Preemerge (PE)	145	184	150
Preflood (PF)	143	171	156
Postflood (POF)	157	172	156
Midseason (MS)	131	182	147
LSD(0.05)	18	NS	NS
Pr > F	0.018	0.611	0.410
CV %	15.4	14.6	9.3

[†] Davis farm untreated check grain yield = 110 bu/acre.
[‡] Brooks farm untreated check grain yield = 191 bu/acre.
[§] Wimpy farm untreated check grain yield = 143 bu/acre.

ONGOING PROJECT
RICE CULTURE

INFLUENCE OF SEEDING RATES ON RICE SALINITY TOLERANCE

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

ABSTRACT

Soil salinity affects a significant amount of rice acreage in Arkansas each year. While a large percentage of the rice acreage is potentially susceptible to salinity injury, predicting where and how much acreage will be affected in a given year is difficult due to the dynamics of salt movement in the soil profile as influenced by weather patterns. However, certain areas tend to be affected routinely. Efforts to prevent salinity injury to rice have proven futile over the past few years. The current study was conducted to evaluate the influence of seeding rates on rice salinity tolerance. Four rice cultivars (‘Bengal’, ‘Cypress’, ‘Kaybonnet’ and ‘LaGrue’) were drill-seeded at rates of 32, 40, 44, 48, 56 and 64 seeds/ft^2 in an area that had been salinized for previous studies. Increasing the seeding rate increased stand density and total dry matter in some cases. However, grain yields were not affected by seeding rate, even under saline conditions.

INTRODUCTION

Soil salinity affects a significant amount of rice acreage in Arkansas each year. Although a large percentage of the rice acreage is potentially susceptible to salinity injury, it is difficult to predict where and how much due to the dynamics of salt movement in the soil profile. Data characterizing the water quality of irrigation wells in Arkansas has been compiled to predict areas where saline soils are likely to develop (Baker et al., 1996). While several areas in the state were identified as high-risk areas, continued research efforts are needed to more closely monitor the water quality in some of the areas identified as having high risk potential.

Efforts to prevent salinity injury to rice have proven futile over the past few years. Amending soils with poultry litter and other organic materials provided little benefit for rice or soybeans produced in these conditions. While potassium (K) fertilizers utilized for rice may aggravate salinity injury, the need for K for rice has been shown to be more important. Application of phosphorus has been of limited value on saline soils but has been shown to be beneficial when accompanying application of K to saline soils.

Observations have been made in production fields that salinity stress seems to be reduced in areas that had been double-drilled (i.e. double-seeded). It is hypothesized that increasing the seeding rate may increase the probability that enough seedlings will survive under saline conditions to prevent reductions in productivity in these areas. Therefore, this study was conducted to evaluate the effects of seeding rates on rice salinity tolerance.

MATERIALS AND METHODS

A field study was initiated at the Southeast Research and Extension Center-Rohwer Division during 1997 on a site that had been salinized for previous studies (Wilson et al., 1995). Three areas were utilized: an unsalinized control, a medium-salinity rate (2000 lb/acre/yr of NaCl for 3 years followed by 2000 lb/acre/yr for 2 years of KCl) and a high-salinity rate (4000 lb/acre/yr of NaCl for 3 years followed by 4000 lb/acre/yr for 2 years of KCl). Four rice varieties (Bengal, Cypress, Kaybonnet and LaGrue) were drill-seeded at rates of 32, 40, 44, 48, 56 and 64 seeds/ft^2 into nine-row plots measuring 15 ft long at 6-in. row spacing. Stand counts were made 7 days after emergence (DAE) and 14 DAE, which corresponded to the two- to three-leaf growth stage and the three- to four-leaf growth stage, respectively. Samples were collected from 3 row-ft at the four-leaf growth stage for total dry matter and Cl analyses. Grain yields were determined at maturity from the four center rows of each plot with a small-plot combine and were converted to lb/acre at 12% moisture.

The experiment was arranged in a split-plot design with four replications and with the salt rates as main plots. The subplots were a factorial arrangement of the six seeding rates and four cultivars.

RESULTS AND DISCUSSION

Increasing salinity significantly reduced rice emergence, stand density and total dry matter (Table 1). The percentage of rice seedlings that emerged tended to decrease with increasing seeding rates (Table 2). The decrease reached significance at 48 or more seeds/ft^2. However, the stand density increased with increasing seeding rates above 40 seeds/ft^2. Total dry matter increased significantly at the highest seeding rate.

Total dry matter was significantly affected by salinity and seeding rate in the control and the medium-salinity level (Fig. 1). However, increasing seeding rates did not affect total dry matter at the highest salinity level. With moderate salinity, increasing the seeding rate to 56 seeds/ft^2 significantly increased total dry matter above that obtained with the recommended seeding rate (40 seeds/ft^2).

The influence of salinity on total dry matter by the four rice cultivars was not significantly different at the highest salinity rate (Fig. 2). Total dry matter produced by Bengal was slightly higher than for the other cultivars at the medium-salinity level, but the difference was not significant. Cypress had the highest total dry matter at the four-leaf stage of the four cultivars when no salinity stress was present (Fig. 2).

A trend for reduced yields was observed with the medium level of salinity, but a significant reduction in grain yields was observed in the highest salinity rate (Table 1). Seeding rate did not influence grain yields, irrespective of the salinity level (Fig. 3) or cultivar. Bengal and LaGrue yielded significantly more than Cypress at the medium-salinity level (Fig. 4). Kaybonnet also had less grain yield than Bengal or LaGrue, but the differences were not significant. At the highest rate of salinity, no significant differences were observed among the rice cultivars.

SIGNIFICANCE OF FINDINGS

While increasing seeding rates did not significantly affect rice grain yields under saline conditions, total dry matter and stand density were increased. More research is needed to assess the impact of seeding rates on rice seedling survival under salinity stress.

ACKNOWLEDGMENTS

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Table 1. Influence of salinity on growth parameters of rice during 1997.

		Stand Density‡		Total Dry	
Salt Rate	Emergence†	7 DAE	14 DAE	Matter	Grain Yield
	%	-------- plants/ft^2	--------	g/m^2	lb/acre
Control	60.8	28.1	31.5	26.0	4969
Medium	42.0	19.7	17.7	8.1	4699
High	24.1	11.2	9.6	1.7	1989
LSD$_{(0.05)}$	12.7	2.9	6.0	2.2	478

† Determined 7 days after emergence

‡ DAE = days after emergence.

Table 2. Influence of seeding rate on growth paramters of rice during 1997.

		Stand Density‡		Total Dry	
Seeding Rate	Emergence†	7 DAE	14 DAE	Matter	Grain Yield
seeds/ft^2	%	-------- plants/ft^2	--------	g/m^2	lb/acre
32	47.5	15.2	16.5	10.6	4026
40	45.3	18.1	18.1	11.5	3819
44	44.2	19.5	19.8	12.3	3718
48	41.5	19.9	20.0	12.1	3791
56	38.6	21.6	20.9	12.5	4110
64	36.8	23.5	22.4	13.1	3811
LSD$_{(0.05)}$	5.1	2.4	2.4	2.1	523

† Determined 7 days after emergence.

‡ DAE = days after emergence.

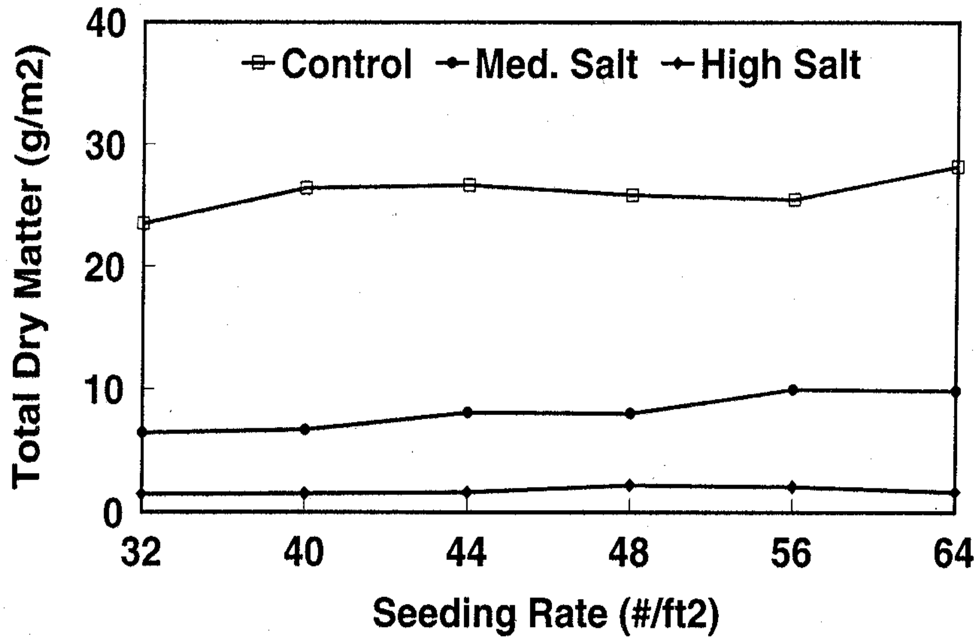

Fig. 1. Influence of seeding rate and salinity on total dry matter accumulation by rice during 1997.

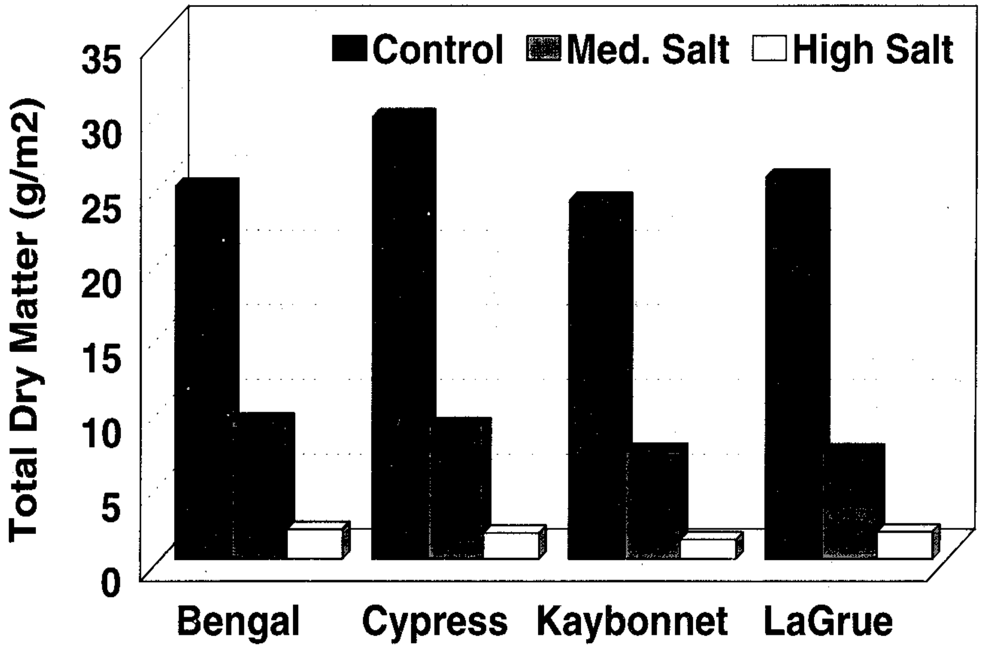

Fig. 2. Influence of salinity on total dry matter production at the four-leaf growth stage of four rice varieties in 1997.

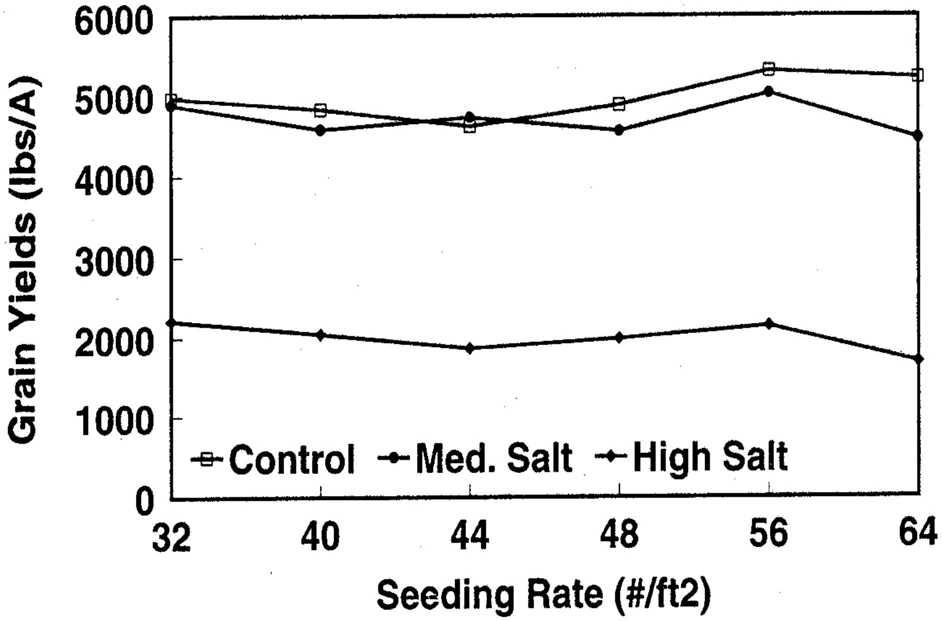

Fig. 3. Influence of seeding rate and salinity on rice grain yields during 1997.

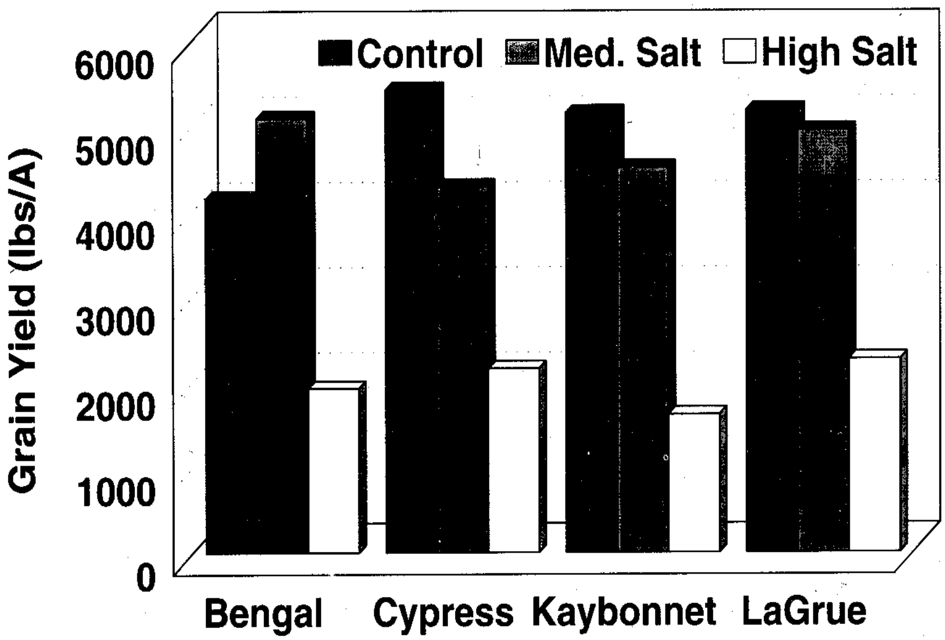

Fig. 4. Influence of salinity on grain yields of four rice varieties in 1997.

EFFECTS OF ROUGH RICE STORAGE HISTORY ON THE END-USE QUALITY OF RICE

M.J. Daniels, B.P. Marks, T.J. Siebenmorgen and R.W. McNew

ABSTRACT

The objective of this study was to quantify the effects of drying treatment and storage conditions on the milling, cooking and amylographic properties of rice. Three cultivars were harvested in either 1995 or 1996. Postharvest variables included two pre-drying treatments and two drying treatments. Storage conditions included three moisture contents and three temperatures. Sub-samples were removed periodically from each storage lot and tested for the following functional properties: head rice yield (HRY), water absorption (WAB), volume expansion (VEX) and amylography. For all treatments, HRY, WAB, VEX and peak viscosity increased during storage. For all storage temperatures, the low-temperature dried rice had significantly ($P<0.005$) greater HRY, cooking properties and peak viscosities than did the high-temperature dried rice. Also, temporary (86 h) wet holding prior to drying significantly ($P<0.001$) reduced cooking properties for the low-temperature dried rice. Storage temperature significantly ($P<0.005$) affected all functional properties except HRY, and storage moisture content (mc) significantly ($P<0.001$) affected HRY, VEX and peak viscosity. The relationships between postharvest parameters and functionality were not simple linear relationships; for example, the interaction of storage duration squared and drying condition significantly ($P<0.001$) affected HRY, peak viscosity and final viscosity.

INTRODUCTION

As value-added uses for rice products continue to expand, so does the need for quantitative data regarding the effects of postharvest parameters on end-use functionalities. Previous research has shown that rough rice storage history can affect both head rice yield and cooking quality of rice (Villareal et al., 1976; Chrastil, 1990; Hamaker et al., 1993; Tamaki et al., 1993). Changes observed during storage include an increase in grain hardness (Dhaliwal et al., 1990; Sajwan et al., 1989; Tsugita et al., 1983), an increase in water absorption and volume expansion (Villareal et al., 1976; Tsugita et al., 1983) and an increase in peak viscosity (Villareal et al., 1976; Tsugita et al., 1983; Hamaker et al., 1993). Previous work has also shown that changes occur most rapidly in the first months of storage when held at 15°C (Perez and Juliano, 1982).

Although previous research has focused on the changes that occur during rough rice storage, these past studies have typically shown the effects of only one or two storage parameters on the functional properties of rice, without considering other postharvest parameters, such as wet holding and drying method. Little work has been done to identify whether interactions of postharvest parameters affect rice during storage. It may be assumed that changes during storage are not linked to just one variable, but to interactions of several factors. Therefore, there is a need to describe the relationship of these interactions to the changes in functional properties.

Consequently, this study was part of an overall research program aimed at mathematically modeling physicochemical changes in rice as functions of rough rice postharvest history. Our hypothesis is that these changes are complex biochemical phenomena, which have not yet been modeled, even as statistical relationships in experimental studies. Therefore, the specific objective of this project was to quantitatively describe the effects of pre-drying methods, drying treatment and storage history (i.e., temperature and duration) on the end-use quality characteristics of rice, including head rice yield, cooking properties and starch functionality.

PROCEDURES

Rice was harvested at the University of Arkansas Rice Research and Extension Center at Stuttgart, Arkansas, and at the University of Arkansas Northeast Research and Extension Center at Keiser, Arkansas, in 1995 and 1996, for two storage studies. All rice was dried in a small-scale laboratory drying system before it was allowed to slowly equilibrate to the target storage mc. The rice was then divided into separate lots and placed into sealed plastic buckets, which were stored in three controlled-temperature chambers. Sub-samples of each lot were removed periodically and subjected to a series of physicochemical analyses.

Fall 1995 Treatments

Only one cultivar, ‘Cypress’ (harvest mc of 20%), was stored in the 1995 study. Postharvest treatments included immediate vs. delayed drying (i.e., held for 86 h at harvest mc before drying), high-temperature (54.3°C, 21.9% relative humidity for 45 min) vs. low-temperature (33°C, 67.8% relative humidity for 45 min) drying, storage temperature (4, 21 or 38°C) and storage duration (0, 3, 7, 12, 18, 25 and 33 weeks).

Fall 1996 Treatments

The 1996 study design was a modification of the 1995 study; it did not include the pre-drying conditions, but it was expanded to include three cultivars and three storage moisture contents. The three cultivars stored were Cypress, ‘Kaybonnet’, and ‘Bengal’. Postharvest treatments included high-temperature (60°C and 16.9% relative humidity for 20 min) vs. low-temperature (43.3°C and 16.9% relative humidity for 75 min) drying, storage mc (10, 12 or 14%), storage temperature (4, 21 or 38°C) and storage duration (0, 3, 6, 9, 12, 18, 25 and 36 weeks).

Head Rice Yield

Head rice yield was determined in triplicate (1995) or duplicate (1996) by first dehulling 150 g of rough rice. The brown rice was then milled in a McGill #2 mill to a target degree of milling of 90 on a Satake model MM-1B milling meter (Satake, Hiroshima, Japan). Head rice was separated from the brokens using a shaker table. HRY was the ratio of head rice weight to the original weight of rough rice.

Water Absorption and Volume Expansion Ratios

Cooking ratios were determined in duplicate. Twenty grams of raw head rice was placed in a wire basket (7 cm tall and 3.5-cm diameter). The wire basket was placed in a 250-ml beaker filled with 200 ml of near boiling water; the beaker was then placed into a kettle of boiling water. The rice was cooked for 20 min and then allowed to drain for 10 min. The water absorption was calculated as the ratio of water absorbed to initial rice weight. The volume expansion was computed as the ratio of cooked rice height to raw rice height.

Amylography

Sixty grams of head rice was ground in a UDY Cyclotec mill (Model 1093, Tecator, Inc., Hoganas, Sweden) with a 0.5-mm screen. The flour was mixed with water to produce a slurry with 8% dry matter, after determining the mc of the flour (Juliano et al., 1985). Subsequently, the slurry was subjected to a defined temperature treatment in a Brabender viscograph-E, according to a modified version of the AACC Method 61-01 (AACC, 1996) for milled rice. The peak and final viscosity were extracted from the resulting amylograph.

Statistical Analysis of Data

An analysis of variance was performed via SAS (1993) to first determine the postharvest factors and interactions that significantly ($p<0.05$) affected each functional property of the rice. The significant factors were subsequently included in polynomial models and analyzed through a general linear model procedure in SAS.

RESULTS AND DISCUSSION

Specific data trends of the 1995 study were reported by Daniels et al. (1997). This discussion will detail trends seen in the 1996 study in relation to the 1995 study and also report the statistical results for both studies.

1996 Data Trends

Similar to the 1995 samples, the HRY of all the 1996 samples increased with storage duration, with the most significant increases occurring in the first 3 months of storage (Figure 1). This is consistent with the results of Perez and Juliano (1982), Barber (1972) and Villareal et al. (1976). As in 1995, the low-temperature dried samples had greater HRY values when compared to the high-temperature dried samples. The lower HRY for the high-temperature dried rice is consistent with previous literature (Abe et al., 1992; Kunze, 1984). Moisture content also affected the rate at which HRY increased during storage.

The 1996 cooking ratios followed the same trends as the 1995 samples when considering drying treatments and storage duration; the cooking ratios increased with storage at 21 or 38°C (Figure 2), and the low-temperature dried samples yielded higher ratios than did the high-temperature dried samples.

In the 1996 storage test, both peak and final viscosity increased with storage duration (Figure 3), with the values for both viscosities seeming to level off after 24 weeks of storage. Similar effects were also reported by Perdon et al. (1997).

Statistical Results

Two conclusions can be postulated from the significant polynomial variables reported in Table 1 and Table 2. First, several terms in both tables include second-order and third-order variables, suggesting that the relationship of postharvest factors to the functional properties of rice are not all explained in simple linear terms. Secondly, the significant interactions of postharvest factors suggest that functional changes cannot be explained by a single factor; rather, a combination of factors must be considered.

The effect of storage temperature was significant for water absorption, volume expansion and peak viscosity for the 1995 study and was significant for all of the functional properties, excluding HRY, in the 1996 study. Storage duration was also significant for all of the functional properties in the 1996 study but was significant only for HRY and the cooking properties in the 1995 study. Drying condition was significant for all of the functional properties for both studies, suggesting that this treatment was one of the most dominant variables inducing changes in the rice.

The additional factors included in the 1996 study (mc and cultivar) were significant for all the functional properties. The interaction of storage duration and drying condition was significant for all functional properties except peak viscosity in the 1996 study. This implies that rough rice drying treatment affects the rate at which age-induced changes occur during rough rice storage.

SIGNIFICANCE OF FINDINGS

The data trends seen in the 1996 study coincided with the results of the 1995 study. Both studies have shown that the changes in the functional properties of rice due to postharvest factors can be statistically modeled. Furthermore, the resulting models have shown that these changes are not always the result of simple linear relationships between the postharvest factors and the functional properties. Further work will test these models to determine the relative importance of postharvest parameters on controlling specific end-use functionalities.

ACKNOWLEDGMENTS

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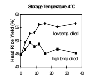
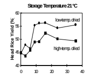
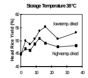






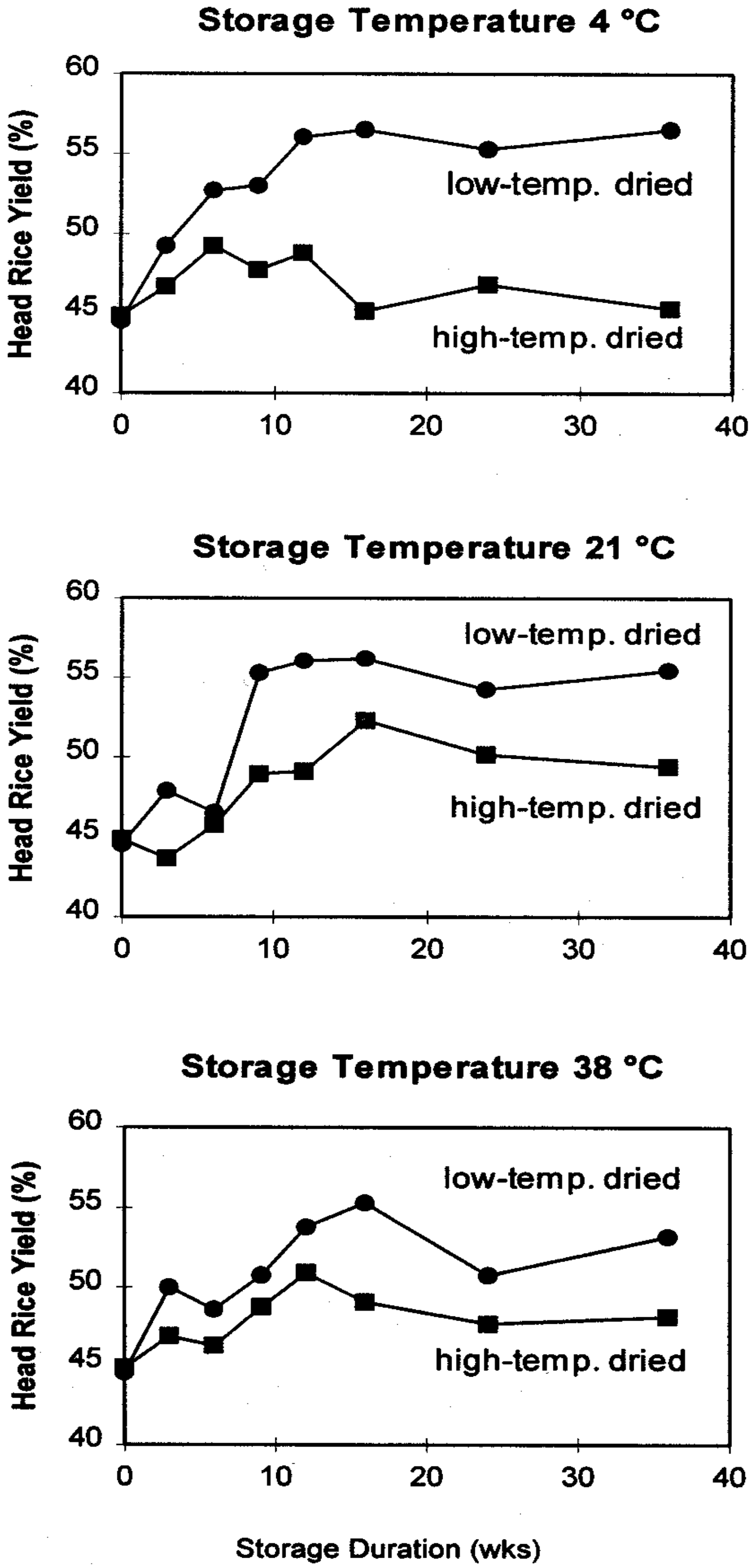


Fig. 1. Head rice yield vs. storage duration for 1996 'Cypress' stored at 12.0% moisture content.

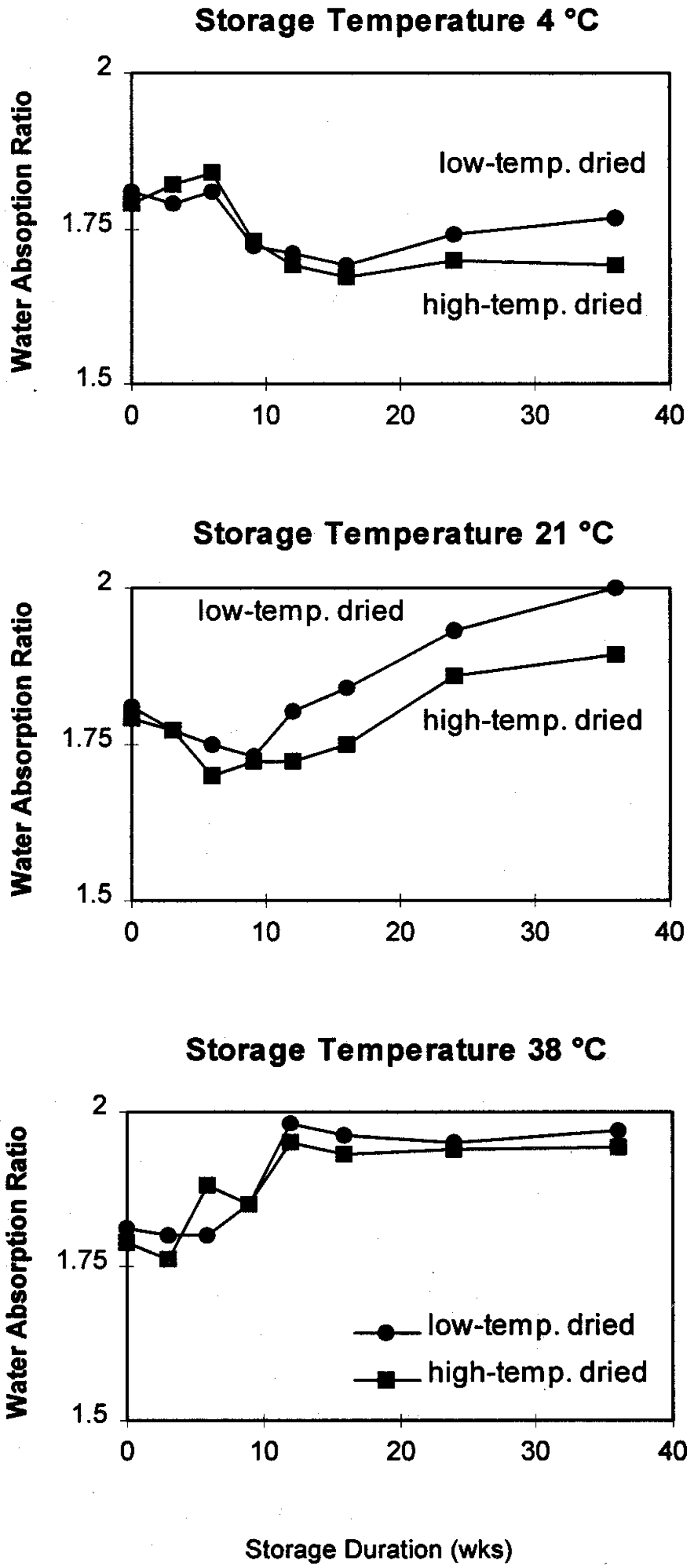
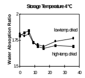
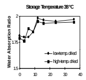


Fig. 2. Water absorption ratio vs. storage duration for 1996 'Cypress' stored at 12.0% moisture content.





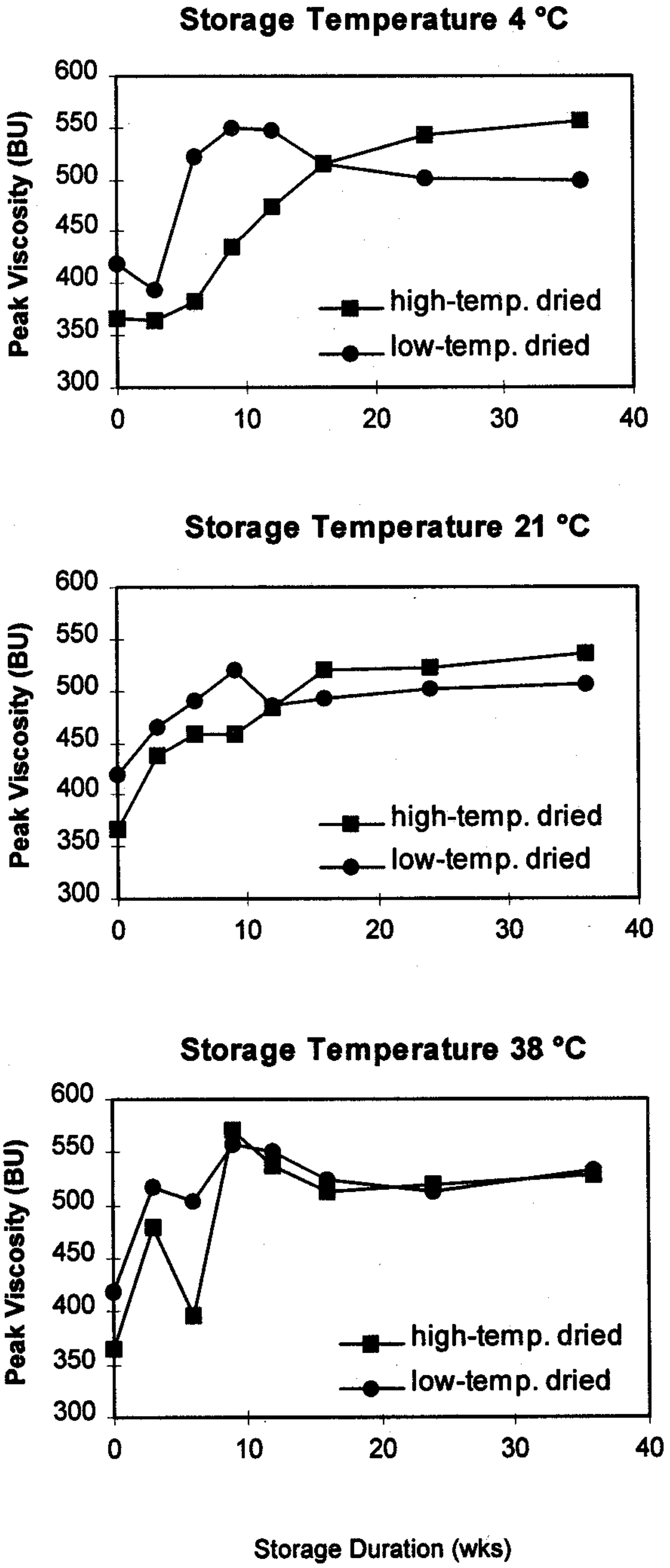


Fig. 3. Peak viscosity vs. storage duration for 1996 'Cypress' stored at 12.0% moisture content.

Table 1. The significant polynomial variables ($p<0.05$) affecting the head rice yield, water absorption, volume expansion, peak viscosity and final viscosity of 1995 'Cypress' long-grain rice during storage.

Property	Highest Order Significant Variables and Variable Interactions of Model†		R^2
HRY	t^2	DC	0.8891
Water Absorption	T^2*t^2*DC	$T^2*HC*DC$	0.9645
Volume Expansion	T^2*t	$T^2*HC*DC$	0.9462
Peak Viscosity	T^2*HC	DC	0.6214
Final Viscosity	no significant variables		NS

† T = storage temperature, t = storage duration, DC = drying condition, HC = pre-drying condition.

Table 2. The significant polynomial variables ($p<0.05$) affecting the head rice yield, water absorption, volume expansion, peak viscosity and final viscosity of 1996 'Cypress', 'Kaybonnet' and 'Bengal' rice during storage.

Property	Highest Order Significant Variables and Variable Interactions of Model			R^2
HRY	t^3*DC*V	$t*DC*MC$	$DC*MC*V$	0.8524
Water Absorption	T^2*t^2*MC	$T*t^2*V$	$T*MC*V$	0.8586
	t^2*DC*V	t^2*MC*V	t^3*V	
Volume Expansion	T^2*t^3*MC	$T^2*DC*MC$	$T*DC*V$	0.8140
	t^2*DC*V	t^2*MC*V	$DC*MC*V$	
Peak Viscosity	T^2*t^2*V	t^2*MC	T^2*t^3	0.8644
	DC			
Final Viscosity	T^2*t^3	T^2*t*V	T^2*DC	0.8264
	$T*MC$	t^3*DC*V	$DC*MC*V$	

† T = Storage Temperature, t = duration, DC = drying condition, MC = moisture content, V = cultivar.

PREPARATION AND CHARACTERIZATION OF SILICA GEL FROM RICE HULL ASH

Savita R. Kamath and Andrew Proctor

ABSTRACT

Rice hulls, a waste co-product of the rice industry, is composed of 20% silica. The objectives of our study were to develop a method to produce silica gel by recovering the silica from rice hull ash and to determine the physical and chemical properties of the rice hull silica gel (RHSG) relative to *Trisyl 300*, a commercial silica gel. Rice hull ash was dispersed in sodium hydroxide, and the resulting sodium silicate solution was acidified with sulfuric acid to obtain silica gel at neutral pH. The RHSG had a moisture content > 65%, a surface area of 258.06 m^2/g, and a particle pore diameter of 113.2 Å. Fourier transform infrared (FTIR) spectroscopy showed similarities in chemical structures for the RHSG and commercial silica gel sample. X-ray diffraction patterns for both the samples showed a broad peak between 15° and 35° 2θ diffraction angle, indicating their amorphous nature. Scanning electron micrographs revealed that RHSG particles were larger in size and less uniform in appearance as compared to *Trisyl 300* particles. Silica gel is widely used in pharmaceutical, cosmetics, paint and speciality chemical industries. Silica gel production from rice hull ash could not only alleviate the rice hull waste disposal problem but also create a commercially viable value-added product.

INTRODUCTION

Arkansas produced approximately 72 million cwt of rice in 1997, making it the largest rice producing state in the U.S. (National Agricultural Statistics Service, USDA, Washington DC). Rice hulls, a co-product of the rice industry that comprises about 20% of the rice grain, poses a significant waste disposal problem (Juliano, 1985; Juliano et al., 1987). Rice hulls consist of 20% silica, which could be used to produce silica gel by a chemical process. Silica gel is widely used in pharmaceutical, cosmetics, paint and speciality chemical applications (Iler, 1979).

The objectives of this study were to develop a prototype silica gel from rice hull ash and to examine the structure and composition of the rice hull silica gel compared to *Trisyl 300*, a commercial silica gel.

PROCEDURES

Rice hull ash (RHA) consisting of 61% silica and 36% carbon was obtained from Producers Rice Mill (Stuttgart, Arkansas), and *Trisyl 300*, a commercial silica gel was obtained from Grace Davison (Baltimore, Maryland).

Preparation of Silica Gel from Rice Hull Ash

Thirty grams of RHA and 1 L of 1 M NaOH were boiled for 1 hr, filtered, and the carbon residue washed with 500 mL of boiling water. The filtrate, which was the sodium silicate solution, was titrated with 1 M H_2SO_4 until the pH of the solution reached neutrality. A soft gel was formed that was aged for approximately 18 hr. After aging, the gel was gently broken and the slurry centrifuged for 10 min at 2500 rpm in a Model CRU-5000 centrifuge (International Equipment Co., Needham Heights, Massachusetts). The gel was washed twice with 400 mL of distilled water and dried in a vacuum oven (Precision, Chicago, Illinois) at 80°C and about 457 mm of Hg for 11 to 13 hr. The dried RHSG was ground in a Swift Model TSK-928 grinder and stored in an air-tight plastic bag.

Characterization of Rice Hull Silica Gel

The moisture content of the RHSG and *Trisyl 300* samples was determined by heating 2-gm samples at 130 ± 3°C for 1 hr in a Blue M air oven (Blue M Electric Co., Blue Island, Illinois). Loss in weight was recorded as the moisture content of the samples. The RHSG and *Trisyl 300* samples were analyzed for their Na, S, K, Ca, P and Mg contents by nitric acid digestion (Campbell and Plank, 1992) and subsequent measurement by a Model D Sequential Inductively Coupled Plasma (ICP) emission spectrometer (Spectro Analytical Instruments, Fitchburg, Massachusetts). An accelerated surface area and porosity system, Micromeritics Model 2010 (Micromeritics Instrument Corporation, Norcross, Georgia) was used to determine the BET-surface area (adsorbate: N_2 at 77 K), average pore diameter and pore volume for the samples.

X-ray diffraction patterns of the samples were obtained by a Philips dual goniometer X'pert XRD system (Philips Electronic Instruments, The Netherlands). The generator voltage was maintained at 45 kV, current at 40 mA and the 2θ diffraction angle was measured from 10° to 60° (Gnanasambandam and Proctor, 1997). The FTIR spectra of both the samples were evaluated by a Nicolet Impact 410 FTIR instrument (Nicolet Analytical Instruments, Madison, Wisconsin). One hundred interferograms were co-added to obtain the final spectra (Adhikari et al., 1994). The morphology of the samples was determined by mounting the samples on aluminum stubs (Ted Pella, Inc., Redding, California) with a double-sided adhesive tape, sputter coated with gold in a Hummer JR sputter coater (Technics EMS, Inc., Springfield, Virginia) prior to examination under a Hitachi Model S-2300 (Hitachi, Tokyo, Japan) scanning electron microscope.

RESULTS AND DISCUSSION

The two steps involved in the RHSG preparation process were: 1) alkali solubilization where it is proposed that the silica present in the RHA dissolves in sodium hydroxide producing a sodium silicate solution and 2) acid precipitation where the sodium silicate solution reacts with sulfuric acid to produce silica gel, as illustrated below:

$$x\,SiO_2 + 2\,NaOH \longrightarrow Na_2O \cdot x\,SiO_2 + H_2O$$

$$Na_2O \cdot x\,SiO_2 + H_2SO_4 \longrightarrow x\,SiO_2\,(gel) + Na_2SO_4 + H_2O$$

The final dried RHSG had twice the volume of the RHA used. Commercial silica gel manufacture differs from the above process in that the sodium silicate solution is prepared by mixing sand (silicon dioxide) with sodium carbonate in a furnace. The acid treatment step is similar.

RHSG and *Trisyl 300* contained 67.47 and 58.19% water, respectively (Table 1). Silica gel is a high-moisture product made up of a network of interconnected microscopic pores with a silicon dioxide core that entraps water and a surface consisting of silanol groups (Iler, 1979). The surface silanol groups are responsible for physically adsorbing water molecules and holding them in place by hydrogen bonding. The water entrapped in the core, the silanol hydroxyl groups and the physically adsorbed water together represent the moisture content in the silica gel samples.

Table 1 shows the elemental content of RHSG and *Trisyl 300*. RHSG contained significantly more sodium (Na) and sulfur (S) than *Trisyl 300*. The high concentration of Na and S in RHSG is probably due to the sodium hydroxide and sulfuric acid reagents used in its preparation that did not completely react during the process. Small amounts of sodium sulfate may also be present in the RHSG, contributing to its Na and S concentrations. Minor elements present in RHSG were potassium (K), calcium (Ca), phosphorus (P) and magnesium (Mg) in order of decreasing concentrations. These elements were present in concentrations greater than 0.1% in RHA and may have been carried over into the RHSG.

The BET-surface area (N_2, 77 K) of RHSG was slightly more than half that of *Trisyl 300* (Table 1). The pore diameters for RHSG and *Trisyl 300* were 121.65 Å and 50.69 Å, respectively, indicating that RHSG particles were larger than those of *Trisyl 300* particles. As pore size decreased, particle size decreased, resulting in an increase in the surface area. In silica gel preparation, the particle structure and the pore sizes are determined during the aging process (Leake, 1997). The pore volume for RHSG was 0.799 cm^3/g, and that for *Trisyl 300* was 0.625 cm^3/g.

X-ray diffraction patterns for the RHSG and *Trisyl 300* samples are shown in Fig. 1. A lack of sharp, defined peaks indicates non-crystalline or amorphous material (Chakraverty and Kaleemullah, 1991). The broad 'hump' between 15° and 35° 2θ diffraction angle is characteristic of an amorphous structure (Gnanasambandam and Proctor, 1997).

The key chemical groups present in RHSG and *Trisyl 300* were identified by their respective FTIR spectra (Fig. 2). In general, the FTIR spectra of *Trisyl 300* was sharper and had lower noise and higher intensity compared to the FTIR spectra of RHSG. A broad band between 2800 and 3750/cm indicates surface OH groups (Adhikari et al., 1994; Yates et al., 1997). This stretch is due to the silanol OH groups and the adsorbed water bound to the silica surface by hydrogen bonds. A sharper peak or shoulder at about 3700/cm in both spectra is due to the silanol OH group. The bending vibration peak for H-OH is shown at 1650/cm (Proctor et al., 1995) and is more pronounced in the spectra of *Trisyl 300*. The peak between 1250-1400/cm in the *Trisyl 300* spectra is due to the structural siloxane bonds (Si-O-Si) and is evident to a lesser degree in the RHSG spectra.

The scanning electron micrographs for RHSG and *Trisyl 300* are shown in Fig. 3. The RHSG particles range from < 5 µm to > 40 µm in size. *Trisyl 300* particles seemed to be more uniform in appearance with sizes ranging from < 5 µm to 25 µm. The lack of uniformity in the RHSG particle size is a result of the laboratory grinding process, which differs from the industrial process of micronization that produces uniformly sized particles.

SIGNIFICANCE OF FINDINGS

A rapid, simple and low-energy method has been developed to produce silica gel from rice hull ash. The cost effectiveness of this process would be considerable in that conventional silica gel production requires smelting of sand in a furnace to produce sodium silicate. This high-energy, expensive process could be eliminated by producing sodium silicate via alkali solubilization of the silica present in rice hull ash and subsequent acid treatment at relatively modest temperatures. Production of RHSG not only would alleviate the problems associated with rice hull waste disposal but would also generate a commercially viable value-added product with varied applications.

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Table 1. Chemical and physical properties[†] of rice hull silica gel (RHSG) and *Trisyl 300*.

Properties	RHSG	*Trisyl 300*
Moisture content (%)	67.47 ± 3.38	58.19 ± 1.44
Sodium (%)	2.037 ± 0.223	0.014 ± 0.001
Sulfur (%)	1.261 ± 0.143	0.009 ± 0.0
Potassium (%)	0.038 ± 0.011	0.007 ± 0.001
Calcium (%)	0.008 ± 0.001	0.011 ± 0.0
Phosphorus (%)	0.004 ± 0.001	0.001 ± 0.0
Magnesium (%)	0.002 ± 0.001	0.002 ± 0.001
Surface area (m^2/g)	258.06 ± 3.94	462.75 ± 0.274
Pore diameter (Å)	121.65 ± 11.96	50.69 ± 0.057
Pore volume (cm^3/g)	0.7986 ± 0.004	0.625 ± 0.003

[†] means of triplicate determination.

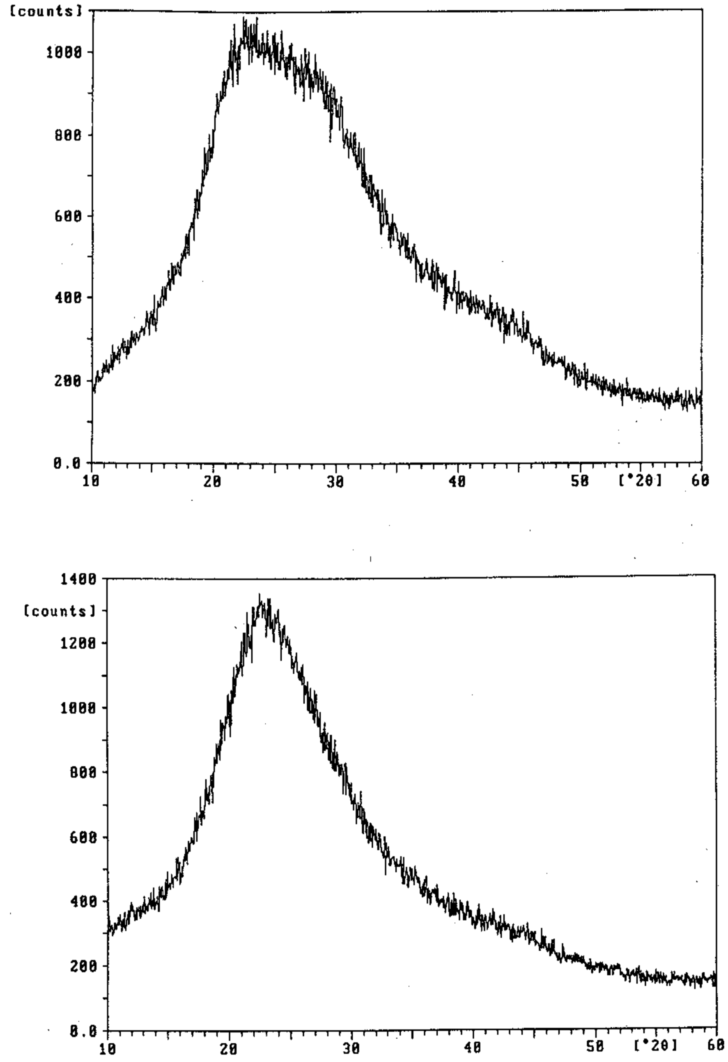

Fig. 1. X-ray diffraction patterns for 1) Rice Hull Silica Gel and 2) *Trisyl 300*.

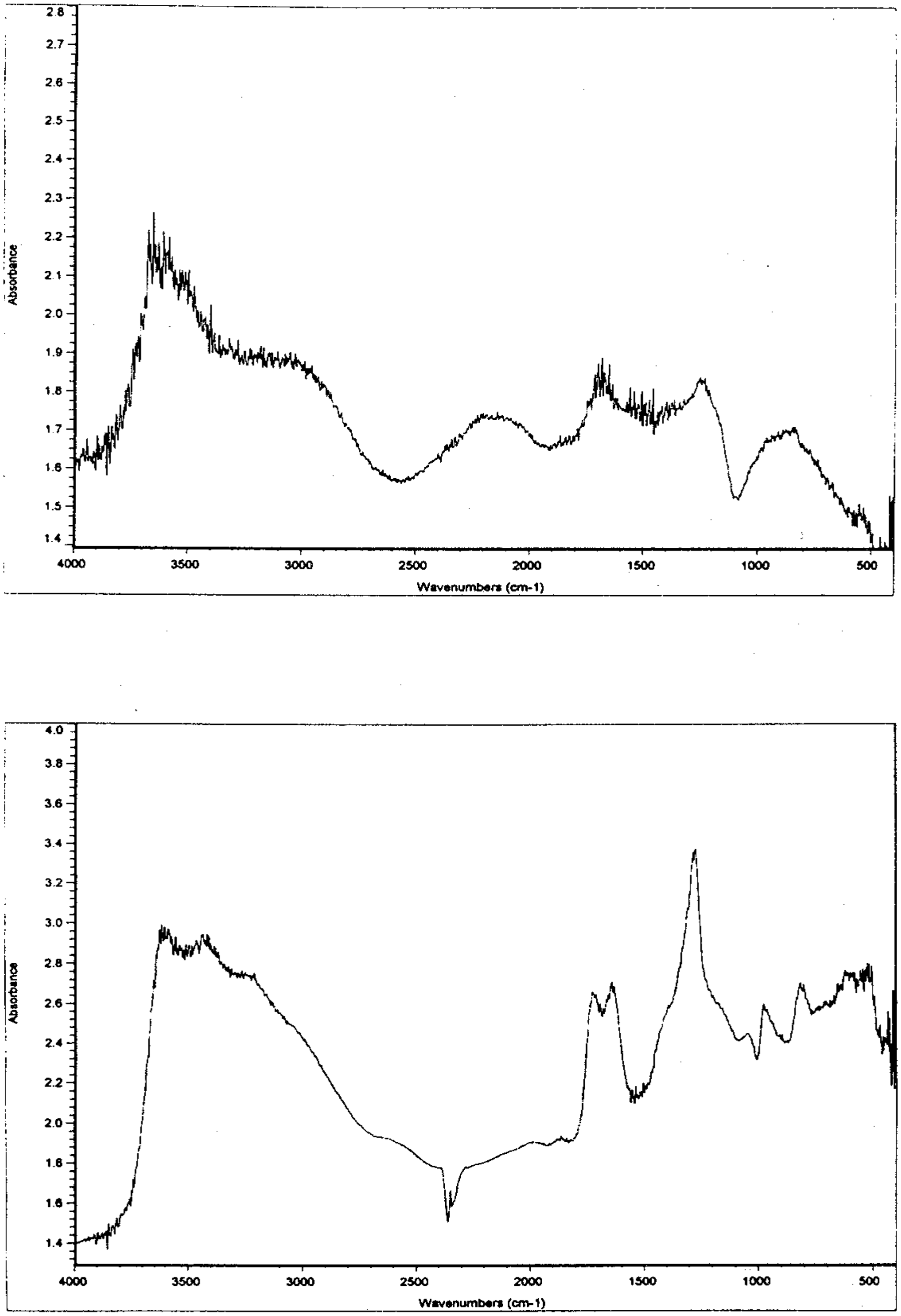

Fig. 2. Fourier Transform Infrared (FTIR) spectra of 1) Rice Hull Silica Gel and 2) *Trisyl 300*.

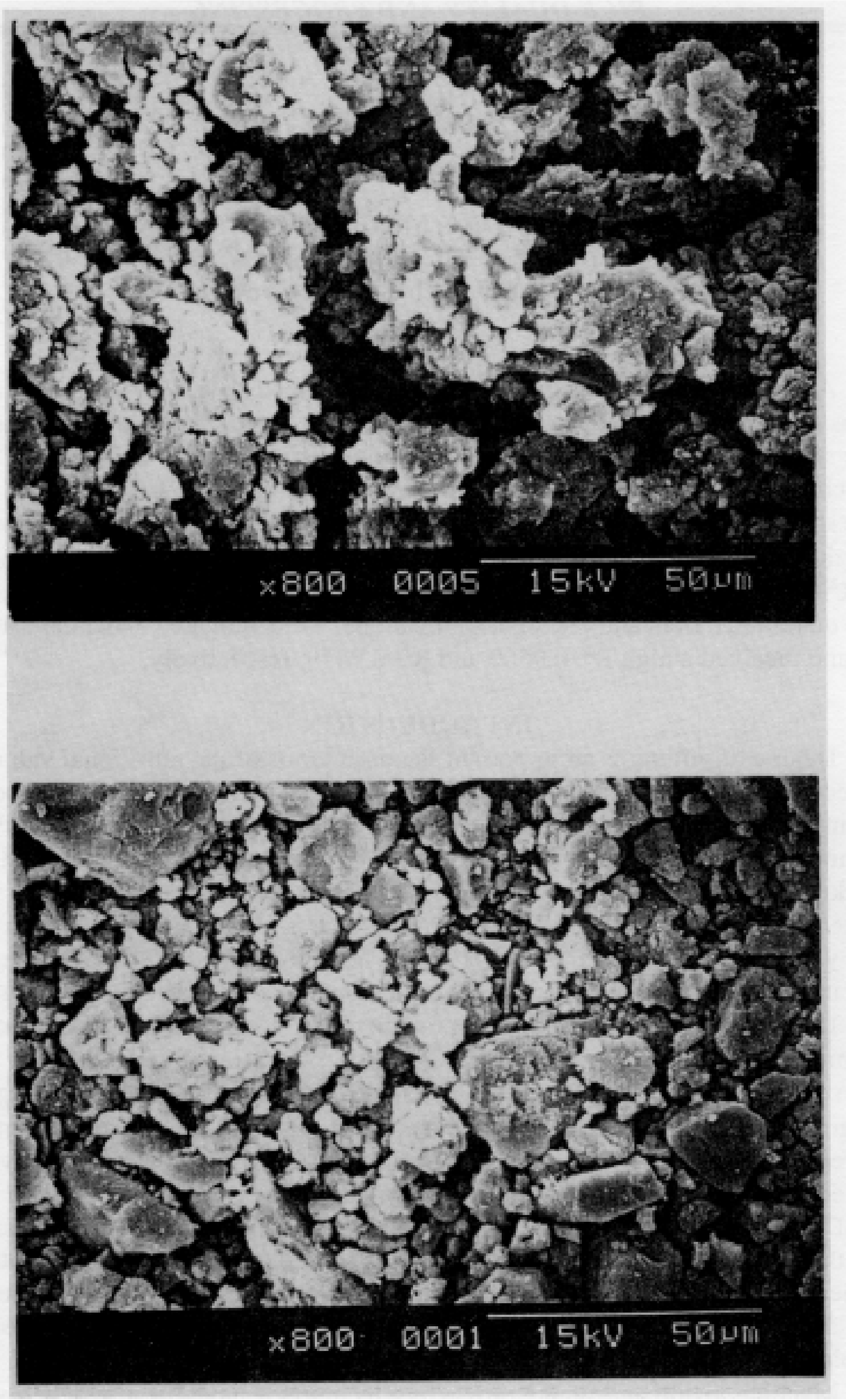

Fig. 3. Scanning electron micrographs, magnified 800x, for 1) Rice Hull Silica Gel and 2) *Trisyl 300.*

ONGOING PROJECT
RICE QUALITY AND PROCESSING

DIGITAL IMAGING METHOD FOR RAPID MEASUREMENT OF RICE DEGREE OF MILLING

W. Liu, Y. Tao, T.J. Siebenmorgen and H. Chen

ABSTRACT

A digital image analysis method was developed to quickly and accurately measure the degree of milling (DOM) of rice. The digital image analysis method was statistically compared to a chemical analysis method for evaluating DOM, which consisted of measuring surface lipids concentration (SLC) of milled rice. The surface lipid area percentage (SLAP) obtained by the image analysis method and the SLC obtained by chemical analysis had a high coefficient of determination of R^2=0.9819 using a quadratic model and R^2=0.9703 using a logarithmic model. The quadratic model and the logarithmic model were validated using the test data set and received a high R^2=0.9502 and R^2=0.9459, respectively.

INTRODUCTION

Degree of milling is an important factor in terms of the nutritional value and the economic return of the milled rice. Low-DOM-level rice contains more protein, vitamins, minerals and lipids than high-DOM rice (Wadsworth et al., 1991). Although low-DOM-level rice has greater nutritional value, it often has a lower market appeal because most consumers prefer the taste and appearance of well-milled rice. Additionally, the degree to which rice is milled inversely affects head rice yield (Sun and Siebenmorgen, 1993). Therefore, adjusting DOM during the rice milling operations is essential for optimizing quality and economic return.

DOM can be measured by several methods, including visual inspection, chemical analysis and optical measurements. Traditionally, DOM has been determined through visual inspection by trained personnel. For official grading, this judgment is made by comparing a sample to one of four official samples representing the four DOM grades (under milled, lightly milled, reasonably well milled and well milled) defined by the United States Standards for Milled Rice (USDA, 1979). The closest similarity between the official representative sample and the inspection sample determines the DOM grade. Visual inspection is not only subjective but also lacking in terms of quantitatively assessing the milling degree. For accurate measurement, more objective and quantitative methods must be employed to determine DOM.

Machine vision and image processing techniques have been widely applied throughout the agricultural and food processing fields, particularly in the quality inspection and sorting of food materials. Machine vision techniques provide a quick and objective means for measuring or evaluating the visual features of products. Researchers reported using these techniques for fruit inspection (Tao et al., 1990; Tao, 1997; Wen and Tao, 1997), corn kernel breakage and stress crack classification (Liao et al., 1993) and detection (Yie et al., 1993) and wheat classification (Zayas et al., 1996; Zayas and Steele, 1996; Shatadal et al., 1995). However, there are few reports on using machine vision to measure DOM of rice. Fant et al. (1994) discussed using gray-scale intensity to measure DOM. Although they classified rice into the DOM grades recognized by the United States Standards for Milled Rice, they did not attempt to quantify DOM on a linear scale.

This paper presents an image analysis method for quantitative measurement of the SLC of the milled rice kernels as an indication of DOM. The specific objectives of the research were: (1) to develop a digital image analysis system to measure the DOM (expressed quantitatively as SLC) of rice kernels and (2) to evaluate the performance of the machine vision system by correlating the results to a chemical analysis method.

PROCEDURES

System Overview

A machine vision system using an area-scan CCD color camera was developed, as shown in Figure 1. The color camera, equipped with a 50-mm lens and a 40-mm C-mount lens extension tube, was mounted in an enclosure that housed a fiber optic lighting source and a rice roller conveyer. The camera was set 101.6 mm (4 in.) above the roller conveyer, and the red channel of the camera was used to capture the images. A fiber optic lighting source was used to illuminate the rice kernels. The fiber optic lighting source was set 101.6 mm (4 in.) apart and 88.6 mm (3.5 in.) above the rice roller conveyer. The roller rotated the rice kernels to enable the camera to view each rice kernel to capture a full surface image. Two operational modes, manual rotation and motorized automatic scan, were developed for capturing the rice kernel images. Only manual rotation mode was used in this research. To reduce reflection of the ambient light, the internal surface of the enclosure and the surface of the roller were painted flat black. A personal computer with an image digitizer and image processing boards was used to collect the rice kernel images. Under the above configuration of the imaging system, the horizontal resolution of each rice kernel image was 6.998×10^{-4} in./pixel (1.775×10^{-2} mm/pixel) and the vertical resolution was 1.748×10^{-4} in./pixel (4.44×10^{-2} mm/pixel).

Surface Lipid Extraction Using Chemical Component Analysis

Surface lipids were extracted using a Soxtec System HT, which consisted of an extraction unit and a service unit (Chen et al., 1997). A 5-g head rice sample was weighed into a cellulose extraction thimble 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 liter of distilled water) supplied by the service unit. The vapor was condensed into the thimble to extract most of the surface lipids 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 lipids on the surfaces of the kernels. After rinsing, the fluid flow through the condenser was discontinued, and the solvent from the thimble was allowed to drain for 15 min. The extraction cup was heated at 100 °C for 30 min to measure dry matter, which represented the surface lipids extracted. The SLC was the weight of the surface lipids (W_{sl}) expressed as a percentage of the weight of the milled rice (W_m), which was 5 g in this experiment:

$$SLC = \frac{W_{sl}}{W_m} \times 100\ (\%) \qquad (1)$$

Surface Lipid Evaluation by Image Analysis

The SLC was also evaluated by the machine vision system. The milled rice kernel image (MRKI) was acquired by the machine vision system. Under the manual rotation mode, the MRKI of each rice kernel was obtained by combining two images representing two sides of the rice kernel. The MRKI is processed to remove the background by using a threshold $T_0 = 10$. This resulted in a binary rice image (BRI):

$$BRI\ (x,y) = \begin{cases} 1, & \text{if } MRKI\ (x,y) > T_0 \\ 0, & \text{otherwise} \end{cases} \qquad (2)$$

where the (x, y) is the coordinate of a pixel in the MRKI and BRI.

The whole rice surface area was measured from the BRI by counting the number of pixels in a window containing the rice kernel.

$$AREA_{whole} = \sum_{y=0}^{L-1} \sum_{x=0}^{W-1} BRI\ (x,y) \qquad (3)$$

where the L and W represented the length and the width, respectively, of the window containing the rice kernel in the BRI, and the $AREA_{whole}$ is the whole rice kernel surface area. The surface lipid image (SLI) is contingent upon the MRKI based on the threshold T_1:

$$SLI\ (x,y) = \begin{cases} 1, & \text{if } MRKI\ (x,y) > T_1,\ T_0 < T_1 \leq 255 \\ 0, & \text{otherwise} \end{cases} \qquad (4)$$

The upper limit of T_1 was 255, which was determined by the 8-bit image digitizer. The surface lipid area was calculated by summing the pixels in the window that surrounded the surface lipid area in the SLI.

$$AREA_L = \sum_{y=0}^{M-1} \sum_{x=0}^{N-1} SLI\ (x,y) \qquad (5)$$

where the M and N represented the length and the width of the window surrounding only the surface lipid area in the SLI, and $AREA_L$ is the entire surface lipid area of the rice kernel surface.

For given values of T_1, the SLAP can be calculated by the following formula:

$$SLAP = \frac{AREA_L}{AREA_{Whole}} \qquad (6)$$

During image processing, the threshold T_0 and T_1 can be adjusted by the user for sensitivity adjustment and calibration. Examples of a raw rice kernel image and the resulting surface lipid images at three values of T_1 are shown in Figure 2.

Samples and Experimental Procedure

The rice used for this study consisted of 17 samples of long-grain rice (‘Kaybonnet’) with different DOMs. All samples were selected from a single lot and milled for various durations ranging from 5 to 45 s. Using the solvent extraction procedure described above, the surface lipid concentration of each sample with two replications was determined.

From each of the 17 samples, the image processing system was used to analyze 40 randomly selected rice kernels. These 40 kernels were separated into two groups of 20 kernels each. The first 20 from each sample were used to establish the calibration equations, and the other 20 were used to test the accuracy of the calibration equations. The front lighting was adjusted for the highest contrast between the surface lipid and endosperm. To control intensity, a plane plastic reference material of 2 mm long by 2 mm wide was placed in the camera’s field of view. The lighting system and the camera aperture were adjusted so that the maximum intensity level of the plastic reference material remained constant at 130 under a full intensity scale of 255. A total of 1360 images (17 samples x 40 kernels/sample x 2 images/kernel) were collected.

The rice data were analyzed using regression techniques provided by SAS software (SAS, 1993). Statistical models were developed by using the REG procedure and the GLM procedure in the SAS software.

RESULTS AND DISCUSSION

Figure 2 shows a milled rice kernel image and surface lipid images extracted at three values of T_1 (130, 145 and 160). The square block is the intensity control reference material. The rice edge in the surface lipid images has been added for visual clarity. From these images, surface lipid distribution was clearly observed.

Table 1 shows the SLC obtained by the solvent extraction procedure and the surface lipid areas percentage (SLAPs) obtained by the image analysis method for creating the calibration equation. SLC data of each sample in Table 1 are the average of two replications. SLAP (T_1=130), SLAP (T_1=145), SLAP (T_1=160) values are the average of 20 replications of SLAP image processing results at the threshold values (T_1) of 130, 145 and 160, respectively. These values represent the calibration data set used to develop the statistical models. As the value of threshold T_1 increased, the SLAP decreased. The REG procedure in SAS suggested that the SLAP values at the threshold T_1=130 were significant at the 0.05 significance level, while the SLAP values at the threshold T_1=145 and 160 were not significant at the 0.05 significance level. Therefore, the SLAP values at the threshold T_1=130 were used for developing calibration equations. The T_1 value under 130 was not used in this study because the processed images could not represent the actual surface lipid images when the T_1 value was less than 130 based on the system setting.

Figure 3 shows a strong exponential relationship between SLC and milling duration as indicated by a high coefficient of determination (R^2) of 0.9779.

Also, Figure 4 shows a strong exponential relationship between SLAP and milling duration as indicated by a high coefficient of determination (R^2) of 0.9723.

Figure 5 shows the quadratic relationship between SLC obtained by the solvent extraction procedure and SLAP obtained by the image analysis method. The non-linearity between SLC and SLAP is believed to be due to the fact that the solvent extraction procedure extracts the entire surface lipid mass while the image analysis method indicates the amount of surface lipids by surface area. The relation between SLC and SLAP was:

$$SLC = -15.905SLAP^2 + 7.9795SLAP + 0.1852 \qquad (7)$$

with R^2=0.9819, where SLAP value was obtained by the image analysis method at threshold T_1=130.

Figure 6 shows the semi-logarithmic plot of SLAP obtained by image analysis vs. SLC obtained by the solvent extraction procedure and illustrates the linear relationship between the two methods. The resulting calibration equation gives:

$$SLC = 0.41161n(SLAP) + 1.7846 \qquad (8)$$

with R^2=0.9703.

The high coefficients of determination (R^2=0.9819 in Figure 5 and R^2=0.9703 in Figure 6) indicate a significant correlation between these two analysis methods. Therefore, once the SLAP data are obtained by the image analysis method, the SLC can be predicted by either quadratic regression Equation 7 or logarithmic regression Equation 8. To test the accuracy of these regression equations, the validation rice group (data given in Table 2) was used.

In Table 2, the SLAP was obtained from the validation group by the image analysis method for testing the accuracy of the calibration equations. The SLAP data of each sample were the average of 20 replications in the test group. The predicted SLC values were calculated by Equations 7 and 8, and the relative error was calculated by:

$$\text{Error} = \frac{\text{Actual SLC - Predicted SLC}}{\text{Actual SLC}} \qquad (9)$$

where Actual SLC represents the SLC value obtained by the solvent extraction procedure in Table 1.

The error values in Table 2 indicate the accuracy of the image analysis method. From Table 2, the average errors of the predicted SLC values of the calibration Equations 7 and 8 are -1.03 % and -1.08%, respectively. The small average errors indicate that both calibration equations are accurate and can predict the SLC from the solvent extraction procedure if the SLAP from image analysis is given.

Figures 7 and 8 show the relationship between the actual SLC value obtained by the solvent extraction procedure and the predicted SLC value of Equations 7 and 8, respectively. The linear relationship in either of these figures indicates that the predicted SLC values were close to the actual SLC values. The linear relationship also shows that the calibration equation was accurate over the range of DOM levels tested.

Results obtained in this study were based on one rice cultivar, Kaybonnet long-grain rice. Other rice cultivars and types (short- and medium-grain) should be tested in further research.

In summary, a machine vision system was developed to evaluate rice DOM by measuring SLAP values of individual kernels. Two statistical models, a quadratic calibration equation and a logarithmic calibration equation, were obtained to predict the SLC of milled rice. The small predicted errors indicated the accuracy of both calibration equations. In contrast to the time-consuming solvent extraction procedure, the image analysis method using machine vision can quickly obtain the SLAP value of milled rice. By using the statistical model developed in this study, the SLC value from the solvent extraction procedure was easily and rapidly predicted.

SIGNIFICANCE OF FINDINGS

Digital imaging has great potential for rapid measurement of rice degree of milling. Machine vision can be a useful tool in providing an alternative method to manual and chemical analysis methods in estimating surface lipid contents of milled rice.

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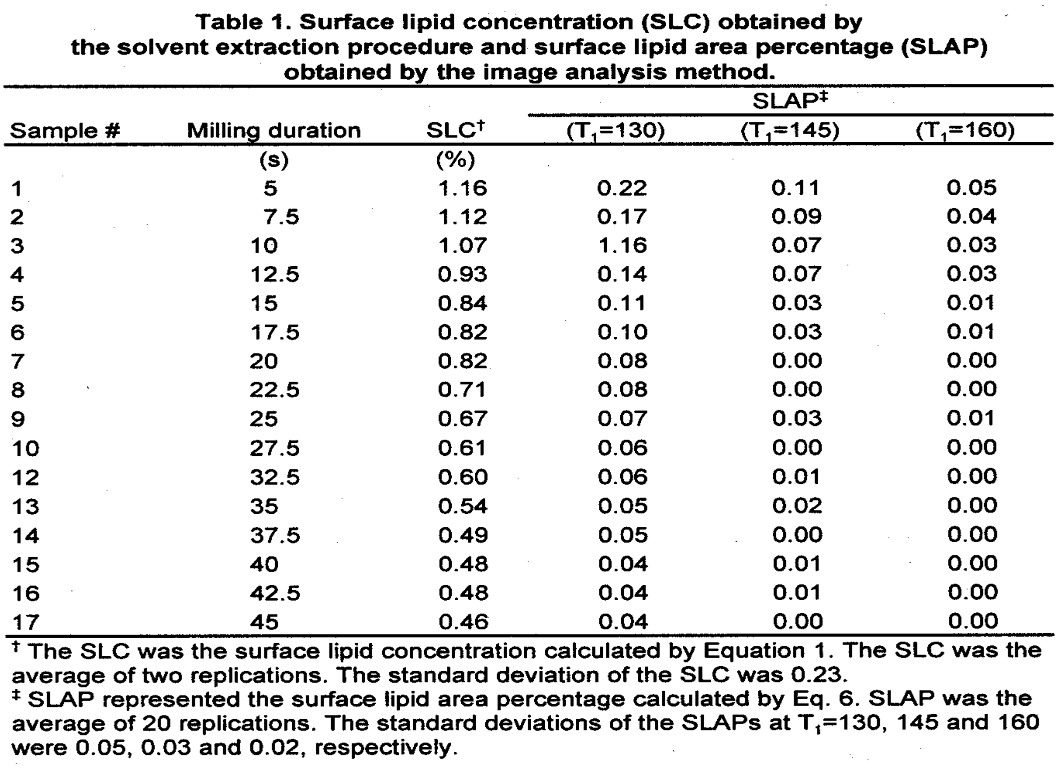

Table 1. Surface lipid concentration (SLC) obtained by the solvent extraction procedure and surface lipid area percentage (SLAP) obtained by the image analysis method.

			SLAP‡		
Sample #	Milling duration	SLC†	(T_1=130)	(T_1=145)	(T_1=160)
	(s)	(%)			
1	5	1.16	0.22	0.11	0.05
2	7.5	1.12	0.17	0.09	0.04
3	10	1.07	1.16	0.07	0.03
4	12.5	0.93	0.14	0.07	0.03
5	15	0.84	0.11	0.03	0.01
6	17.5	0.82	0.10	0.03	0.01
7	20	0.82	0.08	0.00	0.00
8	22.5	0.71	0.08	0.00	0.00
9	25	0.67	0.07	0.03	0.01
10	27.5	0.61	0.06	0.00	0.00
12	32.5	0.60	0.06	0.01	0.00
13	35	0.54	0.05	0.02	0.00
14	37.5	0.49	0.05	0.00	0.00
15	40	0.48	0.04	0.01	0.00
16	42.5	0.48	0.04	0.01	0.00
17	45	0.46	0.04	0.00	0.00

† The SLC was the surface lipid concentration calculated by Equation 1. The SLC was the average of two replications. The standard deviation of the SLC was 0.23.

‡ SLAP represented the surface lipid area percentage calculated by Eq. 6. SLAP was the average of 20 replications. The standard deviations of the SLAPs at T_1=130, 145 and 160 were 0.05, 0.03 and 0.02, respectively.

Table 2. An accuracy analysis of calibration Equations 7 and 8.

Sample #	Milling duration (s)	SLAP†	Predicted SLC value of Eq. 7‡	Error of Eq. 7	Predicted SLC value of Eq. 8	Error of Eq. 8§
1	5	0.23	1.18	-0.02	1.18	-0.02
2	7.5	0.22	1.17	-0.05	1.16	-0.04
3	10	0.14	1.00	0.06	0.98	0.08
4	12.5	0.11	0.86	0.08	0.87	0.07
5	15	0.14	0.97	-0.16	0.96	-0.15
6	17.5	0.11	0.89	-0.09	0.89	-0.09
7	20	0.08	0.74	0.09	0.77	0.06
8	22.5	0.08	0.72	-0.01	0.74	-0.04
9	25	0.07	0.65	0.03	0.67	0.00
10	27.5	0.06	0.63	-0.02	0.65	-0.06
11	30	0.06	0.61	-0.03	0.63	-0.07
12	32.5	0.06	0.61	-0.02	0.63	-0.06
13	35	0.05	0.56	-0.04	0.58	-0.07
14	37.5	0.05	0.52	-0.07	0.52	-0.06
15	40	0.04	0.49	-0.01	0.47	0.02
16	42.5	0.04	0.45	0.07	0.42	0.14
17	45	0.04	0.45	0.02	0.41	0.11
∑error/17 (%)				-1.03		-1.08

† The surface lipid area percentage (SLAP) was calculated by Equation 6 at threshold T_1=130 using 40 kernel images from 20 kernels of each sample.

‡ Error was obtained by Equation 9.

§ Predicted surface lipid concentrations (SLC) value was calculated by Equation 7 or Equation 8. The standard deviations of SLC value obtained by Equation 7 or Equation 8 were 0.24 and 0.24, respectively.

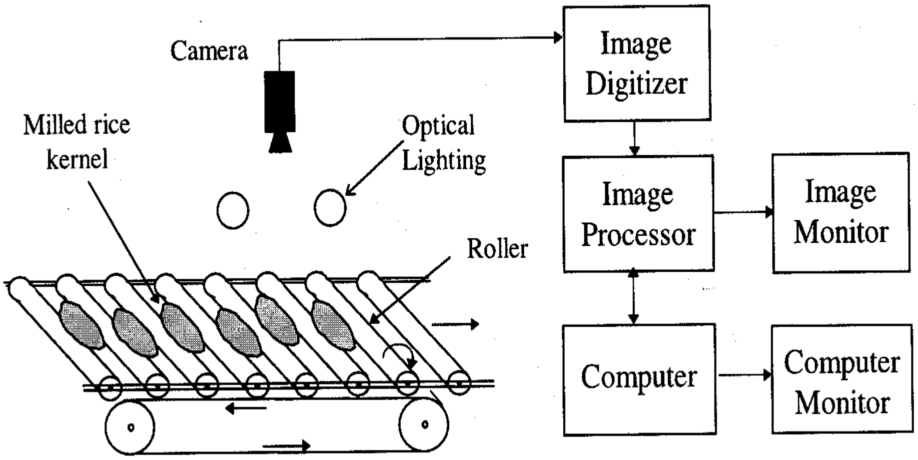

Fig. 1. Schematic of the rice imaging system.

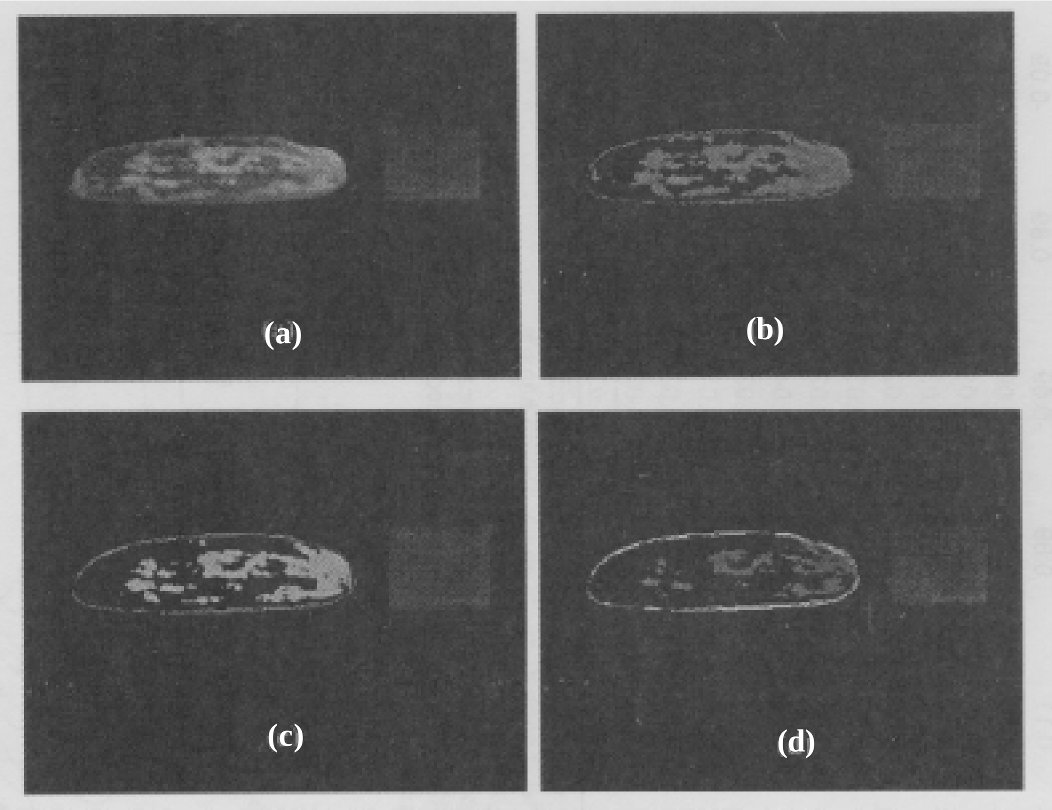

Fig. 2. Image evaluation of surface lipid concentration at three threshold T_1 values. (a) is a milled rice kernel image, (b), (c) and (d) are the lipid extracted from (a) at T_1=130, 145 and 160, respectively. The rice boundary in (b), (c) and (d) is artificially added for visual clarity. The square is a plain plastic reference material for intensity control.

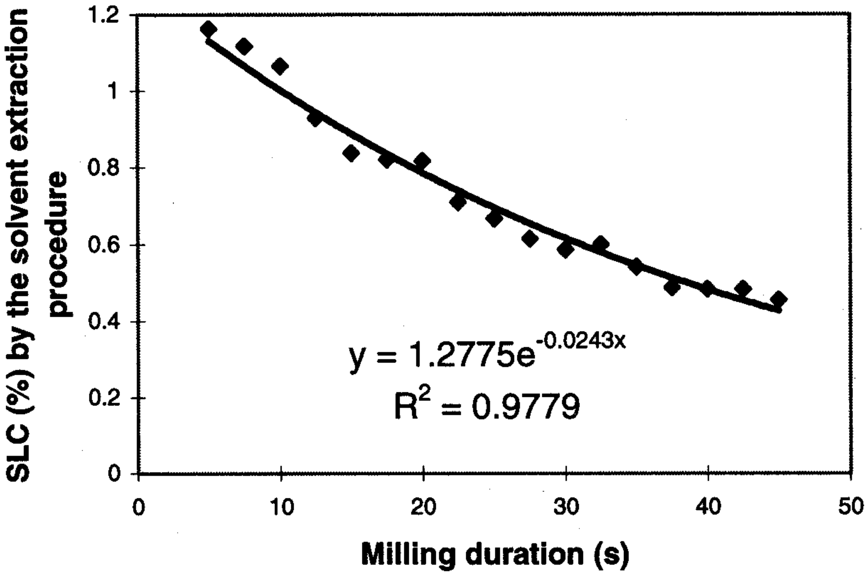

Fig. 3. Surface lipid concentration (SLC) obtained by the solvent extraction procedure vs. milling duration, using the calibration data set.

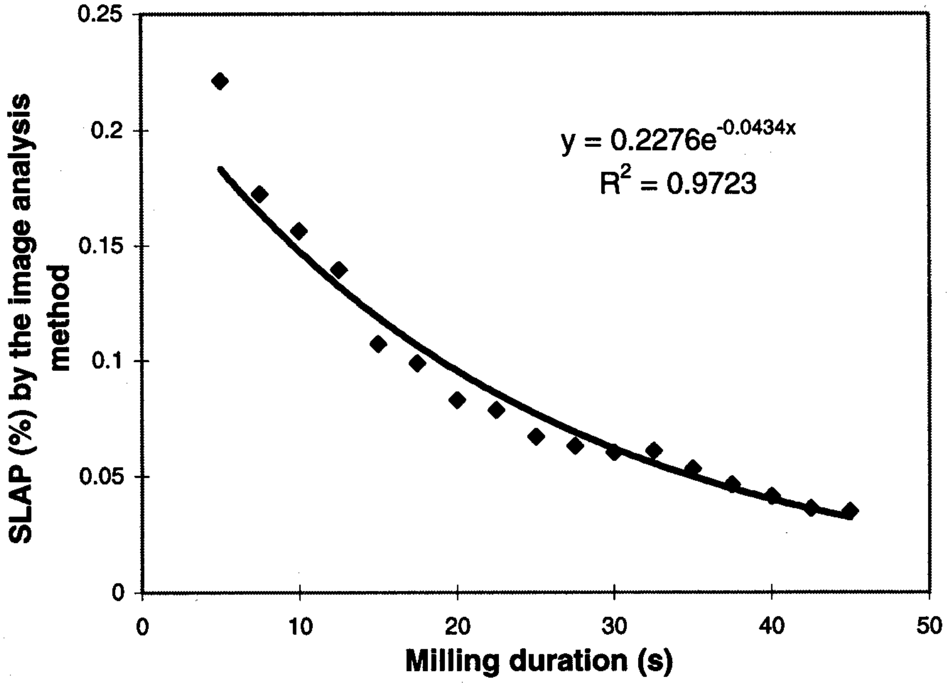

Fig. 4. Surface lipid area percentage (SLAP) obtained by the image analysis method at a threshold T_1 value of 130 vs. milling duration, using the calibration data set.

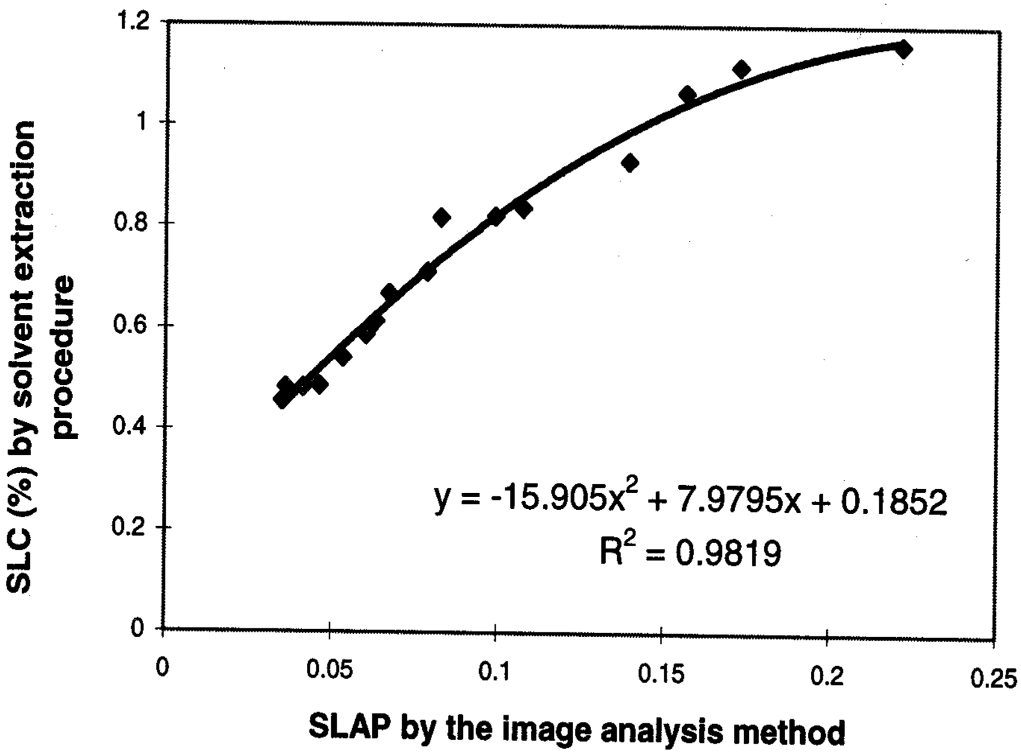

Fig. 5. Surface lipid area percentage (SLAP) obtained by the image anaysis method at a threshold T_1 value of 130 vs. surface lipid concentration (SLC) obtained by the solvent extraction procedure, using the calibration data set.

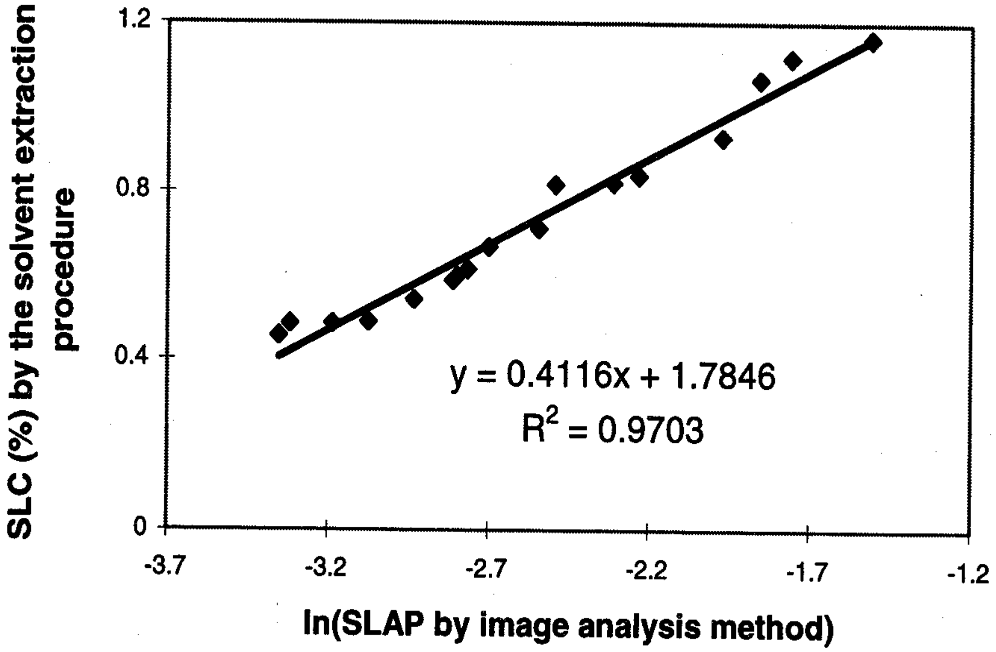

Fig. 6. The logarithmic plot of surface lipid area percentage (SLAP) obtained by the image analysis method at threshold T_1=130 vs. surface lipid concentration (SLC) obtained by the solvent extraction procedure based on the calibration data set.

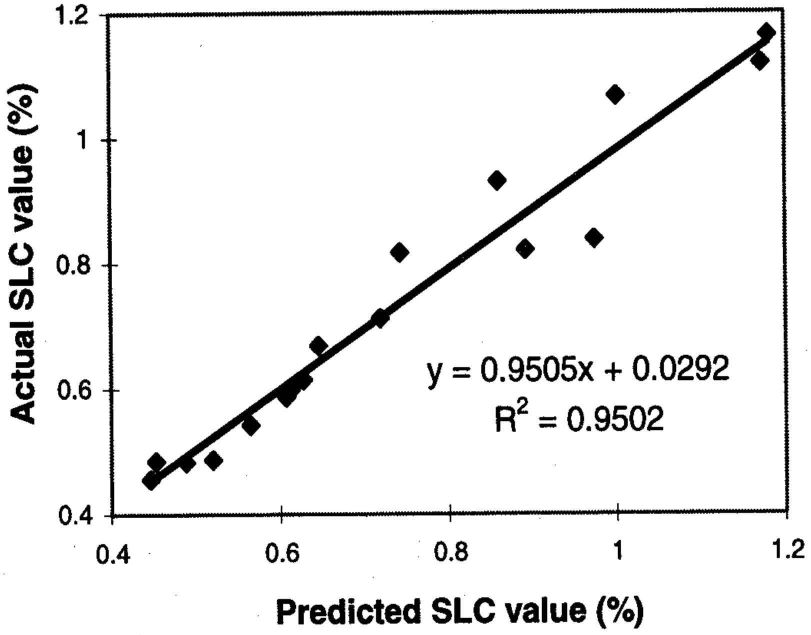

Fig. 7. Predicted surface lipid concentration (SLC) using Equation 7 based on the test data set vs. the actual SLC obtained by the solvent extraction procedure.

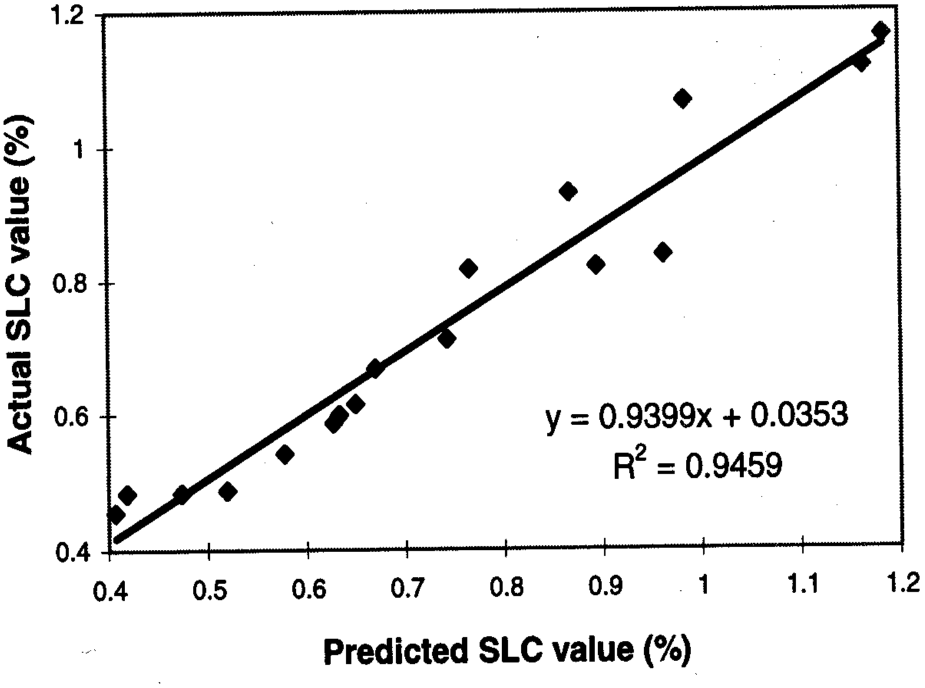

Fig. 8. Predicted surface lipid concentration (SLC) using Equation 8 based on the test data set vs. the actual SLC obtained by the solvent extraction procedure.

BIN-SCALE VERIFICATION OF FUNCTIONAL CHANGES OCCURRING DURING ROUGH RICE STORAGE

B.P. Marks, M.J. Daniels and T.J. Siebenmorgen

ABSTRACT

Bin-scale storage studies have been conducted for 2 years in which samples of rough rice are removed from the bins periodically and tested for functional properties, including head rice yield, cooking behavior and amylography (i.e., peak and final viscosity). Preliminary data have confirmed that head rice yield and peak viscosity increase significantly ($p<0.05$) during the first four months of storage; however, the increases were substantially less than those observed in corresponding laboratory-scale storage studies. Current and future efforts are evaluating whether laboratory-based models for age-induced functional changes might be applied to accurately predict changes in rice quality during bin-scale storage.

INTRODUCTION

Rough rice storage history is known to affect end-use properties of rice (Villareal et al., 1976; Tsugita et al., 1983; Sajwan et al., 1989; Chrastil, 1990; Dhaliwal et al., 1990; Hamaker et al., 1993; Tamaki et al., 1993). Because of this knowledge, it is common practice to hold (i.e., age) new crop rough rice for 60 to 90 days prior to milling, in order to effect desirable changes in both milling and processing quality. However, the previous research in this area has yet to result in practical models that might quantitatively predict changes in rice properties as functions of rough rice storage conditions. Such models could be useful tools in optimizing both on-farm and commercial storage management to deliver rice that most closely meets the specifications of a target market.

Recently, we have shown that statistical models can be used to identify which postharvest parameters have significant effects on the milling, cooking and amylograph properties of rice (Perdon et al., 1997) and how the postharvest parameters interact to influence age-induced changes in rice properties. However, these models were developed with data from laboratory-scale storage studies. While such studies have the advantage of allowing a wide range of postharvest treatment, they do not exactly replicate bin-scale storage. The main differences are that the temperature and moisture content are held constant in the laboratory studies, while temperature and moisture actually fluctuate during bin-scale drying and storage. Therefore, there is a need to determine whether storage models developed in laboratory studies are applicable to real-world storage systems.

This project is part of an overall program aimed at developing quantitative, predictive models for the physicochemical properties of rice, as functions of storage history (i.e., time, temperature, moisture, microbial populations, previous postharvest treatments, etc.), in order to better maintain and improve the quality of rice and rice products. The specific objectives of this on-going field study are:

1. To validate previous and on-going laboratory studies with respect to changes in rice quality.
2. To evaluate the performance of two on-farm drying and storage systems 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 focuses on the current results for objective 1. The project is continuing through the 1997-98 storage season, during which additional data are being collected for all three objectives.

PROCEDURES

Bin Drying and Storage

In 1996, three on-farm bins near DeWitt, Arkansas were loaded with rice at harvest (one with cv. 'Bengal' and two with cv. 'Cypress'); the average initial moisture contents (mc) of the three bins were 20.2, 15.7 and 14.7%, respectively. Samples of rice were taken periodically (0 to 24 wks), from depths of 3 and 6 ft. The same procedures are being repeated in 1997 (two bins of Cypress, with initial mc of 18.1 and 19.0%), with additional sampling at a depth of 9 ft. Samples are analyzed for mc, head rice yield (HRY), amylography and cooking behavior. The fans on these bins are controlled by the Sentry-Pac™ system, both for drying and subsequent aeration during storage. The management procedures used by the producer are being monitored, as are the actual air conditions during drying and storage.

In 1997, an additional on-farm study was initiated in which Bengal and Cypress were both dried in a two-stage drying process utilizing a continuous crossflow dryer followed by natural-air in-bin drying. The initial mc was 20.0 and 17.5% for Bengal and Cypress, respectively. The dryer was operated at two different conditions (130°F air for 60 min and 118°F for 20 min). For each condition, nine small lots (~20 lb) were taken from the dryer outlet and equilibrated to 10, 12 or 14% mc and are being stored at 40, 70 or 100°F in a laboratory storage study. The changes in functional properties during aging for the constant-condition laboratory samples will be compared with the changes occurring for the same rice stored in farm-scale bins at the test site.

Functional Analyses

Head rice yield is determined by dehulling and milling 150 g of rough rice in a laboratory milling system (McGill #2; Seedboro Equip. Co., Chicago, Illinois) to a milling degree of 87 to 93 on a Satake MM-1B milling meter (Satake, Hiroshima, Japan). Head rice is separated from the brokens on a shaker table, and HRY is calculated as the ratio of head rice weight to the original rough rice weight.

Cooking ratios are determined in duplicate. Twenty grams of raw head rice are placed in a wire basket (7 cm tall and 3.5-cm diameter). The wire basket is placed in a 250-ml beaker filled with 200 ml of near boiling water; the beaker is then placed into a kettle of boiling water. The rice is cooked for 20 min and allowed to drain for 10 min. The water absorption is calculated as the ratio of water absorbed to initial rice weight. The volume expansion is calculated as the ratio of cooked rice height to raw rice height.

For amylography, 60 g of head rice are ground in a UDY Cyclotec mill (Model 1093, Tecator, Inc., Hoganas, Sweden). The flour is mixed with water to produce a slurry with 8% dry matter, after determining the mc of the flour (Juliano et al., 1985). Subsequently, the slurry is subjected to a defined temperature treatment in a Brabender viscograph-E, according to a modified version of the AACC Method 61-01 (AACC, 1996) for milled rice. The peak and final viscosity are extracted from the resulting amylograph.

Based on the functional analyses described above, analyses of variance are being conducted to determine which postharvest parameters significantly affect these quality factors. Subsequently, we will evaluate the accuracy of models developed from laboratory-scale studies in predicting functional changes in bin storage.

RESULTS AND DISCUSSION

Thus far, experimental results indicate that functional changes are similar but less dramatic during bin-scale storage than during laboratory-scale storage. For example, the increase in HRY in the bin-scale study (Figure 1) was statistically significantly ($p<0.05$); however, the increase was substantially less than that observed in the laboratory-scale study (Figure 2). The difference might be attributed to the differences in storage conditions. The rice in the laboratory-scale study was held at constant temperature and moisture. In contrast, the rice in the bin-scale study was subjected to both fluctuating mc and temperature during drying and storage. It is possible that these fluctuations in storage conditions might reduce the magnitude of the positive effects occurring during aging. Because of the uncontrolled conditions during the bin study, the HRY for each bin was modeled as a function of only storage duration, which resulted in R2 values of 0.22 to 0.48. In contrast, the laboratory-based statistical model included temperature, mc and storage duration, to result in an R2 value of 0.84, implying that the variation in HRY was more fully explained by the storage conditions.

Similar results have been obtained for the cooking and amylograph properties. The R2 values of statistical models based on the bin data range from 0.23 to 0.51 and 0.46 to 0.65 for cooking and amylograph properties, respectively. Again, these models included only storage duration. In contrast, models for the same properties, based on the laboratory-scale data, resulted in R2 values of 0.79 for water absorption during cooking and 0.73 for peak viscosity (Daniels et al., 1998). These models included temperature, mc and storage duration in explaining the variation in functional properties during storage.

It remains to be determined whether the models developed from laboratory-scale tests might be applied to accurately predict age-induced changes in rice quality during bin-scale storage. The effects of fluctuating storage conditions (i.e., temperature and moisture) need to be evaluated in the laboratory-scale tests to determine whether this is what offsets the positive aging effects that have been previously observed.

SIGNIFICANCE OF FINDINGS

Preliminary data verify that statistically significant increases in rice quality occur due to aging during rough rice storage. There is a need to further evaluate whether recently developed models, based on laboratory-scale studies, can be accurately applied to predict functional changes in rice during bin storage. If this is possible, and the effects of transient conditions can be included, then these models could be useful tools in developing improved management recommendations for rice storage.

ACKNOWLEDGMENTS

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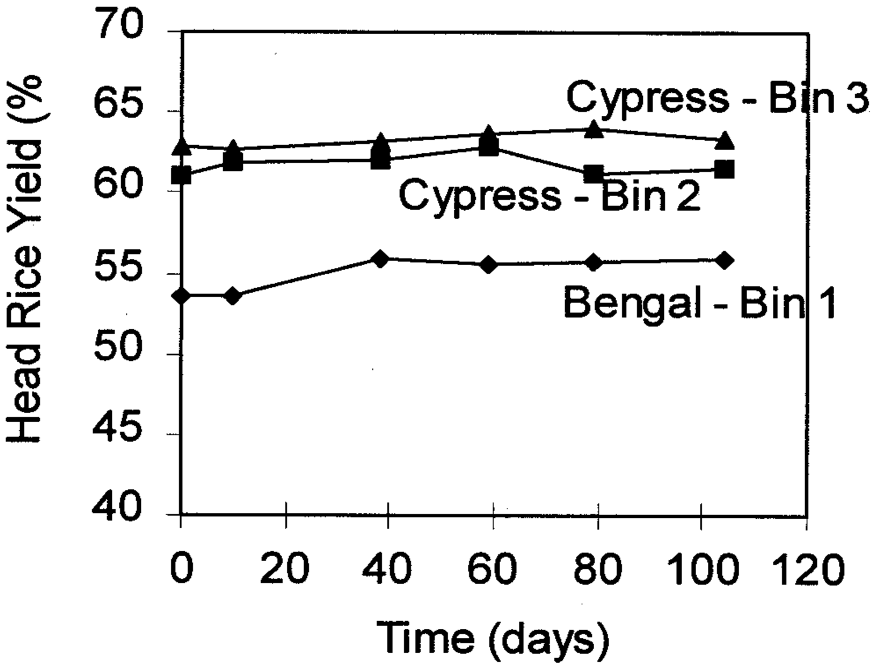

Fig. 1. Head rice yield versus storage duration for rice stored in the 1996-97 bin-scale storage study. Each data point represents the average of samples probed from six locations in each bin.

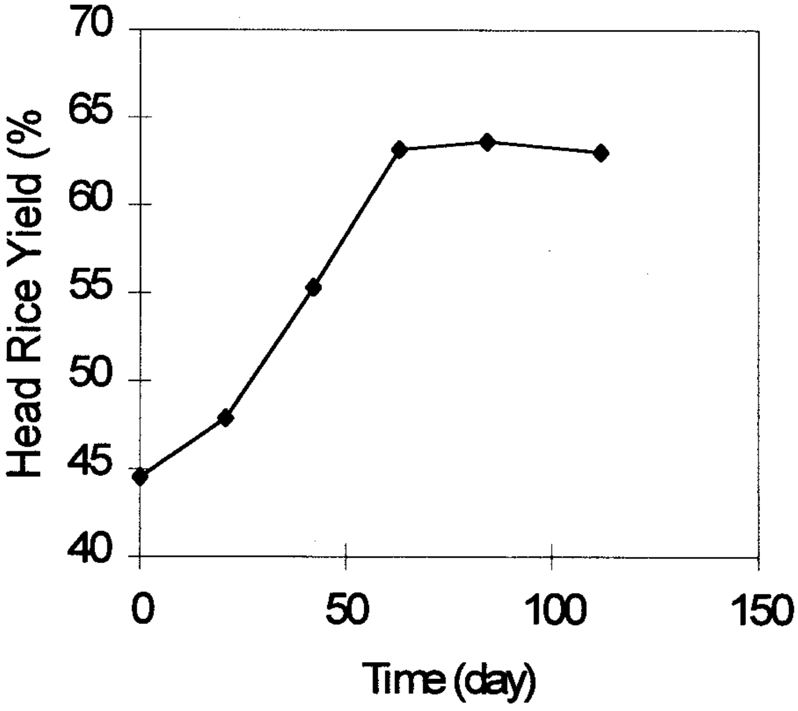

Fig. 2. Head rice yield versus storage duration for low-temperature dried 'Cypress' rice stored at 12% moisture content and 70°F in the 1996-97 laboratory-scale storage study (Daniels et al., 1998).

SENSORY PROFILING OF COOKED RICE AND ITS CORRELATION TO INSTRUMENTAL PARAMETERS USING AN EXTRUSION CELL

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ABSTRACT

Cooked rice texture of samples subjected to various processing and storage conditions was evaluated using both descriptive sensory methods and an instrumental cell extrusion test. Ten sensory textural characteristics were evaluated, and five instrumental parameters were used to evaluate predictive models for the sensory characteristics evaluated. Non-linear predictive models with R-squares ranging from 0.22 to 0.70 were obtained for sensory attributes such as adhesiveness to lips, hardness, cohesiveness of mass, roughness of mass, toothpull, toothpack and particle size.

INTRODUCTION

Texture of cooked rice has been shown to be affected by factors such as rice cultivar, amylose content and gelatinization temperature (Juliano and Perez, 1983; Del Mundo et al., 1989). Okabe (1979) reported that hardness and stickiness govern palatability of cooked rice, with hardness being the more important parameter.

Sensory profiling or descriptive analysis methods consist of formal procedures for assessing, in a reproducible manner, specific attributes of a sample and rating their intensity on a suitable scale. These methods can be used for evaluating aroma, flavor, appearance and texture, separately or in combination. As such, descriptive sensory profiling is the most sophisticated sensory tool available to the sensory professional (Stone and Sidel, 1993). Results from descriptive analysis provide a complete sensory description of an array of products and provide a basis for distinguishing those sensory attributes that are important for acceptance by consumers (Stone and Sidel, 1993).

Apart from the use of sensory techniques, an alternative approach to the evaluation of texture properties involves the use of instruments specially designed for the evaluation of the physical characteristics of foods. One of the most popular methods (Del Mundo et al., 1989) involves the use of an Ottawa Texture Measuring System extrusion cell. With this empirical method, the maximum force during the extrusion process is recorded and used to correlate with the sensory perception of hardness (Del Mundo et al., 1989). However, correlations between sensory and instrumental data are often poor (Perez et al., 1993; Del Mundo et al., 1989; Rousset et al., 1995). As a result, there is a need to develop instrumental methods that accurately predict texture sensory characteristics of cooked rice.

The objectives of this study were (1) to evaluate correlations between descriptive sensory attributes and instrumental parameters and (2) to evaluate predictive models for textural sensory characteristics of rice using instrumental parameters as predictors.

MATERIALS AND METHODS

Postharvest Treatments

Two long-grain rice cultivars ('Kaybonnet' and 'Cypress') and one medium-grain rice cultivar ('Bengal') were harvested from the University of Arkansas Rice Research and Extension Center in Stuttgart, Arkansas in September 1996 with harvest moisture contents of 19.1, 16.5 and 17.5% (wet base), respectively. The rice was brought immediately to the rice processing labs at Fayetteville and cleaned using a Carter-Day Dockage Tester (Carter-Day Co., Minneapolis, Minnesota). It was then placed in plastic, air-tight buckets and stored at -10°C for about 1 month. The rice was then dried in a laboratory-scale dryer with a drying temperature of 43.3°C with 38.2% relative humidity (rh) for 75 min. After drying, rice samples were placed in wooden-framed, wire-mesh trays (where the layer of rice was 0.5-in. deep) and were allowed to equilibrate in air-controlled chambers until reaching a moisture content (mc) of 10, 12 and 14%, respectively. The rice was then placed in air-tight plastic buckets. A bucket of each treatment was then placed into respective storage temperatures of 4, 21 and 38°C. Samples were stored for 24 weeks before evaluation using instrumental texture and sensory analyses.

After a 24-week storage duration, samples were allowed to equilibrate to room temperature. A McGill sample sheller (husker) was used to remove the hulls and a McGill No 2 mill to remove the bran. Samples were milled to a constant degree of milling (DOM) set to @ 90. The DOM was measured using a Satake Milling Meter MM-1B.

Instrumental Texture Analysis

Sample Preparation

A 100-g milled rice sample was added to four cups of boiling water and the mixture brought back to boil. Cooking time was then adjusted to 20 min. Okabe (1979) reported that cooked rice texture changes rapidly after cooking. As a result, the rice samples were sifted immediately after cooking and rinsed for 5 min under cold water. Samples were then spread on plastic trays and covered with aluminum foil. Samples were stored at 4°C until testing. Samples were allowed to equilibrate to room temperature for 30 min.

Extrusion Test

A cylindrical extrusion cell (40 mm in diameter and 70 mm deep) was used in conjunction with a Texture Analyzer (model TAXT2, Texture Technologies, Scarsdale, New York). Perez et al. (1993) reported that an extrusion plate with holes between 3.2 and 4.8 mm in diameter best discriminated among U.S. long-grain and U.S. medium-grain cultivars. In addition, preliminary studies (data not shown) in our laboratory demonstrated the effectiveness of an extrusion cell featuring 3.2-mm-diameter holes.

Thirty-five grams of rice was weighed out in the extrusion cell for each test repetition. The cross head speed was set to 5 mm/s for a total travel of 60 mm. Data were acquired via the X-trad software (version 3.7). Force (Kg) required to extrude the sample was recorded over time (s).

Force-Deformation Curves Analysis

Five instrumental parameters—i.e. initial slope [S_{init} (Kg/s)], maximum slope [S_{max} (Kg/s)], maximum load [H (Kg)], average load [H_{avg} (Kg)] and area under the curve [A (Kg.s)]—were extracted from each force/deformation curve using the X-Trad software (Fig. 1)

Sensory Methodology

Nine professionally trained panelists (Sensory Spectrum, Chatham, New Jersey), employed by the Institute of Food Science and Engineering at the University of Arkansas, developed a sensory profile of cooked rice samples. During panel orientation, 10 textural attributes, including adhesiveness to lips, hardness, denseness, cohesiveness of mass after three chews, cohesiveness of mass after eight chews, roughness of mass, toothpull, particle size, toothpack and loose particles, were identified by the panelists as adequately describing the texture profile of cooked rice (Table 1). Intensities for each of the 10 sensory attributes studied were evaluated on a 15-cm continuous scale. The intensities for texture attributes were assessed by comparison with carefully chosen references having assigned intensities for a particular attribute. A list of the references used in the evaluation is provided in Table 1.

Samples were cooked for 20 min in household steam rice cookers (National, model SR-W10FN) with a 1:2 (vol:vol) rice to water ratio and immediately presented to the panel. The order of sample presentation was randomized across treatments but not randomized across panelists because of limited sample availability and the importance of serving temperature. Samples were presented at 71°C in glass bowls insulated with Styrofoam cups and covered with watch glasses. The panelists were instructed to monitor temperature during the test using digital thermometers and to complete the evaluation before the temperature of the sample reached 60°C. A reference rice sample was presented as a warm-up sample at the beginning of each session.

Statistical Analysis

Means for each sample evaluated were calculated for all sensory attributes as well as for instrumental parameters using PROC MEANS (SAS, 1993). Mean values were used to evaluate correlations (PROC CORR, SAS, 1993) between sensory and instrumental data. Reduced regression models were evaluated using PROC STEPWISE (Stepwise option), including all significant variables ($p<0.1$).

RESULTS AND DISCUSSION

Correlation Between Sensory Attributes and Instrumental Parameters

Hardness was found to be most highly correlated with initial slope (S_{init}, $r = 0.60$, $p<0.001$), maximum slope (S_{max}, $r = 0.60$, $p<0.001$) and maximum load (H, $r = 0.60$, $p<0.001$) (Table 2). Hardness was correlated to a lesser degree to average load (H_{avg}, $r = 0.49$, $p<0.05$) and area under the curve (A, $r = 0.52$, $p<0.01$). Cohesiveness of mass after eight chews was found to be negatively correlated with maximum slope ($r = -0.52$, $p<0.01$). Roughness of mass was found to be correlated with initial slope ($r = 0.44$, $p<0.05$) and maximum load ($r = 0.39$, $p<0.05$). Particle size was significantly correlated ($p>0.05$) with all five instrumental parameters and most highly correlated with maximum slope ($r = 0.53$, $p<0.01$). Finally, toothpack was negatively correlated with maximum slope ($r = -0.43$, $p<0.05$).

Correlations Among Sensory Attributes

Adhesion to lips was significantly correlated to cohesiveness of mass after eight chews ($r = 0.57$, $p<0.005$), toothpull ($r = 0.57$, $p<0.005$) and toothpack ($r = 0.54$, $p<0.005$) (Table 2). If it is assumed that adhesion to lips is a measure of rice stickiness, its correlation with toothpull and toothpack seem logical. It is also expected that a rice exhibiting higher stickiness will exhibit a higher cohesiveness of mass. Hardness was most highly correlated with roughness of mass ($r = 0.66$, $p<0.001$) and particle size ($r = 0.59$, $p <0.005$). It is likely that samples exhibiting higher hardness sustained shearing and compression strains applied during chewing and ultimately also yielded higher intensities for roughness of mass and particle size. This observation is supported by the negative correlation reported between hardness and cohesiveness of mass after eight chews ($r = -0.49$, $p< 0.01$). Cohesiveness of mass after three and eight chews was found to be correlated with toothpull ($r = 0.56$, $p<0.005$; $r = 0.65$, $p<0.001$, respectively). Previous discussion showed that the more sticky the sample, the better its mass holds together (i.e. higher cohesiveness of mass) during mastication. It is then expected that samples with higher cohesiveness of mass (i.e. also stickier) will yield higher values for toothpull (i.e. force required to separate the jaws during mastication). Roughness of mass was most highly correlated with loose particles ($r = 0.76$, $p<0.0001$). Particles not reduced to a paste during chewing were perceived as roughness in the chewed sample and as loose particles after swallowing.

Predictive Models for Sensory Attributes Using Instrumental Parameters

Predictive models were reported for seven of the 10 sensory attributes evaluated. Adhesiveness to lips was best predicted by a semi-logarithmic model ($R^2 = 0.47$) using maximum slope (S_{max}) and area under the curve (A) as predictors (Table 3). Hardness was equally best predicted ($R^2 =0.62$) by the semi-logarithmic and the power models using S_{init}, H_{avg}, and H (i.e. maximum load) as predictors. The weights attributed to the predictors were of different signs. An increase in S_{init} and H contributed to an increase in predicted perceived hardness while an increase in H_{avg} tended to decrease predicted hardness values. The opposite effect that H and H_{avg} have on the prediction of hardness and the similar weights that both parameters carry suggest that the ratio of H to H_{avg} may be an important predictor of cooked rice perceived hardness. Meullenet et al. (1997) also reported that S_{min} and H were important instrumental parameters for the prediction of food hardness. Intensities reported by the panel for the cohesiveness of mass evaluated after three chews (Cm_1) were not predictable from the instrumental parameters obtained with the extrusion cell. However, the initial and maximum slopes were useful in determining predictive models of cohesiveness of mass evaluated after eight chews (Cm_2). The best model reported was of the power type ($R^2 = 0.48$). Increasing values of S_{max} contributed to a decrease in the predicted values of Cm_2 while increasing values of S_{init} contributed to an increase in predicted scores of Cm_2. The exponents associated with both S_{init} and S_{max} were almost identical (0.31, -0.32) but of different signs. This result suggests that the ratio of S_{init} to S_{max} may be a reasonably good predictor of cohesiveness of mass (i.e. evaluated after eight chews). Roughness of mass was poorly predicted by a power model ($R^2 = 0.22$) including S_{init} as a single predictor. Toothpull was described best by a linear model ($R^2 = 0.42$) including S_{max} and A (i.e. area under the curve) as predictors. Particle size was poorly predicted by a linear model ($R^2 = 0.28$) including S_{max} as a sole predictor. Toothpack was relatively accurately predicted by a semi-logarithmic model ($R^2 = 0.70$) comprising S_{max}, S_{init}, H_{avg} and H. No significant models were reported for the sensory attribute loose particles. In general, the R-squares reported for the models in Table 3 are lower than those reported by Meullenet et al. (1997). However, one has to consider that the models reported by Meullenet et al. (1997) used a wide variety of foods representing a wide spectrum of intensities on the sensory scales. In the present study, the spectrum of sensory intensities was very narrow (about 2 points on the 15-point universal scale), explaining the relatively low R-squares reported.

SUMMARY AND CONCLUSIONS

The prediction of sensory attributes from an instrumental test was shown to be a difficult task. Hardness was reasonably well predicted (R^2=0.62) using non-linear models and instrumental parameters, including the maximum load of the force-deformation curve. However, the accurate prediction of sensory hardness has not been demonstrated, and the predicted values are merely estimates. It has been shown that accurate predictive models can be derived from instrumental tests when textural properties of foods vary greatly and obvious differences can be reported (Meullenet et al., 1997; Perez et al., 1993; Del Mundo et al., 1989). In the present study, the objective was to attempt the prediction of sensory attributes using a set of rice samples exhibiting small differences. The relatively low R-squares reported are most probably due to the small spread of the data. Toothpack was predicted well ($R^2 = 0.70$) using a non-linear model. This result was anticipated since the mechanism of action of the extrusion cell used in this experiment is imitative of tooth packing during mastication. As for the other sensory attributes evaluated, the quality of the predictive models evaluated varied from poor to average. Obviously, a lot more work is necessary to develop predictive models of textural sensory characteristics for food products, such as cooked rice, exhibiting small differences. However, the use of additional instrumental parameters as well as various statistical procedures such as principal components should allow the development of a reliable instrumental test designed to accurately predict sensory characteristics of cooked rice.

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Table 1. Vocabulary for sensory texture attributes of cooked rice.

Sensory Attributes	Definition	Technique	References
Surface:			
Adhesiveness to lips	The degree to which the sample adheres to lips	Compress sample between lips, release and evaluate	Cherry tomato 0.0; Nougat 4.0; Breadstick 7.5; Pretzel rod 10.0
First bite:			
Hardness	The force required to compress the sample	Compress or bite through the sample with molars	Cream cheese 1.0; Egg white 2.5; American cheese 4.5; Hot dog 5.5; Olive 7.0; Peanut 9.5; Almond 11.0; Life Savers 14.5
Denseness	The compactness of the cross section of the sample	Place the sample between molars and compress	Whipped cream 1.0; Marshmallow fluff 2.5; Nougat center 5.0; Cream cheese 13.0
Chewdown:			
Cohesiveness of mass *After three or eight chews*	The amount the chewed sample holds together	Chew the sample with molars three times and evaluate	Licorice 0.0; Carrot 2.0; Mushroom 4.0; Hot dog 7.5; American cheese 9.0; Brownie 13.0
Roughness of mass	The amount of roughness perceived in the chewed sample	Chew the sample with molars eight times and evaluate	Jello 0.0; Orange peel 3.0; Cooked oatmeal 6.5
Toothpull	The force required to separate the jaws during mastication	Chew three times and evaluate	Clam 3.5; Caramel 5.0; Jujubes 15.0
Particle size	The amount of space the particle fills in the mouth	Place the sample in the mouth and evaluate	Rice grain 0.5; Tic Tac 2.5; M&M 4.0; Mike&Ikes 6.0; Cherry Bite 11.0
Toothpack	The amount of product packed into the crowns of your teeth after mastication	Chew sample eight times, expectorate and feel the surface of the crowns of the teeth with tongue	Captain Crunch 5.0; Heath Bars 10.0
Loose particles	The amount of particles remaining in and on the surface of the mouth after swallowing	Chew sample eight times with molars, swallow and evaluate	Carrot 10.0

Table 2. Pearson's correlation coefficients between instrumental and sensory attributes.[†].

	Instrumental parameters[‡]					Sensory attributes								
	Sinit	*Smax*	*Havg*	*H*	*A*	*Adhes*	*Hard*	*Cm_1*	*Cm_2*	*Rough*	*Tpull*	*Parz*	*Tpack*	*Loose*
Initial slope *(Sinit)*	1.0	0.76	0.86	0.85	0.89	n.s.[§]	0.60	n.s.	n.s.	0.44	n.s.	0.40	n.s.	n.s.
Maximum slope *(Smax)*		1.0	0.79	0.85	0.79	n.s.	0.60	n.s.	-0.52	n.s.	n.s.	0.53	-0.43	n.s.
Average load *(havg)*			1.0	0.98	0.98	n.s.	0.49	n.s.	n.s.	n.s.	n.s.	0.42	n.s.	n.s.
Maximum load *(h)*				1.0	0.95	n.s.	0.60	n.s.	n.s.	0.39	n.s.	0.47	n.s.	n.s.
Area under the curve *(A)*					1.0	n.s.	0.52	n.s.	n.s.	n.s.	n.s.	0.45	n.s.	n.s.
Adhesion to lips *(Adhes)*						1.0	n.s.	n.s.	0.57	n.s.	0.57	n.s.	0.54	n.s.
Hardness *(Hard)*							1.0	n.s.	-0.49	0.66	n.s.	0.59	-0.49	0.39
Cohesiveness of mass after three chews *(Cm_1)*								1.0	0.65	n.s.	0.56	n.s.	n.s.	n.s.
Cohesiveness of mass after eight chews *(Cm_2)*									1.0	n.s.	0.65	-0.57	0.42	n.s.
Roughness of mass *(Rough)*										1.0	n.s	n.s.	n.s.	0.76
Toothpull *(Tpull)*											1.0	n.s	0.59	n.s.
Particle size *(Parz)*												1.0	n.s	n.s.
Toothpack *(Tpack)*													1.0	n.s.
Loose particles *(Loose)*														1.0

[†] Total number of observations: N=27.

[‡] Definitions for instrumental parameters and sensory attributes are provided in Figure 1 and Table 1, respectively.

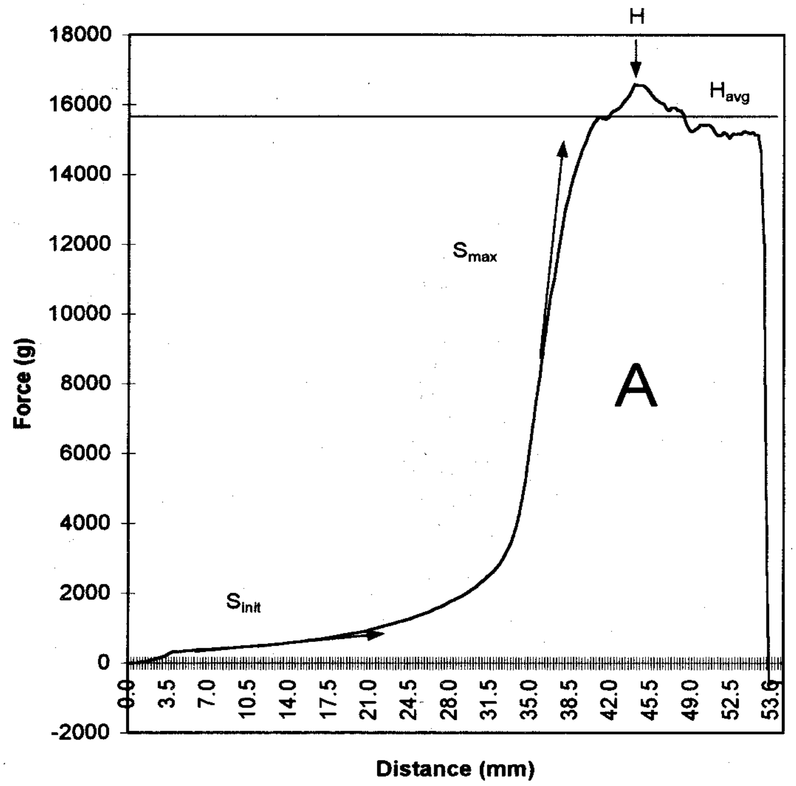
[§] n.s. = correlation not significant ($p>0.05$).

Table 3: Predictive models for sensory parameters using instrumental parameters[†].

Sensory attribute	Model type	R-square	Model
Adhesiveness to lips *(Adhes)*	Linear	0.42	$Adhes = 10.75 - 0.29\ S_{max} + 0.06\ A$
	Semi-logarithmic	**0.47**	**$Adhes = 3.15 - 3.29\ \mathrm{Log}\ (S_{max}) + 3.93\ \mathrm{Log}\ (A)$**
	Power	0.46	$Adhes = 50.4\ (S_{max})^{-0.29}\ (A)^{0.36}$
Hardness *(Hard)*	Linear	0.36	$Hard = 3.42 + 0.07\ S_{max}$
	Semi-logarithmic	**0.62**	**$Hard = 3.38 + 0.92\ \mathrm{Log}\ (S_{init}) - 3.25\ \mathrm{Log}\ (H_{avg}) + 3.38\ \mathrm{Log}\ (H)$**
	Power	**0.62**	**$Hard = 16.43\ (S_{init})^{0.22}\ (H_{avg})^{-0.79}\ (H)^{0.83}$**
Cohesiveness of mass after three chews *(Cm₁)*	Linear	--	n.s.
	Semi-logarithmic	--	n.s.
	Power	--	n.s.
Cohesiveness of mass after eight chews *(Cm₂)*	Linear	0.45	$Cm2 = 4.84 - 0.14\ S_{max} + 1.19\ S_{init}$
	Semi-logarithmic	0.47	$Cm2 = 8.01 - 1.49\ \mathrm{Log}\ (S_{max}) + 1.43\ \mathrm{Log}\ (S_{init})$
	Power	**0.48**	**$Cm2 = 180.71\ (S_{max})^{-0.32}\ (S_{init})^{0.31}$**
Roughness of mass *(Rough)*	Linear	0.19	$Rough = 5.19 + 0.68\ S_{init}$
	Semi-logarithmic	0.21	$Rough = 5.87 + 0.79\ \mathrm{Log}\ (S_{init})$
	Power	**0.22**	**$Rough = 58.88\ (S_{init})^{0.13}$**
Toothpull *(Tpull)*	Linear	**0.42**	**$Tpull = 1.37 - 0.08\ S_{max} + 0.02\ A$**
	Semi-logarithmic	--	n.s.
	Power	--	n.s.
Particle size *(Parz)*	Linear	**0.28**	**$Parz = 0.80 + 0.02\ S_{max}$**
	Semi-logarithmic	0.24	$Parz = 0.59 + 0.18\ \mathrm{Log}\ (S_{max})$
	Power	0.23	$Parz = 0.39\ (S_{max})^{0.18}$
Toothpack *(Tpack)*	Linear	0.63	$Tpack = 1.42 - 0.04\ S_{max} - 0.39\ S_{init} + 0.21\ H_{avg} - 0.14\ H$
	Semi-logarithmic	**0.70**	**$Tpack = 0.79 - 0.45\ \mathrm{Log}\ (S_{max}) - 0.42\ \mathrm{Log}\ (S_{init}) + 2.86\ \mathrm{Log}\ (H_{avg}) - 2.18\ \mathrm{Log}\ (H)$**
	Power	0.63	$Tpack = 2.43\ (S_{max})^{-0.46}\ (H_{avg})^{2.18}\ (H)^{-1.77}$
Loose particles *(Loose)*	Linear	--	n.s.
	Semi-logarithmic	--	n.s.
	Power	--	n.s.

[†] Definitions for instrumental parameters and sensory attributes are provided in Figure 1 and Table 1, respectively. Only instrumental predictors with a $p<0.15$ were included in the models. Models were evaluated using PROC STEPWISE of SAS (1993).

[‡] n.s. = correlation not significant ($p>0.05$).



Instrumental parameters and definitions

S_{Init} the initial slope of the force/ deformation curve

S_{max} is the maximum slope of the force / deformation curve

H is the maximum load recorded during extrusion

H_{avg} is the average load across the flattened part of the force / deformation curve

A is the area under the force / deformation curve or total work during the extrusion test

Fig. 1. Sample force/deformation curve and definitions of instrumental parameters expected.

SENSORY QUALITY OF COOKED RICE AS AFFECTED BY ROUGH RICE MOISTURE CONTENT, STORAGE TEMPERATURE AND STORAGE DURATION

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ABSTRACT

The effects of postharvest variables (i.e. rough rice moisture content, storage temperature and storage duration) on sensory quality of three rice cultivars grown in Arkansas (i.e. ‘Cypress’, ‘Kaybonnet’ and ‘Bengal’) were evaluated using a professional descriptive sensory panel. Four textural (hardness, stickiness, cohesiveness of mass and roughness of mass) and four flavor attributes (sulfur, starch, grainy and cardboard) were identified to be most important in describing the sensory characteristics of cooked rice. Postharvest conditions were shown to have significant effects on rice sensory quality. Preliminary regression models were generated to illustrate the effects of each postharvest variable and their interactions on sensory quality of cooked rice.

INTRODUCTION

Studies of the relationship between postharvest handling of rice and sensory quality have been limited in scope and number. As rice consumption continues to expand, there is an increasing need for quantitative data regarding the effects of postharvest handling on sensory characteristics of cooked rice. Sensory analysis techniques have been used to evaluate the effects of postharvest handling on cooked rice quality (Okabe, 1979; Perez and Juliano, 1983; Chrastil, 1990; Rousset et al., 1995). However, these studies provided information only on the effects of single postharvest variables (i.e. rough rice moisture content, drying conditions and storage duration), falling short of evaluating possible interactions between postharvest variables. As a result, the effect of postharvest handling on sensory quality of cooked rice needs to be thoroughly investigated using a reliable sensory tool so that sensory characteristics of cooked rice can be evaluated in a quantitative and reproducible manner.

Descriptive sensory profiling, the most sophisticated sensory methodology available, provides the tools to intensify specific sensory characteristics (Stone and Sidel, 1993). Sensory profiling is useful in evaluating sensory changes over time with respect to processing conditions and shelf life (Meilgaard et al., 1991). In addition, the spectrum methodology is a sensory method designed to provide universal sensory intensities, especially adequate to provide reliable results for shelf-life studies. As such, the spectrum descriptive analysis is the most appropriate sensory tool to evaluate the effects of postharvest handling conditions on sensory characteristics of cooked rice.

The objective of this investigation was to study the effects of postharvest parameters such as rough rice moisture content, storage temperature and storage duration on the sensory quality of the three predominant rice cultivars grown in the state of Arkansas.

MATERIALS AND METHODS

Postharvest Treatments

Two long-grain rice cultivars (Kaybonnet and Cypress) and one medium-grain rice cultivar (Bengal) were harvested from the University of Arkansas Rice Research and Extension Center at Stuttgart, Arkansas, in September 1996 with harvest moisture contents of 19.1, 16.5 and 17.5% (wet base), respectively. The rice was brought immediately to the Biological and Agricultural Engineering lab at Fayetteville and cleaned using a Carter-Day Dockage Tester (Carter-Day Co., Minneapolis, Minnesota). Rice samples were dried using a Parameter Control Generator Unit in a laboratory-scale dryer with a drying temperature of 43.3°C with 38.2% relative humidity (rh) for 75 min. After drying, rice samples were placed in wooden-framed, wire-mesh trays (where the layer of rice was 0.5 in. deep) and allowed to equilibrate in air-controlled chambers until reaching a moisture content (mc) of 10, 12 or 14%, respectively. The rice was then placed in air-tight plastic buckets. A bucket of each treatment was then placed into its respective storage temperatures of 4, 21 or 38°C. Samples were stored for up to 24 weeks and evaluated for sensory characteristics at 0, 6, 12 and 24 weeks. At sampling times, samples were allowed to equilibrate to room temperature. A McGill sample sheller (husker) was used to remove the hulls and a McGill No. 2 mill to remove the bran. Samples were milled to a constant degree of milling (DOM) set to @ 90. The DOM was measured using a Satake Milling Meter MM-1B.

Sensory Methodology

Nine panelists trained in descriptive analysis techniques according to the Spectrum methodology (Sensory Spectrum, Chatham, New Jersey) developed a sensory profile of cooked rice. After several orientation sessions, the panel identified four textural attributes (i.e. adhesion to lips, hardness, cohesiveness of mass, roughness of mass) and four flavor attributes (i.e. sulfur, cardboard, starch and grainy) that were most important to describe the texture and flavor profiles of cooked rice (Table 1). Intensities for each of the eight attributes were evaluated on a 15-cm continuous scale (Meilgaard et al., 1991). The intensities for texture attributes were assessed by comparison with carefully chosen references having assigned intensities for a particular attribute. A list of the references used in the evaluation is provided in Table 1.

Samples were cooked for 20 min in household steam rice cookers (National, model SR-W10FN) with a 1:2 (vol:vol) rice to water ratio and immediately presented to the panel. The order of sample presentation was randomized across treatments but not randomized across panelists because of limited sample availability and the importance of serving temperature. Samples were presented at 71°C ±1 in glass bowls insulated with Styrofoam cups and covered with watch glasses. Panelists were instructed to monitor temperature during the test using digital thermometers and to complete the evaluation before the temperature of the sample reached 60°C ± 2. Sensory scores were given by panelists using paper ballots and numbers between 0 and 15. A reference rice sample was presented as a warm-up sample at the beginning of each session. Samples were presented monadically (i.e. one at a time). Panelists were allowed a 10-minute break between sample evaluations and instructed to rinse their palate with unsalted saltine crackers and water.

Statistical Data Analysis

The experiment was treated as a 3 x 3 x 3 full factorial design with repeated measurements over time. Independent variables were cultivar (Bengal, Kaybonnet and Cypress), rough rice storage moisture content (10, 12 or 14%) and rough rice storage temperature (4, 21 or 38°C). The sensory evaluation was conducted after 0, 6, 12 and 24 weeks of storage. Sensory data were analyzed for the various sampling times via a treatment x subject design (Stone and Sidel, 1993), for which all subjects evaluated all samples once. Sensory attributes were predicted using multiple regression models including variables such as rough rice moisture content, storage temperature, storage duration, their quadratic terms and interactions. PROC STEPWISE (SAS, 1993) was used to determine regression models including only significant variables ($p<0.15$). The models presented here are not cultivar specific, but models for each of the three cultivars studied will be published elsewhere.

RESULTS AND DISCUSSION

Effects of Postharvest History on Cooked Rice Texture

Cooked kernel hardness was affected by rough rice moisture content (MC) and storage duration (Fig. 1). The postharvest variables involved in the regression model explained 57% (R^2=0.57) of the total data variation. Kernel hardness was found to be lowest at time zero for samples equilibrated at 14% MC. Hardness in cooked rice increased to a maximum after 20 weeks of storage and slightly decreased after 24 weeks of storage, regardless of storage temperature. An explanation for this phenomenon, taking place as part of the aging process, is still to be investigated. It is not known yet whether the change in hardness is due to a change in water absorption and volume expansion or to a change in the physical properties of the starch. Juliano and Perez (1983) showed that rice cooking rates were mainly influenced by the reactivity of the rice constituents with water. As a result, the differences observed for hardness between samples using the rice cooker method show that the rate of cooking is a function of postharvest history.

Adhesion to lips in cooked rice samples, a measure of rice stickiness, was affected by rough rice moisture content, storage temperature and storage duration (R^2=0.54; Fig.2a and 2b). Rice stickiness decreased with increasing rough rice mc and storage temperature. The stickiest rice samples were those stored at a 10% moisture content and 4°C. It has been reported (Kurasawa et al., 1962; Mossman et al., 1983; Chrastil, 1990) that rice stickiness decreases during storage. Similar results were reported in this study. However, rice stickiness first increased during the early weeks of storage to a maximum after 6 to 10 weeks, depending on the storage temperature. In the predictive models established for this study, rough storage mc plays an important role in rice stickiness.

Cooked rice cohesiveness of mass was affected by rough rice mc, storage temperature and duration (R^2=0.53; Fig. 3a and 3b). Cohesiveness of mass increased with storage duration. Increasing rough rice mc resulted in higher cohesiveness of mass after 24 weeks of storage. Increasing storage temperatures resulted in decreasing sensory intensity perceived for cooked rice cohesiveness of mass. Interaction among all three variables studied significantly influenced the regression model.

Roughness of mass was significantly affected by both rough rice mc and storage duration (R^2=0.81; Fig. 4). Roughness of mass decreased with increasing rough rice storage mc. Roughness of mass also decreased to a minimum after 20 weeks of storage and then slightly increased at the 24-week sampling.

Effects of Postharvest History on Cooked Rice Flavor

Sulfur aroma notes were detected in cooked rice samples at relatively low intensities (Fig. 5a and 5b). However, perceived intensities were affected by rough rice moisture content, storage temperature and duration (R^2=0.45). Sulfur aroma notes were found to be lowest at time zero in samples equilibrated to 10% moisture content. Sulfur aroma notes increased in intensity with increasing rough rice moisture contents and increasing storage duration. Lower storage temperatures resulted in higher sulfur aroma note intensities. This result may be explained by volatilization of the sulfur compounds at higher storage temperatures (i.e. 38°C). Sulfur aroma notes also seem to be a product of rice aging. Champagne et al. (1997) also reported that undesirable hay-like and sewer-like flavors (i.e. most probably similar to sulfur aroma notes) were higher in samples dried to 15% than in samples dried to 12%. One important additional finding of our studies is the effects that both storage duration and temperature have on the perception of these undesirable flavor characteristics.

Starch flavor note intensities were significantly affected by both rough rice storage mc and storage duration (R^2=0.62; Fig. 6). Starch flavor notes were lowest for samples stored at 14% MC for 24 weeks. A significant interaction was found between storage mc and storage duration. For samples with mc of 10%, little effect of storage duration was reported. However, at higher storage mc (i.e. 14%), starch flavor notes rapidly decreased during storage.

Grainy flavor notes, an indicator of raw grain flavor, were affected by all three postharvest variables studied (R^2=0.50; Fig. 7a and 7b). In general, grainy notes decreased over time. However, increasing storage temperatures and storage moisture contents increased perceived grainy notes. This result is somewhat surprising, and the perception of grainy flavor notes in samples stored at higher temperature may be due to off-flavor notes not necessarily characteristic of raw grain.

Cardboard flavor notes, an indicator of slight oxidation, were perceived at low intensities and were affected by rough rice mc, storage temperature and duration (R^2=0.34; Fig 8a and 8b). At low storage temperatures (i.e. 4°C), storage duration showed little effect on oxidation notes. However, at high storage temperatures (i.e. 38°C), oxidation notes increased rapidly with increasing storage duration. Increasing rough rice storage moisture content significantly increased the perceived cardboard notes.

SUMMARY AND CONCLUSIONS

Postharvest conditions were shown to have very significant effects on cooked rice quality evaluated by sensory evaluation. The significance of these findings is two-fold. First, loss of quality during storage can be greater if storage conditions are poor. Second, these data show that rice quality can be optimized by carefully controlling some of the postharvest conditions such as rough rice storage mc, storage temperature and duration. It is probably not very realistic at this point to foresee that rough rice storage temperature can be monitored. However, it seems that optimizing postharvest parameters such as rough rice storage mc as a function of the predicted storage duration would help optimize Arkansas rice quality for rice destined to consumer or processing markets. The data presented represent only the 1996 crop and additional data are being generated on the 1997 crop so that storage recommendations to optimize rice quality during storage can be formulated.

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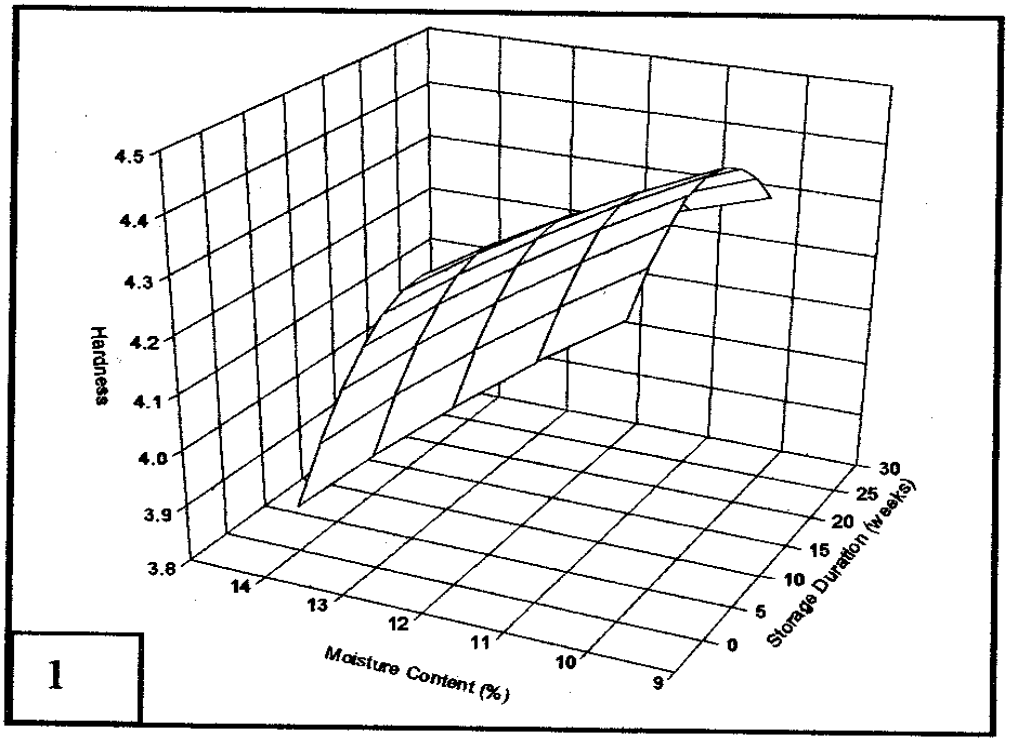

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Fig. 1. Effects of rough rice moisture content and storage duration on cooked rice hardness.

Table 1. Definitions and references used to evaluate rice sensory attributes.

Sensory Attribute	Definition	Reference and assigned intensities
Aroma:		
Sulfur note	Aromatics associated with hydrogen sulfide.	Hard boiled eggs for 5 minutes, peeled, cut and placed in refrigerator overnight Intensities assigned according to the Universal Aromatic Scale
Flavor:		
Starch note	Aromatics associated with starch of a particular grain source.	Rice flour paste: ratio 1:1 water to rice flour Intensities assigned according to the Universal Aromatic Scale
Grainy note	A general term used to describe the aromatics of raw grain, which cannot be tied to a specific grain by name.	Rice Krispies; Shredded wheat; Multi Grain Cheerios Intensities assigned according to the Universal scale
Cardboard note	Aromatics associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging.	Wet cardboard Intensities assigned according to the Universal scale
Texture:		
Adhesion to lips	Degree to which the sample sticks to the lips. Compress the sample between lips, release and evaluate.	Tomato 0.0; Nougat 4.0; Pretzel rod 10.0; Rice Krispies 15.0
Hardness	Force required to compress the sample. Compress or bite through the sample one time with molars and evaluate	Cream cheese 1.0; Egg white 2.0; American cheese 4.5; Hotdog 5.0
Cohesiveness of mass	Degree to which samples maintain in a "wad". Chew the sample with molars 8 times and evaluate	Licorice 0.0; Carrots 2.0; Mushroom 4.0; Hot dog 7.5; Brownie 13.0; Dough 15.0
Roughness of mass	Amount of roughness perceived in the chewed sample. Chew sample with molars and evaluate	Orange peel 3.0; Cooked oats 6.5

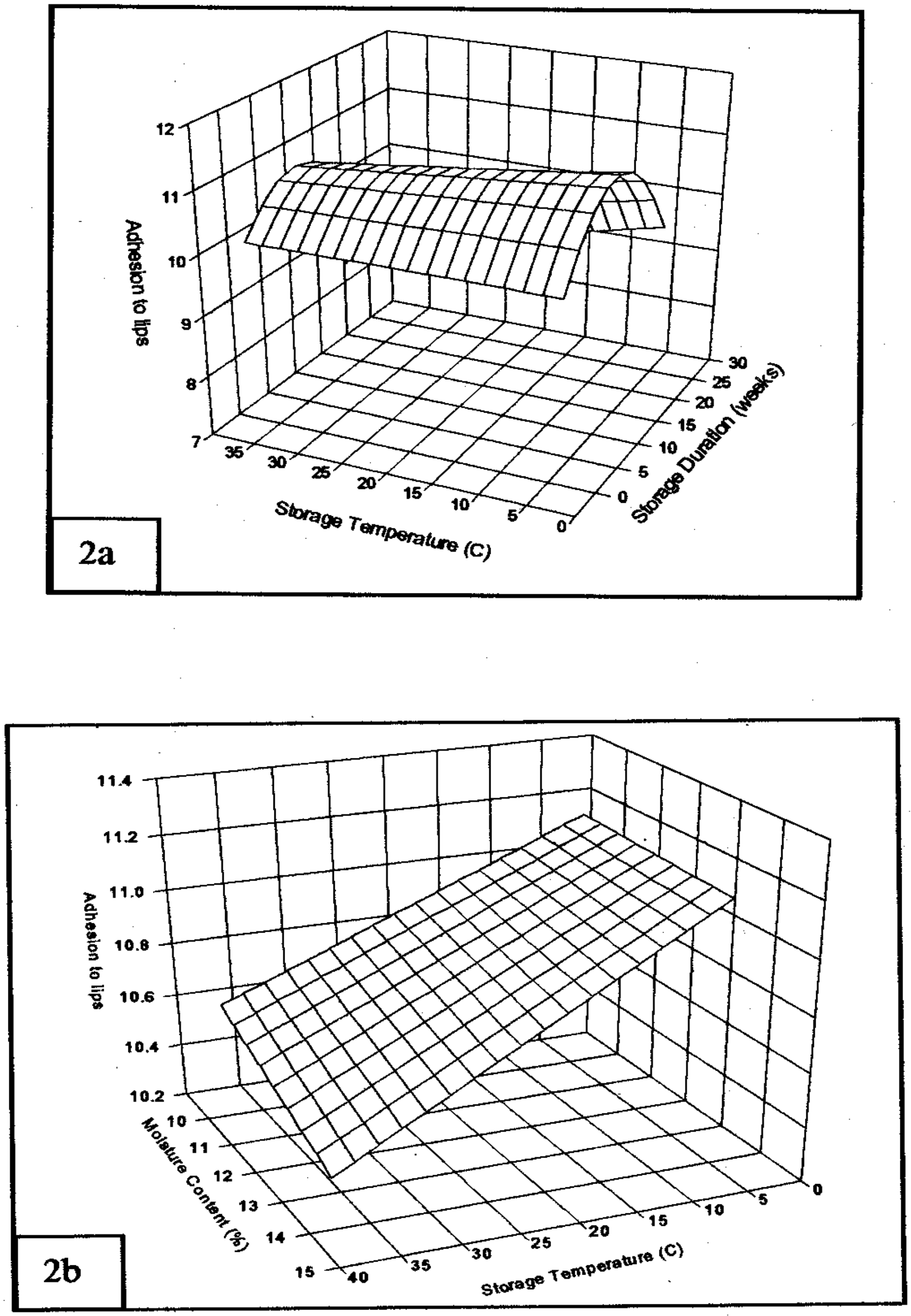
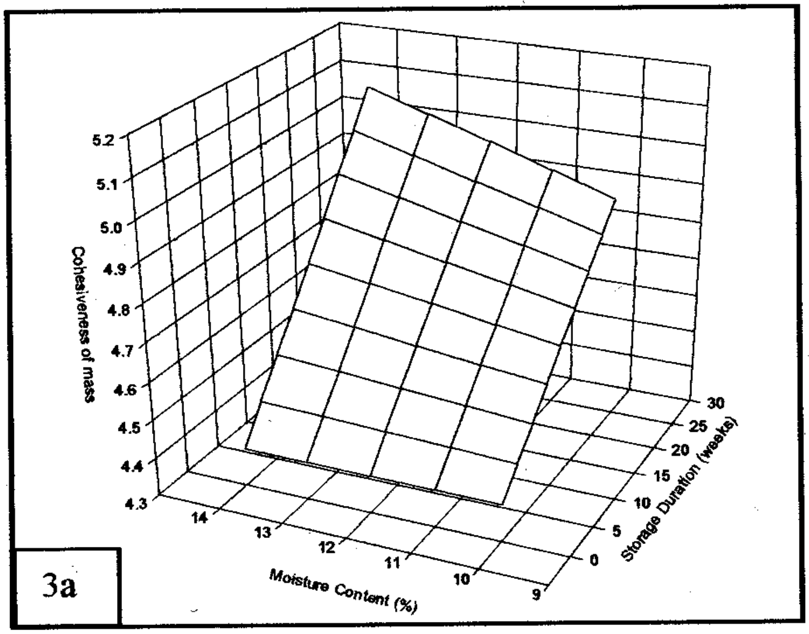


Fig. 2a and 2b. Effects of rough rice storage temperature, storage duration and rough rice moisture content on cooked rice adhesion to lips.



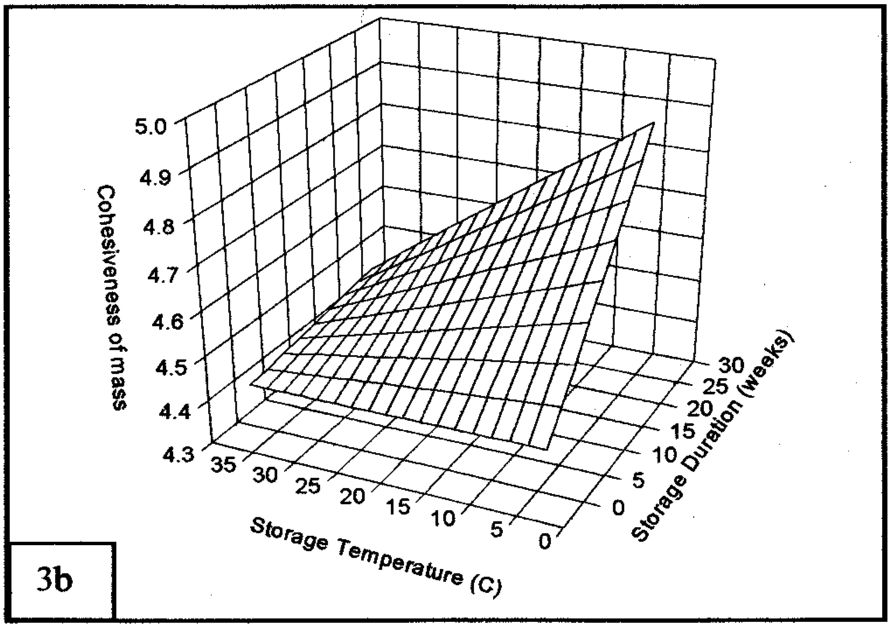


Fig. 3a and 3b. Effects of rough rice storage temperature, storage duration and rough rice moisture content on cooked rice cohesiveness of mass.

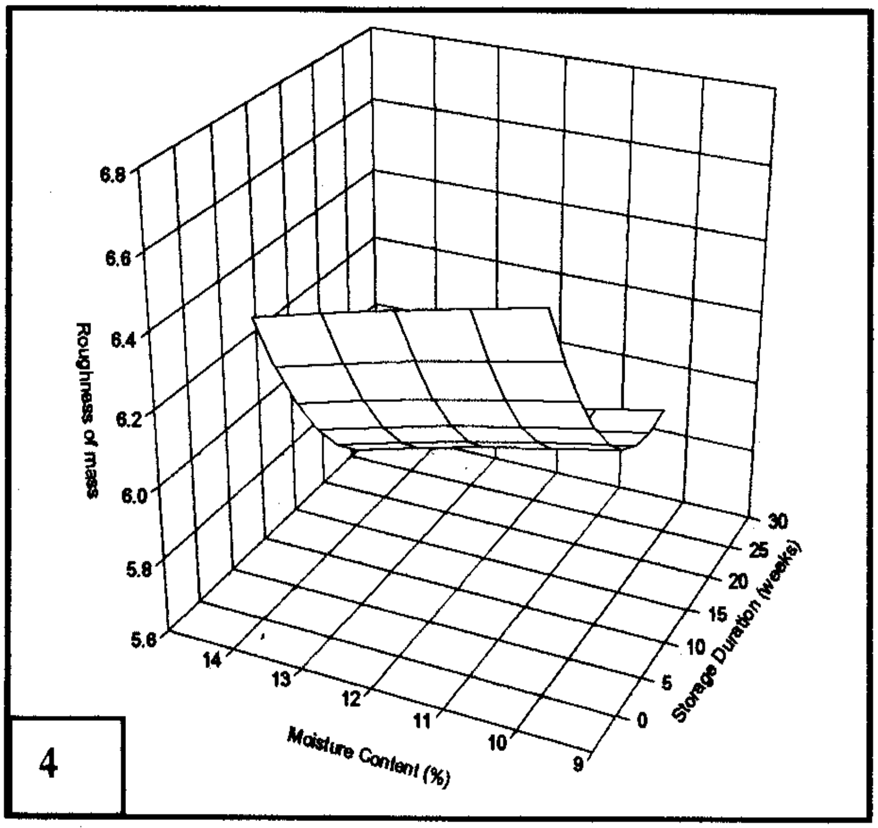


Fig. 4. Effects of rough rice moisture content and storage duration on cooked rice roughness of mass.

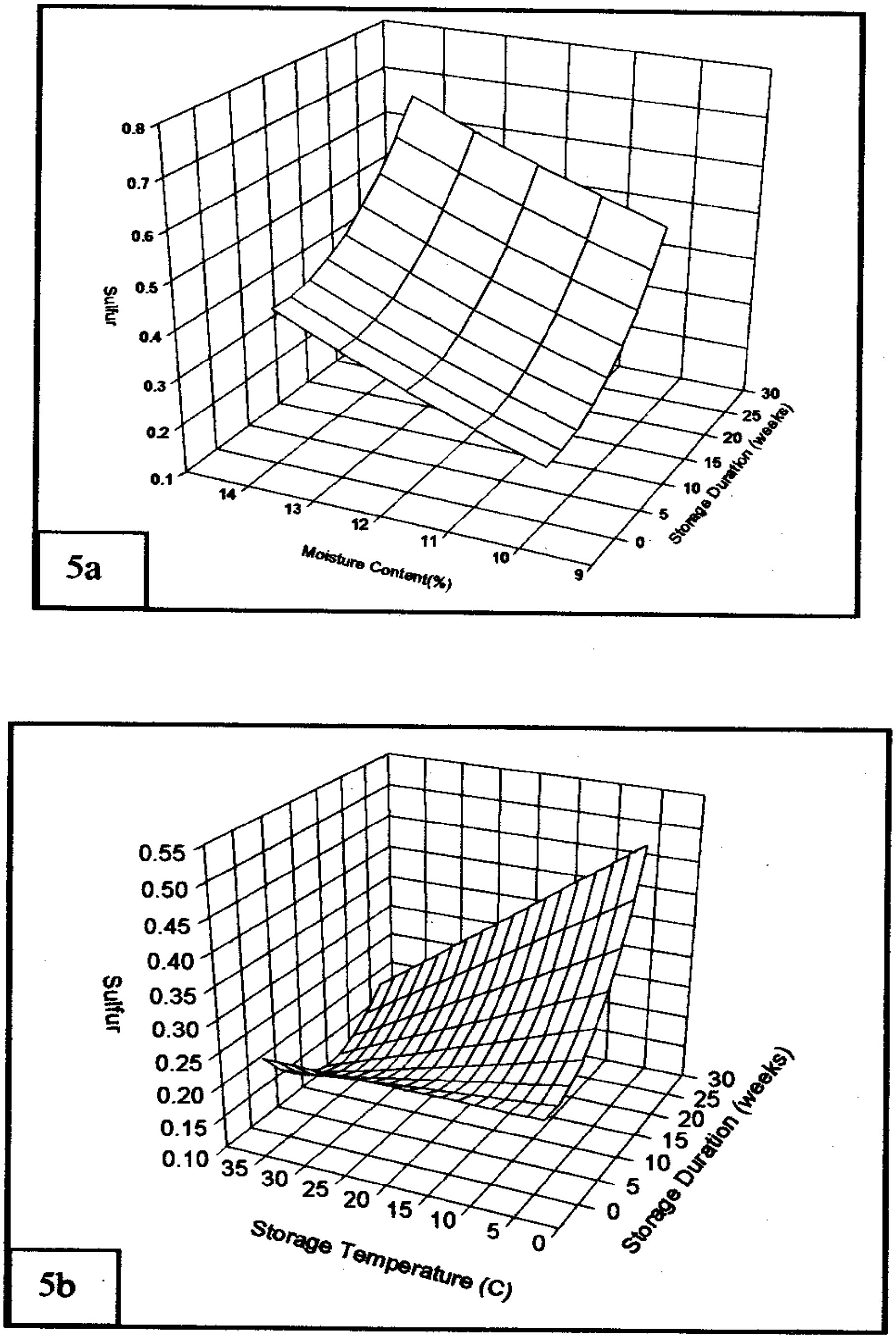


Fig. 5a and 5b. Effects of rough rice storage temperature, storage duration and rough rice moisture content on sulfur aroma in cooked rice.

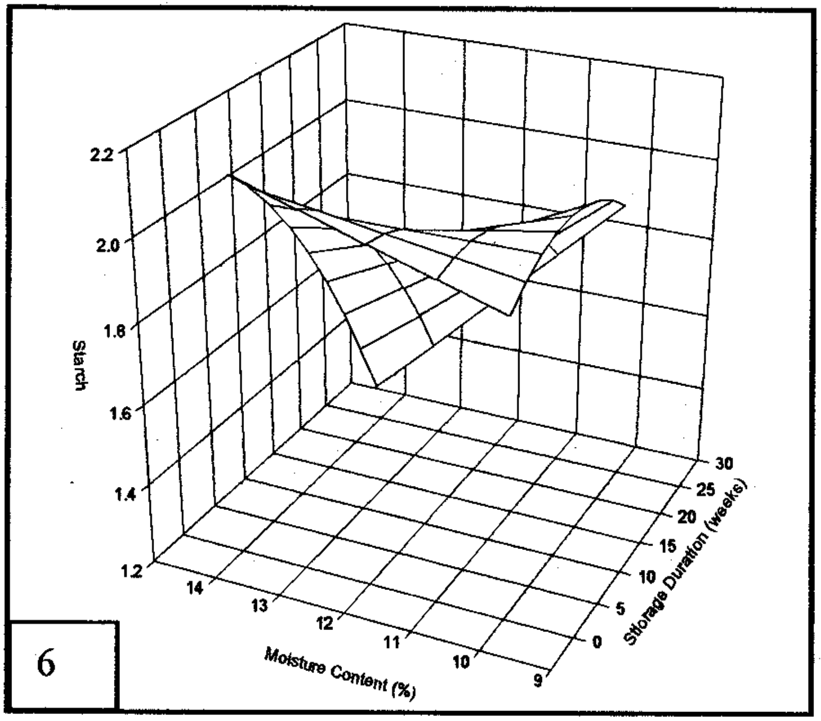
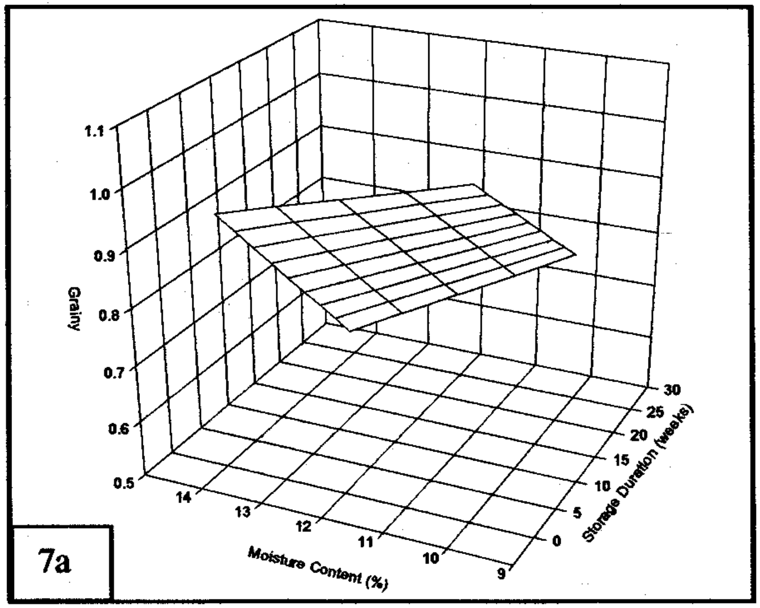


Fig. 6. Effects of rough rice moisture content and storage duration on starch flavor notes in cooked rice.



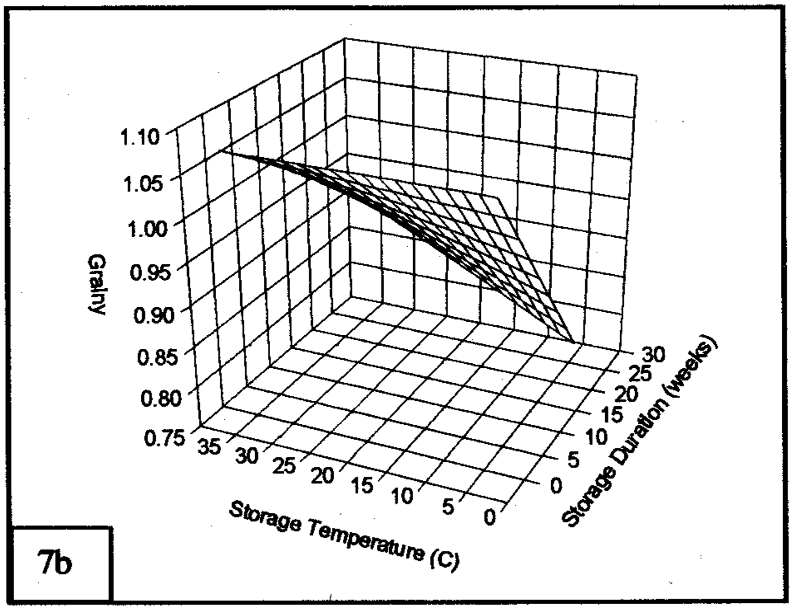


Fig. 7a and 7b. Effects of rough rice storage temperature, storage duration and rough rice moisture content on grainy flavor notes in cooked rice.

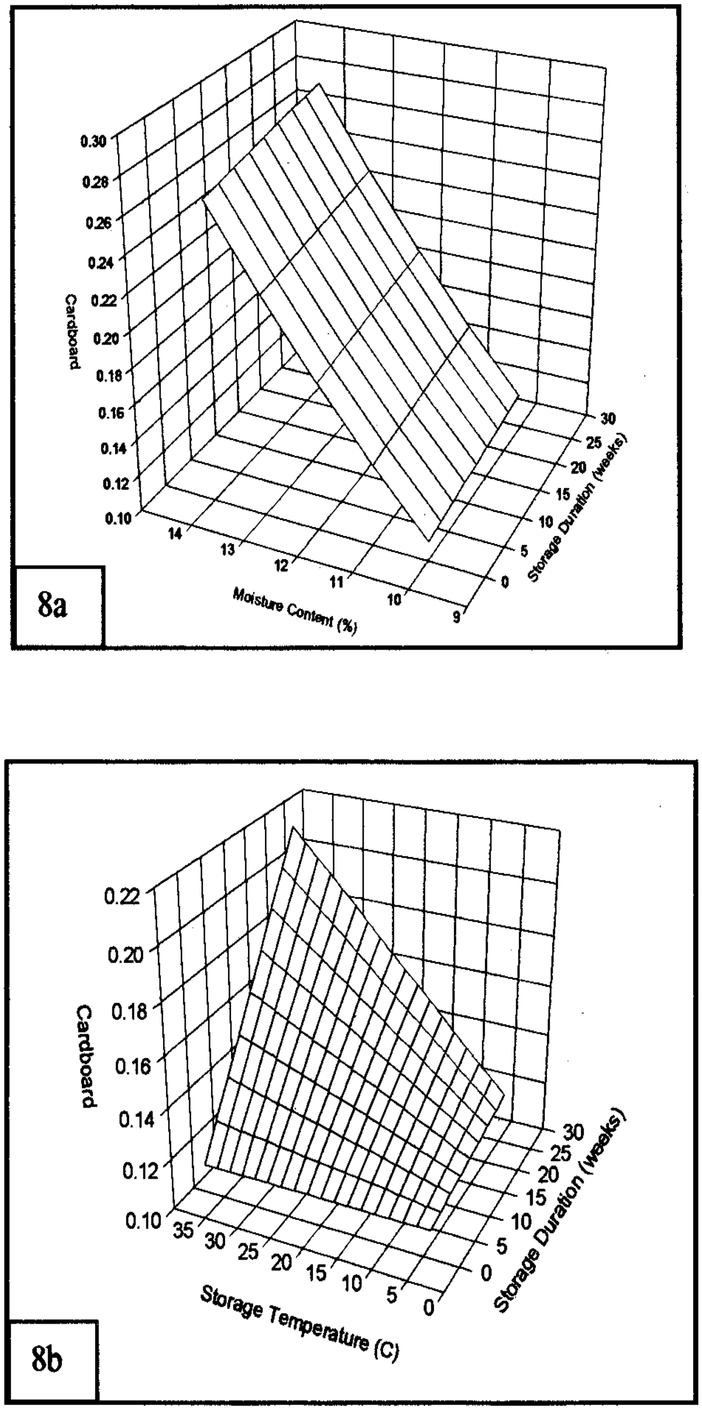


Fig. 8a and 8b. Effects of rough rice storage temperature, storage duration and rough rice moisture content on cardboard flavor notes in cooked rice.

ONGOING PROJECT
RICE QUALITY AND PROCESSING

ROUGH RICE SURFACE TEMPERATURE MEASUREMENT DURING DRYING

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

ABSTRACT

Two cultivars, ‘Cypress’ (long-grain) and ‘Bengal’ (medium-grain), were harvested at several moisture contents and dried at three drying air conditions (A: 110°F, 38% relative humidity (RH); B: 125°F, 25% RH; C: 140°F, 17% RH). Additionally, ‘Kaybonnet’ (long-grain) was harvested at 19.5% moisture content (MC) and dried at several temperature and relative humidity combinations. The temperature of the rice during drying was measured and summarized in terms of a heating rate constant. For Bengal and Cypress, the effect of drying air condition and harvest moisture content (HMC) on the rate at which the rice temperature rose during drying was quantified. For Kaybonnet, which was dried at several drying air conditions, the rate at which the rice temperature rose during drying was quantified in terms of the air temperature and relative humidity.

INTRODUCTION

The rough rice drying process has traditionally been considered as a combined heat and mass transfer process in which moisture diffuses through the kernel to be transferred by evaporation from the surface of the kernel. Rough rice properties that affect drying have been shown to be a function of mc as well as temperature. Some examples of these properties are the moisture diffusivity (Steffe and Singh, 1990; Tolaba et al., 1997), the modulus of elasticity and the coefficient of thermal expansion. The temperature-dependence of the modulus of elasticity and the coefficient of thermal expansion (Prasad et al., 1975) has typically been assumed to be linear in nature; however, some researchers have noted changes in the slopes of the linear relationships above approximately 53°C in rough rice (Arora et al., 1973) and 43°C in corn (Ekstrom et al., 1966; Gustafson et al., 1979). Because of the dependence of these properties on moisture and temperature, the heat and mass transfer processes are most appropriately considered as coupled phenomena. Thus, temperature has a critical role in the understanding of rough rice drying.

The starch in the endosperm consists of two forms of polysaccharides: amylose and amylopectin. Since these polymers are the building blocks of rice starch and since starch is formed in a biological system, starch is considered to be a biopolymer. As a biopolymer, the temperature of the rice becomes central to the understanding of the drying process. Biopolymers have unique properties that can be attributed to the principles of polymeric materials. For a biopolymer, the concept of a glass transition (T_g) becomes especially relevant during drying. The T_g is the temperature at which an amorphous region changes from a glassy to a rubbery state. This transition affects changes in the material properties, including the coefficient of thermal expansion and the elastic modulus (Nicholls et al., 1995). Perdon (1998) proposed that the previously observed changes in the temperature-dependence of the material properties of rice (Arora et al., 1973) and corn (Ekstrom et al., 1966; Gustafson et al., 1979) are observations of the glass transition.

When stress cracking is considered in mathematical models of rough rice drying, the coefficient of thermal expansion and the elastic modulus are important parameters within the model. Because of the temperature dependence of these material properties and others, accurate prediction of rough rice temperature is necessary for an accurate finite element model. Because of this temperature dependence, surface temperature measurement has been used as a means of validating drying models (Sokhansanj and Bruce, 1987). Because temperature is relatively easy to monitor during drying operations, the possibility of using surface temperature to prevent quality head rice yield (HRY) reduction is a promising application of the results of this research.

The objectives of this study were to measure the surface temperature during rough rice drying using infrared (IR) and thermocouple (TC) thermometers. From these measurements, the effects of cultivar, HMC and drying air conditions on the surface temperature were investigated.

MATERIALS AND METHODS

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

Rice was harvested from both the Rice Research and Extension Center, Stuttgart, Arkansas, and the Northeast Research and Extension Center, Keiser, Arkansas. Since another focus of this year's drying research was the effect of cultivar and HMC, the harvest included two long-grain cultivars (Kaybonnet and Cypress) and one medium-grain cultivar (Bengal). Each cultivar at each harvest location was harvested at 'high' (>20%) and 'medium' (18-20%) MC levels. During the fall 1996 trials, 12 harvest location/HMC/cultivar combinations were processed.

Immediately after harvest, foreign matter was removed from the rough rice 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 air conditions (A: 110°F, 38% RH; B: 125°F, 25% RH; C: 140°F, 17% RH), which represent equilibrium moisture contents[1] of 8.6, 6.8 and 5.4%, respectively. Additionally,

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[1] Equilibrium moisture contents are % wet basis, as calculated using the Chung Equation (ASAE, 1995).

Kaybonnet, harvested from the Rice Research and Extension Center at 19.5% HMC, was dried at various drying air conditions, as shown in Figure 1.

Conditioned air was supplied by one of three 300 CFM Parameter Generation and Control temperature and relative humidity control units to each of three drying chambers. Each of the three 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 330 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.

TC temperatures were measured from the center, front panel of each drawer. 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 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. 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. Surface temperature was measured and recorded at 30-second intervals throughout each drying trial.

RESULTS AND DISCUSSION

During the fall harvest drying, IR and TC surface temperatures were recorded; during the Kaybonnet drying, only IR temperatures were recorded. From each drying trial, the surface temperature data (Figure 2) was fit to Equation [1]. The dimensionless temperature ratio was calculated using the maximum and minimum temperatures from each data set.

Each temperature response was modeled as:

$$\frac{T - T_i}{T_a - T_i} = 1 - e^{-\frac{1}{\tau} \bullet t} \qquad [1]$$

where: T = surface temperature (°F)
T_a = maximum grain temperature (°F)
T_i = minimum grain temperature (°F)
$1/\tau$ = heating rate constant (min)
t = time (min).

The heating rate constant was calculated with the nonlinear regression package available through the SAS system (The SAS System for Windows™ Release 6.10, Sas Institute Inc., Cary, North Carolina).

Heating Rate

The heating rate constant summarized the rate of increase of the rough rice surface temperature. The effects of drying air conditions, cultivar and HMC on the heating rate constant were investigated by exploring which statistical models described the heating rate constants resulting from the fall and Kaybonnet tests.

Kaybonnet tests

The data from the Kaybonnet tests were used to investigate the dependence of the heating rate constant on the drying air conditions (Figure 3 and Figure 4). The following model was tested with the REG linear regression package:

$$\frac{1}{\tau} = \beta_o + \beta_1 \cdot T_a + \beta_2 \cdot RH + \beta_{12} \cdot T_a \cdot RH + \beta_{11} \cdot T_a^{\,2} + \beta_{22} \cdot RH^2 \qquad [2]$$

The final model included terms for the air temperature, relative humidity and their interaction. Because of the dependence of the heating rate constant on the air temperature and relative humidity, dependence of the heating rate constant on the air equilibrium moisture content (EMC) could also be assumed. The heating rate increased with air temperature and air relative humidity. While the increase in the heating rate with temperature was intuitive, the increase in the heating rate as relative humidity was not as easily explained. At lower air relative humidities, the drying rate is faster than at higher air relative humidities, due to more rapid evaporation with resultant cooling at the kernel surface. The trend of increasing heating rate constant with air relative humidity suggested that decreased evaporative cooling at the higher drying air relative humidities resulted in less evaporative cooling, a lower drying rate and a smaller heating rate constant.

Fall tests

The data from the fall tests were used to investigate the dependence of the heating rate constant on HMC within a cultivar. Bengal and Cypress, harvested at Stuttgart, were chosen for this analysis. The following model was tested with the GLM linear regression package for each of the two cultivars:

$$\frac{1}{\tau} = \beta_0 + \beta_1 \cdot COND + \beta_2 \cdot HMC + \beta_{12} \cdot COND \cdot HMC \qquad [3]$$

For Bengal (Figure 5), only the drying air condition significantly influenced the heating rate constant. The regression was significant ($p < 0.05$) with a relatively high R^2 (0.88).

However, for Cypress, the drying air conditions (A, B and C) and the HMC were significant. At higher HMCs, the heating rate was lower (Figure 6), suggesting the influence of greater evaporative cooling causing slower heating of the kernel surface. For example, according to the model, a 1 percentage point increase in HMC effected a decrease in the heating rate constant of 8%.

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. The heating rate constant was affected by the drying air temperature and relative humidity and the HMC. These findings will be used to validate a finite element model that is currently being developed to predict when kernel fissuring occurs during drying.

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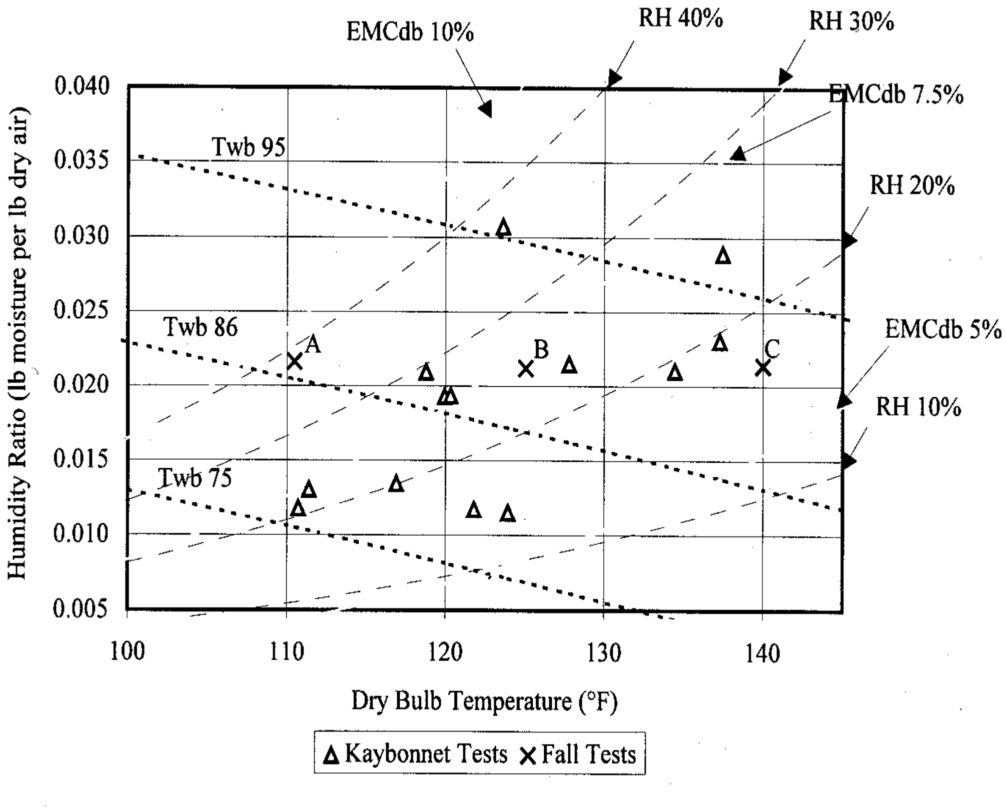

Fig. 1. Psychrometric chart with drying air conditions of the 'Kaybonnet' and fall tests labeled. Wet bulb temperatuer (Twb), relative humidity (RH) and equilibrium moisture content (EMC) lines are included for clarity.

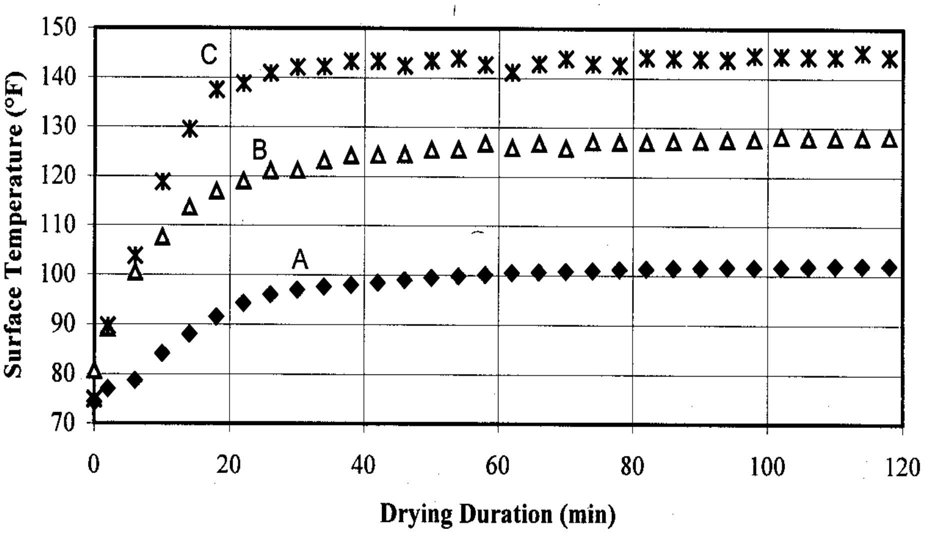

Fig. 2. Rough rice surface temperature response for 'Bengal', harvested at 26% MC and dried at drying air conditions A: 110°F, 38% RH; B: 125°F, 25% RH; and C: 140°F, 17% RH.

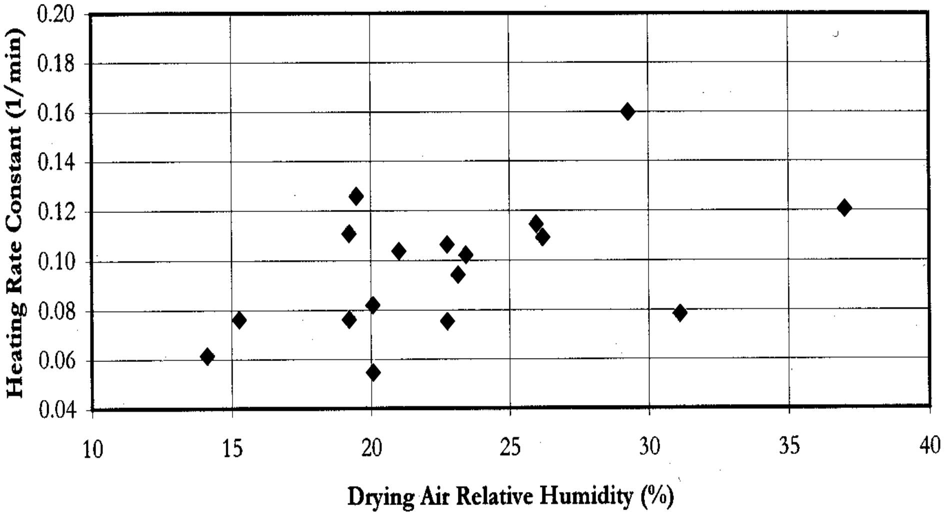

Fig. 3. Heating rate constant as a function of drying air relative humidity. Each data point is the result of one of the 'Kaybonnet' tests.

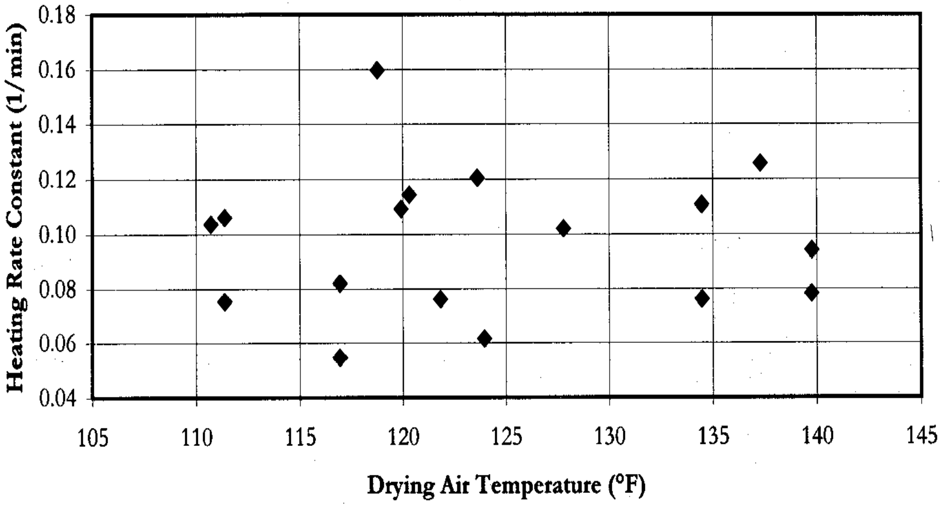

Fig. 4. Heating rate constant as a function of drying air temperature. Each data point is the result of one of the 'Kaybonnet' tests.

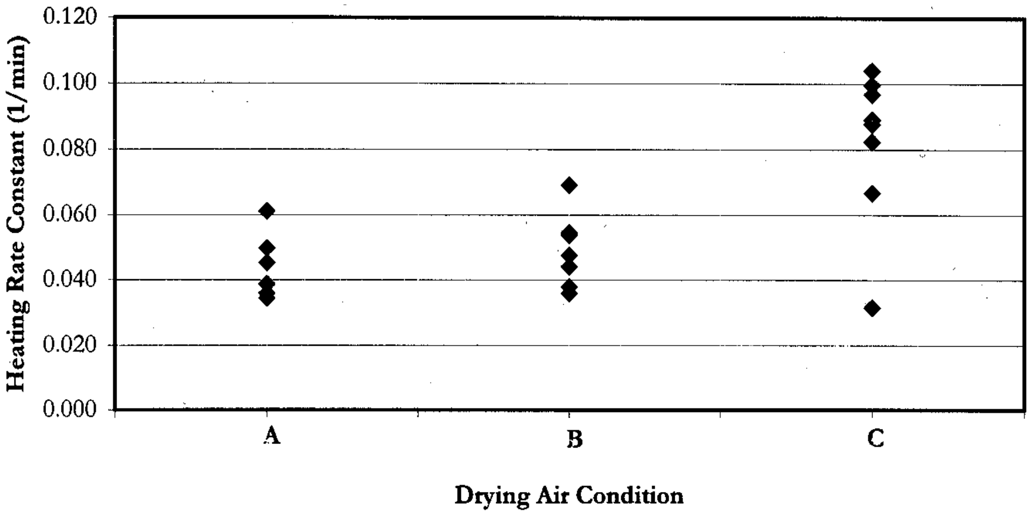

Fig. 5. The heating rate constant as a function of drying air condition (A: 110°F, 38% RH; B: 125°F, 25% RH; and C: 140°F, 17% RH), including all 'Bental' harvest moisture contents (HMC), ranging from 17% to 26% HMC.

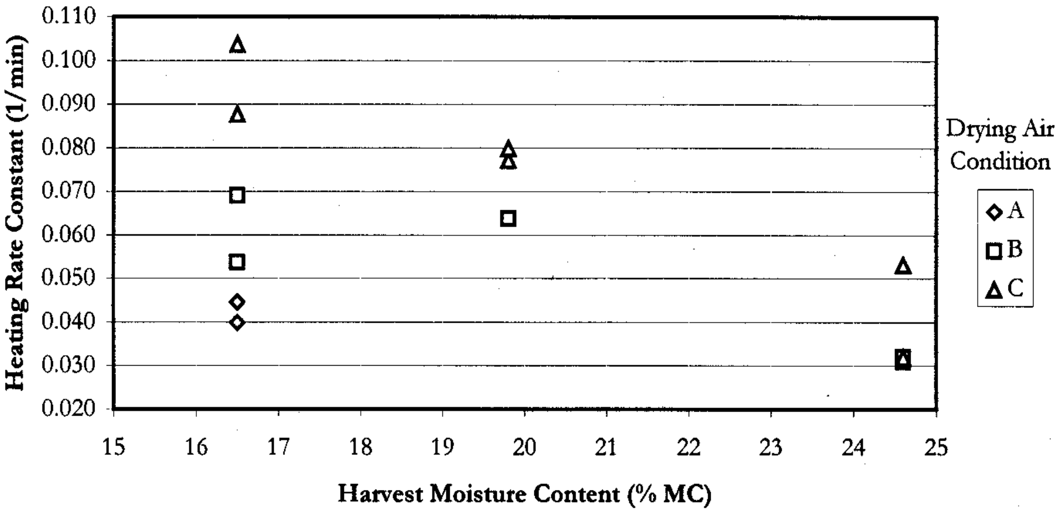

Fig. 6. The heating rate constant for cultivar 'Cypress' as a function of harvest moisture content, for each of the drying air conditions (A: 110°F, 38% RH; B: 125°F, 25% RH; and C: 140°F, 17% RH).

EFFECT OF TILLAGE SYSTEM ON SHEATH BLIGHT OF RICE

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

A long-term field experiment on seedbed tillage and sheath blight disease was continued in 1997 at the Pine Tree Experiment Station at Colt, Arkansas. Cultivars ‘Katy’ and ‘Lacassine’ were planted in conventional, stale-seedbed and no-till seedbeds featuring permanent plots with separate water systems on Site 1, and ‘Hutcheson’ soybeans were drill planted on Site 2. Levels of *Rhizoctonia solani* sclerotia in plot seedbeds were determined prior to planting with Site 1 having 2 to 18 viable sclerotia/ kg dry soil, depending on the treatment. A significantly higher level was found in the Lacassine x stale-seedbed plots. Sheath blight incidence for Site 1 (percentage of infected tillers) was 5, 15 and 6% for Lacassine and 2, 4 and 1% for Katy on conventional, stale-seedbed and no-till treatments, respectively. Vertical development of sheath blight ranged from 3 in the Katy plots to 5 to 7 in the Lacassine plots on a 0 to 9 scale. Rice yields in 1997 were 104, 114 and 95 bu/acre for Katy and 133, 113 and 82 for Lacassine on conventional, stale-seedbed and no-till plots, respectively. Soybean plots on Site 2 in 1997 yielded 67, 70 and 62 bu/acre (12%) for previous year Katy x conventional, stale-seedbed or no-till treatments, respectively, and 70, 65 and 62 bu/acre for previous year Lacassine x conventional, stale-seedbed or no-till treatments.

INTRODUCTION

Importance of certain rice diseases changes over time in response to different rice production schemes. Sheath blight was once a minor disease until semidwarf cultivars, high seeding rates, short crop rotations and heavy nitrogen (N) fertilization became common. These practices can also increase severity of many other rice diseases, including blast, 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 also adopted reduced tillage practices, primarily for soil conservation and other reasons (USDA, 1992). The most common crop rotation is currently rice-soybean-rice with the only seedbed preparation done in the fall. This “stale seedbed” is not disturbed until the following spring when winter vegetation is killed with a herbicide. The rice or soybean crop is then planted into the stale seedbed with conservation tillage planting equipment. An increasing number of growers have adopted true “no-till” rice production where the crop is planted directly into the previous crop residue without tillage at any time. Previous studies have been conducted in Arkansas and Louisiana (Bollich et al., 1992; Smith, 1992) on the effect of reduced tillage on fertilizer, weed control and other agronomic practices in rice, but no assessment of effect on rice diseases was made. Since survival between host crops of the sheath blight fungus has been linked to infected rice residue, increased sheath blight problems would be predicted if 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). On the other hand, diseases like take-all of wheat have declined where reduced tillage has been adopted (Brooks and Dawson, 1968). In California, 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 has been available, this research project was undertaken to determine the effect of reduced tillage practices on sheath blight of rice in a rice-soybean-rice rotation.

PROCEDURES

A long-term field experiment was established at the Pine Tree Experiment Station at Colt, Arkansas, on a site with a cropping history of rice and soybeans. Large permanent plots (20 x 50 ft) with separate water systems to prevent exchange of soil, water and sheath blight 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 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, 20 soil cores (3 in. dia x 2 in. deep) were randomly collected from each plot, bulked and dried for 2 weeks. Bulk samples were wet sieved according to the method of 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 plots received only fall tillage. Glyphosate was applied about 7 days before planting to kill existing vegetation on stale-seedbed and no-till plots.

Rice was planted on 18 April 1997 using a minimum tillage drill with 7 in. row spacings. All plots were watered and managed separately after planting to prevent exchange of soil- or water-borne inoculum between plots. Planting of Hutcheson soybeans on Site 2 was done in May using the drill and row spacings listed 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, weighed and values 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 1 ranged from 2 to 18/kg dry soil depending on the treatment. Sclerotia level in the Lacassine x stale-seedbeds was significantly higher than for other treatments (Table 1). This level was much higher than the previous year (Table 1).

Final disease incidence for sheath blight for multiple years and both sites (when in rice) are listed in Table 2. Only the Lacassine x stale seedbed treatment had significantly higher sheath blight incidence on Site 1 in 1997 (Table 2). Sheath blight severity was moderate, ranging from 5 to 7 on Lacassine (0-9 scale; Table 2). Rice yield for the no-till plots at Site 1 were usually significantly lower than other tillage treatments (Table 3). Poor seedling survival in the no-till plots after emergence resulted in extremely thin and erratic stands. It was hypothesized that salt damage was the primary factor underlying seedling death. Yields overall were lower than previous years, probably because of increasing soil pH and salinity, the long cold spring in 1997 and loss of N fertilizer before flooding.

Soybean yields for Site 2 averaged 62 to 70 bu/acre, with a 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 trend toward higher sheath blight incidence on stale seedbed and lower yield on no-till plots was again observed in 1997. 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 N fertilizer management are maintained. Increasing soil problems related to pH and salinity on reduced tillage seedbeds remain a growing concern, as well. Further research in these areas should be continued and improved control options investigated.

ACKNOWLEDGMENTS

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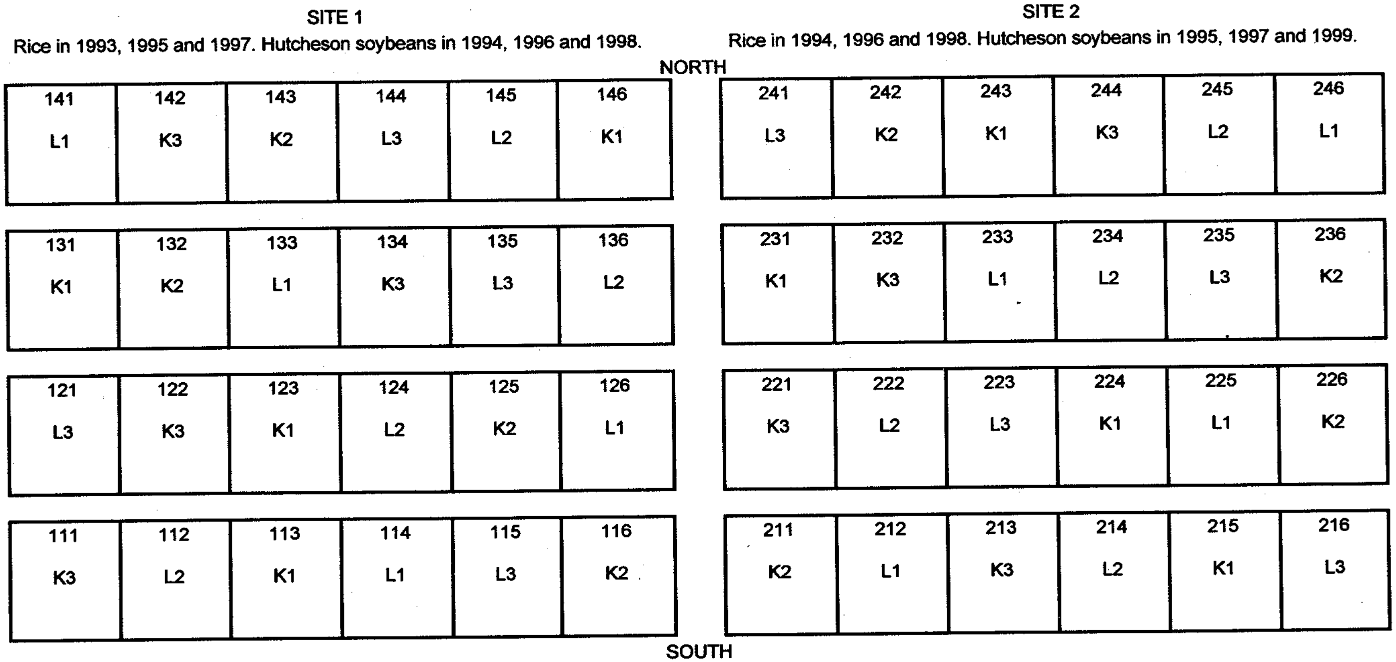

SITE 1

Rice in 1993, 1995 and 1997. Hutcheson soybeans in 1994, 1996 and 1998.

SITE 2

Rice in 1994, 1996 and 1998. Hutcheson soybeans in 1995, 1997 and 1999.

NORTH

141 L1	142 K3	143 K2	144 L3	145 L2	146 K1
131 K1	132 K2	133 L1	134 K3	135 L3	136 L2
121 L3	122 K3	123 K1	124 L2	125 K2	126 L1
111 K3	112 L2	113 K1	114 L1	115 L3	116 K2

241 L3	242 K2	243 K1	244 K3	245 L2	246 L1
231 K1	232 K3	233 L1	234 L2	235 L3	236 K2
221 K3	222 L2	223 L3	224 K1	225 L1	226 K2
211 K2	212 L1	213 K3	214 L2	215 K1	216 L3

SOUTH

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 111 = site 1, rep 1 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 ft 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 diseases, Colt, Arkansas.

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

		Viable Sclerotia per kg dry soil (mean) (Site 1)					Viable Sclerotia per kg dry soil (mean) (Site 2)			
Rice Cultivar	Tillage	1993	1994	1995	1996	1997	1994	1995	1996	1997
Katy	Conventional	1	2 a[†]	2 a	6 a	5 a	7 a	3 a	3 a	2 a
Katy	Stale-seeded	ND	8 a	2 a	4 a	6 a	9 a	5 a	3 a	7 a
Katy	No-till	1	9 a	4 a	2 a	2 a	11 a	8 a	5 a	10 a
Lacassine	Conventional	ND	8 x	2 x	5 x	6 x	9 x	7 x	5 x	3 x
Lacassine	Stale-seeded	2	8 x	2 x	9 x	18 y	11 x	18 x	12 y	21 y
Lacassine	No-till	1	9 x	4 x	6 x	5 x	7 x	15 x	15 y	12 x

[†] Means followed by the same letter within cultivar by column are not significantly different according to Tukey's HSD test (P=0.05).

Table 2. Final sheath blight incidence and severity in reduced tillage experiment field plots at Pine Tree Station, Colt, Arkansas.

		Final Sheath Blight Incidence and Severity									
		Site 1 - 1993		Site 1 - 1995		Site 1 - 1997		Site 2 - 1994		Site 2 - 1996	
Cultivar	Tillage	% IF[†]	Severity[‡]	% IF	Severity	% IF	Severity	% IF	Severity	% IF	Severity
Katy	Conventional	1.0 a[§]	3	2.0 a	3	2.0 a	3	1.0 a	3	0.8 a	3
Katy	Stale-seeded	0.5 a	3	5.0 a	3	4.0 a	3	0.5 a	3	1.2 a	3
Katy	No-till	0.5 a	3	2.0 a	3	1.0 a	3	0.5 a	3	1.5 a	3
Lacassine	Conventional	3.0 x	4	9.0 x	5	5.0 x	7	3.0 x	7	1.5 x	5
Lacassine	Stale-seeded	7.5 x	5	19.0 y	7	15.0 y	7	7.5 x	7	4.0 x	7
Lacassine	No-till	1.5 x	4	11.0 x	5	6.0 x	7	1.5 x	7	3.5 x	5

[†] % IF = percent infected tillers.

[‡] Severity ratings on a scale of 0-9.

[§] % 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			
Treatment	Rice 1993	Soybeans 1994	Rice 1995	Soybeans 1996	Rice 1997	Rice 1994	Soybeans 1995	Rice 1996	Soybeans 1997
Katy - Conventional	148 a[†]	61 a	133 a	58 a	104 ab	165 a	76 a	133 a	67 ab
Katy - Stale-seeded	158 a	64 a	134 a	58 a	114 a	156 a	73 ab	126 a	70 a
Katy - No-till	159 a	68 a	99 a	57 a	95 b	161 a	68 b	93 b	62 b
Lacassine - Conventional	176 x	61 x	151 x	60 x	133 x	201 x	71 x	153 x	70 x
Lacassine - Stale-seeded	180 y	64 x	149 y	58 x	113 y	188 y	74 x	169 x	65 xy
Lacassine - No-till	160 y	68 x	108 y	53 x	82 z	177 y	69 x	81 y	62 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)

KERNEL SMUT OF RICE IN ARKANSAS - 1997

R.D. Cartwright, W.J. Ross, C.E. Parsons, F.N. Lee,
S.R. Vann and G.E. Templeton

ABSTRACT

Kernel smut of rice continues to be a major disease problem in Arkansas, causing widespread yield and quality losses on cultivars ‘Cypress’, ‘Alan’, ‘Newbonnet’, ‘LaGrue’ and others. In 1997, kernel smut severity in grower fields was much worse than normal, especially on cultivars Cypress and LaGrue. Severity was heavily influenced by excessive nitrogen fertilization and rains during heading. Research on development of a more natural mist inoculation technique for screening potentially smut-resistant rice germplasm continued at the Rice Research and Extension Center. A total of 18 cultivars and an experimental variety were inoculated during late boot to early heading and maintained under nightly mist, then hand harvested and the level of smut determined. Results from this nursery in 1997 were not reliable due to insect and other damage, and data were supplemented by kernel smut evaluation of cultivars at three disease monitoring locations. ‘Katy’ and ‘Lemont’ remain two of the most field-resistant long-grain cultivars and Cypress, LaGrue and Newbonnet the most susceptible.

INTRODUCTION

Kernel smut of rice was very severe on several rice cultivars in Arkansas during 1997, 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 in continuous rice, water-seeded systems preferred by a few growers.

Kernel smut is caused by the fungus *Neovossia horrida* (Takah.) Padwick & A. Khan = [*Tilletia barclayana* (Bref.) Sacc. & Syd. in Sacc.] (Whitney, 1989), which closely resembles the Karnal bunt of wheat fungus, *Neovossia indica* (Mitra) Mundkur = (*Tilletia indica* Mitra) (Royer and Rytter, 1988). It was believed that *Neovossia horrida* 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). Other research has determined that the fungus was capable of infecting florets before anthesis and confirmed that the infection process was enhanced by high moisture during the heading phase (Cartwright et al., 1995).

Kernel smut infection has historically been difficult to induce under controlled conditions; however, improvements in the boot injection technique (Lee et al., 1991), used originally in research on Karnal bunt of wheat, has 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., 1991). 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 to attempt development of a more natural inoculation procedure. The basic development of a mist inoculation method was done in the greenhouse at Fayetteville, about 200 miles 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 Rice Research and Extension Center, near Stuttgart, Arkansas, in May 1997. A total of 18 cultivars and one experimental variety were hand-seeded in single 3 ft-rows, and each plot was positioned to receive nightly mist (12 hrs) using overhead mist nozzles connected to a charcoal-filtered water supply and timer. 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 2- to 3-day intervals for a total of three inoculations. Inoculum was prepared each day and kept cool until just before use. Some plants were entering anthesis at the last inoculation. Inoculation was done in the late afternoon, and mist treatments were applied immediately after the first inoculation and continued nightly until all cultivars had finished flowering. Misting usually began about 8 pm each day and continued until 8 am the next morning. Ten random panicles were collected from each row when the base of each panicle was filled and firm. Panicles were stored in paper bags, and the number of smutted grains per panicle was determined using the KOH method (Lee at al., 1991).

RESULTS AND DISCUSSION

Results of the two previous mist inoculation experiments at Pine Tree Station near Colt, Arkansas, are presented in Table 1. Level of kernel smut under the misted, inoculated plots was consistently higher than 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; therefore, 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 per panicle or less (Table 1). By contrast, known susceptible cultivars such as Cypress or Newbonnet had much higher smutted grain levels (Table 1). Smut levels in the 1997 field experiment could not be determined with confidence, due to kernel damage by insects and other fungi. So nursery results were supplemented by data from uniformly infected disease monitoring plots at three locations (Table 2). The screening method may require further refinement but appears to offer a reasonably practical and reliable means of screening germplasm for kernel smut resistance under field conditions. The testing will be scaled up in 1998 to accommodate additional germplasm.

SIGNIFICANCE OF RESULTS

Implementation of the kernel smut field screening technique will greatly enhance the ability of the Arkansas Rice Breeding Program to develop improved smut resistant cultivars. Currently, the level of kernel smut resistance for any developed U.S. rice cultivars is not known at the time of release and is subsequently determined in grower fields—a less-than-ideal situation.

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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[†].

	Mist / Inoculated		Mist / Not Inoculated		No Mist / Inoculated		No Mist / Not Inoculated		Rating[‡]	
Cultivar	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Bengal	2.5	1.7		0.8	0.3	1.1	0	0.1	R	R
Cypress	7.8	11.0		1.6	0.9	4.2	0.1	0.6	VS	VS
Katy	2.4	2.0		0.6	0.1	0.4	0	0.1	VR	VR
Kaybonnet	2.5	3.7		0.9	0.5	2.2	0	0.4	MS	MS
Lemont	2.2	2.5		0.6	0.3	1.3	0	0.8	VR	VR
M202	6.2	8.9		2.2	1.1	6.8	0	0.6	VS	VS
Mars	4.6	2.3		0.8	1.4	1.5	0	0.2	VR	VR
Newbonnet	6.6	13.8		1.4	0.5	8.2	0	0.7	VS	VS
Drew	3.8	5.1		0.7	0.7	3.3	0	0.1	MS	MS

[†] Data = number of smutted grains per panicle based on 10 panicles per 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.

Table 2. Kernel smut in rice disease monitoring plots - 1997.

	Smutted grains per panicle (40 panicles per site).					
Cultivar	Lawrence	Clay	Pine Tree	Average	Maximum	Reaction[†]
Koshihikari	0.3	0.3	0.6	0.4	0.8	R
Lacassine	0.9	1.0	1.3	1.1	1.8	R
RU9601053	1.0	1.2	1.1	1.1	1.6	R
Lemont	1.6	1.2	1.4	1.4	2.3	R
Katy	1.8	1.5	1.2	1.5	2.3	R
Jefferson	1.4	1.7	1.6	1.6	2.3	MS
Kaybonnet	1.1	1.5	2.3	1.6	3.1	MS
Priscilla	1.2	2.0	1.8	1.7	2.6	MS
Bengal	1.1	0.9	3.1	1.7	4.0	MS
Jodon	0.8	2.0	2.3	1.7	3.4	MS
Drew	2.3	2.6	2.7	2.5	3.2	MS
AB647	3.3	2.5	2.2	2.7	6.2	S
M204	2.8	3.8	2.7	3.1	5.0	VS
Lafitte	3.7	3.8	3.3	3.6	6.1	S
Cypress	1.6	4.3	6.4	4.1	8.7	VS
Litton	3.1	4.8	4.4	4.1	6.6	S
Lagrue	2.4	7.1	5.4	5.0	7.2	VS
M202	3.5	6.9	4.5	5.0	8.2	VS
Newbonnet	3.9	7.0	4.8	5.2	8.0	VS

[†] 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.

QUALITY CHARACTERISTICS OF LONG-GRAIN RICE MILLED IN TWO COMMERCIAL SYSTEMS

H. Chen, T.J. Siebenmorgen and K. Griffith

ABSTRACT

A long-grain rice cultivar, ‘Kaybonnet’, was milled to three degree of milling (DOM) levels in two commercial milling systems (a single-break, friction milling system and a multi-break, abrasion and friction milling system) and separated into five thickness fractions. For rice milled in both milling systems, the thinnest kernel fraction (<1.49 mm) had much higher bran content as indicated by the surface lipids content (SLC) than the other kernel fractions. Protein content decreased with increasing kernel thickness to 1.69 mm, after which it remained constant. For rice milled to a given DOM level, the multi-break system produced fewer brokens than did the single-break system.

INTRODUCTION

The function of rice milling is to produce well-milled rice that is essentially free of bran and contains a minimum amount of broken kernels. Rough rice comprises kernels of various sizes. In the rice industry, rice is typically milled as an unfractionated bulk. Chen and Siebenmorgen (1997) reported that unfractionated milling in a pilot-scale single-break mill (Satake BA-7) produced milled rice in which the bran content decreased with increasing kernel thickness to an average kernel thickness of 1.67 mm, after which the bran content remained constant. It was also observed that as the overall DOM level was increased, i.e., as the milling process progressed, thinner kernels were milled at a greater bran removal rate than thicker kernels.

The previous research did not include the use of commercial milling systems. It is yet unknown whether the previous conclusions from laboratory and/or pilot-scale single-break mills remain valid for commercial single-break milling systems. Additionally, multi-break milling systems have become more popular in the rice industry in recent years. Consequently, the objective of this research was to investigate the effects of conventional, unfractionated milling in both single-break and multi-break commercial milling systems on remaining bran content, protein content and breakage across thickness fractions.

PROCEDURES

The two milling systems investigated in this research were a single-break friction milling system and a multi-break abrasion and friction milling system, both of which were parts of commercial milling operations. The former consisted of a Satake BA-15 friction mill. The latter comprised a Satake VTA vertical rice whitener and two Satake KB-40 rice polishing machines, configured in series. In the second KB-40 machine (third break) of the multi-break milling system, a water mist was injected into the air stream just prior to the air entering the milling chamber.

A long-grain rice cultivar, Kaybonnet, from the same lot, with a rough rice moisture content (MC) of approximately 14% (wet basis), was milled in each of the two commercial milling systems. Samples at three DOM levels (low, medium and high) were collected at the outlet of the two milling systems. Head rice was then separated from brokens using a Satake test rice grader. Using a Carter-Day laboratory precision sizer, the head rice was separated into five thickness fractions (<1.49, 1.49-1.59, 1.59-1.69, 1.69-1.74 and >1.74 mm). Each thickness fraction was then measured for protein content and SLC as an indicator of the amount of bran remaining on kernels.

Surface lipid content of the milled head rice samples from each thickness fraction was determined using a Soxtec System HT extractor. Prior to extraction, a 5-g head rice sample from each thickness fraction was placed in cellulose extraction thimbles (diameter 26 mm, length 60 mm) and dried in a convection oven at 100°C for 1 hr. Surface lipids were extracted for 1 hr with 50 ml of petroleum ether (boiling point 35 to 60°C). The SLC was calculated as the amount of the extracted surface lipids expressed as a percentage of the original head rice mass (5 g). For each milled rice sample, two subsamples of 5 g were measured for SLC.

Protein content of milled rice samples was measured by means of the Dumas technique (Schmitter and Rihs, 1989). Head rice samples from each thickness fraction were ground in a UDY cyclone sample mill. For protein measurement, 50 mg of ground sample was placed into a tin capsule and loaded into a Fisons NA-2000 Nitrogen/Protein Analyzer. The sample was melted and converted to combustion gases at 900°C in a combustion reactor. Nitrogen was then separated from the combustion gases and detected by a thermal conductivity detector. Protein content (expressed as a dry basis) of each sample was calculated as the detected nitrogen content multiplied by a calibration constant of 5.95. For each sample, duplicate measurements were performed.

RESULTS AND DISCUSSION

Surface Lipid Content

Fig. 1 shows the change in SLC across thickness fractions at each of the three DOM levels for unfractionated rice milled in the single-break (a) and multi-break (b) milling systems. At low and medium DOM levels, the rice milled in the two milling systems had similar trends in the change of SLC across thickness fractions. Statistical analysis showed that the thinnest kernel fraction (<1.49 mm) had higher SLC than the other four thickness fractions, and the SLCs among these four fractions were not significantly different. At the high DOM level, the rice milled in the two systems showed a slightly different trend in the change of SLC across thickness fractions. For the rice milled in the single-break system, SLC decreased with increasing kernel thickness to a thickness of 1.69 mm, after which it remained constant. For the rice milled in the multi-break system, SLC decreased with increasing kernel thickness to a thickness of 1.59 mm, remained constant until a thickness of 1.69 mm, and then increased by a small, yet significant amount. All results obtained from the single-break system, as well as the trends at low and medium DOM levels for the multi-break system, agreed with those from similar tests using a pilot-scale single-break milling system (Chen and Siebenmorgen, 1997).

The differences between the SLC of the thinnest kernel fraction and the average SLC of the other four thickness fractions were 0.21, 0.09 and 0.08 percentage points, respectively, at low, medium and high DOM levels for the rice milled in the single-break system. The corresponding differences were 0.18, 0.09 and 0.02 percentage points for the rice milled in the multi-break system. This indicates that in both milling systems, increasing milling pressure or duration (i.e., changing DOM from a low to high level) caused the thinnest kernel fraction to be milled at a greater bran removal rate than the other kernel fractions. These results also agreed with the observations from the pilot-scale single-break milling system tested by Chen and Siebenmorgen (1997).

Protein Content

Fig. 2 shows the protein content of each thickness fraction of rice milled to each of the three DOM levels in the two systems. There were similar trends in the distribution of protein content across thickness fractions for the rice milled in the two systems. In all cases, for a given DOM level, protein content decreased significantly with increasing kernel thickness to 1.69 mm, after which it remained constant. For both systems, the rice milled to the low DOM level tended to have the highest protein content, and the rice milled to the high DOM level had the lowest protein content. As more surface bran was removed, the protein content of the milled rice kernels was reduced.

Rice Breakage

Rice breakage was quantified by the weight of broken rice expressed as a percentage of the total weight of milled rice. Fig. 3 shows the relationship between rice breakage and SLC for the unfractionated rice milled from the two commercial systems. In Fig. 3, points with the least SLC represent the highest DOM levels, and vice versa. The breakage for the three DOM levels ranged from 11.4 to 13.3% for the rice milled in the multi-break system and from 15.7 to 19.3% for the rice milled in the single-break system. At a representative DOM level of 0.4% SLC, rice breakage in the single-break system was 4 to 6 percentage points higher than that in the multi-break system.

The correlation coefficient (R) between breakage and SLC was -0.93 for the rice milled in the single-break system and -0.20 for the rice milled in the multi-break system. Breakage was highly associated with SLC for the single-break system, implying that as bran was removed, kernels were broken, and thus rice breakage increased as milling progressed. There was a weak relationship between rice breakage and SLC for the multi-break system. In the multi-break milling system, the rice breakage that was observed occurred primarily in the early milling stages; as more bran was removed, rice breakage did not increase considerably.

SIGNIFICANCE OF FINDINGS

For the Kaybonnet long-grain rice milled in the two commercial milling systems, the thinnest kernel fraction (thickness <1.49 mm) had higher SLC (an indication of the amount of bran remaining on kernels) than the other kernel fractions. Additionally, protein content decreased with increasing kernel thickness to 1.69 mm, after which it remained constant. These results could have ramifications in end-use processing operations since the amount of bran on kernels often determines their processing performance. Also these results show that the thin milled rice kernels could be potentially valuable for new products requiring high protein rice.

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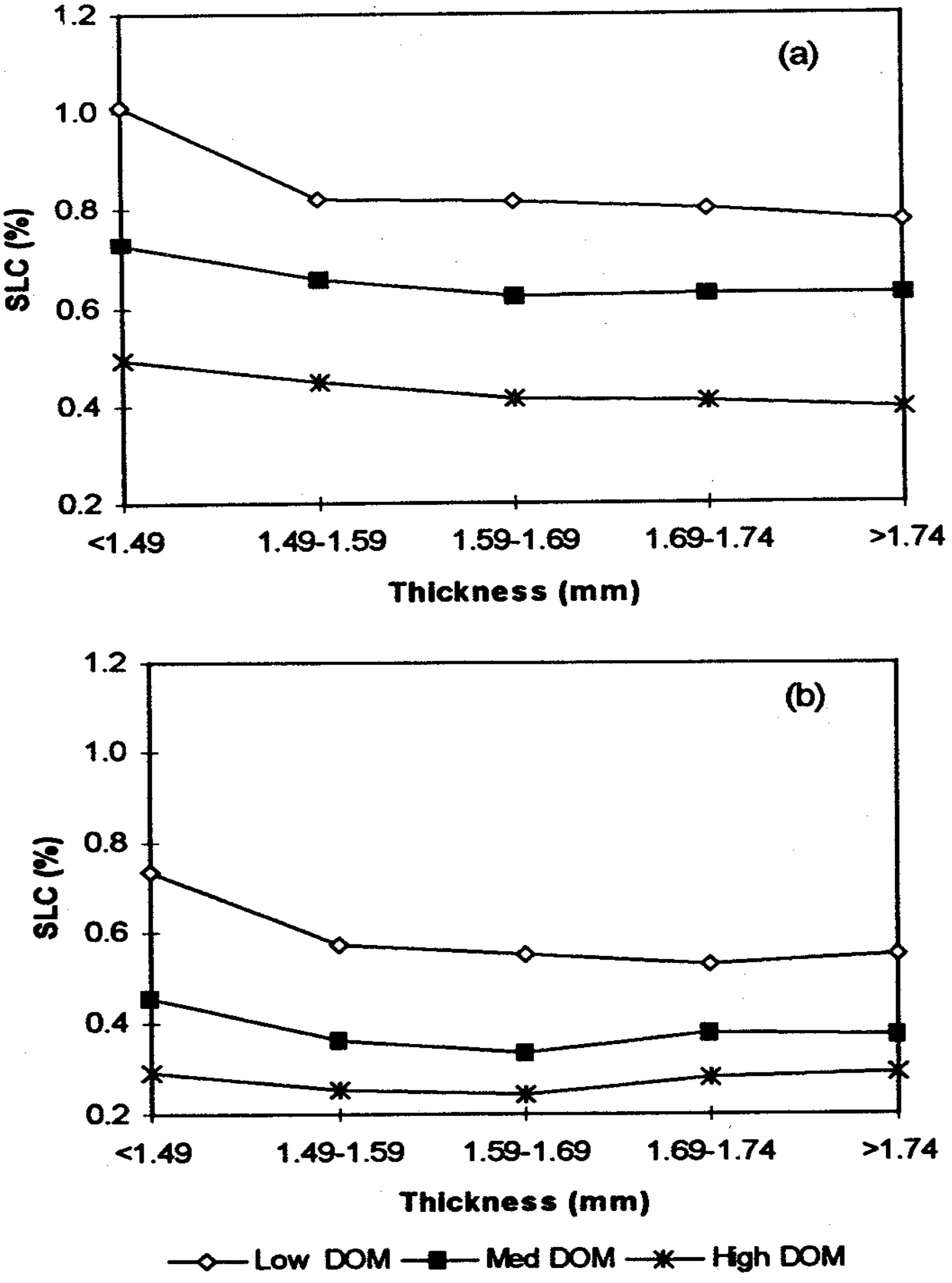

Fig. 1. Surface lipid content (SLC) of kernel thickness fractions from 'Kaybonnet' long-grain rice milled as an unfractionated bulk to three degree of milling (DOM) levels in two commercial systems; (a) single-break milling system, (b) multi-break milling system.

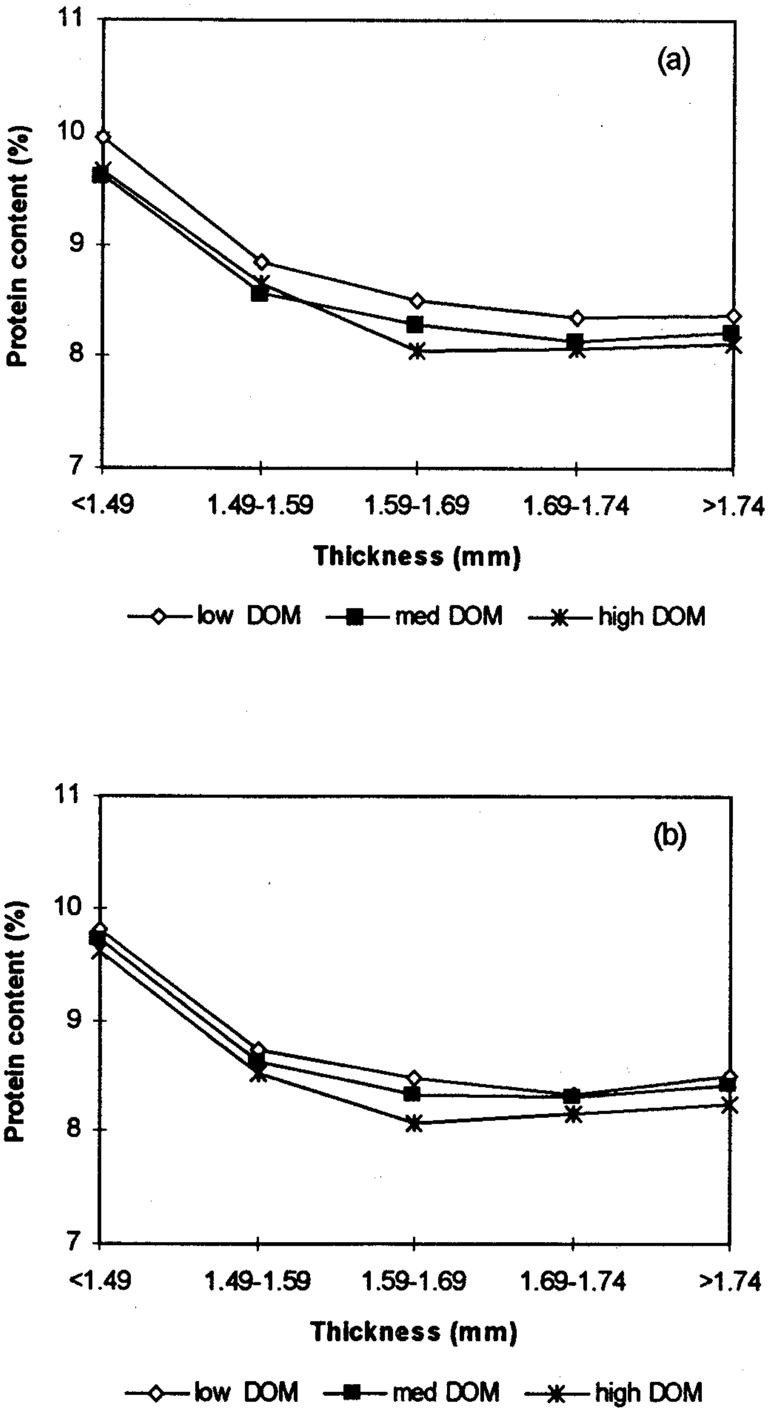

Fig. 2. Protein content of kernel thickness fractions at the indicated degree of milling (DOM) levels for 'Kaybonnet' long-grain rice milled in two commercial systems; (a) single-break milling system, (b) multi-break milling system.

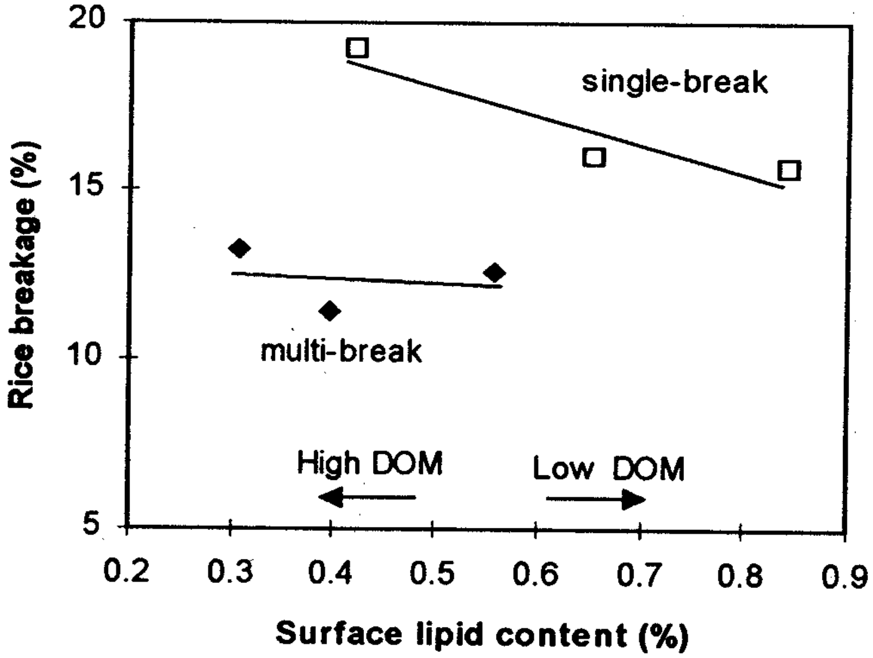

Fig. 3. Relationship between rice breakage and surface lipid content of non-fractionated rice milled in two commercial systems.

EFFECTS OF ROUGH RICE HANDLING ON GELATINIZATION AND RETROGRADATION OF RICE FLOUR

J. Fan, B.P. Marks and M.J. Daniels

ABSTRACT

The effects of pre-drying procedures, drying condition and rough rice storage history on the gelatinization and retrogradation properties of three rice cultivars (‘Bengal’, ‘Kaybonnet’, ‘Cypress’) were studied via differential scanning calorimetry (DSC). The 1995 storage study with Cypress rice indicated that rough rice storage temperature had a significant effect on the gelatinization characteristics of the rice flour ($P<0.001$). The rice stored at 38 °C exhibited higher gelatinization enthalpy and peak temperature than did the rice stored at 4 and 21 °C. The pre-drying conditions had no significant effect on the gelatinization enthalpy but did on the peak temperature. The rough rice pre-drying conditions and drying temperature had little effect on the retrogradation enthalpies and temperatures of gelatinized rice flour. Additional DSC tests with stored Bengal and Kaybonnet in 1996 indicated that cultivar and storage duration significantly ($P<0.05$) affected gelatinization and retrogradation of rice flours. Gelatinization enthalpies and temperatures for Bengal and Kaybonnet significantly increased as storage duration increased ($P<0.05$).

INTRODUCTION

Storage of freshly harvested rough rice is an important step in postharvest operations. Particularly during the first few months after harvest, several important functional properties are changing (Perdon et al., 1997). Villareal et al. (1976) and Perez and Juliano (1981) reported a major increase in amylograph peak viscosity during the early stage of storage. Villareal et al. (1976) and Chrastil (1990) also observed that swelling ability and water uptake ratio of cooked rice kernels increased during storage. In addition, the cooked rice becomes harder and less sticky after rough rice storage at a higher temperature or moisture content (mc; Perez and Juliano, 1981; Tamaki et al., 1993).

Thermal properties of rice, which are important in value-added application, might also be influenced by postharvest handling. Russell and Juliano (1983) used DSC to characterize the gelatinization properties of eight rice starches. The gelatinization behavior of whole-grain milled rice was investigated by Normand and Marshall (1989), who found that the whole rice grain exhibited two endothermic transitions associated with starch gelatinization, whereas rice flour exhibited only one endotherm. Using the DSC technique, Fan and Marks (1998) recently reported that grain type and cultivar have significant effects on gelatinization and retrogradation properties of milled rice flours.

The objective of this project was to determine the effects of rough rice pre-drying, drying and storage conditions on the gelatinization and retrogradation behaviors of rice flour via differential scanning calorimetry.

PROCEDURES

The rough rice used in the 1995 storage study was cultivar Cypress (long-grain), which was harvested at the University of Arkansas (UofA) Rice Research and Extension Center (RREC), Stuttgart, Arkansas, at a mc of 20.5% in the fall of 1995. The rough rice for the 1996 storage study was cultivars Bengal (medium-grain) and Kaybonnet (long-grain). The Bengal was harvested at RREC (18.0% mc), and the Kaybonnet was harvested at the UofA Northeast Research and Extension Center, Keiser, Arkansas (18.3% mc).

In 1995, subsequent postharvest variables included two pre-drying conditions (dried immediately or dried after 86 h wet holding), two drying conditions [low temp. = 33°C, 67.8% relative humidity (rh), 45 min; high temp. = 54.3°C, 21.9% rh, 45 min] and four storage treatments (no storage and storage at 4, 21 and 38°C for 20 weeks). After the drying treatments and prior to storage, the rough rice was placed in thin layers in a controlled condition chamber (33°C, 67.8% rh) and equilibrated to 12.5 mc over a period of approximately 2 weeks. Subsequently, each lot of rice was placed in a sealed plastic bucket and stored for 20 weeks in one of three storage chambers (4, 21 and 38°C).

In 1996, the subsequent postharvest variables were two storage moisture contents (12 and 14%), three storage temperatures (4, 21 and 38°C) and four storage durations (0, 3, 9 and 16 weeks). After drying, the samples were equilibrated and prepared for storage as described for the 1995 samples.

After the prescribed storage durations, subsamples were removed and equilibrated to room temperature in sealed plastic bags. Each rough rice sample (150 g) was hulled and milled for 30 s in a McGill #2 laboratory mill (Seedboro Equipment Co., Chicago, Illinois). The head rice was collected on a shaker table with 4.76-mm holes (Seedboro Equipment Co., Chicago, Illinois) and then ground to flour in a laboratory cyclone mill equipped with a 0.5-mm screen (UDY Co., Fort Collins, Colorado).

Gelatinization and retrogradation of the rice flours were investigated via a differential scanning calorimeter (Pyris 1, Perkin-Elmer Co., Norwalk, Connecticut). Rice flour (3.5 to 4.5 mg) was weighed into an aluminum DSC sample pan, and distilled water was added to give a water:flour (dry solid) ratio of 2.5:1. The sealed sample pans were first heated in the DSC from 20 to 110°C, with a heating rate of 10°C/min, to determine the gelatinization enthalpy and temperature. For the retrogradation measurements, the gelatinized rice sample pans were then held at 4°C for 7 days and rescanned in the DSC from 20 to 90°C at 10°C/min. Temperature and enthalpy for gelatinization and retrogradation were extracted from the DSC thermograms via Pyris series data analysis software.

RESULTS AND DISCUSSION

Figure 1 shows representative DSC thermograms for the gelatinization peak (curve A) and the retrogradation peak (curve B) of the same sample (after gelatinization). The gelatinization of 1995 Cypress rice flour occurred at a temperature range of ~74 to 85°C. The associated enthalpy for gelatinization varied from 7.8 to 9.7 J/g, depending on the postharvest treatments (Table 1).

The endothermic peaks of retrogradation were at a much lower temperature, typically ranging from 46 to 63°C (Figure 1). In addition, transition peaks of retrogradation appeared broader than those of gelatinization. The enthalpy for retrograded rice gels varied from 5.1 to 6.7 J/g, which was about 60 to 70% of the gelatinization enthalpy.

Based on the 1995 data, storage treatment had a significant effect on the gelatinization enthalpy and peak temperature ($P<0.001$, Table 2). Pre-drying condition exerted no significant effect on the gelatinization enthalpy but did on the peak temperature ($P<0.001$). In addition, pre-drying condition and storage treatment had a significant interactive effect on both the gelatinization enthalpy and peak temperature.

The mean gelatinization enthalpy and peak temperature showed little change when the Cypress was stored at a relatively low temperature, either 4 or 21°C. However, rice storage at a high temperature (38°C) significantly increased the gelatinization peak temperature and enthalpy. The rice stored at 38°C for 20 weeks exhibited an average 0.6 J/g increase in gelatinization enthalpy and an approximately 1.0°C increase in peak temperature compared to the control sample (i.e., rice without storage). At the storage temperature of 4°C, the immediately dried rice had a lower gelatinization enthalpy (7.9 J/g) than did the same rice with delayed drying (8.4 J/g), even though their gelatinization temperatures were similar.

The retrogradation properties of Cypress were less affected by pre-drying procedure and drying temperature than were the gelatinization properties. Of all the variables, only storage treatment had a significant ($P<0.05$) effect on retrogradation enthalpy. The rice that was not stored had an average retrogradation enthalpy of 5.3 J/g, which was 1.0 J/g lower than those for rices stored at 21°C and 38°C. Unlike gelatinization, the retrogradation properties of rice were affected little by storage temperature.

Additional results from the 1996 tests indicate that cultivar and storage duration also have a significant effect ($P<0.01$) on the gelatinization enthalpy and peak temperature. Bengal and Kaybonnet (12% storage mc) had initial gelatinization enthalpies of 9.7 and 8.3 J/g. Their gelatinization enthalpies increased to 10.9 and 8.8 J/g, respectively, after 16 weeks of storage at 38°C (Figure 2). Their gelatinization temperatures also significantly increased with storage duration, particularly at a high storage temperature (38°C). Additionally, cultivar, storage temperature and storage duration significantly ($P<0.05$) affected retrogradation enthalpy and/or temperatures. Even though Kaybonnet had a much higher gelatinization temperature (~75°C) than did Bengal (~70°C), they exhibited similar retrogradation temperatures (55-56°C). Rough rice storage mc had no significant effect on the gelatinization and retrogradation of rice tested in this study.

SIGNIFICANCE OF FINDINGS

This study demonstrates that wet holding, drying condition and rough rice storage history all significantly affect the gelatinization and/or retrogradation properties of rice flour. The gelatinization temperature and associated enthalpy of rice flour are significantly affected during the first few months of rough rice storage, particularly at a high storage temperature. Given that the quality and functionality of rice flour in value-added applications are greatly influenced by these properties, it may be possible to suggest particular postharvest management strategies that optimize starch properties for a specific end-use application.

ACKNOWLEDGMENTS

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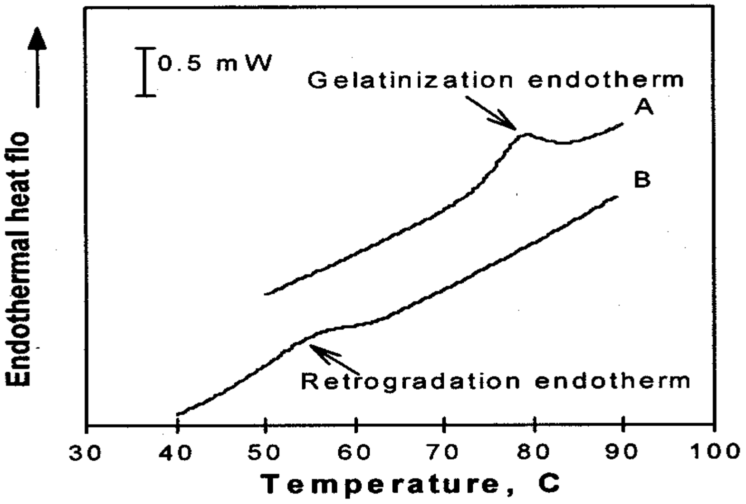

Fig. 1. Sample differential scanning calorimetry scans for the first run of 1995 Cypress rice flour (Curve A) and second run (Curve B) of the same sample after being stored at 4°C for 7 days. The weight of dry rice flour in the sample was 3.7 mg.

Table 1. Enthalpy (ΔH) and peak temperature (T_p) for gelatinization and retrogradation of 1995 Cypress rice flour after different drying and storage treatments.

			Gelatinization		Retrogradation	
Pre-drying condition	Drying temperature	Storage treatment †	ΔH (J/g)	T_p (°C)	ΔH (J/g)	T_p (°C)
Immediate	High	Before storage	8.6	78.6	5.4	55.2
Immediate	High	4 °C	7.8	78.5	6.2	55.1
Immediate	High	21°C	9.0	78.5	6.3	54.8
Immediate	High	38°C	9.7	79.8	6.3	55.9
Delayed	High	Before storage	8.5	78.1	5.2	55.4
Delayed	High	4°C	8.6	78.1	6.1	55.6
Delayed	High	21°C	8.5	78.4	6.3	54.9
Delayed	High	38°C	9.0	79.6	6.4	54.7
Delayed	Low	Before storage	8.7	78.1	5.5	55.4
Delayed	Low	4°C	8.1	78.3	5.6	55.3
Delayed	Low	21°C	8.3	78.2	6.7	55.1
Delayed	Low	38°C	9.0	79.6	6.6	55.4
Immediate	Low	Before storage	9.0	79.4	5.1	55.4
Immediate	Low	4°C	8.3	78.4	6.2	55.4
Immediate	Low	21°C	8.6	78.6	5.8	55.6
Immediate	Low	38°C	9.3	79.5	5.9	55.7

† Storage treatment included zero time storage and storage at 4, 21 or 38°C for 20 weeks.

Table 2. Analysis of variance for gelatinization enthalpy and peak temperature for 1995 'Cypress' rice flour.

Source of Variation†	Gelatinization enthalpy (ΔH)				Gelatinization peak temperature (T_p)			
	Degree of freedom	Mean square	F value	Prob>F	Degree of freedom	Mean square	F value	Prob>F
DT	1	0.0798	0.50	0.4831	1	0.1153	1.37	0.2494
PDC	1	0.2151	1.36	0.2524	1	1.3704	16.32	0.0003*
ST	3	2.6246	16.54	0.0001*	3	4.4475	52.97	0.0001*
DT*PDC	1	0.0133	0.08	0.7737	1	0.0147	0.17	0.6788
DT*ST	3	0.2689	1.69	0.1865	3	0.1812	2.16	0.1110
PDC*ST	3	0.5616	3.54	0.0247*	3	0.3842	4.58	0.0085*

† DT: drying treatment, PDC: pre-drying condition, ST = storage treatment.

* significant at α=0.05.

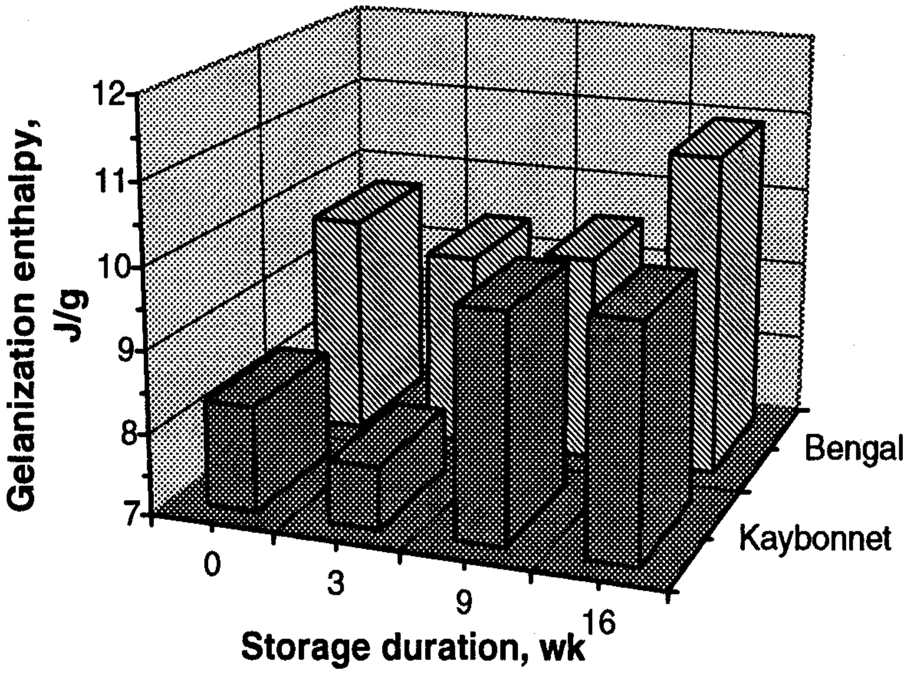

Fig. 2. Changes in gelatinization enthalpy of 'Bengal' And 'Kaybonnet' rice flour as a function of rough rice storage duration at 38°c.

EQUILIBRIUM MOISTURE CONTENTS OF THREE COMMON LONG- AND MEDIUM-GRAIN RICE CULTIVARS

J. Fan, T.J. Siebenmorgen, B.P. Marks and L. Du

ABSTRACT

The equilibrium moisture contents (EMCs) of two long-grain rice cultivars (‘Kaybonnet’ and ‘Cypress’) and one medium-grain cultivar (‘Bengal’) differing in harvest moisture content (HMC), harvest location and drying treatment were measured at drying temperatures of 4, 21 and 38°C with relative humidities (RH) ranging from 11 to 96%. Cultivar, HMC and drying treatment significantly affected the EMC of rice, particularly under the conditions of low equilibration temperatures and high relative humidities. The EMC for Bengal rough rice was generally 0.5 to 1.8 percentage points higher than that for Kaybonnet or Cypress. Rough rice with a higher HMC gave higher EMCs at most relative humidities. Rapid drying of rice resulted in a decrease in EMC at low equilibration temperature. There was little to no effect of cultivar, harvest and drying conditions on the EMC at the high equilibrium temperature. At most relative humidities, the EMC values for Bengal, Kaybonnet and Cypress rough rice were approximately 0.5 to 2.0 percentage points higher than previously published data indicated.

INTRODUCTION

Knowledge of the equilibrium moisture content (EMC) of rough rice and its constituent fractions is necessary for the optimization of most postharvest operations, including drying and storage. In early investigations of rice sorption, Karon and Adams (1949) observed that there were differences in sorption behaviors between rice constituent fractions of ‘Rexoro’ rice. The EMC values for the milled rice at a temperature of 25°C were higher than those of rough rice, hulls and bran. Juliano (1964) reported that waxy rice had significantly higher EMCs at higher relative humidities than nonwaxy rices at 27.5 and 32.5°C.

Many controllers being used for rice drying and storage utilize the concept of EMC as the basis for control strategies. The Arkansas Cooperative Extension Service also recommends measuring air temperature and RH as a means of determining the EMC, and then bases further recommendation on the calculated EMC values (Anon, 1987). In both of the above instances, EMC is calculated based on one of the two published equations, the Chung or the modified Henderson equations (ASAE, 1995). Neither equation accounts for the type of rice (long, medium or short grain). The equations were also developed using cultivars that may have had different constituent properties than current cultivars. Observed difference between measured MCs and predicted EMCs have prompted many to question the accuracy of the published equations.

The objectives of this study were to provide EMC data for three common rice cultivars (Bengal, Kaybonnet and Cypress) and to determine the effects of harvest moisture content and drying treatment on the EMCs of rough and milled rice.

PROCEDURES

Three rice cultivars were used: Bengal (medium-grain), Cypress and Kaybonnet (long-grain). 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 1996. The rice was grown under the recommended management procedures provided by the Arkansas Cooperative Extension Service. A summary of the rice lots is given in Table 1.

After harvest, the rice was immediately transported to the University of Arkansas Rice Processing Lab and cleaned using a dockage tester. To elucidate the effect of drying treatment on rice EMC, rough rice lots harvested at Stuttgart at a high HMC (19.1-22.5%) were subjected to two drying treatments: A (43.5°C, 38.2% RH, for 30 min) and B (60°C, 16.9% RH, for 30 min) in a thin-layer drier. The moisture contents (MCs) of Bengal, Kaybonnet and Cypress rice were 19.9, 17.7 and 18.5%, respectively, after drying treatment A and 15.8, 14.6 and 15.9%, respectively, after drying treatment B.

The milled rice was produced by milling rough rice subsamples from the lots harvested from Stuttgart at a low HMC. Before milling, the MC of the rough rice was brought to ~12.5% using a conditioning chamber held at a temperature of 21°C and relative humidity of 50%. The milling procedure consisted of hulling 150 g of rough rice in a McGill sample huller (Rapsco, Brookshire, Texas) and milling the resultant brown rice for 30 s in a McGill no. 2 laboratory mill (Rapsco, Brookshire, Texas). All the rice samples were placed in plastic bags and held in a storage room at 4°C until the EMC tests.

Seven sealable containers, constructed of Plexiglass, with dimensions of 18 x 12 x 10 in., were used for the EMC tests. Tested samples consisted of six rough rices from Stuttgart, three rough rices from Keiser, six drying-treated rough rices, and three milled rices (whole kernels). Eighteen screen containers, each holding about 50 g of rice, were suspended above saturated salt solutions in the air-tight EMC containers for at least 5 or 6 weeks at a given surrounding temperature to allow equilibrium between the air and the rice. The EMCs of the rice were tested under three surrounding temperatures: 4, 21 and 38°C. Seven salt solutions were used: lithium chloride, potassium acetate, potassium carbonate, magnesium nitrate, sodium chloride, potassium chloride and potassium nitrate. These solutions provided RHs ranging from 11% to 96%.

Moisture content measurements were conducted following the procedures recommended by ASAE (1995). Ten- to fifteen-gram subsamples were dried in a conventional, convection oven at a temperature of 130°C for 24 hrs. The MC was calculated based on the weight difference in the sample before and after oven drying. A non-linear regression procedure (SAS, 1990) was employed to determine the coefficients of the Chung equation when fit to this data.

RESULTS AND DISCUSSION

Figure 1 shows the EMC curves for three rough rice cultivars (Bengal, Kaybonnet and Cypress) harvested at a low MC (14-17%). At an equilibrium temperature of 4°C, the three cultivars exhibited no significant difference in the

EMC values at low RHs. However, when RHs were greater than 55%, the cultivar difference in the EMC became apparent. The EMC for Bengal was 1.1 to 1.8 percentage points higher than that for Kaybonnet and 0.5 to 0.9 percentage points higher than that for Cypress. As the equilibration temperature increased to 21°C, the cultivar differences in EMC at high relative humidities became less; the EMC for Bengal was only 0.5 to 1.2 percentage points higher than that for Kaybonnet or Cypress (Figure 1B). At 38°C, the difference in EMC values between the cultivars over the RH range of 10 to 90% was less than 0.6 percentage points (Figure 1C). As expected, the EMC of rice decreased with an increase in temperature at a given RH.

Kaybonnet harvested at a higher MC gave higher EMC values (4°C) than that harvested at lower MCs when RHs were greater than 60% (data not shown here). The magnitude of this effect of HMC on the Kaybonnet EMC decreased as the equilibrium temperature increased from 4 to 21°C and essentially disappeared at 38°C. Compared to the effect on Kaybonnet, the effect of HMC on Cypress EMC at 4°C was small. For the three cultivars studied, harvest location (Stuttgart or Keiser) did not show significant effects on the EMC of rough rice at most RH levels.

The EMC for Kaybonnet was significantly affected by drying treatments at both the 4 and 21°C equilibration temperatures. Over the RH range of 45 to 90%, the EMC at 4°C for Kaybonnet without drying treatment was 0.6 to 1.5 percentage points higher than that dried under the rapid drying treatment (condition B). The gentle drying treatment (condition A) showed less effect on the EMC than did drying treatment B. In addition, the difference in EMC between the dried and non-dried rice decreased with increasing temperature.

When Bengal, Kaybonnet and Cypress rough rice was milled, the resulting head rice EMC values were approximately 0.6 to 1.5 percentage points higher than those of the corresponding rough rice at temperatures of 4, 21 and 38°C. The higher EMC value for milled rice is mainly due to its higher starch and protein content and lower fiber content (Juliano and Bechtel, 1985). The difference in the EMC values for white rice across cultivars was less than 1.0 percentage point.

Figure 2 indicates that there were significant deviations between the EMC data reported herein and those predicted by the Chung EMC equation (ASAE, 1995). In most equilibration RHs/temperatures combinations, the EMC data for the rough rice used in this study were approximately 0.5 to 2.0 percentage points higher than that calculated from the Chung EMC equation.

Table 2 summarizes the coefficients of the Chung equation for Bengal, Kaybonnet and Cypress cultivars, which were obtained from nonlinear regression of our experimental data. The coefficients in Table 2 allow for calculation of EMC values of Bengal, Kaybonnet and Cypress cultivars based on our data.

SIGNIFICANCE OF FINDINGS

Data on the EMC are normally used for drying rate calculations and the design and control of rice drying and storage conditions. Our results indicate that cultivar, harvest MC and drying treatment significantly affected the EMC values of rice, particularly at lower temperatures and/or higher relative humidities. In addition, there are significant deviations in the EMC of the rice studied in this work from previously published data. New coefficients of the Chung equation were provided to give more accurate predictions of the EMC values of Bengal, Kaybonnet and Cypress rice grown in Arkansas.

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Table 1. Harvest locations and moisture contents (HMCs) of the rough rice used in determine equilibrium MCs.

Location and cultivar	Low HMC %(wb)[†]	High HMC %(wb)
Stuttgart		
Bengal (medium-grain)	17.4	22.5
Kaybonnet (long-grain)	14.1	19.1
Cypress (long-grain)	16.5	19.8
Keiser		
Bengal (medium-grain)	-	22.4
Kaybonnet (long-grain)	-	19.5
Cypress (long-grain)	-	20.9

[†] wb = wet basis

Table 2. Coefficients of the Chung equation for 'Bengal', 'Kaybonnet' and 'Cypress' cultivars harvested at different moisture contents and locations.

	MC=E-F*ln[-(T+C)*ln(RH)][†]			
Rice source	C	E	F	SEM[‡]
Bengal				
Rough rice				
HHMC [Stuttgart][§]	35.436	0.31879	0.050437	0.0077
LHMC [Stuttgart]	36.429	0.31429	0.049243	0.0085
HHMC[Keiser]	33.593	0.31307	0.049317	0.0084
White rice				
LHMC [Stuttgart]	*50.643*	*0.33414*	*0.049080*	*0.0073*
Kaybonnet				
Rough rice				
HHMC [Stuttgart]	37.444	0.30325	0.046424	0.0081
LHMC [Stuttgart]	40.923	0.29472	0.044043	0.0078
HHMC[Keiser]	36.277	0.29520	0.044853	0.0086
White rice				
LHMC [Stuttgart]	*53.409*	*0.31782*	*0.044774*	*0.0085*
Cypress				
Rough rice				
HHMC [Stuttgart]	34.840	0.30308	0.047996	0.0082
LHMC [Stuttgart]	38.222	0.30100	0.045793	0.0079
HHMC[Keiser]	34.252	0.29993	0.045940	0.0089
White rice				
LHMC [Stuttgart]	*54.502*	*0.32294*	*0.045709*	*0.0080*
Rough rice (Chung equation, ASAE, 1995)	35.703	0.29394	0.046015	0.0086

[†] T: temperature, °C; RH: relative humidity, decimal; MC: moisture content, decimal dry basis.

[‡] SEM: standard error of moisture.

[§] HHMC: high harvest moisture content; LHMC: low harvest moisture content.

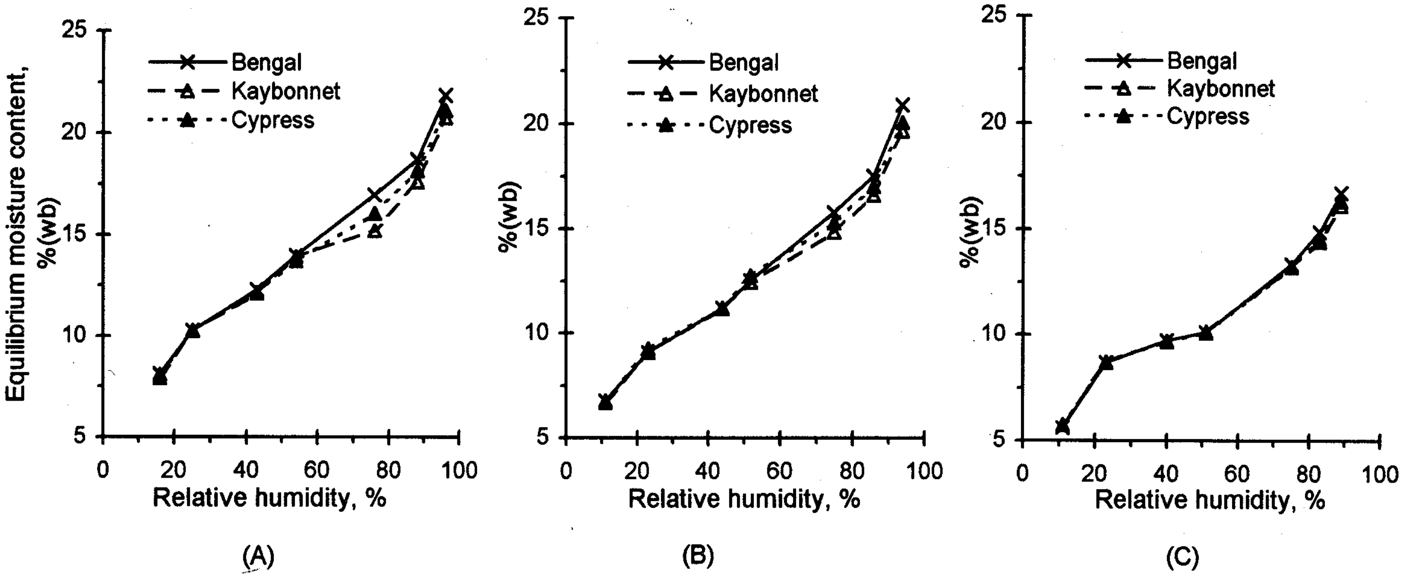

Fig. 1. Equilibrium moisture contents of 'Bengal', 'Kaybonnet' and 'Cypress' rough rice harvested at 14-17% moisture content and equilibrated at temperatures: A 4°C, B 21°C, C 38°C.

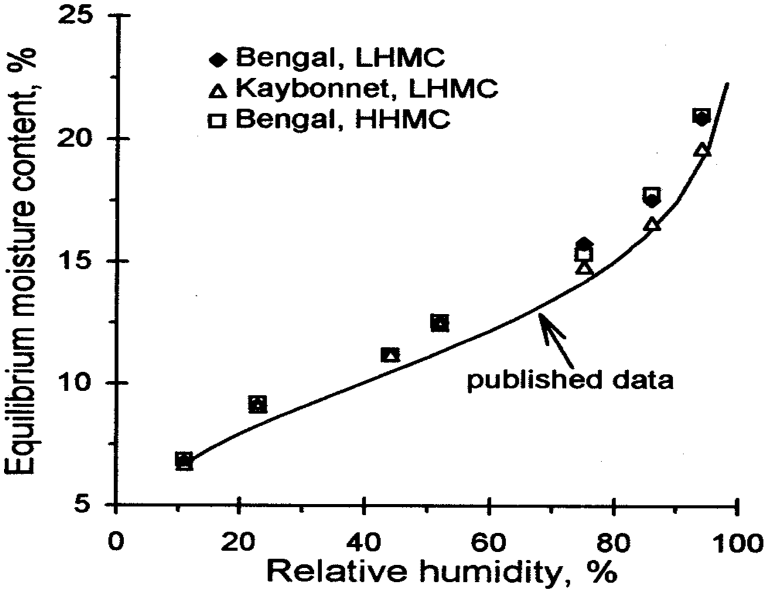

Fig. 2. Comparison of the equilibrium moisture contents of some rough rices used in this study with those from published data (Chung equation, ASAE, 1995).

RICE MILL AIR CONDITIONS CAUSING RICE KERNEL BREAKAGE IN MEDIUM-GRAIN CULTIVARS

B.J. Lloyd and T.J. Siebenmorgen

ABSTRACT

Medium-grain milled rice of two cultivars (‘Bengal’ and ‘Orion’) was exposed to air conditions of 30°C and relative humidities (RHs) ranging from 23% to 82%. The kernels were then subjected to a mechanical roller mechanism to determine the extent of fissure damage resulting from each air condition treatment. Milled rice at lower moisture content (MCs) experienced more fissure damage at higher RH conditions and less damage at lower RH conditions. Milled rice at higher MCs experienced less fissure damage at higher RH conditions and more damage at lower RH conditions.

INTRODUCTION

Milled rice kernels have been shown to rapidly fissure and eventually break-up due to certain air conditions within the milling plant environment. Milled kernels rapidly gain or lose moisture from the environment depending on the temperature/relative humidity of the surrounding air and the MC of the kernels (Kunze and Choudhary, 1972; Lu et al., 1993). This moisture migration into and out of the kernel causes tensile or compressive stresses to occur in the starchy endosperm of the milled kernel (Stermer, 1968). Depending on the gradient between the kernel MC and the equilibrium moisture content (EMC) of the surrounding air, these stresses can cause kernels to fissure during post-milling operations, which can lead to kernel breakage and a significant reduction in head rice yield (HRY) for the rice miller as well as affecting end-users in value-added products that utilize rice.

Past research at the University of Arkansas (Siebenmorgen et al., 1998) identified the air conditions causing milled rice kernel breakage in long-grain cultivars. A test apparatus and an experimental procedure were developed to quantify kernel breakage as a function of air temperature and RH, kernel MC and kernel temperature in long-grain cultivars.

As a continuation of the milled rice breakage project, two medium-grain cultivars were selected to determine the relative fissuring response of medium-grain kernels at a range of MCs exposed to various air conditions representing a mill environment.

MATERIALS AND METHODS

The experimental procedure was divided into two separate ‘conditioning’ procedures.

Constant Kernel Moisture Content and a Range of Relative Humidities

Two cultivars of medium-grain rice Bengal and Orion were grown and harvested as foundation seed at the University of Arkansas Rice Research and Extension Center at Stuttgart, Arkansas. Two 50-lb sacks from each cultivar at a MC of 12.5%, as measured by a Shizuoka Seiki Co. Model CTR-800A individual kernel moisture meter, were used for this project. Samples of 150 g of rough rice were dehulled in a laboratory-scale Satake paddy husker and then milled in a McGill No.2 laboratory mill to a degree of milling of 150 as determined by a Satake MM-1B Whiteness Meter.

The milled rice samples were exposed to a precisely controlled air stream generated using a Parameter Generation and Control (PG & C) relative humidity/ temperature control unit. The control unit maintained air conditions within (+/-) 0.5°C and/or (+/-) 0.5% RH. The PG & C unit was coupled to a testing chamber from which a fan circulated the conditioned air through four 4-in.-diameter ducts. A screened sample cup was placed in each duct into which approximately a 10-g sample of the milled rice was placed. The air flow in each duct was regulated by an in-line valve. The valve in each duct was adjusted to produce an airflow that 'fluidized' the rice on the screen surface. For each temperature/RH condition, two sub-samples of Bengal and two sub-samples of Orion were exposed for 20 min.

Constant High and Low Relative Humidities and a Range of Moisture Contents

Three samples of Bengal medium-grain rice at MCs of 10.4%, 12.5% and 14.8% as measured in the rough rice stage were used. Samples were dehulled and milled as previously described. A 10-g sample of milled rice from each MC sample was exposed to a low RH condition of 23.5% RH and 30°C for 20 min. A 10-g subsample from each MC lot was also exposed to an air stream at a high RH condition of 75% RH and 30°C for 20 min.

Mechanical Breakage Test

The samples were exposed for 20 min and then allowed to equilibrate for 24 hr in sealed plastic bags at an ambient temperature of approximately 23°C. Each sample was then placed in a mechanical roller mechanism developed at the University of Arkansas Rice Processing Laboratory (Siebenmorgen et al., 1997). The roller mechanism measures the extent of fissuring damage incurred by the kernels exposed to the different air conditions. This device consists of two cylinders rotated by an electric motor. One cylinder is hard plastic, and the other is covered with neoprene rubber. A spring force pushing the cylinders together applies a compressive force of approximately two pounds to each individual kernel as it passes between the rollers. Fissured kernels break, while the stronger kernels remain intact. After all kernels passed through the device, each sample was collected and the broken kernels removed using a Seedburo sizer-shaker. The percentage of broken kernels, expressed as a percentage of the original sample mass, was reported as the brokens percentage.

RESULTS AND DISCUSSION

Kernel Damage at Different Relative Humidities

It was found that medium-grain rice kernels at a typical milling MC of 12.5% are very susceptible to fissuring at both high and low RHs. Increased kernel damage was found at low (<40%) and high (>75%) RH levels (Fig. 1). At the mid-range RH conditions, 40% to 75% of the samples experienced the minimal amount of damage of approximately 15% brokens. Thus a 'milling' window of optimal post-milling air conditions for medium-grain cultivars was shown to occur in this range. When comparing the results of the same experiment for long-grain cultivars (Siebenmorgen et al., 1998), the medium-grain milling 'window' was narrower. This was speculated to occur because medium-grain kernels are thicker (greater minor axis) than long-grain kernels; thus moisture migration from the center to the surface of the kernel cannot occur as rapidly and thus increasing the potential for moisture gradients sufficient to create stresses that lead to fissuring. The optimal RH for the medium-grain cultivars tested was 55% at 30°C. Both cultivars tested responded similarly.

Kernel Damage at Different Moisture Contents

Figures 2 and 3 show that kernel MC drastically affects the amount of fissuring at high and low RH. The moisture transfer gradient between the air and the rice kernels dictates the rate of moisture transfer to or from the kernel, which in turn produces the stress gradients that produced fissuring and resultant broken kernels. Samples at low MC experienced more breakage at high RH (Fig. 2), and samples at high MC experienced more breakage at low RH (Fig. 3). Figure 2 shows that an increase in one percentage point in MC corresponded to an increase of approximately 10 to 30 percentage points in brokens for MCs in the range of 10% to 15%.

SIGNIFICANCE OF FINDINGS

Medium-grain milled rice cultivars are very susceptible to fissuring caused by moisture transfer, even greater than long-grain milled rice cultivars. Post-milling air conditions that would cause the least amount of fissuring fell in the relative humidity range of 40%<RH<75% at 30°C for rice at 12.5% rough rice MC. The MC of the milled rice is a critical parameter that determines the extent of damage depending on the environmental condition. High-MC rice is more susceptible to breakage at a low RH, and low-MC rice is more susceptible to breakage at a high RH. Therefore, air conditions in mills could be altered or milling schedules adjusted depending on mill air conditions to achieve the minimal amount of post-milling breakage.

ACKNOWLEDGMENTS

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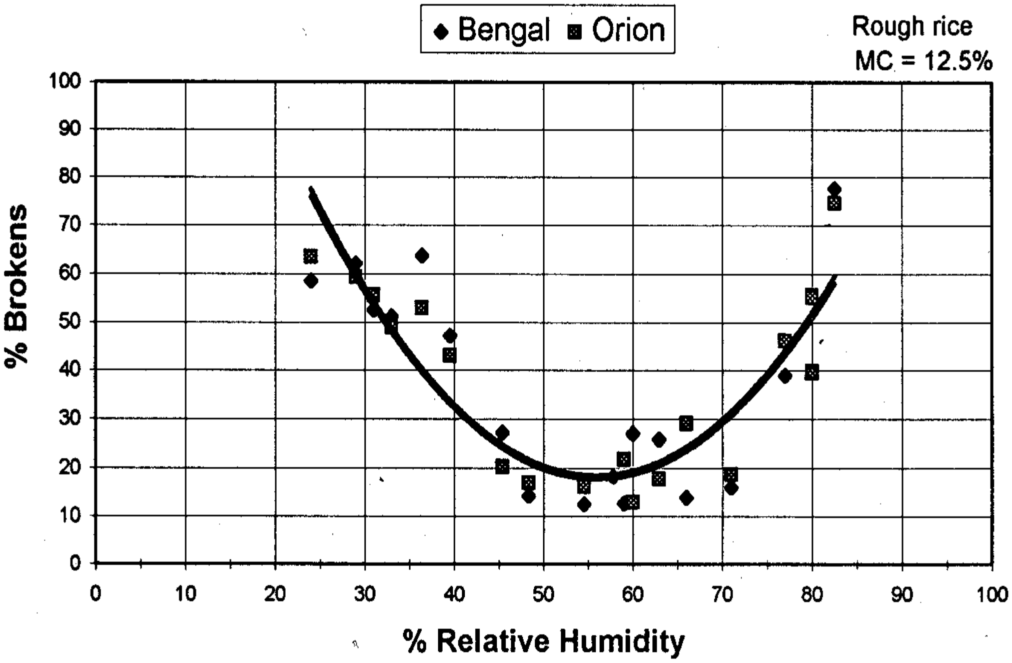

Fig. 1. Medium-grain milled rice kernel breakage response to 20 min of exposure to air at 30°C and a range of relative humidities for two medium-grain rice cultivars.

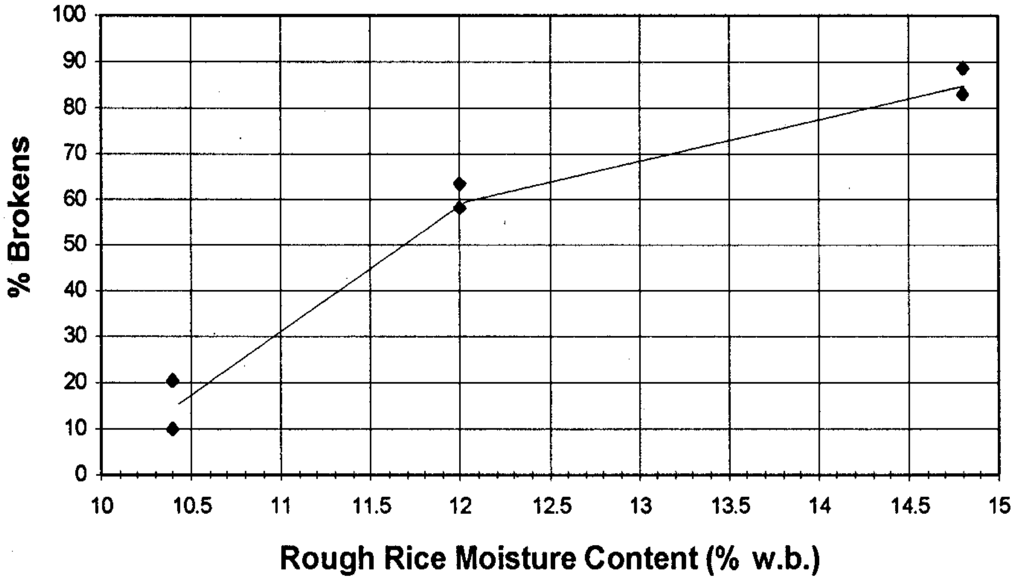

Fig. 2. Medium-grain milled rice kernel breakage response to 20 min of exposure to air at 30°C and 24% relative humidity for Bengal at a range of moisture contents.

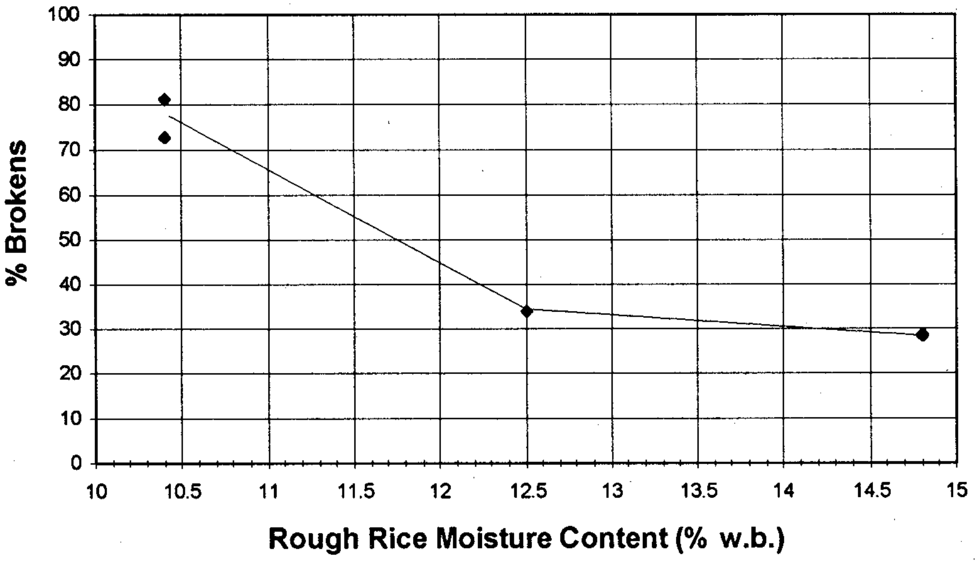

Fig. 3. Medium-grain milled rice kernel breakage response to 20 min of exposure to air at 30°C and 75% relative humidity for Bengal at a range of moisture contents.

RICE SEED INFESTED WITH *PYRICULARIA GRISEA* AS A PRIMARY INOCULUM SOURCE OF RICE BLAST

D.H. Long, D.O. TeBeest, J.C. Correll and F.N. Lee

ABSTRACT

Field experiments were conducted in 1996 and 1997 to determine if seed infested with *Pyricularia grisea* could initiate rice blast epidemics and if this inoculum could persist during the season and affect leaf, collar and neck blast incidence. A tagged isolate of *P. grisea* that could not utilize sulfate sulfur was grown on autoclaved rice seed for 7 days at 25°C. The seed was applied to the soil surface at seedling emergence rates of 0, 0.5, 5, 25 and 50 seed/ft^2 in plots containing the blast-susceptible cultivar 'M201'. Leaf blast symptoms were first detected in the inoculated plots 45 days after seeding in both 1996 and 1997. Results indicate that number of days after seeding appears to be more important to the initial onset of disease than does plant maturity. Over 90% of the lesions sampled from rice seedlings (45 to 55 days after seeding) contained the tagged isolate, indicating that the inoculum originated from the infested seed. Blast was not detected in the control plots (no infested seed) in 1997 and not until 65 days after seeding in 1996. The blast disease increased most rapidly in plots with 50, 25 and 5 infested seeds/ft^2; however, in 1996 the 0.5-seed/ft^2 treatment did cause up to 40% leaf blast incidence at mid-season. At the end of the season, the tagged isolate was recovered from over 90% of the leaf, collar and neck blast lesions, indicating that inoculum from infested seed at the beginning of the season was responsible for initiating and perpetuating the epidemic.

INTRODUCTION

Rice blast, caused by the pathogen *Pyricularia grisea*, is one of the most destructive diseases of rice worldwide. Sources of primary inoculum that initiate rice blast epidemics have been difficult to identify under field conditions (Kingsolver et al., 1984). Potential primary inoculum sources are infested seed and rice residue. Lee (1994) studied potential primary inoculum sources in Arkansas and concluded that the rice blast pathogen could survive on infested rice seed and rice residue under Arkansas conditions and that these sources were likely sources of primary inoculum. According to Kingsolver et al. (1984), infested seed is not a viable source of primary inoculum because *P. grisea* does not survive well in the soil matrix under anaerobic conditions and also does not compete well with other fungi (Ou, 1985). However, shallow-planted rice seed infested with *P. grisea* have been shown to sporulate on the soil surface in greenhouse studies (Chung and Lee, 1983) and under field conditions (Agarwal et al., 1989; Filippi and Prabhu, 1997). Infested seed that sporulate on the soil surface have been proposed to be the inoculum that initiates rice blast epidemics.

Our working hypothesis is that infested seed of *P. grisea* on the soil surface at plant emergence will sporulate under field conditions and the dissemination of these spores, via wind, rain or physical contact with a healthy seedling, will initiate infection on seedlings. Therefore, there were three specific objectives in this study: 1) to determine if blast-infested seed on the soil surface can initiate rice blast epidemics, 2) to determine the effect of inoculum load (amount of infested seed/ft^2) on development of leaf blast and 3) to determine if inoculum originating from infested seed can lead to late-season leaf, collar and neck blast.

PROCEDURES

Inoculum Preparation

A tagged isolate of race 1C17 of *P. grisea* (18/1) that could not utilize sulfate-sulfur was grown on 200 g of autoclaved (30-min) M201 seed in a 1-L flask for 7 days at 24°C with a 12-hour illumination cycle. Cultures of the tagged isolate were maintained on rice bran agar (20 g rice bran, Riceland; 15 g agar, Sigma; and 1000 mL of distilled water) at 24°C with a 12-hour illumination cycle and could be readily discerned from wild-type isolates (background inoculum) by using a selective medium containing sulfate sulfur (Harp and Correll, 1997). Twenty agar plugs (0.25-in.) from a 7-day-old culture of *P. grisea* were transferred to a single flask using aseptic techniques and were plugged with a foam stopper. Each flask was then shaken vigorously for 30 s to mix mycelial plugs throughout the seed. After the 7 days, infested seeds were allowed to air dry and then stored at 4°C until use.

Field Experiments

Field experiments were conducted at the Pine Tree Branch Experiment Station at Colt, Arkansas, during 1996 and 1997. The experimental sites were precision leveled for optimum water management and were bordered by trees on the north. The susceptible cultivar M201 was drill-seeded at 110 lb/acre in 5 x 16-ft plots of nine rows spaced 7 in. apart. Treatments were applied in a randomized complete block design with four replications per treatment. Artificially infested seed were applied to the soil surface at plant emergence rates of 0, 0.5, 5, 25 and 50 seed/ft^2. Five-foot (1996) and 10-ft (1997) barrier plots of ‘Kaybonnet’, a blast-resistant cultivar, surrounded each experimental treatment and were used to reduce inter-plot interference (contamination). Experiments were seeded on 15 April 1996 and 6 May 1997. The experimental area received the recommended nitrogen (N) fertilization rate for a 3-way-split application, but all N (urea) was applied as a single preflood application (Helms, 1990).

The incidence of leaf blast was measured weekly for experiments conducted in 1996 and 1997. The incidence of leaf blast early in the season was determined by surveying all plants in the center three rows of each plot until approximately 1% leaf blast incidence was present. After this point, 12 (1996) to 25 (1997) arbitrarily selected plants in each plot were examined to determine disease incidence.

Disease symptoms from leaves, collars and necks were collected throughout the season and the proportion of lesions caused by the tagged isolate was determined. Growth of *P. grisea* colonies from disease tissue greater than 0.5 in. on rice bran agar amended with 0.1% sodium selenate after 4 days confirmed the presence of a tagged isolate of *P. grisea.*

RESULTS AND DISCUSSION

Sporulation of *P. grisea* was detected on the infested seed (inoculum) on the soil surface for three weeks in 1996 and for 2 weeks in 1997. These data indicate that infested seed may produce inoculum that could initiate primary lesion formation on seedlings. Other researchers also have hypothesized that sporulation of *P. grisea* on infested seed could serve as the primary inoculum source that initiates rice blast epidemics (Agarwal et al., 1989; Filippi and Prabhu, 1997; Lee, 1994).

During 1996 and 1997, leaf blast symptoms were first detected on seedling plants 45 days after seeding (35 days after inoculation/plant emergence), although the degree day accumulation of thermal units (DD50) for the two years was 697 and 1218, respectively (Figures 1 and 2). For M201, an accumulation of 1250 DD signifies the beginning of reproductive growth (internode elongation), while accumulations above 2300 indicate heading stage. In 1996, the first disease symptoms were identified on rice plants during active tillering stage (697DD); in 1997, the first disease symptoms were identified during internode elongation stage (1218 DD). Differences in plant maturities over the first 45 days were attributed to warmer temperatures in 1997 (6 May seeding date) than in 1996 (15 April seeding date). Thus, the initial onset of disease for both years appears to be more dependent on time than on plant maturity.

Over 96% of the lesions sampled between 45 and 55 days (seedling plants) were caused by the tagged isolate, indicating that the inoculum originating from the infested seed initiated the epidemic. The use of a tagged isolate (sulfate non-utilizing) in this study clearly showed that a mechanism other than systemic transmission may be important in the transmission of inoculum from seed to seedlings.

In 1996, blast developed in all treatments; however, disease increased most rapidly in plots with 5 or more infested seed/ft^2. At rates of 5, 25 and 50 infested seed/ft^2, leaf blast incidence was 55, 75 and 80%, respectively. Blast increased the slowest in the treatment containing only 0.5 seed/ft^2, reaching only 40% leaf blast incidence (Figure 1). No disease was detected in the control plots (no infested seed) in 1997 and not until 65 days after seedling emergence in 1996. These data indicate that although more disease was observed at the higher infested seed rates used, low levels of infested seed (inoculum) on the soil surface can initiate rice blast epidemics.

Disease pressure was lower in 1997 than in 1996, in that lower levels of leaf blast were detected in the 5, 25 and 50 infested seed/ft^2 treatments (1, 3 and 21% leaf blast incidence, respectively). No disease was observed in the lowest treatment (0.5 seed/ft^2) or the control plots in 1997. The lower disease incidence levels observed in 1997 were attributed to adult plant resistance. Increased disease resistance to rice blast with plant age (adult resistance) has been reported in the literature and has been described in many of the cultivars grown in Arkansas (Long, 1996). The initial onset of disease in 1997 was observed during the internode elongation stage (reproductive growth), while in 1996, the first disease symptoms were observed during active tillering stage (vegetative growth).

In 1996 and 1997, arbitrarily collected samples of leaf, collar and neck blast symptoms were examined to determine the frequency of the tagged isolate in infected tissue. The tagged isolate was recovered from >85% of the leaf blast lesions collected throughout the season and >80% of the collar rot lesions (Table 1). In 1997, the percentage of tagged isolates recovered from infected necks was

>90% and consistent with the high frequency of the tagged isolate in the leaf blast phase of the disease. However, a low percentage of the tagged isolate was recovered from infected necks (5%) in 1996. This high level of background contamination of wild-type isolates of *P. grisea* was attributed to an experiment adjacent to the experimental area whereby disease pressure by wild-type isolates was very high. The above results indicate that seed infested with *P. grisea* contributed inoculum that initiated and sustained the epidemic up through neck blast infections late in the season.

SIGNIFICANCE OF FINDINGS

Data from these experiments indicated that rice blast can be initiated by rice seed infested with *P. grisea* and that relatively small amounts of inoculum (small number of infested seed on the soil surface) can initiate rice blast epidemics. Furthermore, the initial onset of disease appears to be more dependent on time than on plant maturity. During both years (1996 and 1997), the initial disease symptoms on rice seedlings were observed 45 days after seeding; however, plant maturity differed between the 2 years. Even though the initial onset of disease did not appear to be dependent on plant maturity, the perpetuation of disease afterwards appears to be influenced by plant age. However, inoculum from infested seed at the beginning of the season was responsible for initiating seedling blast and perpetuating the disease (neck blast). A better understanding of the temporal and spatial dynamics of rice blast disease early in the season may be beneficial in developing effective management strategies for controlling rice blast.

ACKNOWLEDGMENTS

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Table 1. Frequency of the tagged isolate of *P. grisea* found in leaf, collar and neck lesions from experiments seeded on 10 April 1996 and 6 May 1997.

Sample Date	Lesion Type	% Tagged Isolate	Sample Date	Lesion Type	% Tagged Isolate
06/19/96	leaf blast	96%	07/07/97	leaf blast	100%
07/04/96	leaf blast	89%	0714/97	leaf blast	100%
07/19/96	leaf blast	85%	08/02/97	leaf blast	98%
07/19/96	collar rot	83%	08/02/97	collar rot	100%
8/14/96	neck blast	5%	08/27/97	neck blast	90%

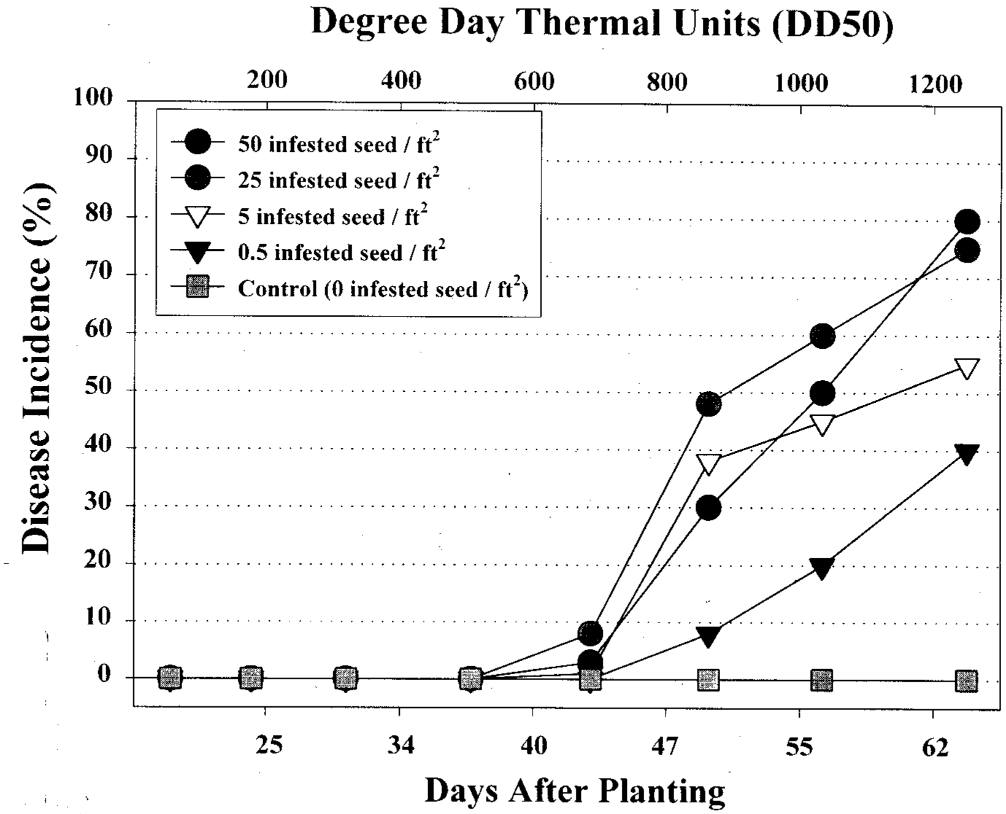

Fig. 1. Disease progress for leaf blast incidence (as %) on 'M201' for different infested seed treatments (# of infested seed/ft²) placed on the soil surface at seedling emergence. Experiments were seeded 5 April 1996.

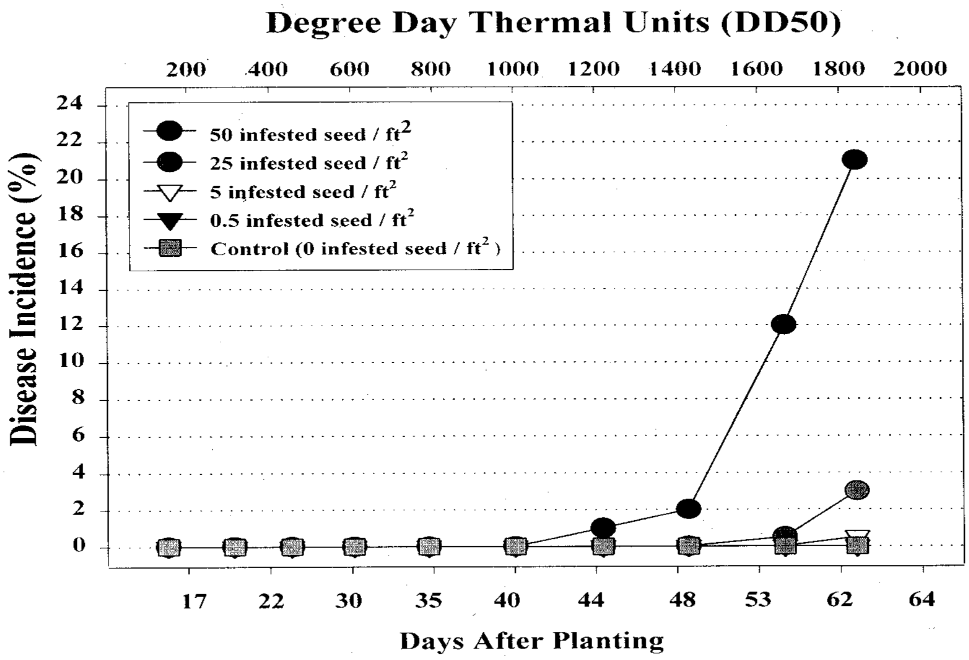

Fig. 2. Disease progress for leaf blast incidence (as %) on 'M201' for different infested seed treatments (# of infested seed/ft^2) placed on the soil surface at seedling emergence. Experiments were seeded on 6 May 1997.

EFFECTS OF ROUGH RICE WET HOLDING, DRYING TREATMENT, STORAGE TEMPERATURE AND STORAGE DURATION ON SENSORY PROFILE OF COOKED RICE

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ABSTRACT

In both domestic and international markets, the end-use quality of rice affects its market value and acceptability to consumers. The effect of various postharvest processing treatments on sensory characteristics of cooked rice (cultivar ‘Cypress’) were investigated. Cooked rice quality was affected by rough rice wet holding, drying temperature, storage temperature and storage duration. Perceived starchy notes were significantly influenced ($P<0.05$) by drying temperature. Sulfury notes were affected by both drying and storage temperature of rough rice. Clumpiness scores decreased ($P<0.05$) over storage time. Hardness increased ($P<0.05$) with delayed rough rice drying and with increasing storage temperatures and decreased ($P<0.05$) with increasing temperatures. Perceived cohesiveness of mass decreased ($P<0.05$) with increasing storage temperatures.

INTRODUCTION

Much work has been done investigating the effect of postharvest handling of rice on raw product quality. However, studies of the relationship between postharvest handling and sensory properties have been limited. As rice consumption continues to expand, there is an increasing need for quantitative data regarding the effects of postharvest handling on sensory characteristics of cooked rice. Sensory analysis techniques have been used by several researchers to evaluate the effects of storage (Chrastil, 1990; Perez and Juliano, 1983; Okabe, 1979), processing (Rousset et al., 1995) and cultivar (Perez et al., 1993; Kumari and Padmavathi, 1991; Damardjati et al.,1986; Juliano et al.,1984) on end-use quality. The approach taken by previous researchers to profile the texture of cooked rice, with the exception of a study by Rousset et al. (1995), was limited to a few characteristics such as hardness and stickiness that were evaluated by either untrained or experienced panelists. The effect of postharvest handling on sensory profile of cooked rice can be thoroughly investigated by a professionally trained descriptive panel capable of evaluating a wide range of sensory properties in a quantitative and reproducible manner.

Such research involves sensory profiling or descriptive analysis methods consisting of formal procedures for assessing, in a reproducible manner, specific product attributes of suitable scales. These methods can include evaluations for aroma, flavor, appearance and texture, separately or in combination (ISO, 1994). As such, descriptive sensory profiling is the most sophisticated sensory methodology available (Stone and Sidel, 1993). Trained panelists differentiate and rate intensities of food sensory characteristics. Descriptive analysis provides a complete sensory description of an array of products and a basis for distinguishing those sensory attributes that are important for acceptance by consumers (Stone and Sidel, 1993). Sensory profiling is useful in evaluating sensory changes over time with respect to processing conditions and shelf life (Meilgaard et al., 1991). As such, descriptive analysis is to be the most appropriate sensory tool to evaluate the effects of drying and storage conditions on sensory characteristics of cooked rice. The objective of this investigation was to study the effect of postharvest parameters such as drying conditions, storage temperature and storage duration on the sensory characteristics of cooked rice.

MATERIALS AND METHODS

Postharvest Treatments

Long-grain rice, cultivar Cypress, was harvested from Stuttgart, Arkansas, in September 1995, at a moisture content (mc) of 20.5% (wet basis). One hundred fifty pounds of rice was cleaned in a Carter-Day Dockage Tester (Carter-Day Co., Minneapolis, Minnesota) and mixed thoroughly before being divided into two lots via a Boener divider (Seedboro, Chicago, Iillinois). The first lot was prepared for immediate drying, while drying of the second lot was delayed for 86 hr. Both immediate and delayed drying lots were subsequently divided into two lots, which were dried under two different drying conditions in a laboratory-scale drying system. Both drying treatments consisted of exposing a thin layer (< 4 cm) of rice for 30 min in a drying chamber, followed by slow equilibration to the final mc. The high-temperature drying treatment was 54.3°C and 21.9% relative humidity (rh), and the low-temperature treatment was 33°C and 67.8% rh. Subsequent equilibration occurred over several days in a controlled chamber set at 33°C and 67.8% rh until the rice reached 12.5% mc. After drying, each lot was further divided into air-tight buckets for storage at three temperatures (4, 21 and 38°C). Sensory evaluation was performed after 0, 4 and 20 weeks of storage.

Sensory Methodology

Eight professionally trained panelists (21st Sensory, Inc., Bartlesville, Oklahoma) were recruited to participate in this experiment. During panel orientation, eleven attributes, including aroma, flavor and texture characteristics, were identified by the panelists as adequately describing the sensory profile of cooked Cypress rice (Table 1). Intensities of overall sensory impact, grain flavor note, sulfur flavor note, clumpiness, roughness of mass, hardness, gluiness, moisture absorption, cohesiveness of mass and geometry of slurry were each evaluated on a 15-cm continuous scale (Meilgaard et al., 1991). Flavor and aroma note intensities were evaluated by comparison with the references provided by the universal intensity scale (Meilgaard et al., 1991). The intensities for texture attributes were assessed by comparison with carefully chosen references having assigned intensities for a particular attribute (Table 1). Intensity references for the texture attributes were assigned during the panel orientation sessions. Samples were cooked for 20 minutes in household steam rice cookers (National, model SR-W10FN) with a 1:2 (vol:vol) rice to water ratio and immediately presented to the panel. The order of sample presentation was randomized across treatments but not randomized across panelists because of limited sample availability and the importance of serving temperature. Samples were presented at 71°C in Styrofoam cups with plastic lids, and panelists were instructed to monitor temperature during the test and to complete the evaluation before the temperature of the sample reached 60°C. Reference rice samples (Table 1) were presented as warm-up samples at the beginning of each session. Panelists were allowed a 10-min break between each sample and were instructed to rinse their palate with unsalted crackers and water.

Statistical Data Analysis

The experiment was treated as a 2 x 2 x 3 full factorial design with repeated measures over time. Independent variables were pre-drying treatment (immediate vs. delayed drying), drying temperature (high vs. low temperature drying) and storage temperature (4, 21 or 38°C). The sensory evaluation of all treatments was conducted after 0, 4 and 20 weeks of storage. Sensory data were analyzed for the various sampling times via a treatment x subject design (Stone and Sidel, 1993) for which all subjects evaluated all samples once. PROC GLM (SAS, 1993) and Duncan’s multiple comparison tests (α= 0.05) were used to evaluate the effects of experimental treatments on sensory profiles reported by the descriptive panel.

RESULTS AND DISCUSSION

Effect of Immediate Versus Delayed Drying on Sensory Profiles of Cooked Rice

No significant (α=0.05) effect of immediate versus delayed drying was reported by the descriptive panel on the sensory perception of rice samples. The Duncan’s Multiple Comparison tests in this section were compiled using the entire data (i.e., combining all processing and storage treatments). The effect of immediate versus delayed drying will be discussed below, where data were analyzed for only one sampling time: i.e., week 0, week 4, week 20 analyzed as separate data sets.

Effect of Rough Rice Drying Temperature on Sensory Profiles of Cooked Rice

The rough rice drying temperature was reported by the descriptive panel to significantly influence (α=0.05) cooked kernel hardness and cohesiveness of mass (Fig. 1). Kernel hardness was greater in samples dried at low temperature, and cohesiveness of mass was lower (α=0.05) in samples dried at low temperature.

Effect of Rough Rice Storage Temperature on Sensory Profiles of Cooked Rice

Of 11 sensory attributes evaluated, five exhibited significant differences between intensities (α=0.05) due to rough rice storage temperature (Fig. 2). The effect of storage temperature was observed only on textural characteristics. Perceived intensities for clumpiness, hardness, gluiness, cohesiveness of mass and geometry of slurry were found to be significantly different for samples stored at various temperatures (4, 21 and 38°C). Clumpiness, the degree to which kernels adhere to each other, was found to significantly decrease as storage temperature increased from 4 to 38°C. The same trend was observed for gluiness, but no significant difference was observed between samples stored at 20 and 38°C. Cooked kernel hardness was significantly greater in rice stored at 38°C. Cohesiveness of mass, the degree to which samples hold together when chewed, significantly decreased with increasing storage temperatures. Finally, the geometry of the slurry was found to be grittier for samples stored at 38°C as compared to samples stored at 4°C.

Effect of Rough Rice Storage Duration on Sensory Profiles of Cooked Rice

Storage duration had a significant (α = 0.05) effect on sensory intensities for eight of the 11 attributes evaluated (Fig. 3). Storage duration significantly influenced both flavor and texture notes. The overall sensory impression (sum of total sensory impression including aromatics, basic tastes and feeling factors) was found to be greater before storage (week 0) than after 4 weeks of storage. The starch note, an aromatic associated with starch flavor, was found to significantly decrease between week 0 and week 4. The intensity of the stale note (i.e., slightly oxidized but not rancid; Civille and Lyon, 1996) was significantly greater after 4 and 20 weeks of storage than at 0 weeks. The intensity of the sulfur note, an aromatic associated with the rice cultivar studied (Cypress), significantly decreased after 20 weeks of storage. This phenomenon was most probably the result of the volatilization of the sulfur compounds during extended storage. Clumpiness significantly decreased between weeks 0 and 4. This result is in accordance with results reported by Juliano (1985) and Perez and Juliano (1981). Hardness of cooked samples was found to be significantly greater at week 4 than at week 0 and week 20. This is in partial conflict with data published by Pushpamma and Reddy (1979). They reported that firmness of cooked rice increased with storage duration. Gluiness was observed to be greatest at week 0 and lowest at week 4. Moisture absorption, the degree to which saliva is absorbed by the sample, was found to be significantly higher for rice sampled at week 4 than at weeks 0 and 20.

Effect of Rough Rice Drying Temperature and Wet Holding on Cooked Rice Before Storage

At week 0, no significant differences (α=0.05) in the perception of the sensory attributes of cooked rice were found between samples dried at high and low temperatures (Table 2). However, the effect of wet holding was found to significantly ($P<0.05$) affect both clumpiness and hardness. Samples in which drying was delayed (i.e., wet held) were clumpier and less hard than samples dried immediately after harvest. The wet holding period in this experiment was designed to simulate an extended delay in drying, as might occur during the peak harvest season. It is interesting that this first step in postharvest system influences the sensory characteristics of the final product (i.e., cooked rice). No other significant differences were attributed to wet holding of the rough rice.

Effect of Rough Rice Drying Temperature, Wet Holding and Storage Temperature after 4 and 20 Weeks of Storage

After 4 weeks of storage, the effect of drying temperature became apparent (Table 3). A more gentle drying (i.e., lower drying temperature) resulted in a significantly ($P<0.05$) greater roughness and hardness and a lower overall rice impression, starchy note and cohesiveness of mass. After 20 weeks of storage, the same trends were observed, and significant differences were also observed for sulfury notes, clumpiness and moisture absorption. Samples dried at low temperature were found to exhibit significantly ($P<0.05$) greater clumpiness and lower starchy notes and moisture absorption. Nehus (1997) reported that glass transition of rice starch occurs between 53 and 55 °C. He hypothesized that this glass transition may influence the functionality of rice starch. The high drying temperature used in this experiment

(53°C) was sufficient for the rice starch possibly to have reached glass transition and, therefore, influence the sensory profile of cooked rice.

The effects of immediate versus delayed drying after 4 weeks of storage were significant ($P<0.05$) for overall sensory impression, hardness and geometry of slurry. Rice samples submitted to a wet holding period exhibited a higher overall sensory impression, a lower hardness and a less gritty geometry of slurry than did those dried immediately. These results are in general accordance with those reported for the rice samples evaluated before storage. The sensory profiles reported by the descriptive panel for samples stored for 20 weeks differ from those reported for 0 and 4 weeks of storage. Samples subjected to delayed drying were found to be harder and exhibited higher moisture absorption than did samples dried immediately after harvest. The perceived hardness of the samples with delayed drying was not significantly different ($P>0.05$) for samples evaluated after 4 and 20 weeks of storage. On the other hand, samples dried immediately after harvest exhibited a significant decrease in hardness after 20 weeks of storage. No obvious explanation of this result can be proposed at this time. However, this phenomenon may be due to changes in the starch functionality and will be further investigated.

After 4 weeks, rough rice storage temperature significantly ($P<0.05$) affected sulfury notes, hardness, cohesiveness of mass and geometry of slurry (Table 3). Sulfury notes significantly decreased as storage temperature increased from 4 to 38°C. Sulfur compounds are probably volatilized at a higher rate as temperature increases. Sulfury notes significantly decreased after 20 weeks of storage across all storage temperatures. For samples tested after four weeks of storage, perceived hardness intensities increased ($P<0.05$) as storage temperatures increased from 4 to 38°C. The least hard samples also exhibited a significantly higher cohesiveness of mass and a less gritty geometry of slurry. After 20 weeks of storage, increasing storage temperatures resulted in decreased clumpiness, gluiness and cohesiveness of mass.

SUMMARY AND CONCLUSIONS

Sensory profiles of cooked rice samples (cultivar Cypress) were significantly affected by rough rice wet holding, drying temperature, storage temperature and storage duration. Delayed drying of rough rice decreased perceived hardness after samples were stored for at least 4 weeks. High drying temperature resulted in less-firm cooked kernels, a phenomenon hypothesized to result from glass transition occurring in rice starch. Elevated storage temperatures (38°C) were found to decrease cooked rice clumpiness and sulfur flavor notes faster than did low storage temperatures (4 and 20°C). Storage duration up to 20 weeks resulted in a significant decrease of sulfury notes, clumpiness, gluiness and moisture absorption and an increase of cardboardy notes. In general, these results indicate that all aspects of postharvest handling, from pre-drying procedures to rough rice storage duration, significantly influence various aspects of cooked rice quality.

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Table 1. Definitions of rice sensory profile attributes.

Sensory Attribute	Definition	Reference and assigned intensities
Overall impact	The sum of total sensory impressions of the food in the mouth including aromatics, basic tastes and feeling factors	Uncle Ben's converted rice 5.0
Aroma:		
Sulfur note	Aromatics associated with sulfur compounds	
Flavor:		
Starch note	Aromatics associated with starch flavor	
Stale note	Aromatics associated with slightly oxidized but not rancid substances and packaging flavor effects	
Texture:		
Clumpiness	Degree to which kernels adhere to each other	Uncle Ben's converted rice 1.0
Roughness	Feel of the kernel from smooth to rough	Uncle Ben's converted rice 3.0, Cheerios 6.0
Hardness	Force required to penetrate kernels with teeth	Uncle Ben's converted rice 3.0
Gluiness	Degree to which kernels stick together when chewed	Uncle Ben's converted rice 2.0
Moisture absorption	Degree to which saliva is absorbed	Uncle Ben's converted rice 5.0, Popcorn 7.0
Cohesiveness of mass	Degree to which samples maintain a "wad"	Uncle Ben's converted rice 4.0
Geometry of slurry	Smooth to gritty, lumpy and inconsistent	Uncle Ben's converted rice 7.0, salsa 10.0, carrot 13.0

Table 2: Effect of drying temperature and wet holding on sensory profiles of cooked rice before storage.

	Initial Sensory Profiling (week 0)			
Sensory Attributes	High temp drying	Low temp. drying	Immediate drying	Delayed drying
Overall sensory impression	4.33 a[†]	4.53 a	4.44 a	4.42 a
Starchy	3.70 a	3.85 a	3.76 a	3.80 a
Cardboardy	1.60 a	1.46 a	1.41 a	1.64 a
Sulfury	0.96 a	1.43 a	1.23 a	1.16 a
Clumpiness	3.18 a	3.24 a	2.93 b	3.48 a
Roughness	3.00 a	2.99 a	3.01 a	2.98 a
Hardness	2.62 a	2.79 a	2.83 a	2.58 b
Gluiness	3.60 a	3.55 a	3.47 a	3.68 a
Moisture absorption	5.14 a	5.25 a	5.22 a	5.17 a
Cohesiness of mass	4.96 a	5.10 a	4.90 a	5.15 a
Geometry of slurry	6.82 a	6.55 a	6.60 a	6.77 a

[†] Means within a row and a block with different associated letters are significantly different from each other (Duncan Multiple Comparison Test, $\alpha=0.05$)

Table 3. Effect of drying temperature, wet holding and storage temperature after 4 and 20 weeks of storage on sensory profiles of cooked rice.

	4 Weeks						
	High temp. drying	Low temp. drying	Immediate drying	Delayed drying	Storage temperature		
Sensory Attributes					4°C	21°C	38°C
Overall sensory impression	4.33 a[†]	4.17 b	4.18 b	4.32 a	4.32 a	4.27 a	4.17 a
Starchy	3.58 a	3.43 b	3.51 a	3.50 a	3.54 a	3.52 a	3.45 a
Cardboardy	2.33 a	2.43 a	2.28 a	2.47 a	2.40 a	2.33 a	2.51 a
Sulfury	1.51 a	1.51 a	1.44 a	1.58 a	1.76 a	1.59 a	1.17 b
Clumpiness	2.70 a	2.67 a	2.60 a	2.78 a	2.72 a	2.76 a	2.58 a
Roughness	2.88 b	3.01 a	3.00 a	2.89 a	2.85 a	2.99 a	2.99 a
Hardness	2.94 b	3.32 a	3.40 a	2.87 b	2.98 b	3.07 ab	3.34 a
Gluiness	2.85 a	2.85 a	2.83 a	2.88 a	2.89 a	2.80 a	2.87 a
Moisture absorption	5.77 a	5.76 a	5.81 a	5.72 a	5.77 a	5.88 a	5.65 a
Cohesiveness of mass	4.95 a	4.71 b	4.85 a	4.81 a	4.96 a	4.88 ab	4.66 b
Geometry of slurry	6.50 a	6.70 a	6.72 a	6.48 b	6.45 b	6.61 ab	6.74 a

	20 Weeks						
	High temp. drying	Low temp. drying	Immediate drying	Delayed drying	Storage temperature		
Sensory Attributes					4°C	21°C	38°C
Overall sensory impression	4.36 a	4.40 a	4.41 a	4.34 a	4.25 b	4.35 ab	4.54 a
Starchy	3.61 a	3.69 a	3.61 a	3.69 a	3.66 a	3.58 a	3.72 a
Cardboardy	2.48 a	2.59 a	2.49 a	2.58 a	2.60 a	2.38 a	2.63 a
Sulfury	0.98 a	0.62 b	0.80 a	0.80 a	0.78 a	0.69 a	0.93 a
Clumpiness	2.35 b	2.73 a	2.54 a	2.53 a	3.16 a	2.41 b	2.05 c
Roughness	2.96 a	2.82 a	2.83 a	2.95 a	2.92 a	2.78 a	2.97 a
Hardness	2.69 a	2.81 a	2.61 b	2.90 a	2.72 ab	2.60 b	2.94 a
Gluiness	3.03 a	3.15 a	3.03 a	3.16 a	3.54 a	3.08 b	2.65 c
Moisture absorption	5.44 a	5.14 b	5.17 b	5.41 a	5.31 a	5.20 a	5.35 a
Cohesiveness of mass	4.88 a	4.74 a	4.74 a	4.88 a	5.30 a	4.79 b	4.33 c
Geometry of slurry	6.72 a	6.94 a	6.70 a	6.96 a	6.70 a	6.79 a	7.00 a

[†] Means within a row and a block with different associated letters are significantly different from each other (Duncan Multiple Comparison Test, ∝=0.05).

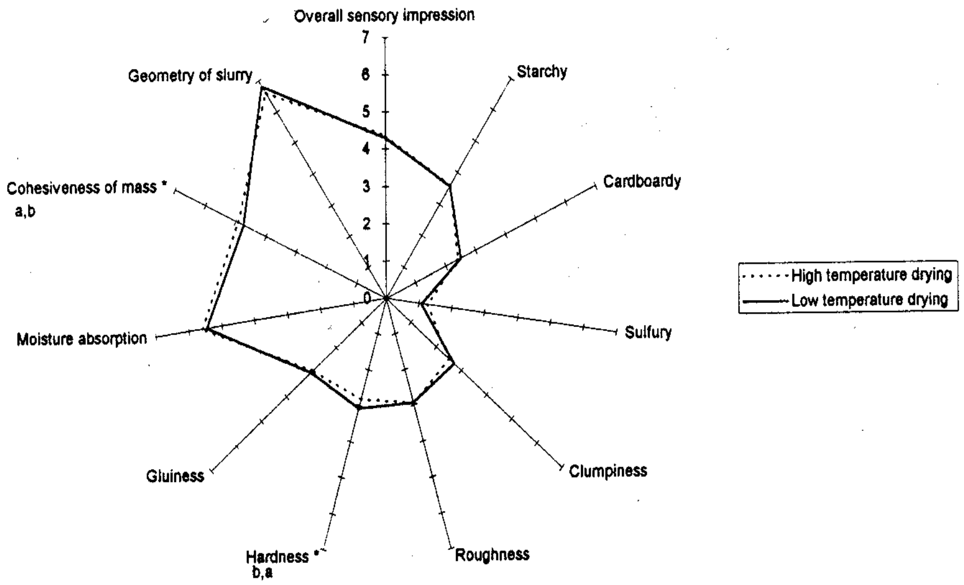

Fig. 1: Effect of drying temperature on sensory profile of cooked rice. Letters associated with the different attributes represent the results of Duncan's multiple comparison tests. The first and second letter(s) are associated with high and low drying temperatures respectively. Different letters indicate significant differences (α=0.05) between treatments.

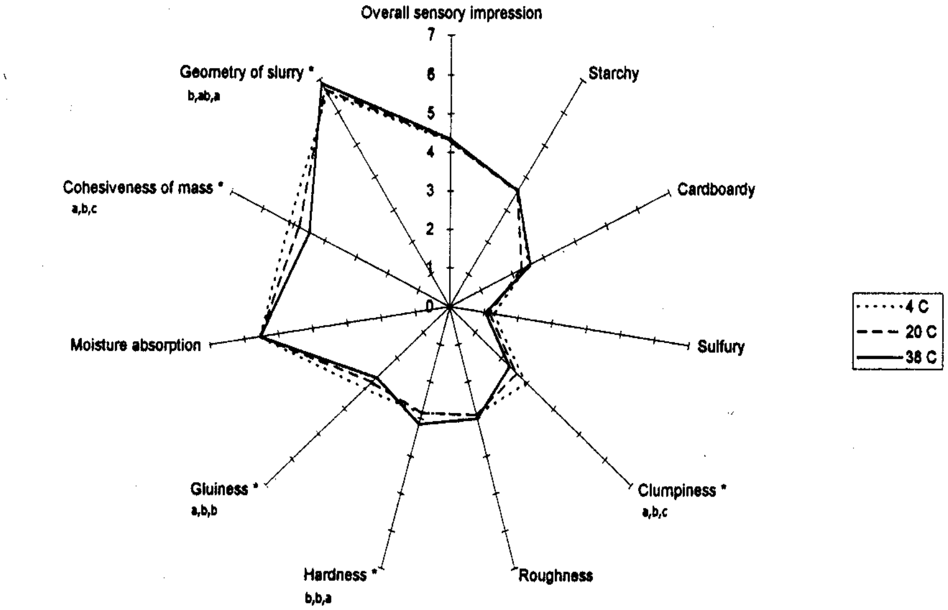

Fig. 2: Effect of storage temperature on sensory profiles of cooked rice. Letters associated with the different attributes represent the results of Duncan's multiple comparison tests. The first, second and third letter(s) are associated with results from storage temperatures 4, 21 and 38°C respectively. Different letters indicate significant differences (α=0.05) between treatments.

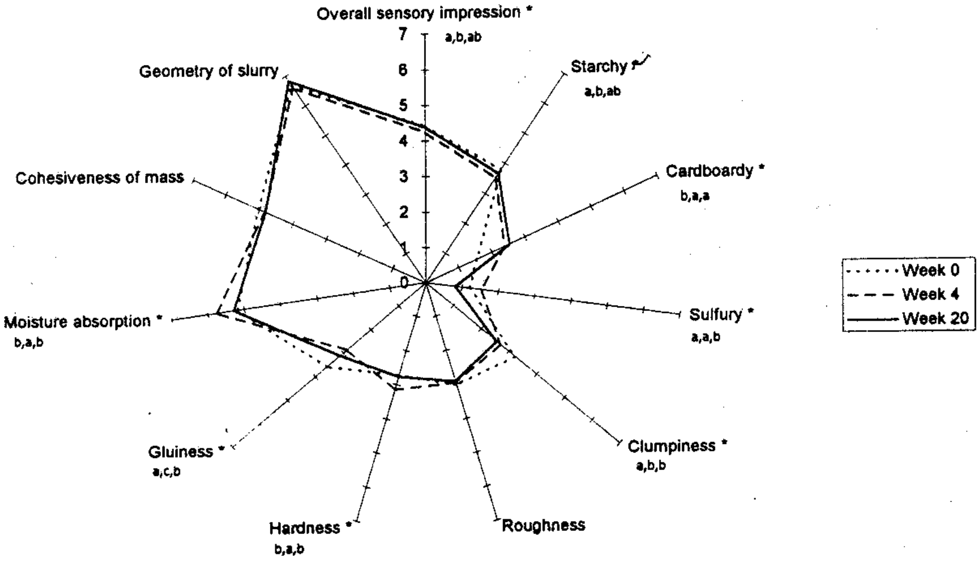

Fig. 3: Effect of storage duration on sensory profiles of cooked rice. Letters associated with the different attributes represent the results of Duncan's multiple comparison tests. The first, second and third letter(s) are associated with results from weeks 0, 4 and 20 respectively. Different letters indicate significant differences ($\alpha=0.05$) between treatments.

INFLUENCE OF NITROGEN FERTILIZER RATE, APPLICATION TIMING AND TILLAGE ON GRAIN YIELDS OF WATER-SEEDED RICE

R.J. Norman, P.K. Bollich, C.E. Wilson, Jr. and N.A. Slaton

ABSTRACT

Several different N fertilizer application timings were investigated in water-seeded conventional till and no-till rice. No consistent N fertilizer application time was found for the no-till, water-seeded rice, but the best method with the conventional till rice was when all of the N fertilizer was applied preplant and incorporated with the floodwater or by tillage. In water-seeded rice the N fertilizer is more difficult to manage properly when it is not incorporated several inches deep into the soil, which is impossible in a no-till system. Because it takes 7 to 8 weeks for water-seeded rice to take up the preplant N fertilizer, it is more susceptible to nitrification/denitrification losses the closer the fertilizer is to the soil surface. Thus, water-seeded, no-till rice will require more N fertilizer than conventional till rice, and the management of that N will be erratic and much more difficult in no-till.

INTRODUCTION

Water-seeding and no-till have begun to be used more often in rice production in Arkansas in recent years (Helms et al., 1995). In addition, some rice has begun to be grown using a combination of water-seeding and no-till. In the conventional till, water-seeded system, all of or most of the nitrogen (N) fertilizer is recommended to be applied preplant soil incorporated, preferably with tillage equipment, alternatively with the floodwater. In the no-till, water-seeded system, the N fertilizer cannot be mechanically incorporated, and it has been attempted to soil incorporate the N with the floodwater. Observations made of commercial fields by rice producers, extension agents and researchers indicate that the water-seeded rice that is no-till requires more N fertilizer than that which is conventional till, and some farmers have stated that no-till, water-seeded rice requires as much as 40 lb N/acre more than conventional till, water-seeded rice to achieve the same yields. Because of these observations, we initiated a study to compare the two tillage systems to see if conventional till, water-seeded rice does require less N fertilizer than no-till, water-seeded rice and to evaluate several different N application methods and timings in the two tillage systems to see if there are alternative ways or better ways to fertilize water-seeded rice in Arkansas. A companion study was performed at the University of Louisiana Rice Research Station, Crowley, Louisiana.

PROCEDURES

The study was conducted in 1996 and 1997 at the University of Arkansas Rice Research and Extension Center, Stuttgart, Arkansas, on a Crowley silt loam (Typic Albaqualfs). In both years, the stale seedbed was disked and land-planed in the fall. Roundup D-PAK herbicide at a rate of 20 oz/acre was applied in the spring, approximately 2 weeks prior to seeding, to burndown the vegetation on the stale seedbed, no-till plots. On the day of seeding, the preplant N fertilizer treatments that were to have the preplant N tilled in had the N applied, and the conventional till plots were tilled with a rototiller to a 3-in. depth and grooved. The plots were flooded to a 2- to 4-in. depth and the presoaked rice (‘Cypress’) seeded in the plots by hand at a 120- lb/acre rate. About 5 days after seeding, the plots were drained for pegdown. The rice was allowed to pegdown for a few days, after which appropriate treatments received pegdown N fertilizer and the plots were flooded to a 2- to 4-in. depth, and the flood was maintained until rice maturity.

The N fertilizer was applied at rates of 80, 120 and 160 lb N/acre. A number of different application timings were utilized. Treatments common to both the conventional and no-till treatments were: i) all of the N fertilizer applied preplant and incorporated with the floodwater; ii) all of the N fertilizer applied on to the mud after draining for pegdown; iii) 50% of the N fertilizer applied preplant and incorporated with the floodwater, 25% applied 1 week after the five-leaf stage and 25% applied 3 weeks after the five-leaf stage; and iv) 50% of the N fertilizer applied onto the mud after draining for pegdown, 25% applied 1 week after the five-leaf stage and 25% applied 3 weeks after the five-leaf stage. To evaluate incorporation of N fertilizer applied preplant with the floodwater versus the tiller, the conventional till plots had two additional treatments that were identical to treatments i) and iii), except the preplant N fertilizer was soil incorporated with the rototiller.

A split plot experimental design with four replications was used. The mainplot was N fertilizer rate, and the subplot was N timing and tillage operation. Statistical analysis of the yield data was conducted using programs of SAS INC. Means were by LSD at the 5% level of probability.

RESULTS AND DISCUSSION

The influence of N fertilizer rate and application timing/tillage on rice grain yields are shown in Tables 1 and 2, respectively. There was no interaction of N fertilizer rate by application timing/tillage. Rice grain yields displayed no significant increases when more than 120 lb N/acre was applied in either year of the study (Table 1).

In 1996, the highest yields in the no-till treatments were obtained when the N fertilizer was applied all on the mud after draining for pegdown or 50% on the mud at pegdown with 25% each applied 1 week and 3 weeks after the five-leaf stage (Table 2). Lowest yields were produced in the no-till treatments when all or most of the N fertilizer was applied preplant and incorporated with the floodwater. Two treatments in the conventional till plots where all of the N fertilizer was applied preplant incorporated were lost in 1996 due to poor stands. In the remaining conventional till treatments, the best yields were produced when the N fertilizer was applied 50% on the mud at pegdown with 25% each applied 1 week and 3 weeks after the five-leaf stage. There was no significant difference in rice grain yield for the remaining conventional till treatments.

In 1997, the highest grain yields were obtained in the conventional till treatments. Best yields in the no-till treatments occurred when 50% or all of the N fertilizer was applied preplant and incorporated with the floodwater. Application of all or 50% of the N fertilizer on the mud at pegdown resulted in very poor yields in the no-till treatments in 1997. In the conventional till treatments, the highest grain yields resulted when all of the N fertilizer was applied preplant incorporated with the floodwater or by tillage. These two preplant N treatments in the conventional till treatments also greatly out-yielded all no-till treatments. The next best grain yield in the conventional till was when 50% of the N fertilizer was applied preplant incorporated with the floodwater or by tillage and the remainder applied at 1 week and 3 weeks after the five-leaf stage. The two worst treatments were when 50% or all of the N fertilizer was applied on the mud at pegdown.

The data in 1997 best illustrate the lower yields observed in commercial water-seeded fields that are planted no-till compared to conventional till. The N fertilizer is more difficult to manage properly when it is not incorporated several inches deep into the soil, which is impossible in a no-till system. Because it takes 7 to 8 weeks for water-seeded rice to take up the preplant N fertilizer, it is more susceptible to nitrification/denitrification losses the closer the fertilizer is to the soil surface. In conventional till, the soil is worked several inches deep, and the preplant N fertilizer is more deeply incorporated into the soil with the floodwater than in a no-till system. Thus, it appears that water-seeded, no-till rice will require more N fertilizer than water-seeded, conventional till rice.

The variability of the grain yields in the no-till treatments between 1996 and 1997 indicates that there is no “best” time to apply N fertilizer in water-seeded no-till rice. Preplant N fertilizer is subject to nitrification/denitrification losses, and N fertilizer applied on the mud at pegdown is subject to ammonia volatilization losses if there are good drying conditions. So it appears that water-seeded, no-till rice will require more N than conventional till rice, and the management of that N will be erratic and, thus, much more difficult. Results from this same study in Louisiana were remarkably similar.

SIGNIFICANCE OF FINDINGS

No consistent N fertilizer application time was found for the no-till water-seeded rice, but the best method with the conventional till rice was when all of the N fertilizer was applied preplant and incorporated with the floodwater or by tillage. These findings are very similar to the companion study conducted in Louisiana. With water-seeded rice the N fertilizer has to be placed several inches deep into the soil in order for it to be minimally affected by nitrification/denitrification losses during the 7 to 8 weeks required for the rice plant to completely take up the preplant N fertilizer; this is impossible in the water-seeded, no-till system. Thus, water-seeded, no-till rice will require more N than conventional till rice, and the management of that N will be erratic and much more difficult in no-till rice.

ACKNOWLEDGMENTS

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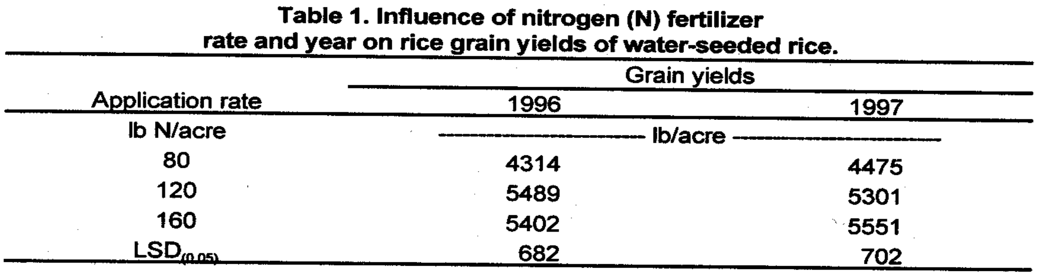

Table 1. Influence of nitrogen (N) fertilizer rate and year on rice grain yields of water-seeded rice.

Application rate	Grain yields	
	1996	1997
lb N/acre	lb/acre	
80	4314	4475
120	5489	5301
160	5402	5551
$LSD_{(0.05)}$	682	702

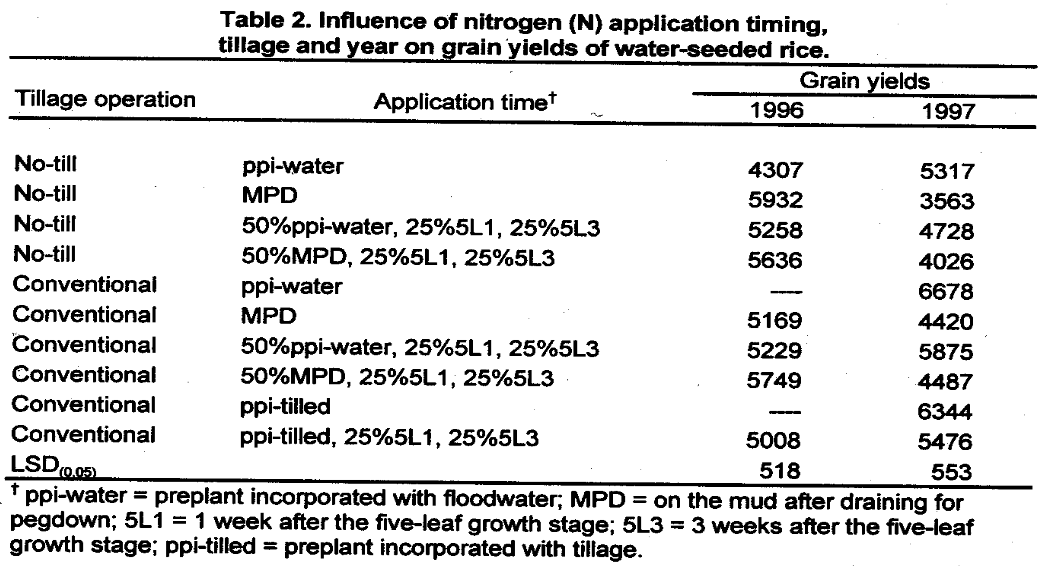

Table 2. Influence of nitrogen (N) application timing, tillage and year on grain yields of water-seeded rice.

Tillage operation	Application time[†]	Grain yields	
		1996	1997
No-till	ppi-water	4307	5317
No-till	MPD	5932	3563
No-till	50%ppi-water, 25%5L1, 25%5L3	5258	4728
No-till	50%MPD, 25%5L1, 25%5L3	5636	4026
Conventional	ppi-water	—	6678
Conventional	MPD	5169	4420
Conventional	50%ppi-water, 25%5L1, 25%5L3	5229	5875
Conventional	50%MPD, 25%5L1, 25%5L3	5749	4487
Conventional	ppi-tilled	—	6344
Conventional	ppi-tilled, 25%5L1, 25%5L3	5008	5476
$LSD_{(0.05)}$		518	553

[†] ppi-water = preplant incorporated with floodwater; MPD = on the mud after draining for pegdown; 5L1 = 1 week after the five-leaf growth stage; 5L3 = 3 weeks after the five-leaf growth stage; ppi-tilled = preplant incorporated with tillage.

RICE RESPONSE TO LIME, CHICKEN LITTER AND PHOSPHORUS APPLICATION

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ABSTRACT

Precision land leveling procedures performed on silt loam soils often result in poor growth of crops. Phosphorus (P) and chicken litter amendments are currently recommended for rice grown on recently leveled soils. A greenhouse experiment was initiated to examine the effect on wheat and rice dry matter production of lime, chicken litter and P application to an acidic subsoil (pH 4.3) exposed during land leveling. Soil was obtained from the Gilbert Bonner farm in Monroe County, Arkansas, in the fall of 1996. Calcium carbonate was applied to the soil at rates of 0, 1000 and 2000 lb/acre before seeding wheat. Following harvest of wheat shoots, chicken litter (0 and 1000 lb/acre) and triple-super phosphate (0 and 80 lb P_2O_5/acre) treatments were imposed on lime treatments. Wheat dry matter production increased with the addition of lime. However, rice root and shoot dry matter production declined due to lime application. Phosphorus and chicken litter should both be applied to this soil to help restore productivity. Lime application may be beneficial if upland crops such as wheat and soybean are to be grown during the first several seasons after leveling. Data suggest that lime application may reduce rice growth.

INTRODUCTION

Land leveling procedures often result in poor growth of crops due to removal of topsoil. In some cases acidic (pH < 5.0) subsoils are exposed. Previous research efforts have established that phosphorus (P) and chicken litter can increase crop production on leveled soils. However, the effect of lime application to exposed acidic subsoils has not been evaluated. Although rice (*Oryza sativa* L.) may produce normal yields on acidic soils, rotation crops may be sensitive and produce very low yields.

Each year growers ask questions that cannot be answered based on current production recommendations. Answers to such questions must be provided based on sound agronomic principles. Occasionally small, applied studies can be conducted in grower fields or in the greenhouse to provide a research-based answer for a grower's specific question. A greenhouse study was conducted to evaluate rice response to lime, chicken litter and P fertilizer on an acid soil exposed from land leveling from Monroe County, Arkansas.

MATERIALS AND METHODS

An acidic subsoil (pH 4.3) exposed from land leveling was collected in the fall of 1996 from the Gilbert Bonner farm near Clarendon, Arkansas. Two greenhouse studies were conducted at the Rice Research and Extension Center, Stuttgart, Arkansas. The soil was air-dried and sieved to pass through a 2-mm screen. Lime (calcium carbonate, 38-40% Ca) treatments were mixed with 3 kg of soil and allowed to react for 24 days. Lime treatments were 0, 1000 and 2000 lb/acre. Two experiments were conducted, first with wheat and then with rice. Due to low soil test K, potassium (K) chloride was applied to all lime treatments at a rate equal to 100 lb K_2O/acre. Wheat (‘Wakefield’) was seeded on 8 October 1996 and grown for 27 days after emergence. Above-ground dry matter was harvested, dried to a constant weight, weighed and ground in a Wiley mill for elemental analysis.

Soil test levels (Mehlich 3) before planting wheat and rice are presented in Table 1. The soil had very low P levels. The soil pH had increased from 4.3 to 5.0 with application of 2000 lb/acre of lime. The low soil P levels (10 lb/acre) were not improved by liming. Two rates of chicken litter (0 and 1000 lb/acre) and two rates of P (0 and 80 lb P_2O_5/acre) as triple super phosphate were added to the lime treatments of the previous experiment with wheat. Presoaked ‘Kaybonnet’ seeds were planted 6 November 1996. Rice seedlings were thinned to five seedlings per pot five days after emergence. Both rice and wheat were irrigated with distilled water. At the four-leaf rice growth stage (20 days after planting), 200 lb/acre urea and 50 lb/acre ammonium sulfate were applied to dry soil before establishing a permanent flood. Rice was harvested by separating roots from above-ground biomass or shoots on 23 December 1996. Roots and shoots were washed with tap water, rinsed in 0.01 *M* HCl and followed by a final rinse with distilled water. Plant materials were oven-dried, weighed and ground. Nutrient analysis was done by digesting 0.5 g of dry plant material into concentrated HNO_3. Nutrient concentration was determined with an Inductively Coupled Argon Plasma Spectrophotometer.

The design of the first experiment with wheat was a randomized complete block design with four replications. Treatments in the first experiment were the three lime rates. The second experiment was a 3 × 2 × 2 factorial design with treatments arranged in a randomized complete block design with four replications. Treatments in the second experiment were three rates of lime, two rates of chicken litter and two rates of phosphorus. Analysis of variance was done with SAS, and means were compared using the protected LSD at the 0.05 level of probability.

RESULTS AND DISCUSSION

Wheat Response to Lime

There was a significant increase in dry matter and tissue calcium (Ca) and K concentration due to liming (Table 2). Compared to the control, dry matter increased 42 and 82% from lime rates of 1000 and 2000 lb/acre, respectively. Plant nutrient concentrations of P and magnesium (Mg) were significantly decreased by liming. Phosphorus concentrations in wheat tissue were deficient for all treatments. Increased dry matter production with lime application diluted tissue P, resulting in lower tissue concentrations. Additional dry matter responses would be expected with P fertilization on this soil. Tissue manganese (Mn) concentration also decreased with increasing lime rate. A higher tissue zinc (Zn) concentration was obtained when 1000 lb lime/acre was applied.

Rice Response to Lime, Chicken Litter and Phosphorus

Lime application resulted in a significant decrease in rice dry matter accumulation by both the roots and shoots (Table 3). A positive rice growth response was obtained with application of 1000 lb/acre of chicken litter or 80 lb

P_2O_5/acre as triple super phosphate. Although rice growth was improved by P and chicken litter amendments, dry matter production for this soil is relatively low for the age of these rice plants.

Tissue analysis does not suggest that any one particular nutrient was present in plant shoot tissue at limiting concentrations. Rice is considered very tolerant to high Mn concentrations. However, Mn is present at levels that are considered very high and borderline toxic to tillering rice. The fact that Mn concentrations increased while dry weights decreased with increasing lime rate suggests that Mn may have been toxic (Table 4). Sodium (Na) and iron (Fe) concentrations were very high in rice roots. Lime application decreased root Na and increased shoot Mn concentrations, respectively. Chicken litter was effective in increasing both root and shoot P and K concentrations (Table 5). However, P fertilization increased Na concentrations of both roots and shoots (Table 6). Although application of 80 lb P_2O_5/acre significantly increased P concentration in roots and shoots, it decreased K. Phosphorus application also decreased boron (B), Ca, Mn and Zn levels in the shoots without influencing root concentrations. Application of P with or without lime appears to stimulate Na accumulation in the plant (Table 7). Application of P also lowered Ca concentration while Mg concentration increased, regardless of the amount of lime applied.

SIGNIFICANCE OF FINDINGS

The low P concentration in the wheat plants suggests that P may have been the most limiting nutrient for wheat production on this graded soil. However, the fact that wheat growth improved with lime application suggests that acidic soil pH was also a limiting factor. Rice growth improved with both chicken litter and P application, but lime application decreased both root and shoot dry weights of rice. The increased dry weight response from chicken litter and P supports current University of Arkansas recommendations for precision-graded soils. Lime application to this leveled soil decreased rice growth but increased wheat production. Soybean would be expected to respond to lime similarly to wheat on this acidic soil. It is not known from this study how lime application would influence rice grain yields. Any production input that can increase dry matter production on leveled fields will likely be beneficial in returning soil to normal productivity by incorporation of organic residues. Chicken litter is highly recommended on this soil regardless of crop rotation at a minimum of 1000 lb/acre/year until normal production resumes. Phosphorus and Zn fertilizers would be recommended for all crops. Lime should be applied ahead of upland crop production to adjust soil pH to about 6.0 but avoided immediately before rice production.

Table 1. Selected soil chemical properties from an acidic subsoil exposed by land leveling from Gilbert Bonner farm, Monroe County, Arkansas, used in two greenhouse experiments conducted at the Rice Research and Extension Center, Stuttgart, Arkansas.

Lime	pH	P	K	Ca	Mg	Na	SO_4	Fe	Mn	Cu	Zn	NO_3	E.C	CEC	Base Sat.	K Sat.	Mg Sat.	Na Sat.
lb/ acre							lb/acre —						µhos/cm			%		
0[†]	4.4	10	200	902	619	170	161	148	208	2.0	4.8	127	144	9	54.8	2.6	25.9	3.7
0	4.3	10	267	797	593	165	163	136	207	2.1	5.0	70	184	9	53.6	3.5	25.6	3.7
1000	4.5	10	277	1507	534	166	164	125	179	1.8	3.2	43	153	11	59.9	3.2	19.9	3.2
2000	5.0	10	301	2727	578	166	191	119	135	1.6	2.5	63	191	15	64.5	2.5	15.6	2.3

[†] Soil sample with no lime applied before growing wheat.

Table 2. Wheat (27-day-old plants) growth response to lime application in a greenhouse experiment conducted at the Rice Research and Extension Center, Stuttgart, Arkansas.

Lime Rate	Dry Matter	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
lb/A	g/pot			%					ppm		
0	0.276	0.135	2.98	0.29	0.33	0.27	416	101	780	32.3	6.99
1000	0.393	0.116	3.62	0.41	0.26	0.28	312	101	666	37.1	7.25
2000	0.502	0.112	3.88	0.51	0.26	0.25	397	89	489	31.2	5.02
LSD(0.05)	0.042	0.009	0.15	0.03	0.02	0.01	65	NS	51	1.96	0.87

Table 3. Rice dry matter as influenced by lime, chicken litter and phosphorus applications in a greenhouse test conducted at the Rice Research and Extension Center, Stuttgart, Arkansas.

	Rice dry weight	
Soil Amendments	Roots	Shoots
lb/acre	---------- g/pot ----------	
Lime Rate		
0	0.806	4.300
1000	0.913	4.143
2000	0.688	3.321
LSD (0.05)	0.190	0.405
Chicken Litter		
0	0.703	3.291
1000	0.893	4.494
LSD (0.05)	0.156	0.331
Phosphorus Rate		
0	0.715	2.874
80	0.889	4.969
LSD (0.05)	0.155	0.330

Table 4. Rice root and shoot nutrient concentration as influenced by lime application in a greenhouse test conducted at the Rice Research and Extension Center, Stuttgart, Arkansas.

Root Nutrient Concentration										
Lime	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
lb/acre	%					ppm				
0	0.189	1.06	0.09	0.16	0.26	3485	3317	547	69.2	5.3
1000	0.201	1.07	0.12	0.17	0.27	3049	3816	682	84.1	8.5
2000	0.182	1.03	0.16	0.18	0.27	2769	2328	638	58.3	5.1
LSD(0.05)	0.015	NS[†]	0.01	0.014	NS	407	1339	NS	15.6	NS
Pr>F	0.024	0.61	0.0001	0.032	0.54	0.07	0.14	0.26	0.005	0.18
Shoot Nutrient Concentration										
Lime	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
lb/acre	%					ppm				
0	0.275	3.07	0.25	0.379	0.39	760	81	2328	65.5	16.8
1000	0.280	3.28	0.31	0.376	0.41	676	86	3236	81.1	19.6
2000	0.283	3.22	0.37	0.379	0.41	645	82	3662	60.0	21.2
LSD(0.05)	NS	0.15	0.02	NS	0.016	NS	NS	445	6.3	2.7
Pr>F	0.14	0.07	0.0001	0.28	0.009	0.14	0.39	0.001	0.0001	0.02

[†] NS = Not significant.

Table 5. Rice root and shoot nutrient concentration as influenced by chicken litter application in a greenhouse test conducted at the Rice Research and Extension Center, Stuttgart, Arkansas.

Root Nutrient Concentration

Chicken Litter Rate	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
lb/acre	%					ppm				
0	0.17	0.97	0.12	0.163	0.257	2999	2891	627	69.8	7.5
1000	0.21	1.12	0.13	0.172	0.276	3185	3371	618	71.1	5.3
LSD(0.05)	0.01	0.11	0.008	NS[†]	0.01	NS	NS	NS	NS	NS
Pr>F	0.001	0.011	0.08	0.18	0.04	0.34	0.28	0.99	0.76	0.24

Shoot Nutrient Concentration

Chicken Litter Rate	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
lb/acre	%					ppm				
0	0.25	3.02	0.31	0.367	0.40	753	86.2	3006	68.5	18.2
1000	0.30	3.33	0.31	0.386	0.40	644	80.2	3132	69.3	20.2
LSD(0.05)	0.02	0.12	NS	0.014	NS	75	7.6	NS	NS	2.2
Pr>F	0.001	0.001	0.62	0.003	0.16	0.002	0.046	0.81	0.59	0.06

[†] NS = Not significant.

Table 6. Rice root and shoot nutrient concentration as influenced by phosphorus application in a greenhouse test conducted at the Rice Research and Extension Center, Stuttgart, Arkansas.

Root Nutrient Concentration

P Rate	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
lb P_2O_5/acre	%					ppm				
0	0.097	1.16	0.12	0.14	0.25	1501	2477	612	70.9	7.1
80	0.275	0.95	0.13	0.19	0.28	4555	3769	632	70.3	5.6
LSD(0.05)	0.01	0.11	0.08	0.012	0.01	332	1094	NS[†]	NS	NS
Pr>F	0.001	0.004	0.02	0.001	0.002	0.0001	0.01	0.70	0.92	0.38

Shoot Nutrient Concentration

P Rate	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
lb P_2O_5/acre	%					ppm				
0	0.15	3.28	0.34	0.30	0.40	443	84	3954	81.3	20.5
80	0.39	3.11	0.28	0.45	0.40	922	82	2277	57.6	18.0
LSD(0.05)	0.02	0.121	0.015	0.014	NS	75	NS	363	5.1	2.2
Pr>F	0.001	0.02	0.0001	0.001	0.56	0.0001	0.41	0.001	0.001	0.09

[†] NS = Not significant.

Table 7. Interaction of lime rate and phosphorus rate on rice shoot nutrient concentration of 47-day old plants in a greenhouse test conducted at the Rice Research and Extension Center, Stuttgart, Arkansas.

Lime Rate	Phosphorus Rate	Ca	Mg	S	Na
lb/acre	lb P_2O_5/acre	——————— % ———————			ppm
0	0	0.273	0.277	0.362	377.7
1000	0	0.336	0.307	0.404	422.2
2000	0	0.403	0.314	0.432	519.8
0	80	0.234	0.455	0.412	1045.9
1000	80	0.281	0.444	0.410	930.6
2000	80	0.335	0.444	0.389	770.4
	LSD(0.05)	0.0175	0.016	0.015	86
	Pr>F	0.096	0.035	0.0001	0.0023

STARCH RETROGRADATION AND TEXTURE OF COOKED MILLED RICE DURING STORAGE

A. Perdon, T.J. Siebenmorgen, R.W. Buescher and E.E. Gbur

ABSTRACT

Changes in texture of cooked milled rice were measured as functions of cultivars, storage temperature and storage duration. For ‘Cypress’ and ‘Bengal’, firmness of cooked rice increased by an average of 165% during storage at -13 and 3°C, while stickiness decreased by 100%. Starch retrogradation in Bengal and Cypress also occurred during storage at -13 and 3°C. Starch retrogradation in cooked milled rice for both cultivars showed a common positive linear relationship ($R^2 = 0.80$) with firmness. The relationship of starch retrogradation to stickiness of stored cooked rice was dependent on cultivar and storage temperature.

INTRODUCTION

Development of ready-to-eat rice-based ethnic meals has increased the domestic demand for rice. Incorporation of freshly cooked rice is difficult because it is sticky. However, when cooked rice is allowed to cool and “age,” it becomes firm and easier to handle. In bread, firming during storage, which is also called “staling,” has been attributed to starch retrogradation (Zelesnak and Hoseney, 1986).

Starch is the major component of rice. During cooking, starch gelatinizes, i.e., it absorbs water and loses its crystallinity. After cooking, the gelatinized starch can recrystallize or retrograde when conditions are optimum. Starch retrogradation has been observed during storage of paste made from rice starch (Biliaderis and Juliano, 1993; Perez et al., 1993; Lu et al., 1997; Villareal et al., 1997). Rice is primarily processed and consumed as a whole grain cereal; therefore, studying the changes in texture and starch properties using cooked whole grain is important.

The objective of this study is to determine the effect of storage temperature and duration on starch retrogradation, firmness and stickiness of stored cooked rice from two popular cultivars, Bengal and Cypress. Bengal is a medium-grain cultivar that is sticky after cooking; Cypress is a long-grain cultivar that is firm and fluffy after cooking.

MATERIALS AND METHODS

Bengal and Cypress rough rice, harvested in 1995 from the University of Arkansas Rice Research and Extension Center in Stuttgart, Arkansas, were conditioned to 12.5% moisture content prior to milling. Portions of rough rice (150 g) were dehulled with a McGill sample sheller and milled for 45 s in a McGill No. 2 mill. Only the head rice fraction, separated from brokens with a Seedburo sizer, was used for the test. The degrees of milling (DOM), measured with a Satake MM-1B milling meter, were 92 DOM for Bengal and 95 DOM for Cypress.

Twelve grams of water was added to 8 g of head rice placed in a 30-ml beaker (total of 20 beakers per cultivar). The rice-water mixture was steamed for 20 min (Mossman et al., 1983) and cooled. After cooling for 45 min, the beakers were separated into four sets (5 beakers/set) and placed in sealed plastic bags. Each bag was separately stored under one of the following conditions: in a warm oven (36°C), at room temperature (20°C), in a refrigerator (3°C) or in a freezer (-13°C). Each set was sampled at 0, 24, 48, 72 and 96 h. At these durations, firmness and stickiness of the rice was measured with a TA-X2 texture analyzer. Firmness was measured in terms of the area under the force-time curve, with units in N-s, required to compress the rice. Rice that is firm requires greater positive force. Stickiness was measured in terms of the area under the force-time curve, with units in N-s, required to overcome the adhesion of the compressed rice to the base plate of the analyzer. Rice that is sticky requires greater negative force. After texture measurement, the compressed rice was immediately collected and sealed in small vials for starch retrogradation analysis. All measurements were done in triplicate.

The degree of starch retrogradation was analyzed using a Perkin-Elmer Pyris 1 differential scanning calorimeter. At least 20 to 25 mg of cooked rice from the texture measurements was placed in aluminum sample pans, sealed and heated from 20°C to 90°C at a rate of 10°C/min. The energy required to melt the retrograded starch, enthalpy (ΔH in J/g), was calculated. Enthalpy will increase as the degree of starch retrogradation increases. The relationship between ΔH and measured texture (firmness and stickiness) was analyzed using the SAS statistical program.

RESULTS AND DISCUSSION

Comparison of texture of freshly cooked rice from the two cultivars is shown in Figure 1. Bengal was less firm (less positive force) and more sticky (more negative force) than Cypress. Storage temperature and storage duration also affected the texture of cooked Bengal and Cypress milled rice. Figure 2 shows that Bengal cooked rice becomes firmer during storage at -13 and 3°C. In contrast, the stickiness of cooked rice decreased during storage, especially at lower temperatures. Similar changes were observed for Cypress cooked milled rice.

An increase in enthalpy was also observed for Bengal and Cypress cooked rice stored at low temperatures, -13 and 3°C (Fig. 3). This result suggested that starch retrograded faster at these temperatures than at 20 and 36°C. To determine whether starch retrogradation in cooked rice affected texture, the relationships between enthalpy and texture measurements, firmness and stickiness, were calculated. Cooked rice firmness had a significant linear relation with enthalpy ($R^2 = 0.80$ at $\alpha = 0.05$), and there was a common slope for Bengal and Cypress (Fig. 4). The relationships between stickiness and starch retrogradation were more complicated and depended on cultivar and storage temperature. For example, there was no significant relationship between starch retrogradation and stickiness for cooked rice stored at 36°C for both cultivars. At -13 and 3°C, significant relationships exist for Bengal, but not for Cypress. Stickiness of Bengal cooked rice stored at 3°C had the strongest relation with starch retrogradation.

SIGNIFICANCE OF FINDINGS

Our results showed that starch retrograded, firmness increased and stickiness decreased during storage of cooked milled rice. Knowledge of the effect of post-cooking conditions on cooked rice texture will help its handling during preparation of ready-to-eat meals. Cooling the rice after cooking and storing it at low temperatures will promote starch retrogradation. This “aging” step will result in a firmer and less sticky cooked rice that will make its addition and mixing with other ingredients easier for food processors and developers.

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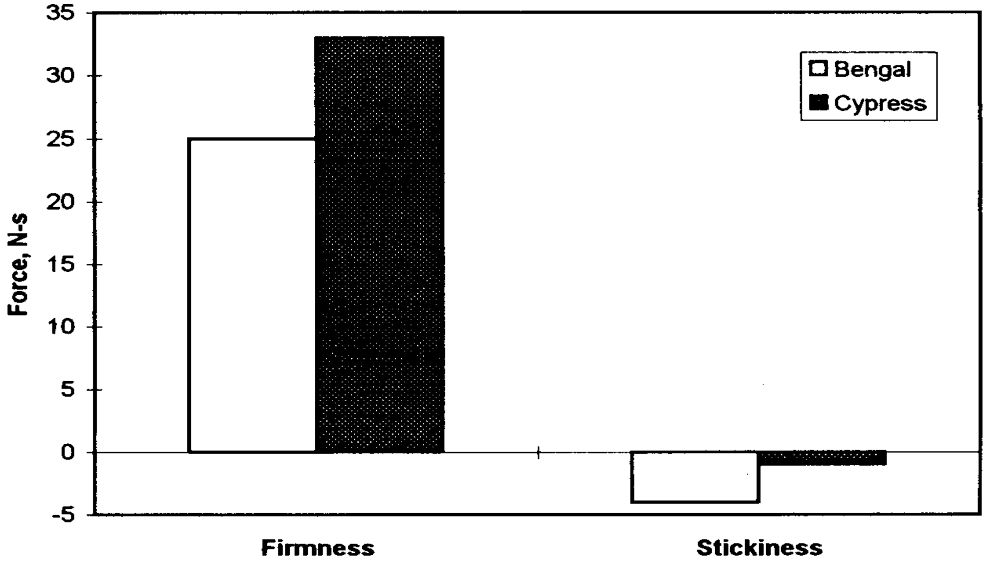

Fig. 1. Texture of freshly cooked ‘Bengal’ and ‘Cypress’ milled rice.

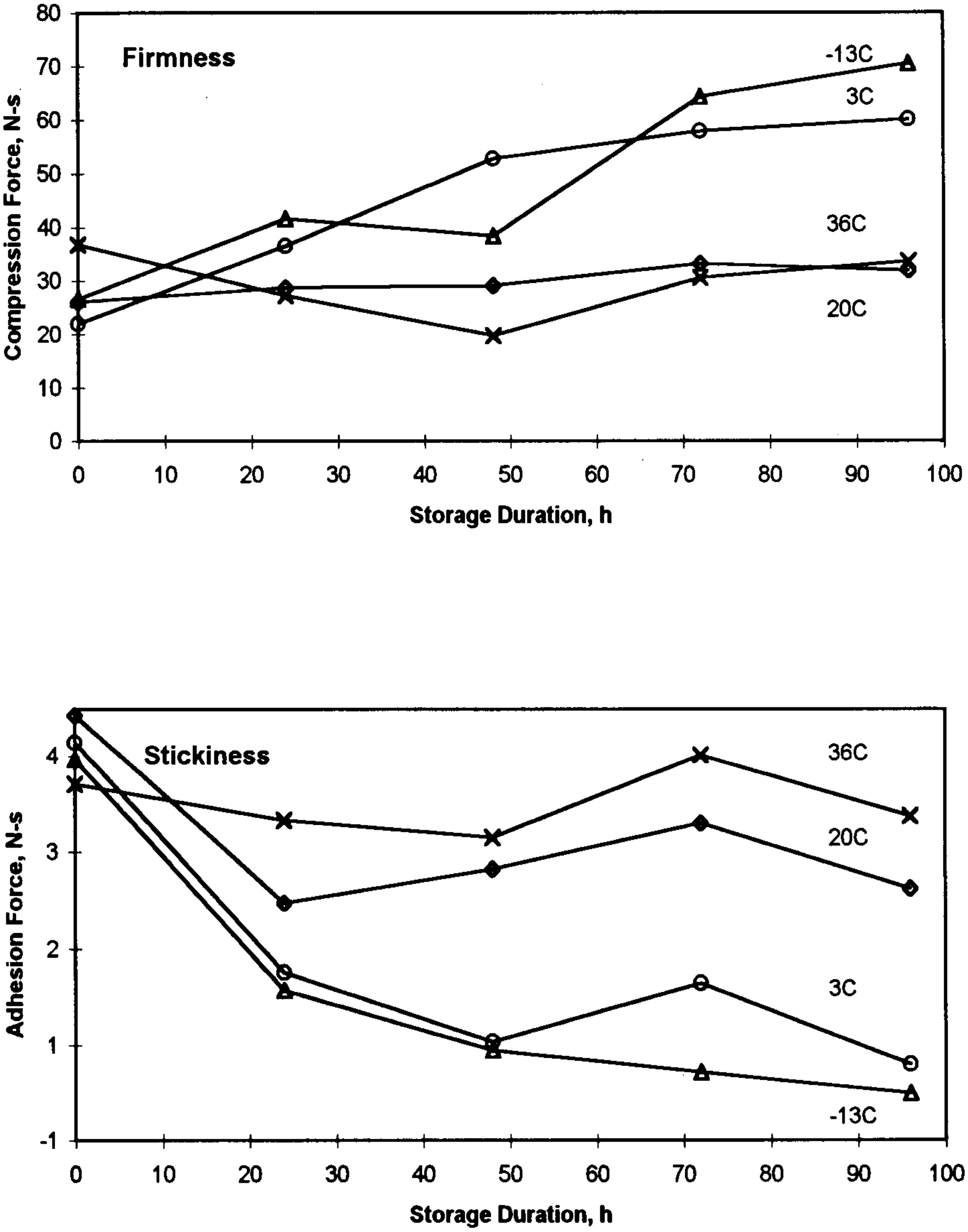

Fig. 2. Changes in firmness and stickiness of 'Bengal' cooked milled rice during storage at different temperatures.

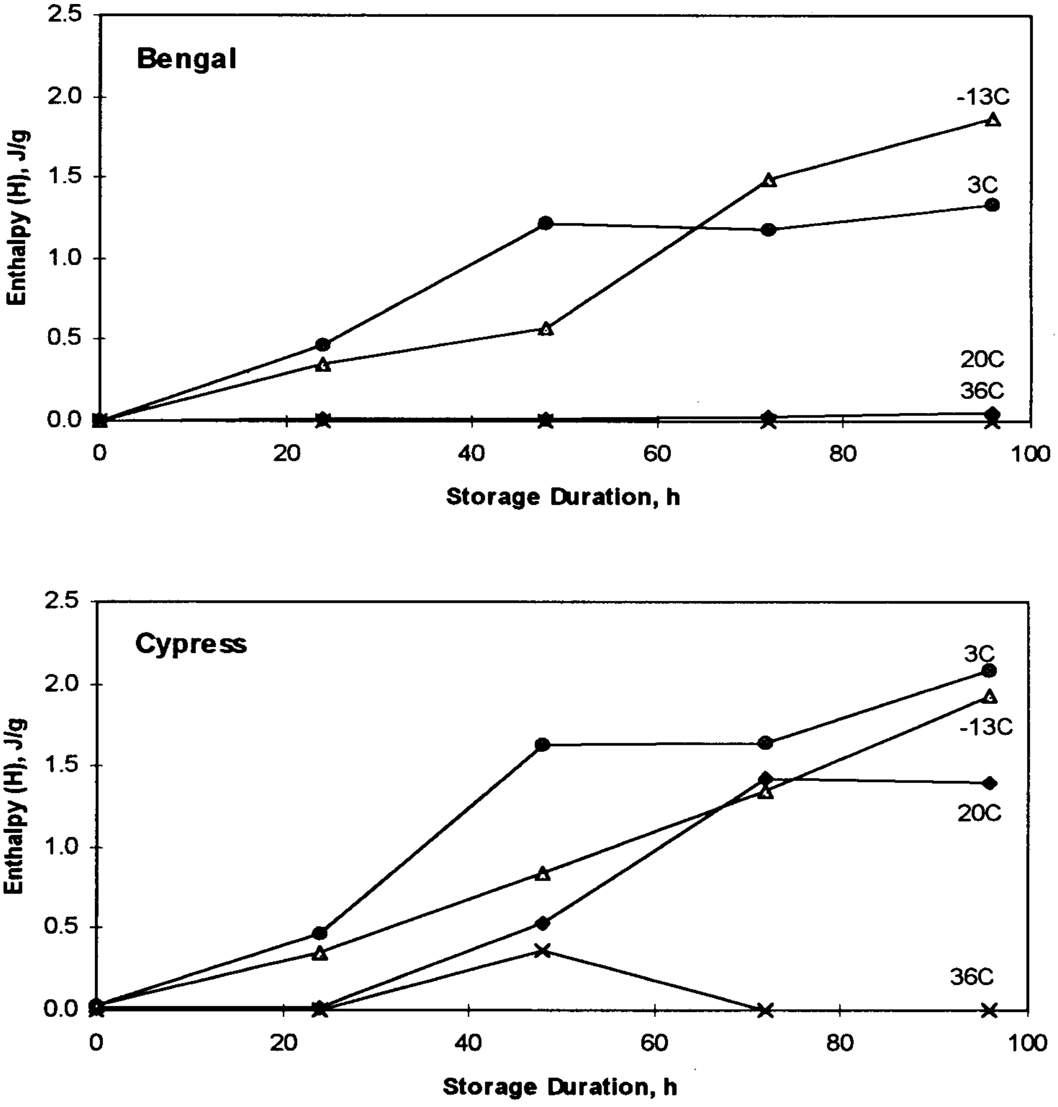

Fig. 3. Changes in degree of starch retrogradation, as measured by changes in enthalpy, in 'Bengal' and 'Cypress' cooked milled rice during storage at different temperatures.

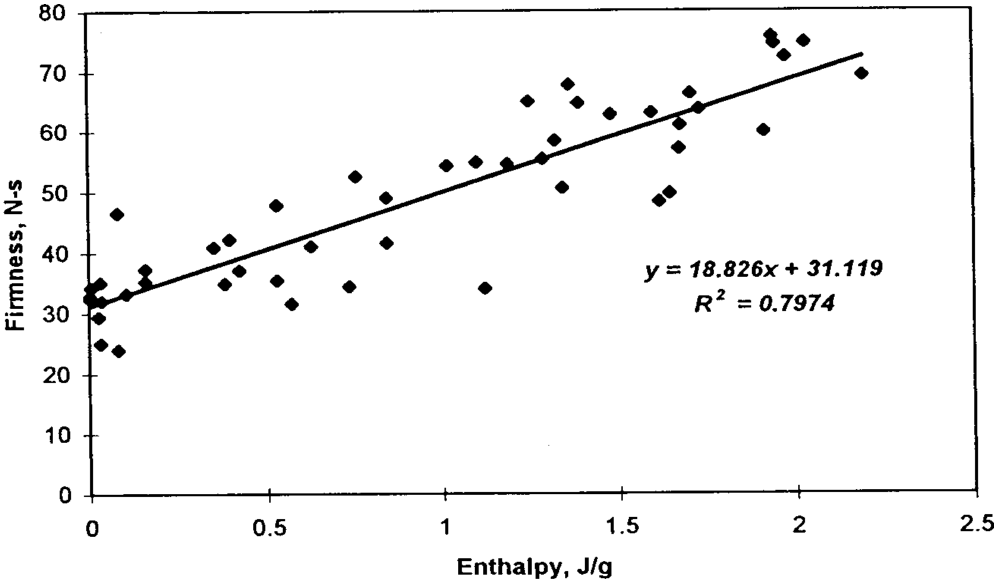

Fig. 4. Relationship of measured firmness 'Bengal' and 'Cypress cooked milled rice with starch retrogradation, as measured by changes in enthalpy.

THE EFFECT OF DEGREE OF MILLING ON RICE AMYLOGRAPH PROPERTIES

A.A. Perdon, T.J. Siebenmorgen, V.K. Griffin and E.R. Johnson

ABSTRACT

Amylography is widely used to assess processing properties of milled rice. We quantified the effect of the degree of milling on the amylograph properties of two medium-grain ('Bengal' and 'Orion') and two long-grain rice cultivars ('Cypress' and 'Kaybonnet'). The peak viscosities for all rice increased with the degree of milling. The rates of increase were higher for medium-grain than for long-grain cultivars. Except for Bengal harvested in 1995, the rates were statistically the same within rice types. Our results suggest the importance of specifying the degree of milling when comparing the amylograph properties of milled rice.

INTRODUCTION

Amylography has been one of the most important tests used in evaluating rice cooking and eating quality (Halick and Kelly, 1959; Juliano, 1982). With the increased utilization of rice in the food industry, which demands consistent raw material, it is important to understand the different factors that affect rice functionality. Numerous studies have been published on the effect of cultivar and storage on rice amylograph properties (e.g. Hamaker et al., 1993; Chrastil, 1994; Perdon et al., 1997). In contrast, the effect of degree of milling on rice amylograph properties has received little attention. The objective of this study is to quantify the relationship between the degree of milling and amylograph properties of different rice cultivars.

MATERIALS AND METHODS

Two medium-grain cultivars, Bengal and Orion, and two long-grain cultivars, Cypress and Kaybonnet, were harvested in 1995 and 1996 from the University of Arkansas Rice Research and Extension Center at Stuttgart, Arkansas. After cleaning and conditioning to 12.5% moisture content, 150-g subsamples of rough rice were dehulled with a McGill sample sheller and milled for 15, 30, 45 and 60 s in a McGill No. 2 mill. All milling for all cultivars was done in duplicate. Only the head rice fraction, separated from brokens with a Seedburo sizer, was used for subsequent testing. The degree of milling (DOM) of each sample was measured with a Satake MM-1B milling meter. Total and surface lipid contents of each sample were also determined with a Soxtec fat extractor using petroleum ether as solvent.

The amylograph properties of each milled rice sample were determined on 8% rice flour slurries (AACC Method No. 61-01, 1996). Regression equations were developed using SAS to relate peak and final viscosities of samples within the same cultivar to their respective DOM and surface lipid content.

RESULTS AND DISCUSSION

For all the cultivars tested, the DOM increased as milling duration increased (Fig. 1). Surface lipid content decreased accordingly with increase in the DOM (Fig. 2). This was expected since rice lipids are predominantly located in the bran layer, which is progressively removed during milling. Overall paste viscosities of the 1995 samples (aged 1 year) were higher than those of the 1996 samples, which were not aged. Previous research showed that amylograph paste viscosity of milled rice increased during storage (Hamaker et al., 1993; Chrastil, 1994; Perdon et al., 1997). Paste viscosities also increased significantly with the degree of milling. Peak viscosity of 1995 and 1996 Cypress and Kaybonnet samples increased by 1.1 BU per unit increase in DOM (Fig. 3a). The rate of increase in peak viscosity across DOM was also similar within the medium-grain cultivars, 2.8 BU per unit increase in DOM, with the exception of Bengal harvested in 1995, which had peak viscosity increasing by 6.2 BU per unit increase in DOM (Fig. 3b). Final viscosities of Cypress and Kaybonnet were not affected by DOM. For Bengal and Orion final viscosities, the effect of DOM was not consistent.

SIGNIFICANCE OF FINDINGS

Food processors usually specify a range of peak and final viscosities for rice from their suppliers. The intent of this specification is to help ensure consistent processing and product quality. Our study showed that for a given cultivar, the amylograph peak viscosity increased with the DOM. Therefore, it is very important to include the DOM when specifying and comparing amylograph properties of milled rice.

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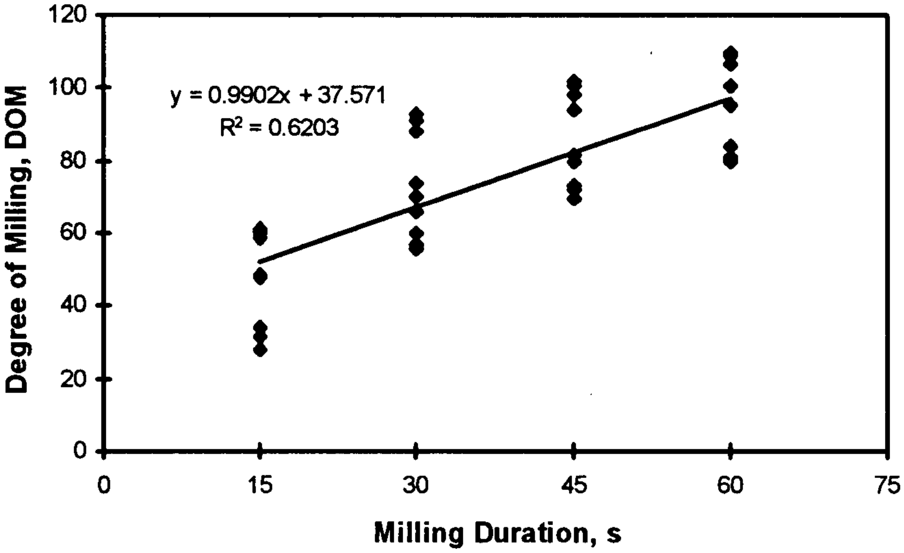


Fig. 1. Effect of milling duration on degree of milling, as measured with a Satake MM-1B milling meter, of milled rice cultivars harvested in 1995 and 1996.

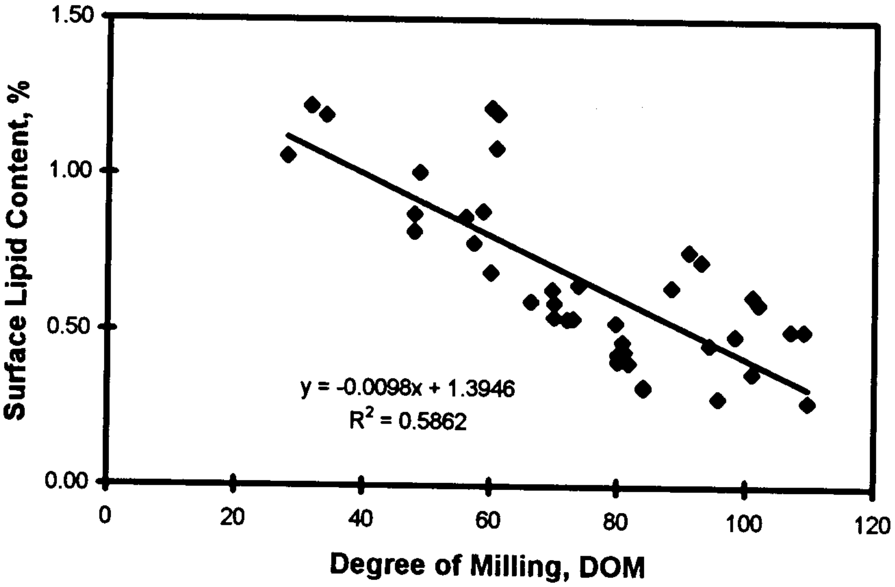
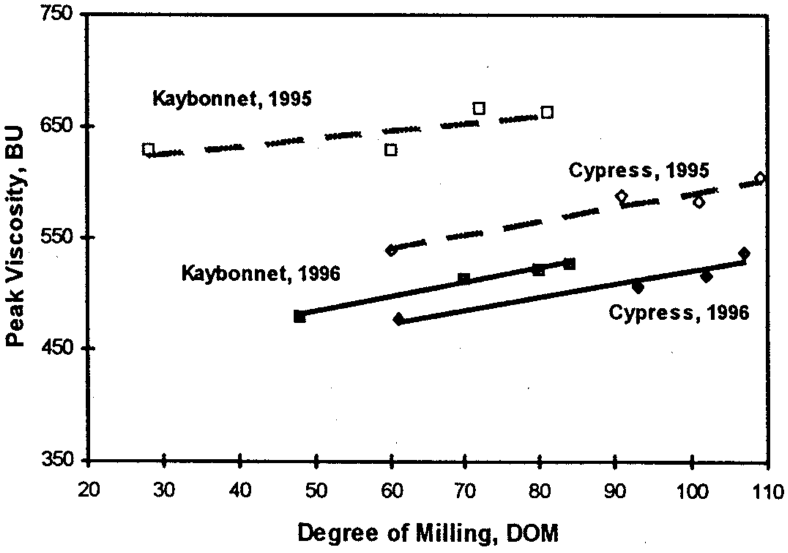


Fig. 2. Effect of degree of milling, as measured with a Satake MM-1B milling meter, on surface lipid content of milled rice cultivars harvested in 1995 and 1996.

(a)



(b)

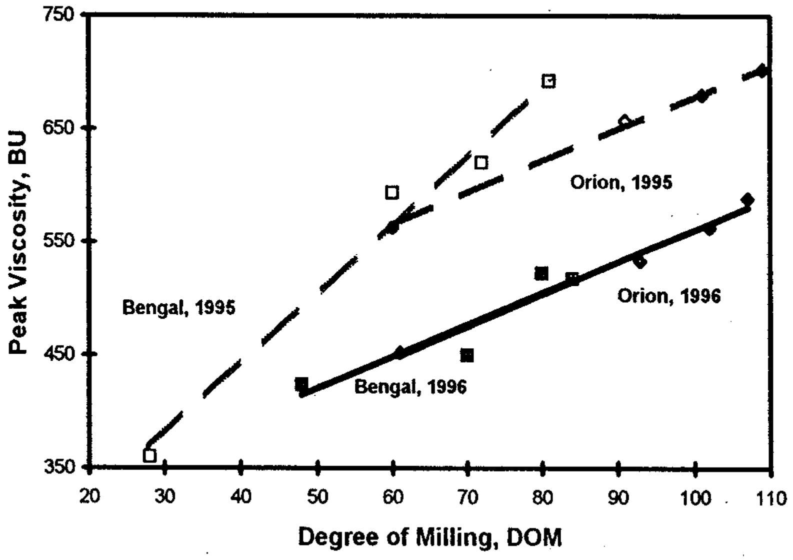


Fig. 3. Effect of degree of milling, as measured with a Satake MM-1B milling meter, on amylograph peak viscosities of milled rice cultivars harvested in 1995 and 1996.

FIELD EVALUATION OF AN ELEMENTAL SULFUR PRODUCT ON RICE GROWTH

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

ABSTRACT

In Arkansas, rice (*Oryza sativa* L.) grown on alkaline silt loams often exhibits poor growth and, in severe cases, stand loss within 2 weeks after flooding. Foliar symptoms are similar to those described for iron toxicity that occurs on acid soils in Asia. Field studies were initiated during 1997 to evaluate the effectiveness of an elemental sulfur (S°) product, called S92 (92% S, Sulfer Works Inc., Calgary, Alberta, Canada), to improve growth and yield of rice grown on alkaline silt loams. Six rates, including 0, 223, 446, 670, 893 and 1785 lb S92/acre, were preplant incorporated on two alkaline field plots in eastern Arkansas. Soil pH was significantly reduced by 34 days after application from 7.5 to below 7.0 by S92 rates greater than 223 lb/acre. Grain yields of 'Drew' and 'Bengal' rice increased by 11 and 18%, respectively, compared with the untreated check. Results suggest that soil acidification can increase rice yields on alkaline silt loam soils. Additional research should concentrate on determining the mechanisms of increased soil nutrient availability, influence on rotational crops and long-term soil management in relation to soil acidification practices.

INTRODUCTION

Alkaline soil conditions (pH > 7.0) are present on about 21% of the rice (*Oryza sativa* L.) acreage in Arkansas according to a 1997 University of Arkansas Soil Test Laboratory summary. Alkaline soil pH may result in iron (Fe), phosphorus (P) and zinc (Zn) deficiencies when cropped to rice. Iron toxicity is a potential physiological disorder for lowland rice that most commonly occurs on unfertile acidic soils. Symptoms are first noticed during active tillering and include bronzing that begins on the lower leaves, inhibited root growth and high tissue Fe concentration (Yamuachi, 1989). Symptoms similar to these have been described in Arkansas for a disorder termed "postflood rice syndrome" (PFS; Slaton et al., 1996). In Arkansas, PFS occurs exclusively on alkaline soils with symptoms becoming most noticeable soon after establishment of the flood on five-leaf seedlings. Plants suffering from PFS usually have lower concentrations of potassium (K), magnesium (Mg), manganese (Mn) and sometimes P but higher values for calcium (Ca) and Fe in comparison to healthy seedlings. Since alkaline soil conditions are more conducive to Fe deficiency rather than toxicity, it is presumed that the high tissue Fe concentrations are a result of the rice plant's inability to oxidize the rhizosphere under flooded conditions. Application of P fertilizer alone or in combination with K fertilizer has proved to reduce bronzing of lower leaves and increase yields, but it usually does not totally alleviate symptoms of PFS (Wilson et al., 1995). Application of KCl alone typically increases leaf bronzing in Arkansas. Zinc application has also failed to increase rice growth or alleviate foliar symptoms of PFS. Draining the flood water usually helps seedlings recover from PFS symptoms. Currently, it is thought that PFS is a complex of multiple nutrient deficiencies, with the most limiting being P. Therefore, it was our objective to determine if soil acidification by use of elemental sulfur (S°) could alleviate PFS symptoms and increase rice growth and yield on alkaline silt loams.

MATERIALS AND METHODS

Field tests were established at the Pine Tree Branch Experiment Station (PTBS), near Colt, Arkansas, and in a grower field in Arkansas County (ARKG), near Almyra, Arkansas, during 1997 to evaluate the effect of a single S° product on rice growth and grain yield. This product will be called *S92* for the duration of this manuscript. The soils at PTBS and ARKG were a Calhoun (fine-silty, mixed, thermic Typic Glossaqualfs) and a Crowley (fine, montmorillinitic, thermic Typic Albaqualfs) silt loam, respectively. Selected soil properties before S92 application are presented in Table 1. Drew and Bengal rice cultivars were seeded at the PTBS and ARKG sites, respectively. Elemental S was applied to the soil on 1 May 1997 and mechanically incorporated before seeding at both locations. Soil was amended with S92 rates equal to 0, 223, 446, 670, 893 and 1785 lb/acre. Rates were calculated using an acre soil slice of 4 in. weighing 1,224,643 lb. Seeding rate, weed control, nitrogen (N) and water management were done by the grower at ARKG following plot establishment. At PTBS, a single application of 120 lb N/acre as urea was applied to a dry soil surface at the five-leaf growth stage and followed immediately by flood establishment, which was maintained until 3 weeks postheading. University of Arkansas Cooperative Extension Service recommendations were used for stand establishment, water management and weed control. Individual plots measured 8 × 16 ft and 6 × 15 ft at ARKG and PTBS, respectively.

To evaluate the influence of S92 rate on soil pH and electrical conductivity (EC), soil samples were taken from each plot 34 days after S92 application (before flooding). Soil pH and EC were measured using a soil weight to water volume ratio of 1:2. At maturity, a 30-ft^2 area was harvested from the center of each plot for grain yield. Reported yields are adjusted to 12% moisture by weight. Grain yield and soil data were analyzed as a split plot design with S92 rates arranged as a randomized complete block with four replications within each location. The whole plot factor was location. Data were analyzed using the GLM procedure of SAS. Differences among treatments were identified using Fischer's least significant difference (LSD) test at the 0.05 significance level of probability.

RESULTS

Soil pH and EC values were averaged across locations and S92 rates since the location × S92 rate interaction was not significant. Soil pH decreased and EC increased as S92 rate increased (Table 2). The 1785-lb/acre rate reduced pH to an average of 6.5 across both locations after 34 days. All S92 rates greater than 223 lb/acre significantly reduced soil pH, with a concurrent increase in soil EC. Between the seeding and flooding measurements, soil pH decreased about 0.3 units, and EC nearly doubled in the untreated checks. Maas and Hoffman (1977) suggested that the critical salinity (saturated paste extract) threshold for rice was 3000 μS/cm. Conversion of this threshold to EC measured in a 1:2 soil-water mixture using data from Sriyotai and Gilmour (1976) suggests that an EC greater than 655

μS/cm is potentially damaging to seedling rice. Although salinity injury symptoms were not observed in this study, the 1785-lb/acre rate increased EC to levels that were potentially harmful to seedling rice.

Treatment effects for grain yield were similar at both locations and among S92 rates. Therefore, data are averaged across locations and rates. Rates greater than 446 lb/acre produced yields significantly greater than the untreated check (Table 2). Although S92 rates of 446 lb/acre or less were not different from the check, a trend for increased yields was observed. Yields were significantly greater at PTBS compared with ARKG, averaging 141 and 122 bu/acre, respectively. Significant grain yield increases, similar to those obtained in this study, were also obtained at the ARKG site with P fertilization during 1997. Previous studies at PTBS have failed to find rice yield responses to K, P and Zn fertilization.

SIGNIFICANCE OF FINDINGS

Rice yields can be increased by acidification of alkaline soils using S° amendments on high-pH problem soils. Additional research is needed to refine recommendations and determine the rates best suited for long-term soil and crop management practices. Sufficient data have been collected during the previous 3 years to make general recommendations to Arkansas growers interested in acidifying alkaline soils used for rice production. However, several factors must be considered before making such recommendations. Due to the current high cost of S° products in Arkansas, growers should use field history in combination with grid soil sample results of problem fields to identify areas that require acidification. Application of S° products to non-alkaline soils would likely reduce soil pH sufficiently to be detrimental to soybean production in the crop rotation. Many products are available that differ in rate of acidification. Therefore, factors that should be considered include application timing, product, rate, soil pH, soil texture and rotational crops. Many of these factors need to be addressed in future research. Recommendations need to be tailored to each field. It is suggested that growers interested in using S° for soil acidification contact their county Extension Agent for additional information on specific recommendations. Finally, it is very impor-tant to point out that application of ammonium sulfate will not have the same effect as S° on soil pH.

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Table 1. Selected soil chemical properties from S92 (an elemental sulfur product) field studies conducted during 1997.

Soil†	pH‡	EC‡	$CaCO_3$	Elemental Concentration§							
				Ca	Mg	K	Mn	Fe	P	Zn	S
		µS/cm	%	lb/acre							
PTBS	7.8	139	0.05	3610	718	156	522	336	26	2.2	18
ARKG	7.9	180	0.05	3238	554	142	226	934	12	2.8	30

† PTBS = Pine Tree Branch Experiment Station, Colt, Arkansas, and ARKG = Arkansas County Grower field.
‡ Soil pH and electrical conductivity (EC) measured in soil weight to water volume ratio of 1:2.
§ Mehlich 3 extractant.

Table 2. Rice grain yield, soil pH and soil electrical conductivity (EC) for field studies conducted during 1997 as affected by S92 (an elemental sulfur product) rate.

S92 Rate	Grain Yield			Soil pH‡			
	PTBS†	ARKG†	Location Mean	PTBS	ARKG	Location Mean	Soil EC‡§
lb/acre	bu/acre						µS/cm
0	132	108	120	7.4	7.6	7.5	338
223	125	120	123	7.2	7.6	7.4	347
446	138	122	130	6.9	7.1	7.0	490
670	148	120	134	6.6	7.0	6.8	609
893	150	131	141	6.5	7.0	6.8	611
1785	155	129	142	6.2	6.8	6.5	775
$LSD_{(0.05)}$	--	--	13	--	--	0.3	166

† PTBS = Pine Tree Branch Experiment Station, Colt, Arkansas, and ARKG = Arkansas County Grower Field.
‡ Soil weight to water volume ratio of sample measurement was 1:2.
§ EC values are the mean of both locations 34 days after S92 application.

INFLUENCE OF TWO ELEMENTAL SULFUR PRODUCTS APPLIED TO AN ALKALINE SILT LOAM ON RICE GROWTH

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

ABSTRACT

Zinc and phosphorus deficiencies are the most common problems associated with rice production on alkaline soils. Acidification of alkaline soils is performed by application of elemental sulfur (S°). Many S° products are available that differ in particle size which influences their rate of breakdown and soil acidification. A field study was established at the Pine Tree Branch Experiment Station, Colt, Arkansas, during 1997 to evaluate the effects two S° products, wettable S (Ws90, Martin Gas Sales, Inc., Kilgore, Texas) and Tiger 90 (Sunbelt Chemical Co., Atmore, Alabama) on soil pH, rice growth and yield on an alkaline silt loam. Each product was applied at rates of 0, 223, 446, 670, 893 and 1785 lb/acre and mechanically incorporated before seeding rice. By day 34 after application, soil pH was reduced about 0.3 units for each 223 lb/acre of Ws90 application (untreated check pH 7.6). Tiger 90 failed to reduce soil pH below 7.0. Tiger 90 and Ws90 rates increased grain yields by 6 to 46% depending on product and rate. The Ws90 resulted in greater yields and total dry matter compared with Tiger 90. Acidification of alkaline soils can increase rice growth and yield. However, results also demonstrate the need to select the proper S° source to fit management needs due to differences in rate of breakdown.

INTRODUCTION

Soil pH influences the availability of several essential nutrients like phosphorus (P), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). In general, as soil pH increases the availability of these elements decreases, especially above pH 7.0. Liming of acid soils is a common management practice used to adjust soil pH and increase production of many crops like soybean. Recommendations for lime application to acid soils are well researched and available from most soil test laboratories. Acidification of alkaline soils is done by application of elemental sulfur (S°). However, specific recommendations for this practice are not available from most soil test laboratories. Recent research has shown that acidification of alkaline silt loams in Arkansas can increase rice yields on problem soils. However, basic information on the application rates and best products is lacking. All S° products may be equally effective over a 10-year period. However, major differences exist among products for breakdown over a 1- to 24-month period due to differences in particle size. Therefore, the objective of this research project was to compare two S° products at several rates to evaluate their effectiveness in reducing soil pH and increasing rice yields on an alkaline silt loam when applied immediately before seeding.

MATERIAL AND METHODS

A single test was established at the Pine Tree Branch Experiment Station (PTBS), near Colt, Arkansas, during 1997 to evaluate effects of two S° products, wettable S TX) and Tiger 90 on rice growth and yield on an alkaline Calhoun silt loam (fine-silty, mixed, thermic Typic Glossaqualfs). These products were chosen because they are both 90% S and 10% bentonite clay products, were available in eastern Arkansas and differed significantly in physical properties. Tiger 90 is manufactured by a “drop-form” technology to produce pastilles that are flat on one side and rounded on the other (Saik, 1995). The Ws90 is a finely divided product that is very difficult and caustic to handle due to its dusty nature. Each product was applied at rates of 0, 223, 446, 670, 893 and 1785 lb/A and mechanically incorporated on 1 May 1997. Application rates were calculated using an acre soil slice 4 in. deep weighing 1,224,642 lb. Selected soil properties before S° application are provided in Table 1. ‘Drew’ rice was drill seeded in plots measuring 6 × 15 ft with 7 in row spacings on 5 May 1997. University of Arkansas Cooperative Extension Service recommendations were followed for stand establishment, water management and weed control. Potassium (K), P and Zn fertilizers were not applied to the plot area since nutrient uptake and growth response to soil pH adjustment were objectives. A single application of 120 lb N/acre as urea was applied to a dry soil surface and followed by flood establishment at the five-leaf growth stage and maintained until 3 weeks postheading. At panicle differentiation (PD) (2 July 1997), a 3-ft segment from the first inside row was harvested for total dry matter (TDM) and nutrient analysis. Plant tissue was rinsed in double deionized water, washed in 0.1 *M* HCl, rinsed a second time in double deionized water and blotted dry. Whole plant tissue was oven dried at 65°C to a constant moisture, weighed, ground in a Wiley mill to pass through a 20-mesh screen for digestion and stored in plastic vials at room temperature until analyzed. Tissue was digested using the HNO_3 and 30% H_2O_2 procedure. A 30-ft^2 area of each plot was harvested for grain yield determination at physiological maturity. Yields were adjusted to a uniform moisture content and are reported as 12% moisture.

RESULTS

All rates of Ws90 significantly lowered soil pH below that of the untreated check 34 days after soil application (Table 2). Additionally, all rates of Ws90 increased soil electrical conductivity (EC). Plant injury from salinity was not observed anytime during the growing season. Only the 446- and 1785-lb/acre rates of Tiger 90 significantly reduced soil pH below that of the check (Table 2). Tiger 90 failed to reduce soil pH below 7.0 by 34 days, indicating that the oxidation rate of S°, which produces acidity (H^+) and sulfate (SO_4-S), for this product was very slow and not adequate for immediate soil pH adjustment. This product may be better suited for fall applications, whereas Ws90 could be applied either in the fall or spring. One advantage of a slow oxidation rate is the lack of a significant increase in EC, thus reducing the likelihood of salinity injury and stand loss. Equation [1] was used to estimate the potential for salinity injury to rice posed by increased EC from S° oxidation (Sriyotai and Gilmour, 1976). Conversion of the critical salinity value (3000 μS/cm EC-saturated paste extract) results in an EC (1:2 ratio) value of 655 μS/cm for initial yield reduction in rice (Maas and Hoffman, 1977). Thus, Ws90 rates greater than 446 lb/acre could possibly have resulted in salinity injury in this study. Yield reduction from salinity is somewhat dependent on plant growth stage and duration of exposure to elevated salt levels. Visual injury symptoms or stand loss was not observed in this study. Rice is less sensitive to SO_4-S salts than either chloride or nitrate salts which may partially explain why damage was not observed.

[Equation 1] $EC_{1:2} = 0.167EC_e + 154$ (units = μS/cm)

Elemental S application increased grain yields by 6 to 46% depending on rate and source. The Ws90 product at all rates, except 223 lb/acre, produced higher grain yields and TDM than the untreated check (Table 2). Only the 670- and 893-lb/acre rates of Tiger 90 produced higher yields than the untreated check. Tiger 90 rates of 446 and 670 lb/acre resulted in increased TDM. Soil pH data suggest that Tiger 90 did not oxidize as rapidly as Ws90. Chapman (1980) reported that sulfuric acid and S° application to an alkaline soil increased rice yield by 25%. Chapman's values compare favorably with the average yield increases of 17 and 31% found for Tiger 90 and Ws90, respectively. Sulfur deficiency in lowland rice may result in yield reductions ranging from 11 to 78%. Rice yield increases from S fertilization have been reported for soils subject to S deficiency (Dana et al., 1994). However, both Chapman (1980) and Moore et al. (1994) failed to find yield responses to SO_4-S application to rice grown on alkaline soils, but, in both cases, rice did respond to S° amendments.

Plant nutrient analysis showed that S source significantly influenced tissue Zn concentration. Application of Ws90 significantly increased tissue Zn concentration (20.2 ppm), but Tiger 90 (18.4 ppm) did not change tissue concentrations of these elements compared with the untreated check (17.2 ppm). Elemental S rates greater than 446 lb/acre increased tissue Zn concentration (data not shown). Tissue Zn concentration for S rates less than or equal to 446 lb/acre were below 20 ppm, which is considered low (Sedberry et al., 1987). Acidification of alkaline problem soils should enable growers to eliminate application of Zn fertilizer.

SIGNIFICANCE OF FINDINGS

Measurements of grain yield, TDM, and nutrient uptake indicate that S° application to an alkaline silt loam improved rice growth. Visual observations made during the season suggested that plots receiving S°, from either product, had more uniform growth and greater biomass production. Untreated checks could visually be distinguished from all plots receiving S° from the time of flood establishment through harvest. Application of Ws90 resulted in lower soil pH and increased EC compared to equal rates of Tiger 90. Soil EC increased to potentially damaging levels with application Ws90 rates greater than 446 lb/acre, although damage was not observed. Application of S° shows great potential for improving rice production on alkaline silt loam soils in Arkansas. Use of fast reacting S° products like Ws90 may be beneficial when applied immediately before seeding. However, other data not presented here suggest that maximum benefits occur when soil pH is adjusted several months before seeding the rice crop. Although yield also increased from application of Tiger 90, the magnitude was less. Soil pH and EC data indicates that Tiger 90 oxidizes (breaks down) slower than Ws90 due to a larger particle size and should be applied several months before seeding for adequate pH adjustment. The slower rate of breakdown may be beneficial in long-term management of soil pH with continued use of irrigation water high in calcium bicarbonates. This would allow for higher rates of application for long term pH management without a sharp increase in salinity. Research must continue to study S° amendments for improving rice growth in order to evaluate the effects of soil acidification on rotation crops and the long-term of soil acidification on soil pH and EC.

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Table 1. Selected soil chemical properties from S tests conducted during 1997 at the Pine Tree Experiment Station, Colt, Arkansas.

Soil†	pH‡	EC‡	$CaCO_3$	Ca	Mg	K	Mn	Fe	P	Zn	SO_4-S
		μS cm^{-1}	%	lbs/A							
PTBS	7.7	162	0.04	3648	726	158	506	352	26	2.6	26

† Mean of soil samples taken from each untreated check plot on 3 May 1997 and extracted with Mehlich 3.

‡ Soil pH and EC (electrical conductivity) measured on a 1:2 ratio (soil wt:water volume)

Table 2. Soil pH, EC, total dry matter (TDM), and rice grain yield on an alkaline Hilleman silt loam at the Pine Tree Experiment Station, Colt, Arkansas, during 1997 as affected by S °source and rate.

Product	Rate	pH†	EC†	TDM	Grain Yield
	lb/acre		μS/cm	lb/acre	bu/acre
None	0	7.6	222	5163	97
Tiger 90	223	7.4	263	5679	109
Tiger 90	446	7.2	346	6463	103
Tiger 90	670	7.3	341	7144	119
Tiger 90	893	7.4	291	5510	123
Tiger 90	1785	7.2	340	5771	111
Wettable S	223	7.1	414	5263	111
Wettable S	446	6.6	599	6513	136
Wettable S	670	6.3	779	7486	127
Wettable S	893	6.0	923	6863	119
Wettable S	1785	5.1	1344	8003	141
$LSD_{(0.05)}$	—	0.3	143	826	22

† pH and EC (electrical conductivity) values reported as 1:2 (soil wt:water volume ratio)

EFFICACY OF LIBERTY (GLUFOSINATE) IN LIBERTY-TOLERANT RICE

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ABSTRACT

Genetically transformed Liberty-tolerant rice has been developed to allow the use of glufosinate (Liberty®), a broad-spectrum herbicide, in rice production. Research to evaluate glufosinate was conducted in 1997 at three locations in Arkansas (Lonoke, Rohwer and Stuttgart) on three different glufosinate-tolerant varieties. Rates of glufosinate were 0, 0.25, 0.375, 0.5 and 0.75 lb ai/acre. Application timings were two- to three-leaf rice (2-3 lf), preflood (PREFLD), postflood (PSTFLD) and sequential applications at 2-3 lf followed by PREFLD or PSTFLD. At Lonoke, 4 weeks after treatment (WAT), broadleaf signalgrass and propanil-resistant barnyardgrass were completely controlled with all rates and timings of glufosinate except the PSTFLD timing. The single application of glufosinate PSTFLD at all rates controlled broadleaf signalgrass 88 to 91% and propanil-resistant barnyardgrass 79 to 86%. By 12 WAT, control of the barnyardgrass was less with some of the 2-3 lf treatments, but, in general, it was excellent with most treatments. Rice yields ranged from 110 to 137 bu/acre and did not differ among treatments. At Rohwer, 4 WAT, barnyardgrass control with glufosinate ranged from 13% (0.25 lb/acre at 2-3 lf) to 100% (0.75 lb/acre at PREFLD), hemp sesbania control was excellent at all rates and timings, and sprangletop control ranged from 5% (0.25 lb/acre at 2-3 lf) to 100% (0.75 lb/acre at PREFLD). Control with glufosinate was less at 7 WAT with all rates and timings for all three weed species. Grain yield from the glufosinate-tolerant cultivars ranged from 0 to 174 bu/acre. At Stuttgart, red rice was controlled at least 80% with all applications of glufosinate at 4 WAT. However, control decreased with the single applications to as low as 41% 9 WAT with glufosinate. Little to no injury occurred with glufosinate-tolerant ‘Cypress’ and ‘Bengal’, but ‘Gulfmont’ was injured 33 to 50% by the PSTFLD application.

INTRODUCTION

Weeds are the number one production constraint in rice (Deshaies, 1997). Grain yield and quality losses due to weeds have been estimated at 15% in the U.S. (Smith, 1988). With the increasing populations of propanil-resistant barnyardgrass and red rice, researchers have looked at glufosinate (Liberty®) to solve these problems.

Glufosinate is a non-selective herbicide that inhibits photosynthesis (Sauer et al., 1987). Because of this non-selectivity, glufosinate has not been an option for use in rice. Genetically transformed glufosinate-tolerant rice has been developed that could allow the use of this broad-spectrum herbicide in rice. Preliminary research has shown excellent potential for controlling several problem weeds with glufosinate, including red rice, with no injury to the tolerant rice (Wheeler et al., 1997). Therefore, the objective of this study was to further evaluate weed control in glufosinate-tolerant rice.

PROCEDURES

Studies were conducted at three locations in Arkansas in 1997 to evaluate glufosinate for control of red rice and other weeds in genetically transformed rice cultivars. A different glufosinate-tolerant rice cultivar was used at each location due to the limited amount of transgenic rice seed. A red rice (*Oryza sativa*) control study was conducted in glufosinate-tolerant Gulfmont rice on a Crowley silt loam soil at the Rice Research and Extension Center at Stuttgart. Control of broadleaf signalgrass (*Brachiaria platyphylla*) and propanil-resistant barnyardgrass (*Echinochloa crus-galli*) was evaluated in transformed Cypress on a Crowley silt loam soil at the University of Arkansas Pine Bluff Research Station at Lonoke. In the study at the Southeast Research and Extension Center at Rohwer on a silty clay loam soil, glufosinate-tolerant Bengal was seeded to evaluate the control of barnyardgrass, hemp sesbania (*Sesbania exaltata*) and sprangletop (*Leptochloa fascicularis*). Rice at all locations was drill seeded. Seeding dates were 7 May at Lonoke, 13 May at Stuttgart and 14 May at Rohwer. Red rice at Stuttgart was broadcast seeded at 200 lb/acre prior to final seedbed preparation. Severe natural infestations of broadleaf signalgrass were present at Lonoke and barnyardgrass, hemp sesbania and sprangletop at Rohwer. Propanil-resistant barnyardgrass was seeded in rows perpendicular to the drilled rice in two rows at Lonoke.

The experimental design for each study was a randomized complete block with four replications. Plot size ranged from 4.5 by 17 ft at Rohwer to 8 by 20 ft at Stuttgart and Lonoke. Herbicide treatments were applied with a CO_2 backpack sprayer. All treatments were applied to two- to three-leaf rice (2-3 lf), just prior to flooding to four- to five-leaf rice (PREFLD), post flood to four- to six-leaf tillering rice (PSTFLD) or sequential applications of these timings. Glufosinate rates were 0, 0.25, 0.42, 0.5 and 0.75 lb ai/acre. Data taken included visual ratings for percent weed control ranging from no control (0%) to complete control (100%) and rice grain yield. Visual ratings were taken 4 and 12 weeks after treatment (WAT) at Lonoke, at 5 and 7 WAT at Rohwer and at 4 and 9 WAT in the red rice study at Stuttgart. The latter study was destroyed prior to harvest to prevent any potential outcrossing of red rice with the cultivar. Data were subjected to analysis of variance, and treatment differences were separated by a least significance test at the 5% significance level.

RESULTS AND DISCUSSION

At Lonoke, broadleaf signalgrass and propanil-resistant barnyardgrass were completely controlled 4 WAT by all rates and timings of glufosinate, except the PSTFLD timing (Table 1). At 4 WAT, the PSTFLD timing of glufosinate at 0.25, 0.375, 0.5 and 0.75 lb/acre controlled propanil-resistant barnyardgrass at 79, 83, 84 and 86%, respectively. Control of broadleaf signalgrass at 4 WAT was slightly higher than for the barnyardgrass at the PSTFLD timing with 88 to 91% control. At 12 WAT, control of the barnyardgrass was less, with some of the 2-3 lf treatments being as low as 53%, but control with the majority of the treatments remained excellent throughout the season (Table 1). Complete control of the broadleaf signalgrass with glufosinate was seen at 12 WAT. The reduction in control from the 2-3 lf timing of glufosinate was due to the lack of residual control with this herbicide, and this allowed for re-infestation with the early timings. Cypress rice yields in the plots treated with glufosinate ranged from 110 to 137 bu/acre and were not significantly different. Yield of the untreated check (UTC) plots averaged 79 bu/acre.

At Rohwer, 4 WAT, barnyardgrass control with glufosinate ranged from 13% (0.25 lb/acre at 2-3 lf) to 100% (0.75 PREFLD). Hemp sesbania control was excellent at all rates and timings. Sprangletop control ranged from 5% with the 0.25-lb/acre rate at the 2-3 lf timing to 100% with the 0.75-lb/acre rate at PREFLD and with all sequential application rates at 2-3 lf followed by PREFLD (Table 2). Control with glufosinate was less at 7 WAT with all rates and timings for all three weed species except with the sequentially applied treatments 2-3 lf followed by PREFLD. Grain yield of the glufosinate-tolerant Bengal ranged from 0 to 174 bu/acre.

Red rice at Stuttgart was controlled at least 80% with all applications of glufosinate at 4 WAT (Table 3). Control was less, however, with the single application of glufosinate. A single application at PSTFLD gave the weakest control of red rice at 9 WAT (as low as 41%). Excellent full-season control of red rice was achieved with all sequentially applied treatments.

Glufosinate applications provided virtually no injury to the glufosinate-tolerant Cypress and Bengal, but glufosinate-tolerant Gulfmont was injured 33 to 50% from the PSTFLD application. Development of the glufosinate-tolerant Gulfmont cultivar has been discontinued (pers. com. S. Linscombe, LSU, 1998).

SIGNIFICANCE OF FINDINGS

This research indicates that glufosinate has the potential to be an excellent rice herbicide. The development of transgenic glufosinate-tolerant rice cultivars allows the option to use glufosinate, a non-selective, broad-spectrum herbicide. The glufosinate technology should provide a break-through for the control of problem rice weeds, including red rice and propanil-resistant barnyardgrass. It could potentially be the most significant herbicide break-through since the development of propanil, as soon as enough well-adapted glufosinate-tolerant cultivars are available.

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Table 1. Weed control by glufosinate herbicide and rice grain yield in glufosinate-tolerant 'Cypress' rice at Lonoke, Arkansas, 1997.

Glufosinate		Broadleaf signalgrass		Propanil-resistant barnyardgrass		
Timing	Rate	4 WAT[†]	12 WAT	4 WAT	12 WAT	Grain yield
	lb ai/acre	% control				bu/acre
UTC[‡]	0	0	0	0	0	79
2-3 lf[§]	0.25	100	100	100	53	119
	0.375	100	100	100	81	122
	0.5	100	100	100	84	124
	0.75	100	100	100	96	137
PREFLD	0.25	100	100	100	100	126
	0.375	100	100	100	95	123
	0.5	100	100	100	100	115
	0.75	100	100	100	100	116
PSTFLD	0.25	88	100	79	100	120
	0.375	88	100	83	100	119
	0.5	90	100	84	98	112
	0.75	91	100	86	100	132
2-3 lf/PREFLD	0.25 followed by 0.25	100	100	100	100	112
	0.375 followed by 0.375	100	100	100	100	110
	0.5 followed by 0.5	100	100	100	100	112
2-3 lf/PSTFLD	0.375 followed by 0.375	100	100	100	100	125
	0.5 followed by 0.5	100	100	100	100	122
	LSD $_{0.05}$	3	NS[¶]	4	15	31

[†] WAT = Weeks after 2-3 lf treatment, applied 2 June 1997.

[‡] UTC = untreated check.

[§] 2-3 lf = two- to three--leaf rice, PREFLD = before flood, and PSTFLD = post flood.

[¶] NS = non-significant.

Table 2. Weed control by glufosinate herbicide and grain yield in glufosinate-tolerant 'Bengal' rice at Rohwer, Arkansas, 1997.

Glufosinate		Weed control						Grain yield
		Barnyardgrass		Hemp sesbania		Sprangletop		
Timing	Rate	4 WAT[†]	7 WAT	4 WAT	7 WAT	4 WAT	7 WAT	
	lb ai/acre	% control						bu/acre
UTC[‡]	0	0	0	0	0	0	0	0
2-3 lf[§]	0.25	13	20	96	69	5	65	36
	0.375	85	40	100	91	46	35	51
	0.5	44	29	100	93	46	53	36
	0.75	66	35	100	93	48	55	42
PREFLD	0.25	90	63	100	95	92	71	87
	0.375	74	59	100	95	93	68	95
	0.5	99	76	100	96	98	81	98
	0.75	100	95	100	97	100	97	165
PSTFLD	0.25	46	46	94	83	43	90	0
	0.375	43	35	97	76	35	90	19
	0.5	46	59	78	91	33	93	22
	0.75	46	58	100	90	38	88	38
2-3 lf/PREFLD	0.25 followed by 0.25	100	84	100	93	99	90	174
	0.375 followed by 0.375	100	87	100	98	100	98	150
	0.5 followed by 0.5	100	95	100	98	100	98	128
2-3 lf/PSTFLD	0.375 followed by 0.375	93	85	100	95	93	92	130
	0.5 followed by 0.5	97	86	100	97	98	92	146
	LSD $_{0.05}$	20	15	12	8	17	23	36

[†] WAT = Weeks after 2-3 lf treatment, applied 5 June 1997.

[‡] UTC = untreated check

[§] 2-3 lf = two- to three-leaf, PREFLD = before flood, and PSTFLD = post flood.

Table 3. Red rice control and rice injury from application of glufosinate herbicide to glufosinate-tolerant 'Gulfmont' rice, Stuttgart, Arkansas, 1997.

Glufosinate		Red rice		Rice injury	
Timing	Rate	4 WAT[†]	9 WAT	4 WAT	9 WAT
	lb ai/acre	---------% Control---------		--------% Injury--------	
UTC[‡]	0	0	8	0	0
2-3 lf[§]	0.25	98	86	0	0
	0.375	100	97	0	0
	0.5	100	99	0	0
	0.75	100	99	0	0
PREFLD	0.25	81	70	4	0
	0.375	94	94	2	0
	0.5	94	93	4	0
	0.75	96	99	3	0
PSTFLD	0.25	80	41	39	43
	0.375	83	45	41	43
	0.5	83	70	43	41
	0.75	84	88	41	38
2-3 lf/PREFLD	0.25 followed by 0.25	100	100	0	0
	0.375 followed by 0.375	100	100	0	0
	0.5 followed by 0.5	100	100	0	0
2-3 lf/PSTFLD	0.375 followed by 0.375	100	99	0	0
	0.5 followed by 0.5	100	100	1	0
	LSD $_{0.05}$	3	20	7	3

[†] WAT = Weeks after 2-3 lf treatment, applied 5 June 1997.

[‡] UTC = untreated check.

[§] 2-3 lf = two- to three-leaf rice, PREFLD = before flood and PSTFLD = post flood.

RICE GERMPLASM TOLERANT TO SULFOSATE (TOUCHDOWN)

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ABSTRACT

Eight germplasm accessions (PI 319703, PI 319704, PI350468, PI 353719, PI 414714, PI 414715, PI 430438 and PI 431481) and two U.S. cultivars (‘Alan’ and ‘Bengal’) were treated with sulfosate (Touchdown®) at 0.5, 1.0 and 1.5 lb ai/acre and evaluated for effects on plant height, days from seedling emergence to heading, plant injury and grain yield. There was a significant reduction in plant height as the rate of sulfosate increased at both 2 and 5 weeks after applying the herbicide. As the rate of sulfosate increased from 0.5, 1.0 and 1.5 lb/acre, the number of days from seedling emergence to heading increased. Also, as the rate of sulfosate increased, the degree of plant injury increased at 3, 4 and 5 weeks after applying the herbicide. The average grain yields of Bengal and Alan, non-tolerant U.S. check cultivars, and PI 431481, a tolerant type, were 918, 2097 and 4447 lb/acre, respectively, when sulfosate was applied at the 1.5 lb ai/acre rate.

INTRODUCTION

Annual grain yield losses due to weeds in rice in the U.S. have been estimated at 17% of the potential production or about 50 million bushels valued at $205 million (Chandler, 1981). More than 50 weed species infest direct-seeded rice and cause major losses in U.S. rice production. Barnyardgrass [*Echinochloa crus-galli* (L.) Wild], hemp sesbania [*Sesbania exaltata* (Raf.) Rydb, ex A.W. Hill], broadleaf signalgrass [*Brachiaria platphylla* (Griseb) Nash], sprangletop (*Leptochloa* spp.) and red rice (*Oryza sativa* L.) are major weed species in rice in the southern rice producing states of Arkansas, Louisiana, Mississippi, Missouri and Texas, where most of the rice is drill-seeded (Smith, 1988). Sulfosate, a herbicide that has a mode of action similar to that of glyphosate (Roundup®), is an environmentally safe, non-selective herbicide that controls weeds in drill-seeded rice. However, U.S. rice cultivars are susceptible to both sulfosate and glyphosate. The objective of this study was to determine the level of tolerance to sulfosate of foreign accessions that had been identified previously as being tolerant to both sulfosate and glyphosate.

PROCEDURE

In 1993, approximately 14,000 of the 16,476 accessions in the USDA, ARS rice germplasm collection were evaluated for tolerance to sulfosate. The accessions were drill-seeded into single rows approximately 4 ft long and 8 in. apart in two replications at the University of Arkansas Rice Research and Extension Center (RREC) near Stuttgart, Arkansas. The seedling rice was treated with 1.5 lb ai/acre of sulfosate at the four- to six-leaf stage of development. A total of 39 accessions survived the sulfosate treatment in both replications and developed mature grain (Dilday et al., 1995). Further studies were conducted on the accessions in 1995 for tolerance to sulfosate (Dilday et al., 1996).

Eight accessions that were selected for tolerance in previous tests [PI 319703 (ICA 5), PI 319704 (ICA 10), PI 350468 (IR 781-92-1-2-1-2-2), PI 353719 (IARI 6598), PI 414714 (Colombia II), PI 414715 (Colombia III), PI 430438 (R 100/1) and PI 431481 (IR 442-2-58-2-1-2-58-2-1-2)] and two U.S. check cultivars [Alan (PI 538253) and Bengal (PI 561735)] were drill-seeded on a farm approximately 15 miles south of Stuttgart, Arkansas, on 7 May 1997. Each entry was seeded into nine-row plots 6 ft x 5 ft (row spacing of 8 in.). The experimental design was a split-plot with four replications. Herbicide rates of sulfosate as the main plot were 0.0, 0.5, 1.0 and 1.5 lb ai/acre. The herbicide was applied at the four- to six-leaf stage or immediately prior to first flood (800 DD-50 heat units after seedling emergence). Nitrogen fertilizer as urea was applied in a 3-way split: preflood (60 lb N/acre), 0.5-in. internode elongation (30 lb N/acre) and 7 days after 0.5-in. internode elongation (30 lb N/acre). Plant height was measured 2 and 5 weeks after the sulfosate was applied and at maturity. Plant injury was estimated as a percentage of the plants that were injured at 3, 4 and 5 weeks after sulfosate was applied as compared to the untreated check. Two 4-ft rows in the center of each plot were harvested for grain yield.

RESULTS

Plant Height

There was a significant reduction in plant height as herbicide rates increased at both 2 and 5 weeks after applying sulfosate (Table 1). However, at maturity there was no significant difference in plant height between the control and 0.5 lb ai/acre of sulfosate. Also, there was no significant difference in plant height between 1.0 and 1.5 lb ai/acre. Furthermore, there was essentially no difference in the relative percentage of reduction in plant height of PI 431481, a tolerant variety, and Alan and Bengal, two non-tolerant check cultivars, at 2 and 5 weeks after applying the herbicide. For example, the percentage reduction in plant height of PI 431481, Alan and Bengal at the 0.5 lb-ai/acre rate at 2 weeks after application was 28, 46 and 58%, respectively; at the 1.0-lb ai/acre rate the percentages were 48, 58 and 64%, respectively, and at the 1.5-lb ai/acre rate the percentages were 57, 53 and 59%, respectively. The percentage reduction in plant height of PI 431481, Alan and Bengal at the 0.5-lb ai/acre rate at 5 weeks after application was 22, 15 and 19%, respectively; at the 1.0-lb ai/acre rate the percentages were 22, 37 and 29%, respectively; and at the 1.5-lb ai/acre rate the percentages were 34, 50 and 38%, respectively.

Days from Emergence to Heading

As the rate of sulfosate increased, the number of days from seedling emergence to heading increased. However, the average delay in heading for the resistant entries was only 2, 6 and 9 days at 0.5, 1.0 and 1.5 lb ai/acre, respectively. The average delay in heading for the non-resistant cultivars, Alan and Bengal, was 14, 20 and 28 days at 0.5, 1.0 and 1.5 lb ai/acre, respectively.

Plant Injury at Three, Four and Five Weeks

As the rate of sulfosate increased, the degree of plant injury increased at 3, 4 and 5 weeks after applying the herbicide (Table 2). Furthermore, the amount of plant injury to Alan and Bengal at 3, 4 and 5 weeks after applying the herbicide was significantly greater than the injury to the tolerant entries. The plant injury to Bengal at 4 and 5 weeks after applying the herbicide was significantly greater than the injury to Alan.

Grain Yield

The average grain yield of Alan and Bengal over all treatments was significantly less than the average grain yield of all the tolerant entries, except PI 430438. The average grain yield over all treatments for Bengal, Alan and PI 431481, the highest yielding entry in the treated plots, was 1997, 2137 and 4167 lb/acre, respectively. Also, the average grain yield of Bengal, Alan and PI 431481 at the 1.5-lb ai/acre rate was 918, 2097 and 4447 lb/acre, respectively.

SIGNIFICANCE OF FINDINGS

Of the three characteristics evaluated (plant injury, plant height and days from seedling emergence to heading), only plant injury at 3, 4 and 5 weeks after applying sulfosate seemed to affect final grain yield. These data suggest that the degree of plant injury from 3 to 5 weeks after applying sulfosate can be used as a selection tool to evaluate a large population of segregating material in the enhancement and plant breeding programs designed to develop sulfosate-resistant cultivars that can be used in a red rice control program.

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Table 1. Rice plant height (cm) at 2 and 5 weeks and at maturity after applying sulfosate at 800 DD50 heat units in 1997.

	Sulfosate rate (lb ai/acre0											
	2 weeks after application				5 weeks after application				Maturity			
Entry	0.00	0.5	1.0	1.5	0.0	0.5	1.0	1.5	0.0	0.5	1.0	1.5
	cm				cm				cm			
ICA 5	16.6	12.5	9.9	9.5	26.0	25.3	21.0	19.3	100.5	102.0	96.5	93.5
ICA 10	16.9	13.7	10.2	7.3	28.0	25.5	23.3	20.3	110.5	112.0	107.5	104.5
PI 350468	16.3	12.0	9.3	7.8	29.3	22.8	23.0	18.8	74.5	68.5	68.5	66.0
IARI 6598	19.6	16.2	10.5	8.0	31.8	26.8	25.3	21.5	91.5	95.5	83.5	86.0
Colombia II	15.8	11.4	8.3	6.9	24.8	24.3	23.0	17.0	97.5	101.0	98.5	93.0
Colombia III	15.1	13.9	8.6	9.8	24.5	22.3	20.8	20.3	98.0	101.5	94.5	95.5
PI 430438	18.9	13.1	11.0	9.7	28.8	25.0	24.3	20.3	95.0	99.0	95.5	94.0
PI 431481	17.4	12.6	9.1	7.4	31.0	24.3	24.3	20.5	93.0	85.0	86.0	77.5
Alan	19.7	10.7	8.2	9.2	30.5	25.8	19.3	15.3	74.0	81.0	74.5	71.0
Bengal	21.0	8.8	7.6	8.7	27.8	22.5	19.8	17.3	66.5	67.0	63.5	62.5
LSD (0.05)	2.3				3.2				8.9			
Mean	17.7 a[†]	12.5 b	9.3 c	8.4 d	28.2 a	24.4 b	22.4 c	19.0 d	90.1 a	91.3 a	86.9 b	84.3 b

[†] Means followed by the same letter within a time after application are not significantly different at the 5% level by LSD.

Table 2. Rice plant injury (% as compared to check) at 3, 4 and 5 weeks after applying sulfosate in 1997.

	Sulfosate rate (lb ai/acre)											
	3 weeks after application				4 weeks after application				5 weeks after application			
Entry	0.00	0.5	1.0	1.5	0.0	0.5	1.0	1.5	0.0	0.5	1.0	1.5
	%				cm				cm			
ICA 5	0.0	6.2	12.5	50.0	0.0	11.3	13.8	28.8	0.0	10.0	20.0	33.7
ICA 10	0.0	6.2	10.0	48.7	0.0	11.3	10.0	27.5	0.0	10.0	13.8	32.5
PI 350468	0.0	17.5	8.8	50.0	0.0	11.3	8.8	27.5	0.0	8.8	8.8	31.3
IARI 6598	0.0	7.5	21.3	57.5	0.0	7.5	12.5	38.7	0.0	7.5	8.8	51.2
Colombia II	0.0	10.0	12.5	48.7	0.0	15.0	13.8	28.8	0.0	15.0	27.5	30.0
Colombia III	0.0	8.8	13.8	50.0	0.0	13.8	11.3	22.5	0.0	23.8	18.8	28.8
PI 430438	0.0	6.2	20.0	56.2	0.0	8.8	15.0	33.7	0.0	15.0	25.0	40.0
PI 431481	0.0	11.3	13.8	26.3	0.0	12.5	10.0	22.5	0.0	7.5	6.2	22.5
Alan	0.0	13.8	54.5	90.7	0.0	13.8	37.5	73.7	0.0	17.5	42.5	83.7
Bengal	0.0	26.3	62.5	98.0	0.0	27.5	43.7	92.5	0.0	36.2	61.2	94.7
LSD (0.05)		15.8				11.3				15.1		
Mean	0.0 d[†]	11.4 c	23.0 b	57.6 a	0.0 d	13.3 c	17.6 b	39.6 a	0.0 d	15.1 c	23.3 b	44.9 a

[†] Means followed by the same letter within a time after application are not significantly different at the 5% level by LSD.