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Cultivar and Seeding Date Effects on Kernel Smut of Rice

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ABSTRACT

Rice (*Oryza sativa* L.) cultivars vary in susceptibility to kernel smut (*Tilletia barclayana*). The incidence and severity of kernel smut is believed to increase as rice seeding is delayed. The research objective was to evaluate the influence of seeding date on kernel smut incidence and severity of rice. Kernel smut incidence and severity and grain yield were evaluated on selected cultivars seeded on three or four dates at 7 site-years in Arkansas. Grain yield was generally greatest when rice was seeded in April and declined as seeding was delayed until June. Kernel smut incidence (r = 0.38) and severity (r = 0.38) were significantly, albeit weakly, correlated with seeding date. Depending on site-year, kernel smut incidence and severity were affected by cultivar, seeding date, or their interaction. Within each site-year, incidence and severity were generally lowest numerically for the first (earliest) seeded rice. With subsequent seedings, kernel smut incidence and severity increased at 1 site-year, remained constant at 2 site-years, or showed no trend (i.e., fluctuated) among seeding dates at 4 site-years, but 3 of the 4 site-years had greater incidence than the first seeding. Cultivars rated highly susceptible to kernel smut generally had greater incidence and severity values than susceptible or moderately susceptible cultivars. Kernel smut incidence and severity averages were not significantly correlated with air temperatures or precipitation for 20 d after anthesis or 7 d before and after anthesis. Data suggest that seeding the least-susceptible cultivars during the earliest recommended period may reduce damage from this disease in most years.

Kernel smut, *Tilletia barclayana* (Bref.) Sacc. and Syd. in Sacc. [=*Neovossia horrida* (Takah.) Padwick and A. Khan] of rice has been considered a minor disease since it traditionally caused small yield losses in the USA; however, the disease seems to have increased in recent years. Cartwright et al. (1994) reported that kernel smut was present in 73% of commercial rice fields surveyed in Arkansas during 1993, with moderate to high levels (positively identified in >20% of the 50 sites evaluated within each field) present in 21% of the fields. When present at moderate to high levels, yield losses attributed to kernel smut vary but have been estimated as high as 10 to 15% (R.D. Cartwright, personal communication, 2005). Kernel smut may significantly diminish rice quality by reducing the percentage of whole rice kernels (i.e., milling yield), while teliospores discolor milled and especially parboiled rice grains to an undesirable gray (Groth and Lee, 2003).

Knowledge of the factors that influence the severity and incidence of kernel smut of rice is limited. Slaton et al. (2004) reported that excessive preflood N fertilization of highly susceptible rice cultivars significantly increased kernel smut severity and incidence in only 1 of 5 site-years, suggesting that environmental conditions, inoculum level, or both significantly influence kernel smut severity and incidence. Disease surveys reported by Cartwright et al. (1994, 1995) verify that the incidence and severity of kernel smut varies among years and that some cultivars consistently have greater levels of kernel smut than others. Grain yield and quality losses attributed to kernel smut can be reduced by selecting the least susceptible cultivars, properly managing N fertilization, and applying a fungicide before heading.

Divergent observations have been reported regarding the influence of seeding date on kernel smut. Templeton et al. (1967) reported that the number of smutted rice kernels was greater for rice that headed on 13 September compared with 16 August. Most rice growers and consultants generalize that late-seeded rice usually has more kernel smut than early-seeded rice. In contrast, Cartwright et al. (1994) reported that early-seeded fields of several susceptible cultivars had severe damage from kernel smut. Although the cultivars and management practices used to produce rice have changed during the past 40 yr, these contrasting observations suggest that annual temperature and rainfall patterns influence the severity of kernel smut during any given year.

Templeton et al. (1967) reported that climatic conditions during rice panicle emergence from booting through anthesis greatly influence the severity of kernel smut. Whitney and Frederikson (1975) and Singh (1975) suggested that kernel smut development is favored by frequent but light rainfall events during heading. Cartwright et al. (1996) showed that rice receiving nightly moisture during heading had significantly greater numbers of smutted kernels per panicle than rice receiving no nightly moisture.

Kernel smut cannot be scouted for because its symptoms are only visible several weeks after infection. Therefore, the use of cultural management practices to control the disease is preferred over the use of fungicides (Slaton et al., 2004). A better understanding of the environmental and rice management factors that influence kernel smut of rice would aid in the development of better cultural management recommendations. The primary objective of this study was to evaluate the influence of seeding date on kernel smut incidence and severity on commercially grown long-grain rice cultivars. A secondary objective was to validate kernel smut

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Abbreviations: DOY, day of year; LHRF, Lake Hogue Research Farm; NEREC, Northeast Research Extension Center; RREC, Rice Research Extension Center.

susceptibility ratings of rice cultivars under different growing conditions. Our hypotheses were that kernel smut incidence and severity would increase (i) as seeding date was delayed due to more favorable environmental conditions for kernel smut infection and (ii) as cultivar susceptibility to kernel smut increased, regardless of the environmental conditions.

MATERIALS AND METHODS

Studies were established in a Dewitt silt loam (fine, smectitic, thermic, Typic Albaqualfs) at the Rice Research Extension Center (RREC) near Stuttgart, AR during 2003 (RREC-03), 2004 (RREC-04), and 2005 (RREC-05); a Sharkey clay (very-fine, smectitic, thermic, Chromic Epiaquerts) at the Northeast Research Extension Center (NEREC) near Keiser, AR in 2003 (NEREC-03), 2004 (NEREC-04), and 2005 (NEREC-05); and a Hillemann silt loam (fine-silty, mixed thermic Albic Glossic Natraqualfs) at the Lake Hogue Research Field (LHRF-05) near Weiner, AR in 2005. Soybean [*Glycine max* (Merr.) L.] was the previous crop grown at all sites, except RREC-04, which was preceded by pearl millet [*Pennisetum glaucum* (L.) L. Br.].

Five long-grain rice cultivars, including Clearfield 161 (CL161), Cocodrie, Francis, LaGrue, and Wells, were selected initially because they differed in susceptibility to kernel smut and were commonly grown in commercial rice fields when this study was started. In 2005, Cocodrie was replaced by 'Cheniere', and LaGrue was replaced by 'Banks' because commercial hectarage of the older cultivars had started to decline. The University of Arkansas Cooperative Extension Service ratings for kernel smut susceptibility were 'Very Susceptible' for Banks, Cheniere, Cocodrie, Francis, and LaGrue; 'Susceptible' for CL161; and 'Moderately Susceptible' for Wells. Ratings were a product of several years of field observations of the different cultivars across Arkansas and represent the most susceptible reaction observed at any site-year. The cultivars selected for this study require 89 to 91 d to reach 50% heading after emergence. The selected cultivars were seeded on 75 to 81% of the commercial rice hectarage in Arkansas from 2003 to 2005, with Wells (39–45%) being the most popular cultivar.

For all studies conducted at the RREC and LHRF, 20 kg P ha^{-1} as triple superphosphate and 50 kg K ha^{-1} as muriate of potash were broadcast before seeding. Phosphorus and K fertilizers were not required on the Sharkey clay soil at the NEREC. Rice was drill-seeded into conventionally tilled seedbeds at 110 kg seed ha^{-1} at the RREC and LHRF. At NEREC, rice was drill-seeded at 135 kg seed ha^{-1} into a stale seedbed that had been prepared the previous fall. Each plot contained nine 4.9-m long rows spaced 0.18-m apart. Plots were separated by a 0.5-m-wide, plant-free alley. Rice seeding and emergence dates for each site-year are listed in Table 1.

Weeds were controlled using 0.3 kg ha^{-1} of clomazone [2-(2-chlorobenzyl)-4,4-dimethylisoxazolidin-3-one] plus 0.4 kg ha^{-1} of quinclorac (3,7-dichloroquinoline-8-carboxylic acid) applied to the soil surface at the RREC and LHRF before rice emergence. At NEREC, 0.4 kg ha^{-1} of clomazone plus 0.6 kg ha^{-1} of quinclorac was applied to the soil surface before rice emergence. At the four-leaf stage, a tank mixture of 3 kg ha^{-1} of propanil (3′,4′-dichloropropionanilide) plus 0.04 kg ha^{-1} of bensulfuron {methyl 2-[(4,6-dimethoxypyrimidin-2-yl) carbamoylsulfamoylmethyl] benzoate}was applied to each seeding date for all site-years.

At the five-leaf stage, a single preflood application of 135 kg N ha^{-1} as urea was broadcast onto a dry-soil surface to each trial conducted on silt loam soils at the RREC and LHRF. For the clay soil at NEREC, each seeding date trial received 165 kg N ha^{-1} as urea in a single preflood application at the five-leaf stage. The recommended single preflood N-fertilizer rates range from 120 kg N ha^{-1} for CL161 and LaGrue to 135 kg N ha^{-1} for Banks, Cheniere, Cocodrie, Francis, and Wells for rice grown on silt loam soils after soybean in rotation. The recommended N rate was increased by 30 kg N ha^{-1} for clayey soils (Slaton, 2001). Although the recommended single preflood N rate varied slightly among cultivars, the rate applied (135 or 165 kg N ha^{-1}) was sufficient or more than sufficient to produce near maximum grain yields for each cultivar. A 10-cm-deep flood was established within 3 d after N was applied (Table 1). Rice management closely followed University of Arkansas Cooperative Extension Service recommendations (Slaton, 2001).

Table 1. Dates of seeding, emergence, flooding, and heading (50% panicle emergence) for studies conducted at Northeast Research Extension Center (NEREC), Rice Research Extension Center (RREC), and Lake Hogue Research Farm (LHRF) during 2003, 2004, and 2005.

		Event			
Year	Site	Seeded (DOY)	Emerged	Flooded	Headed
2003	NEREC	108 (18 Apr.)	2 May	29 May	21 July
		120 (30 Apr.)	12 May	16 June	9 Aug.
		147 (27 May)	10 June	7 July	27 Aug.
		161 (10 June)	16 June	15 July	7 Sept.
2003	RREC	91 (1 Apr.)	21 Apr.	14 May	13 July
		115 (25 Apr.)	2 May	27 May	22 July
		140 (20 May)	29 May	25 June	19 Aug.
2004	NEREC	99 (8 Apr.)	28 Apr.	9 June	18 Aug.
		145 (24 May)	3 June	25 June	25 Aug.
		156 (4 June)	13 June	13 July	11 Sept.
2004	RREC	93 (2 Apr.)	21 Apr.	21 May	15 July
		120 (29 Apr.)	8 May	3 June	14 Aug.
		142 (21 May)	27 May	15 June	27 Aug.
		159 (7 June)	12 July	6 July	2 Sept.
2005	NEREC	110 (20 Apr.)	12 May	9 June	3 Aug.
		126 (6 May)	16 May	16 June	8 Aug.
		140 (20 May)	30 May	8 July	25 Aug.
		157 (6 June)	16 June	25 July	15 Sept.
2005	RREC	80 (21 Mar.)	9 Apr.	18 May	16 July
		105 (15 Apr.)	23 Apr.	26 May	24 July
		157 (6 June)	11 June	13 July	30 Aug.
2005	LHRF	95 (5 Apr.)	20 Apr.	25 May	21 July
		110 (20 Apr.)	2 May	1 June	3 Aug.
		131 (11 May)	20 May	15 June	10 Aug.
		158 (7 June)	17 June	15 July	5 Sept.

† DOY, day of year.

The date of 50% heading was recorded for each plot and averaged by cultivar because at all site-years all cultivars reached 50% heading within 4 d of the overall average (Table 1). Daily precipitation amounts and maximum and minimum temperatures were obtained from National Climatic Data Center (NCDC, 2006) weather stations located at the RREC and NEREC experiment stations (Fig. 1).

Approximately 30 d after anthesis, 25 randomly selected panicles were collected from the seven middle rows of each plot and stored in brown paper bags until kernel smut evaluations were performed. Kernel smut evaluations were performed as described by Slaton et al. (2004). Panicles were soaked in 0.27 *M* KOH overnight, rinsed three times in deionized water, and inspected over a light box to identify smutted kernels. The numbers of total and smutted kernels on each panicle were counted. Kernel smut incidence was calculated as the sum of the number of panicles with at least one smutty kernel divided by the total number of panicles evaluated multiplied by 100. Kernel smut severity was calculated as the total number of smutty kernels divided by the total number of kernels from all panicles and multiplied by 100.

At maturity, 4-m^2 from the middle of each plot was harvested with a small plot combine to determine grain yield.

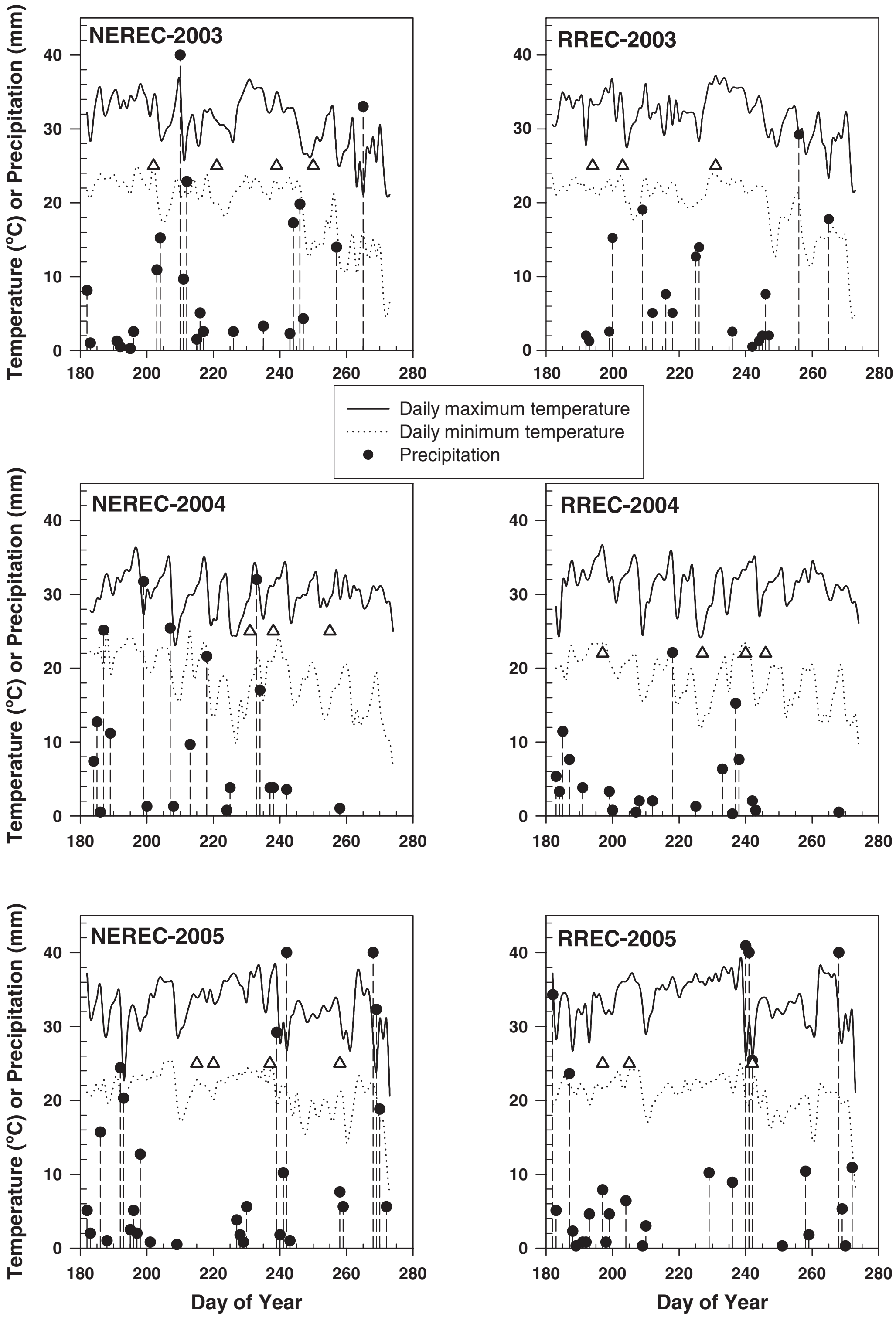

Fig. 1. Minimum and maximum air temperatures and precipitation from 1 July through 30 September at the Rice Research Extension Center (RREC) and Northeast Research and Extension Center (NEREC) during 2003, 2004, and 2005. Precipitation amounts >40 mm were entered as 40 mm. Temperature and precipitation data were obtained from the National Climatic Data Center (2006) for weather stations located at Stuttgart, AR and Keiser, AR. The average date of 50% heading is denoted by an open triangle.

Immediately after harvest, harvested grain weight and moisture was determined for each plot. Final grain yields were calculated and adjusted to a uniform grain moisture content of 120 g H_2O kg^{-1} for statistical analysis.

Each seeding date trial was arranged as a randomized complete-block design with three replicates for each cultivar at the RREC-03 and RREC-05 or four replicates at all other site-years. For each site-year, yield, kernel smut incidence, and

Table 2. Analysis of variance *p* values for rice grain yield, smut incidence, and smut severity as affected by seeding date (SD), cultivar (C), and their interaction for studies conducted at the Northeast Research Extension Center (NEREC), Rice Research Extension Center (RREC), and Lake Hogue Research Field (LHRF) during 2003, 2004, and 2005.

	2003		2004		2005		
Source	NEREC	RREC	NEREC	RREC	NEREC	RREC	LHRFC
	p values						
			Grain yield				
SD	<0.0001	0.0093	<0.0001	<0.0001	<0.0001	0.0001	0.0011
Cult (C)	0.0016	0.4045	<0.0001	<0.0001	<0.0001	0.0006	<0.0001
SD × C	0.0178	0.2592	0.0427	<0.0001	<0.0001	0.1339	<0.0001
			Incidence				
SD	<0.0001	<0.0001	0.5195	0.0032	0.0012	0.0031	0.1119
C	0.0001	0.0007	0.0045	0.0002	0.0004	<0.0001	0.0079
SD × C	0.4617	0.0383	0.2446	0.1394	0.6984	0.0063	0.1648
			Severity				
SD	0.0001	<0.0001	0.1223	0.0234	0.0006	0.0103	0.1306
C	0.0002	0.1270	0.5589	0.0007	0.0090	0.0006	0.0323
SD × C	0.0044	0.2072	0.3080	0.2368	0.0988	0.0402	0.2223

kernel smut severity were analyzed statistically as a randomized complete-block design with a split-plot treatment structure where seeding date was the whole-plot factor and cultivar was the subplot factor. Site-years were analyzed separately because seeding dates varied among site-years. The Fisher's protected LSD procedure ($P < 0.05$) was used to compare treatment means when appropriate. Correlation analysis was performed on the mean values for day of year seeded and headed, grain yield, incidence, and severity for each cultivar, seeding day, and site-year combination. All statistical analyses were performed using SAS version 9.1 (SAS Inst., Cary, NC).

RESULTS

Grain Yield

Grain yield potential, as affected by cultivar and seeding date, is one of the most important factors that grower's use to develop crop management plans but was not the primary focus of this study. Grain yield data are presented to establish that seeding date and cultivar can have a significant influence on rice growth and yield.

The interaction between seeding date and cultivar significantly affected rice grain yields at 5 of 7 site-years (Table 2). Although the cultivar yield ranking fluctuated somewhat among site-years and seeding dates (data not shown), in general, the mean yields tended to be greatest for Francis and Wells; intermediate for Cheniere, Cocodrie, and LaGrue; and lowest for Banks and CL161.

Rice grain yield, averaged across cultivars, was significantly affected by seeding date at each site-year (Table 3). Grain yields were generally greatest when rice was seeded in April or earlier and, for most site-years, declined if seeded in May or June. Grain yield responded to seeding date similarly to that reported by Slaton et al. (2003).

Grain yield was significantly and negatively correlated with the day of year rice was seeded ($r = -0.69$, $P < 0.0001$). Grain yield was also significantly, albeit weakly, correlated with kernel smut incidence ($r = -0.30$, $P = 0.001$) and kernel smut severity ($r = -0.44$, $P < 0.0001$). These correlations do not necessarily indicate that grain yield reductions from delayed seeding were caused by increased levels of kernel smut. These trends suggest that grain yield simultaneously decreases as kernel smut incidence and severity increase with delayed seeding.

Kernel Smut Incidence

Kernel smut incidence, defined as the percentage of panicles with at least one smutted kernel, varied among seeding days, cultivars, or both depending on the site-year (Table 2). The seeding date × cultivar interaction significantly influenced kernel smut incidence only for RREC-03 and RREC-05. Within seeding Day 91 (day of year [DOY]) at the RREC-03, when incidence was lowest, all cultivars had statistically similar kernel smut incidence values, although the highly susceptible culti-

Table 3. Rice grain yield as affected by seeding date, averaged across cultivars, for trials conducted at the Northeast Research Extension Center (NEREC), Rice Research Extension Center (RREC), and Lake Hogue Research Field (LHRF) conducted during 2003, 2004, and 2005.

	2003		2004		2005		
Seeding date†	NEREC	RREC	NEREC	RREC	NEREC	RREC	LHRF
	$kg\ ha^{-1}$						
1	7303	9178	8437	9495	9264	9264	8306
2	7923	8306	9012	10075	8155	9168	7404
3	3578	7298	6915	7762	5670	4672	6945
4	4496	–	–	–	3337	–	6013
LSD(0.05)	866‡	798	542‡	367‡	681‡	573	523‡

† Day of year for each seeding date is listed in Table 1.
‡ Significant ($P < 0.05$) seeding date × cultivar interaction.

Table 4. Kernel smut incidence as affected by the seeding date × cultivar interaction for trials conducted at the Rice Research Extension Center (RREC) during 2003 and 2005.

	Day of year seeded					
	2003 RREC			2005 RREC		
Cultivar	91	115	140	80	105	157
	smut incidence, %					
Cocodrie	13	48	88	–	–	–
LaGrue	2	20	78	–	–	–
CL161	3	12	73	23	47	47
Francis	13	17	88	24	61	75
Wells	5	18	47	17	31	17
Cheniere	–	–	–	27	73	64
Banks	–	–	–	29	59	44
LSD(0.05)†		20			16	
LSD(0.05)‡		19			20	

† To compare cultivar means within a seeding date.
‡ To compare any two means within a site-year.

vars Cocodrie and Francis had greater numerical incidence values (Table 4). Between seeding Days 91 and 115, incidence increased numerically for all cultivars, but the increase was significant statistically only for Cocodrie. For all cultivars at the RREC-03, the greatest incidence was measured on the last seeding day (140 DOY).

Within a seeding date, significant differences in cultivar susceptibility to kernel smut were expressed only on seeding Days 115 and 140 at the RREC-03 (Table 4). On seeding Day 115, Cocodrie had a significantly greater percentage of smutted panicles than the other cultivars, which were similar. On seeding Day 140, Wells had a significantly lower incidence than the other four cultivars.

Similar trends were observed for incidence among seeding days and cultivars at RREC-05 (Table 4). The lowest incidence occurred on seeding Day 80, with no significant differences among cultivars. Kernel smut incidence increased significantly for each cultivar, except Wells, when seeding was delayed from seeding Day 80 to Day 105. Incidence was similar between seeding Days 105 and 157 for each cultivar. Within seeding Days 105 and 157, Wells, the least susceptible cultivar, had lower incidences of kernel smut than all other cultivars except CL161 on seeding Day 105 (Table 4). Data from RREC-03 and RREC-05 suggest that when kernel smut levels were high, presumably due to favorable environmental conditions for kernel smut, the cultivars least susceptible to this disease had fewer smutted panicles.

The main effect of seeding day, averaged across cultivars, significantly affected kernel smut incidence at NEREC-03, RREC-04, and NEREC-05 (Table 2). Seeding day had no significant influence on kernel smut incidence at NEREC-04 and LHRF-05, which had average incidence levels of 38 and 35%, respectively (Table 5). For NEREC-03, kernel smut incidence increased as seeding was delayed from Day 108 (seed date 1) to 120 (seed date 2) and to 147 (seed date 3) and then declined for rice seeded on Day 161 (seed date 4) (Table 5). In contrast, for the RREC-04, rice seeded on Day 120 (seed date 2) contained significantly greater kernel smut incidence than rice seeded on Days 93 (seed date 1), 142 (seed date 3), and 159 (seed date 4), which had similar incidence levels. For NEREC-05, kernel smut incidence was lowest for rice seeded on Day 110 (seed date 1), intermediate for seeding Days 126 (seed date 2) and 157 (seed date 4), and greatest on Day 140 (seed date 3). Overall, 5 of 7 site-years showed significant differences in kernel smut incidence among seeding dates. Kernel smut tended to be lowest for rice seeded on the first (earliest) day, which ranged from 21 March (80 DOY) to 20 April (110 DOY). However, kernel smut incidence did not always increase with delayed seedings, suggesting that environmental conditions (e.g., rainfall, temperature, wind, and humidity) play important roles in determining the level of kernel smut, and environmental conditions favorable for kernel smut may occur at any time during the growing season.

Rice cultivars had significantly different incidence levels, when averaged across seeding days, at NEREC-03, NEREC-04, RREC-04, LHRF-05, and NEREC-05 (Table 2). The numerical incidence rank among cultivars often changed among site-years (Table 6). However, within each site-year, Wells, the least susceptible cultivar, had significantly lower incidence levels than the cultivar or cultivars with the greatest incidence, which tended to be Cocodrie, Cheniere, and/or Francis, which are all rated highly susceptible to kernel smut.

Kernel Smut Severity

Kernel smut severity is defined as the percentage of the total kernels that were partially or fully smutted and indicates the relative frequency of smutted kernels. The seeding date × cultivar interaction significantly affected kernel smut severity at NEREC-03 and RREC-05 (Table 2).

Table 5. Kernel smut incidence as affected by seeding date, averaged across cultivars, for trials conducted at the Northeast Research Extension Center (NEREC), Rice Research Extension Center (RREC), and Lake Hogue Research Field (LHRF) during 2003, 2004 or 2005.

	2003		2004		2005		
Seeding date†	NEREC	RREC	NEREC	RREC	NEREC	RREC	LHRF
	incidence, %						
1	29	7	40	48	19	24	24
2	55	23	39	66	37	54	31
3	79	75	34	47	60	49	48
4	59	–	–	40	38	–	38
LSD(0.05)	14	8‡	NS§	12	14	13‡	NS

† Day of year for each seeding date is listed in Table 1.
‡ Significant ($P < 0.05$) seeding date × cultivar interaction.
§ NS, not significant ($P > 0.05$).

Table 6. Kernel smut incidence as affected by cultivar, averaged across seeding dates, for trials conducted at the Northeast Research Extension Center (NEREC), Rice Research and Extension Center (RREC), and Lake Hogue Research Field (LHRF) during 2003, 2004, or 2005.

	NEREC			2004	2005
Cultivar	**2003**	**2004**	**2005**	**RREC**	**LHRF**
	incidence, %				
Banks	–	–	38	–	32
Cheniere	–	–	51	–	44
CL161	44	29	39	54	36
Cocodrie	66	42	–	61	–
Francis	66	49	42	53	39
LaGrue	56	31	–	46	–
Wells	47	37	28	37	24
LSD(0.05)	11	11	10	10	10

Compared with all other seeding days at NEREC-03, kernel smut severity was greatest for rice seeded on Day 147 (Table 7). The lowest numerical severity values always occurred on the earliest seeding day (Day 108) but were never different statistically than severity measured for rice seeded on Day 120. On seeding Day 120, severity was equal to the severity measured for rice seeded on Day 161. Severity was similar among cultivars within each seeding day except for rice seeded on Days 147 and 161. For example, rice seeded on Day 147 showed that Wells and CL161 had lower severity values than Cocodrie and Francis. For rice seeded on Day 147, severity was greater for Francis than for all other cultivars.

For RREC-05, the lowest numerical severity values occurred for rice seeded on Day 80 (Table 7). For CL161 and Wells, the two least susceptible cultivars, severity remained constant across seeding dates. For Banks, severity was greatest for rice seeded on Day 105, which did not differ from severity measured on Day 157. For Cheniere and Francis, severity measured on seeding Day 80 was significantly lower compared with rice seeded on Days 105 and 157, which were similar.

The main effect of seeding day, averaged across cultivars, significantly affected kernel smut severity at RREC-03, RREC-04, and NEREC-05 (Table 2). Seeding day had no influence on kernel smut severity at NEREC-04 and LHRF-05. For RREC-03, severity was similar for

Table 7. Kernel smut severity as affected by the seeding date × cultivar interaction for trials conducted at the Northeast Extension Research Center (NEREC) during 2003 and Rice Research Extension Center (RREC) during 2005.

	Day of year seeded						
	2003 NEREC				2005 RREC		
Cultivar	**108**	**120**	**147**	**161**	**80**	**105**	**157**
	severity, %						
Cocodrie	0.5	1.0	3.4	2.4	–	–	–
LaGrue	0.5	1.0	2.5	1.2	–	–	–
CL161	0.4	0.7	1.6	0.6	0.3	0.7	0.7
Francis	0.3	0.9	6.0	2.1	0.2	1.2	1.6
Wells	0.2	0.7	1.4	0.7	0.2	0.4	0.4
Cheniere	–	–	–	–	0.3	1.3	1.0
Banks	–	–	–	–	0.3	1.1	0.7
LSD(0.05)†		1.5				0.5	
LSD(0.05)‡		1.6				0.6	

† To compare cultivar means within a seeding date.
‡ To compare any two means within a site-year.

rice seeded on Days 91 (seed date 1) and 115 (seed date 2) but increased significantly when seeding was delayed until Day 140 (seed date 3) (Table 8). For RREC-04, kernel smut severity for rice seeded on Day 120 (seed date 2) was greater compared with rice seeded on Days 93 (seed date 1) and 159 (seed date 4) and similar to rice seeded on Day 142 (seed date 3). For NEREC-05, the lowest severity was measured for rice seeded on Day 110 (seed date 1), and the greatest severity was measured for rice seeded on Day 140 (seed date 3). The data showed that the first or earliest seeded rice consistently had the lowest severity at each site-year. However, kernel smut severity did not always increase incrementally as seeding was delayed.

Kernel smut severity differed among cultivars, averaged across seeding days, for rice seeded at RREC-04, LHRF-05, and NEREC-05 (Table 2). For RREC-04, severity was significantly lower for Wells compared with Cocodrie and CL161 (Table 9). Kernel smut severity for Francis and LaGrue was intermediate. For LHRF-05 and NEREC-05, Wells had lower severity values than Cheneire.

Severity levels for Francis and Cocodrie from seeding Day 147 at NEREC-03 (Table 7) exceeded the Federal Grain Inspection definition for ‘Smutty’ rough rice, which is >3% (USDA, 2005). However, the percentage of smutted kernels from our study and the grading definition of smutty rice may not be directly comparable. When rice is graded, some rice kernels with a gray or black appearance identified as ‘Smutty’ may contain kernel smut spores from nearby smutted kernels that were distributed during harvest, milling, or both but were not partially or fully smutted. Aerially transported smut spores on the surface of grains located near smutted kernels on rice panicles were not counted as smutted kernels in this study.

DISCUSSION

Seeding time influences the severity of many crop diseases, including spot blotch [*Cochliobolus sativus* (Ito & Kuribayashi) Drechs. Ex Dastur (anamorph *Bipolaris sorokiniana* (Sacc.) Shoemaker)] and tan spot [*Pyrenophora tritici-repentis* (Died.) Drechs. (anamorph *Dreschslera tritici-repentis* (Died.) Shoemaker)] of wheat (*Triticum aestivum* L.) (Duveiller et al., 2005) and root rot (*Rhizoctonia solani* Kuhn) of canola (*Brassica napus* L.) (Teo et al., 1988; Huber et al., 1992). In general, the incidence and severity of most diseases as influenced by seeding time seems to be associated with environmental conditions that are favorable to the disease organism, which occur in random years but are more likely to occur in certain months or weeks of the year.

Correlation analysis showed that the day of year seeded was positively and significantly ($P < 0.0001$, $n = 125$), albeit weakly, correlated with average values of kernel smut incidence ($r = 0.38$) and severity ($r = 0.38$). Correlation coefficients were similar for the average day of year that rice reached 50% heading. Although the correlations were significant statistically, the coefficients were relatively low. Visual examination of the data also

Table 8. Kernel smut severity as affected by seeding date, averaged across cultivars, for trials conducted at the Northeast Research Extension Center (NEREC), Rice Research Extension Center (RREC), and Lake Hogue Research Farm (LHRF) during 2003, 2004, and 2005.

	2003		2004		2005		
Seeding date†	NEREC	RREC	NEREC	RREC	NEREC	RREC	LHRF
	severity, %						
1	0.4	0.1	0.4	0.7	0.2	0.3	0.3
2	0.9	0.3	0.7	1.3	0.5	1.0	0.4
3	3.0	1.6	0.6	0.9	1.7	0.9	0.9
4	1.4	–	–	0.6	0.9	–	0.6
LSD(0.05)	0.9‡	0.3	NS§	0.5	0.5	0.4‡	NS

† Day of year for each seeding date is listed in Table 1.
‡ Significant ($P < 0.05$) seeding date × cultivar interaction.
§ NS, not significant ($P > 0.05$).

suggests that there is a weak positive trend for kernel smut incidence and severity to increase as seeding is delayed (Fig. 2). However, seeding day explained only about 15% ($r^2 = 0.15$) of the variation observed in kernel smut incidence and severity. One possible explanation for the relatively weak relationship between kernel smut levels and seeding day is that environmental conditions favorable for kernel smut, rather than specific seeding times, are largely responsible for the level of this disease.

The lowest numerical values of kernel smut incidence and severity were usually measured on the first or earliest seeded rice, which was before 10 April for 5 site-years (Table 1). With subsequent seedings, kernel smut incidence and severity increased at 1 site-year, remained constant (i.e., no significant differences) at 2 site-years, or showed no trend (i.e., fluctuated) among seeding dates at 4 site-years. At the 4 site-years that kernel smut fluctuated among the subsequent two or three seeding dates, incidence was greater than the first seeding date at 3 of the 4 site-years. Sharma et al. (1999) reported that kernel smut incidence followed no consistent trend across the dates that rice was transplanted during a 3-yr study. The Arkansas data suggest that the earliest seeded rice tends to have the lowest levels of kernel smut and that harvested rice from subsequent seeding times often has slightly greater kernel smut incidence and severity. Templeton et al. (1967) observed that kernel smut was more severe in late-maturing rice compared with early-maturing rice. In contrast, Cartwright et al. (1994) indicated that early-maturing rice had severe kernel smut during 1993 in Arkansas. Slaton et al. (2004) showed that rice seeded in early April had high levels of kernel smut incidence and severity. The variability of kernel smut as affected by seeding date reported in the literature plus data presented in this research suggest that environmental conditions must be favorable for the kernel smut fungus to germinate and grow, regardless of the seeding date.

The specific temperature and moisture conditions needed for kernel smut to successfully infect rice kernels have not been defined precisely but have been generalized (Singh, 1975; Whitney and Frederikson, 1975). Whitney and Fredericksen (1975) reported the optimal temperature for kernel smut was 25 to 30°C and generalized that favorable environmental conditions included cloudy skies and high humidity after anthesis. Such conditions may be more apt to occur when panicles emerge on late-seeded rice in Arkansas.

Table 9. Kernel smut severity as affected by cultivar, averaged across seeding dates, for trials conducted at the Rice Research Extension Center (RREC) during 2004 and Northeast Research Extension Center (NEREC) and Lake Hogue Research Farm (LHRF) during 2005.

Cultivar	2004 RREC	2005 NEREC	2005 LHRF
	severity, %		
Banks	–	0.8	0.5
Cheniere	–	1.3	0.7
CL161	1.3	0.7	0.5
Cocodrie	1.1	–	–
Francis	0.8	0.9	0.6
LaGrue	0.8	–	–
Wells	0.5	0.5	0.3
LSD(0.05)	0.4	0.4	0.3

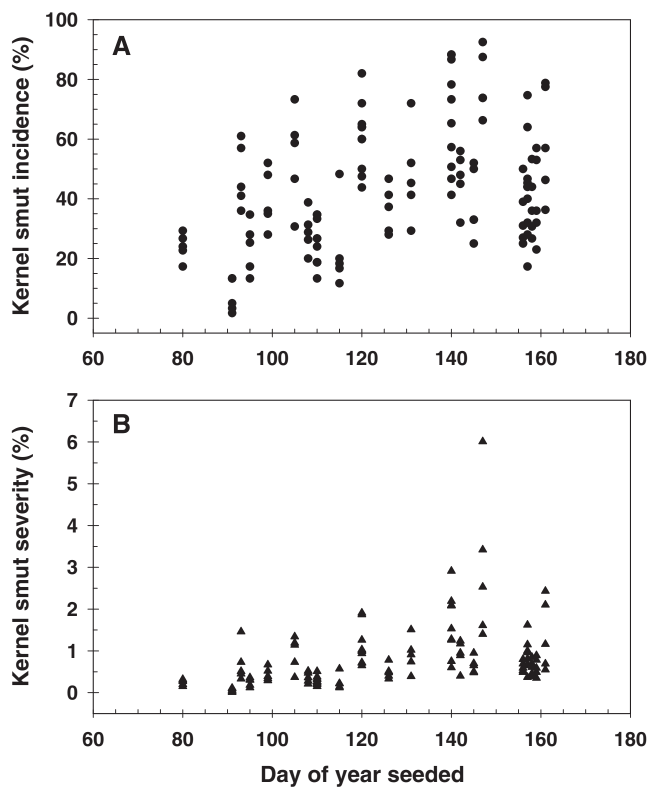

Fig. 2. Relationship between rice seeding day of year (day of year 80 = 21 March, and day of year 161 = 10 June) and kernel smut incidence (A) and severity (B) for all cultivars and site-years from seeding date experiments conducted in Arkansas from 2003 to 2005.

In Arkansas, daily maximum and minimum temperatures usually start to decline by late August (Fig. 1). Kernel smut may be worse in late-seeded rice because of cooler temperatures and shorter daylengths, which may prolong the time that moisture from dew or rainfall remains in the rice canopy. The low levels of kernel smut incidence and severity observed in late-seeded rice during 2004 are attributed to the absence of rainfall after 1 September when panicles from the last two seeding dates for each site would have emerged from the boot (Fig. 1).

Whitney and Fredericksen (1975) reported that completely smutted kernels were likely to occur when environmental conditions were favorable for kernel smut development shortly after anthesis, which allows more time for the fungus to develop before rice reaches maturity. However, the average maximum and minimum temperatures and sum of rainfall occurring 7 d before and after (i.e., 15-d period) the average dates of anthesis or 20 d after anthesis failed to show significant ($P <$ 0.05) relationships with kernel smut incidence and severity, averaged across cultivars, for each seeding date (data not shown). The lack of a significant relationship between kernel smut levels and the evaluated environmental data suggest (i) that the climatic conditions present near or several weeks after anthesis may be less important than previously believed, (ii) that very specific factors other than temperature and rainfall are needed to understand kernel smut, and/or (iii) that the environmental conditions before anthesis control, or at least contribute to, kernel smut severity by influencing teliospore viability.

Partially smutted kernels occur when kernel smut spores inside the enclosed floret do not germinate until the developing rice endosperm is in the dough stage (Whitney and Fredericksen, 1975). Thus, another factor that may influence kernel smut incidence and severity is the length of time between anthesis and maturity. Late-seeded rice matures when air temperatures are usually cooler, which increases the time required for rice to reach the proper moisture content for harvest and the likelihood that environmental conditions will be favorable for spore germination.

Cultivar-susceptibility ratings predicted with reasonable accuracy the incidence, severity, or both of kernel smut at 6 of 7 site-years where kernel smut was present at sufficiently high levels to allow expression of differences in cultivar susceptibility. All cultivars may have low kernel smut incidence and severity when environmental conditions are not favorable for kernel smut infection. When environmental conditions are favorable for kernel smut, cultivars that are rated as highly susceptible to kernel smut tend to have moderate to high levels of incidence with a higher percentage of smutted kernels than cultivars rated as susceptible or moderately susceptible. These data also suggest that cultivar susceptibility ratings for kernel smut are reasonably accurate.

Kernel smut incidence and severity data showed similar trends across cultivars and seeding dates. Kernel smut incidence and severity means for each cultivar and seeding date were highly correlated ($r = 0.89$, $P <$ 0.0001). The relationship between incidence and severity was significant and linear (% Severity = [0.028 × % incidence] − 0.404; $r^2 = 0.79$; $P < 0.0001$). Incidence can be measured quickly because a single smutted kernel denotes a positive count for a smutted panicle. In contrast, severity requires that all smutted and healthy kernels be counted, which is a lengthy process that limits the number of panicles that can be assayed. Therefore, future evaluations involving kernel smut could measure only incidence.

CONCLUSIONS

The incidence and severity of kernel smut were weakly and positively correlated with seeding day. The lowest kernel smut incidence and severity usually occurred for the earliest seeded rice and frequently increased as seeding was delayed. The weak correlation suggests that kernel smut levels may be more dependent on poorly understood environmental conditions that are favorable for kernel smut infection than on specific seeding times. Environmental conditions favorable for kernel smut may occur at any time due to annual variations in temperature and rainfall but may occur more frequently when rice is seeded after the earliest recommended times. Panicles of later-seeded rice may emerge during periods with shorter daylength, cooler temperatures, and perhaps more frequent rainfall, which are environmental conditions that are considered favorable for kernel smut development. This may explain why several researchers and Arkansas growers have generalized that kernel smut is sometimes worse on late-seeded rice. Seeding rice during the earliest recommended period seems to be an effective cultural method of reducing grain yield and quality losses associated with kernel smut. Seeding during the earliest recommended time also tends to maximize rice grain yield potential.

Although cultivars resistant to kernel smut have not been developed, selection of cultivars that are least susceptible to kernel smut is the first step in reducing grain quality and quantity losses from this disease. These data show that the differences among cultivars can be dramatic when high levels of kernel smut are present and that cultivar-susceptibility ratings to kernel smut are reasonably accurate.

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