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INSECT DEVELOPMENT IN MILLED RICE: EFFECTS OF VARIETY, DEGREE OF MILLING, PARBOILING AND BROKEN KERNELS*

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Abstract—Parboiled milled rice was less suitable than raw milled rice for progeny production by *Plodia interpunctella* (Hübner), *Cadra cautella* (Walker), *Lasioderma serricorne* (F.), *Tribolium confusum* Jacquelin duVal, *Rhyzopertha dominica* (F.), *Sitophilus oryzae* (L.) and *Oryzaephilus surinamensis* (L.). The variety 'Dawn' was less suitable than 'Belle Patna', 'Nato' or 'Bluebelle' for all species except *O. surinamensis* and *L. serricorne*. An increase in milling rendered the rice less suitable for these seven species and for *Tribolium castaneum* (Herbst). Broken kernels did not significantly change the number of progeny from any of the species developing during a test period.

INTRODUCTION

PRELIMINARY findings concerning the effects of degree of milling and rice variety on the development of four of the species of insects dealt with here have been reported (McGAUGHEY, 1970). From that report and an earlier one by PINGALE *et al.* (1957) I conclude that the insects preferred brown or lightly milled rice to well milled or rough rice. PINGALE *et al.* (1957) also stated that parboiled rice was less suitable for development of the rice weevil, *Sitophilus oryzae* (*L.*), than hand-pounded or husked rice. TURNEY (1957) observed that the numbers of *Oryzaephilus surinamensis* (L.) developing on rough rice were increased both by a higher moisture content and by an increase in the proportion of broken kernels. These broken rice kernels had undoubtedly lost their husk and were probably broken brown rice kernels. Also, RUSSELL (1968), COHEN and RUSSELL (1970), and BREESE (1960) found that more insects developed in varieties of rough rice that had a higher proportion of kernels with gaping husks.

Because milled rice is a particularly valuable commodity and is milled in, stored in and shipped from warm humid climates where the likelihood of insect infestation is high, more complete information is needed about the development of several species of stored-product insects in this commodity. A test was therefore made with eight species of insects known to occur in various rice products. Particular attention was directed to their success on varieties currently grown in the U.S.A., and to the effects of degree of milling, parboiling and content of broken kernels on the development of insect populations in these varieties.

* Mention of a commercial product in this paper does not constitute an endorsement of this product by the U.S. Department of Agriculture.

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METHODS AND MATERIALS

The test insects were *Plodia interpunctella* (Hübner), *Cadra cautella* (Walker), *Lasioderma serricorne* (F.), *Tribolium confusum* Jacquelin duVal, *Tribolium castaneum* (Herbst), *Rhyzopertha dominica* (F.), *Sitophilus oryzae* and *Oryzaephilus surinamensis*.

The rice varieties used were 'Dawn', 'Bluebelle', 'Belle Patna' and 'Nato'. Dawn and Bluebelle are long grain golden hull varieties; Belle Patna is a long grain variety with a light colored hull; and Nato is a medium grain variety with a light colored hull. Samples of 1970 production of each of these varieties were processed for the tests. The hulls were removed with a McGill sample rice huller and the brown rice was milled to a predetermined degree with a Satake OM-2B sample mill. In trials about 70 per cent of the bran could be consistently removed from these varieties to conform to the "reasonably well milled" official U.S. Department of Agriculture designation for rice. Further milling yielded 'well milled' rice with 95–100 per cent of the bran removed. Parboiled Belle Patna rice was obtained from Uncle Ben's Inc. as brown rice and was milled with a McGill No. 3 sample rice mill to the same degrees of milling as the nonparboiled rice.

Broken kernels were removed from the samples of milled rice with sieves and were added back as necessary to unbroken rice to obtain samples with the appropriate percentage of broken kernels. Because rice is marketed with a range of broken kernels from 4 per cent to as much as 35 per cent, 4 and 25 per cent broken kernels (by weight) were used in the tests.

All tests were made with 150-g samples of rice placed in mason jars with filter paper lids and held at 27°C and 60% r.h. The moisture content of the samples ranged from 11·48 to 12·56 per cent at the time of testing and had reached equilibrium at the temperature and r.h. used. Once equilibrium was reached, 50 unsexed adult beetles were added to each jar and allowed to oviposit. The adults were not removed as sifting might damage the eggs and young larvae. Instead, the adult *T. confusum*, *T. castaneum* and *L. serricorne* were counted after 70 days. *O. surinamensis* after 49 days, *S. oryzae* after 63 days, and *R. dominica* after 77 days, and the 50 original adults were subtracted from the counts. Even though many larvae of varying ages were present in the jars when the adult progeny were counted, these larvae were not counted and overcrowding did not occur. For *P. interpunctella* and *C. cautella*, 50 eggs were placed in each jar and allowed to hatch; then counts were made twice weekly of emerging adults. In separate groups of eggs handled in the same manner the per cent hatch was >95 per cent.

In the first test, each of the four varieties of milled raw rice and milled parboiled Belle Patna rice (well milled and reasonably well milled each with 4 and 25 per cent broken kernels) was evaluated for suitability for development of progeny of *P. interpunctella*, *C. cautella*, *L. serricorne*, *T. confusum*, *R. dominica*, *S. oryzae* and *O. surinamensis*. The tests were replicated four times. A second test was made to determine the effect of degree of milling of raw Belle Patna rice on the development of *T. castaneum* progeny. This test was replicated five times. The rice was well milled and reasonably well milled and contained 4 per cent broken kernels. A third test was made to further evaluate the effect of broken kernels on the development of *T. confusum* progeny. Reasonably well milled Belle Patna rice with 0, 12·5, 25, 37·5 and 50 per cent broken kernels was used. The test was replicated five times.

RESULTS AND DISCUSSION

The results of the first test are summarized in Table 1. Little if any insect development occurred in parboiled rice. However, parboiling is a process that varies considerably

TABLE 1. MEAN NUMBER OF PROGENY THAT DEVELOPED IN FOUR 150-g SAMPLES OF FOUR VARIETIES OF NON-PARBOILED RICE AND ONE VARIETY OF PARBOILED RICE EACH WITH TWO DEGREES OF MILLING AND TWO PERCENTAGES BY WEIGHT OF BROKEN KERNELS. (WM = WELL MILLED, RWM = REASONABLY WELL MILLED)

Degree of milling	Percentage of broken kernels	Mean number of progeny in each variety of nonparboiled rice: Dawn	Belle Patna	Nato	Bluebelle	Mean number of progeny in parboiled Belle Patna rice	Means for*: Broken kernels	Degree of milling
				Plodia interpunctella				
WM	4	0	6	5	1	0	3	
	25	0	5	5	2	0	3	3
RWM	4	28	32	36	37	0	33	
	25	21	33	29	33	0	29	31
	Means	12	19	19	18			
				Cadra cautella				
WM	4	0	2	4	1	0	2	
	25	0	2	6	0	0	2	2
RWM	4	21	25	18	26	7	23	
	25	13	23	18	19	15	18	20
	Means	9	13	11	11			
				Lasioderma serricorne†				
WM	4	152	236(2)	88	252	2	174	
	25	153(3)	55(1)	168(2)	209(3)	1	164	170
RWM	4	297	104	97	281	0	194	
	25	271(3)	151(3)	315(3)	409	2	296	240
	Means	219	140	155	293			
				Tribolium confusum				
WM	4	106	166	187	118	0	144	
	25	111	158	190	134	0	148	146
RWM	4	272	272	259	246	0	262	
	25	237	249	270	283	0	260	261
	Means	182	211	226	195			
				Rhyzopertha dominica				
WM	4	73	119	185	84	3	115	
	25	71	160	204	85	4	130	122
RWM	4	253	359	338	337	2	322	
	25	207	410	390	262	2	317	320
	Means	151	262	279	192			
				Sitophilus oryzae				
WM	4	22	78	187	51	57	85	
	25	26	44	168	43	50	70	77
RWM	4	340	481	475	442	24	435	
	25	278	548	392	387	5	401	418
	Means	166	288	306	231			
				Oryzaephilus surinamensis				
WM	4	166	204	83	6	0	115	
	25	161	187	280	107	0	184	149
RWM	4	285	223	268	52	0	207	
	25	328	283	133	123	0	217	212
	Means	235	224	191	72			

* Include nonparboiled rice only.

† Four replications were not made for every test condition. Where different from four the actual number of replications is indicated in parenthesis by the mean.

depending upon the intended use of the rice. Because the parboiled rice used in this test had been parboiled until it was rather dark, it may have been less susceptible to insect attack than more lightly parboiled rice.

The statistical analyses of the data for numbers of progeny produced by each species in nonparboiled rice are summarized in Table 2. Analyses of variance on square roots of the progeny counts were used. Significant variety and milling differences were apparent for *P. interpunctella, R. dominica, T. confusum, S. oryzae, C. cautella,* and *L. serricorne*. Dawn was more resistant than other varieties tested to five of these six species (Table 1). Only *O. surinamensis* and *L. serricorne* produced more progeny in Dawn than in some of the other varieties.

TABLE 2. ANALYSES OF VARIANCE ON SQUARE ROOTS OF INSECT PROGENY COUNTS

Source	d.f.	Mean squares						
		P. interpunctella	*R. dominica*	*O. surinamensis*	*T. confusum*	*S. oryzae*	*C. cautella*	*L. serricorne*
Variety (*V*)	3	6·73*	75·27*	122·70	10·18*	94·84*	4·37*	62·12*
Milling (*M*)	1	279·73*	767·32*	48·05	273·04*	2421·55*	193·89*	75·63*
V × *M*	3	2·35*	7·66†	15·93	8·16†	43·03*	4·15*	9·13
Brokens (*B*)	1	0·70	0·44	29·27	0·04	9·63	1·13	10·37
V × *B*	3	0·15	6·55†	35·50	1·75	0·92	0·51	34·02*
M × *B*	1	0·76	2·15	16·98	0·28	0·29	1·09	61·20*
V × *M* × *B*	3	0·41	1·70	42·89	0·70	4·48	0·17	12·93
Error	48	0·53	2·09	76·37	2·22	8·55	0·49	6·48‡

* $P < 0·01$.
† $0·01 < P < 0·05$.
‡ Part of the data for *L. serricorne* are based on less than four replications. A least squares analysis was performed taking into account the unequal numbers of observations. The error degrees of freedom were 36.

Degree of milling had a similar overall effect on insect development (Tables 1 and 2). Significantly more progeny of *P. interpunctella, R. dominica, T. confusum, S. oryzae, C. cautella,* and *L. serricorne* were produced in reasonably well milled than in well milled rice. The difference for *O. surinamensis* was not statistically significant. Also *T. castaneum*, which was used only in a second test to measure the effect of degree of milling in raw Belle Patna rice containing 4 per cent broken kernels, produced significantly more progeny ($P < 0·01$) in reasonably well milled (mean 106 progeny/150-g sample) than in well milled rice (mean 26 progeny/150-g sample).

The statistical analyses of the data for *P. interpunctella, R. dominica, T. confusum, S. oryzae,* and *C. cautella* revealed significant interactions between varieties and degrees of milling for these species (Table 2). Therefore, Duncan's Range Tests (DUNCAN, 1955) were made to determine the nature of these interactions. The analyses were made on square roots of the progeny counts and the results are shown in Table 3.

Examination of the means in Table 3 reveals that the relative suitability of the varieties differed according to the degree of milling. Only Dawn always ranked lowest regardless of whether well milled or reasonably well milled. When well milled, Nato, Belle Patna and Bluebelle showed the same relative suitability for the production of progeny by all five species. When reasonably well milled the variety ranking varied among the species. However, for each of the five species, each variety produced significantly fewer insect progeny

TABLE 3. MEAN NUMBER OF PROGENY THAT DEVELOPED IN EACH VARIETY OF RICE AT EACH DEGREE OF MILLING B = BLUEBELLE, BP = BELLE PATNA, N = NATO, D = DAWN VARIETY

Insect	Means of progeny counts in each variety*							
	Reasonably well milled				Well milled			
P. interpunctella	B	BP	N	D	BP	N	B	D
	35a	33a	32a	24b	5c	5c	1d	0d
R. dominica	BP	N	B	D	N	BP	B	D
	384a	364a	299b	230c	195c	139d	84e	72e
T. confusum	B	N	BP	D	N	BP	B	D
	264a	264a	260a	254a	188b	162b	126c	108c
S. oryzae	BP	N	B	D	N	BP	B	D
	514a	433a	414ab	309b	178c	61d	47d	24d
C. cautella	BP	B	N	D	N	BP	B	D
	24a	22ab	18ab	17b	5c	2d	1e	0e
O. surinamensis	D	BP	N	B	BP	N	D	B
	306a	253a	200a	88a	195a	182a	163a	56a
L. serricorne†	B	D	N	BP	B	BP	D	N
	345	286	190	124	233	175	152	115

* Duncan's Range Test (DUNCAN, 1955) was made on square roots of progeny counts; values given are means of untransformed progeny counts. Means for each insect that are followed by the same letter do not differ significantly at the 0·05 probability level.

† Because of unequal numbers of replications a Duncan's Test was not made on the data for *L. serricorne*. Means are presented here for comparison.

when well milled than when reasonably well milled. No significant differences were apparent in the data for *O. surinamensis*. The large variation in the data for this species (Table 2) would allow detection of only large differences; there could exist real differences that are too small to detect with these data.

The means for *L. serricorne* are included in Table 3 for comparison. A Duncan's Range Test was not made on these data because of unequal numbers of replications. Although variety effects were significant (Table 2), the variety rankings did not follow the same pattern with *L. serricorne* as with the other species. However, in all varieties except Belle Patna reasonably well milled rice was more suitable for *L. serricorne* than well milled rice.

Broken kernels had no significant effect on progeny production of any species when they were combined with whole kernels at rates of 4 and 25 per cent (Table 2). The report by TURNEY (1957) of enhanced development of *O. surinamensis* in rough rice by the addition of broken kernels probably reflects a preference by this insect for brown over rough rice as the hull would be partially or completely removed from the broken kernels. However, in the third test conducted with *T. confusum* in reasonably well milled Belle Patna rice with 0, 12·5, 25, 37·5 and 50 per cent broken kernels, the number of progeny did increase slightly as the content of broken kernels increased. The average numbers of progeny/150-g sample were: 152, 183, 185, 190 and 195. Because 12·5 per cent broken kernels caused a greater increase in numbers of progeny of *T. confusum* than successively increased amounts (152–183 progeny/sample), it appears that broken kernels could contribute to progeny production by this insect when present in very small quantities with larger quantities having little added effect. If so, even the 4 per cent broken kernels permitted in U.S. No. 1 rice may contribute to insect progeny production in that rice.

There was a significant interaction between broken kernels and varieties for *R. dominica* and *L. serricorne* (Table 2). Examination of the data in Table 1 reveals that in Nato and

Belle Patna an increase in broken kernels caused a slight increase in the number of *R. dominica* progeny; in Bluebelle and Dawn the number of progeny decreased slightly with an increase in broken kernels. Most of the decrease occurred in reasonably well milled rice. However, the relative suitability of the varieties was the same regardless of broken kernel content. For *L. serricorne*, the number of progeny increased when broken kernels were increased in Bluebelle and Nato; in Dawn and Belle Patna the number of progeny decreased. As a result the suitability of Nato relative to the other varieties was improved by increasing the broken kernels from 4 to 25 per cent. As with *R. dominica*, however, these differences with *L. serricorne* were not always consistent at both degrees of milling, and an interaction is noted between degree of milling and broken kernels for this species (Table 2). Although not consistent among all varieties, increased broken kernels caused a large increase in the number of progeny that developed in reasonably well milled rice, while in well milled rice a very slight decrease in progeny occurred. The reason for these differences is not apparent. Broken kernels do have some of the same attributes as well milled kernels, however well milled rice was less suitable for these species than reasonably well milled rice.

A detailed investigation of the causes of the differences reported is beyond the scope of this work. It is apparent that some varieties of rice show resistance to several species with different feeding habits and that the kind of processing the rice undergoes has a significant effect on the level and kind of insect infestation that is likely to develop. *P. interpunctella*, *R. dominica*, *T. confusum*, *S. oryzae*, and *C. cautella* responded similarly to varieties and degrees of milling. With minor exception the varieties showed the same relative suitability to these species regardless of degree of milling or broken kernel content, and degree of milling had the same effect on these species and *L. serricorne* regardless of variety. The effects of broken kernels were less consistent and where significant they were interrelated with the effects of varieties and degrees of milling. Because of these interactions caution should be used in interpreting results of studies of the effects of factors such as those evaluated in this work. Only *O. surinamensis* was unaffected by variety, milling, or broken kernels.

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