SUSCEPTIBILITY OF ROUGH, BROWN, MILLED, AND BROKEN RICE KERNELS IN DIFFERENT ENVIRONMENTS TO SIX SPECIES OF STORED-PRODUCT INSECTS

by

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INTRODUCTION

Rice is the staple food for nearly half of the world's population and is stored in a variety of forms and under a variety of conditions. This makes the problem of preservation complex.

Rice may be stored in the unhusked state, generally referred to as paddy or rough rice (raw or parboiled); after the removal of the husk, as hulled or brown rice; or after processing, as milled rice (again raw or parboiled). Milled rice may be termed under-milled, medium-milled, fully-milled, or polished, according to the degree to which the outer layers (pericarp and aleurone layers) and the embryo have been removed and grains surface-treated (Prevett, 1971).

McGaughey (1974) concluded that the insects preferred brown or lightly-milled rice to well-milled or rough rice. This agreed with the observations of Pingale et al. (1957), Rossetto (1966), and Prevett (1971) who suggested that raw paddy (rough rice) is the form least susceptible to infestation, and that "husked and lightly-milled rice" is much more susceptible because of the accessibility of the term and endosperm.

The objective of this study was to test the susceptibility of rough, brown, milled, and cracked (broken) kernels of unparboiled rice in six different environments to six species of stored-product insects.

REVIEW OF LITERATURE

Susceptibility of Rough, Brown, and Milled Rice and the Effects of Broken Kernels

Although most studies of the susceptibility of forms of rice to insect infestations were done in one constant environment (temperature and humidity) it was well-established that raw paddy (unparboiled rough rice) is the form of rice least susceptible to infestation and that insects preferred brown or lightly-milled rice (McGaughey, 1970 and 1974; Pingale et al., 1957; Breese, 1960).

Breese (1960), in small-scale experiments, found that rice weevils, Sitophilus oryzae (L.), were unable to feed or oviposit in grains of rough rice with intact husks, even when the moisture content was favorable. It has also been found that lesser grain borers, Rhyzopertha dominica (F.), find it extremely difficult to attack and infest such grains. Prevett (1971) also stated that species that readily attack milled rice can attack paddy only when it has suffered damage to husk, such as may occur during combine threshing or rough handling on concrete drying floors.

Rossetto (1966), using maize weevils, Sitophilus zeamais (Motsch.), infested 1,700 varieties of rough rice from 35 countries. At 75 % RH and 86^{o}F about 20 % of the varieties could be infested; the remainder (about 80 %), were either damaged little, or not at all. Varieties with sound husks were not damaged, and even adult weevils did not chew through the husks of any of the 1,700 varieties when they were free from fungus spots. When there were fungus spots on the husk, the weevils chewed through in some varieties.

To some extent rough rice can be infested by stored-product insects. The three principal pests of paddy as stated by Prevett (1971) and Douglas (1941) are the Angoumois grain moth, Sitotroga cerealella (Olivier); the rice weevil; and the lesser grain borer. However, all three are to some degree limited in their ability to attack paddy.

According to Breese (1964) there appeared to be no doubt that the first instar Angoumois grain moth larvae could bore through the intact husk of many varieties of paddy provided that the moisture content was not exceptionally low, but first instar lesser grain borer larvae did not seem to be able to, even when the moisture content was high. Breese (1964) also suggested that lesser grain borer larvae could exploit extremely narrow cracks which are not easily detected with naked eye, especially when they occur at the tip of the grain beneath the glumes. Prevett (1971) observed that while a grain with an intact husk was almost immune from infestation by lesser grain borer, a grain with a split or separated husk was much more susceptible than one with the husk removed.

If, however, the paddy was merely "shelled" and the bran layers and the germ remained on the kernel, then up to 50 % of the grains became infested, the lesser grain borer larvae beginning their attack at the germ, but if the germs were removed, very few grains became infested. Thus it appears that the endosperm is too hard for penetration by the lesser grain borer larva unless the husk can be used to give support or purchase, or boring can begin at the softer germ.

Breese (1964) also observed that the defective husks of paddy must provide support for the larva of lesser grain borer in its initial attack, otherwise, even a defect which exposes the kernel considerably is of little value.

According to Breese (1964) a rice weevil can feed and oviposit in a paddy grain only when the kernel is exposed by a split or separation which is wider than the snout, i.e., not less than about 0.12 mm. But in laboratory infestations, only about half of the adults were able to leave the grain successfully, the remainder being trapped within the husk. Prevett (1971) also said that adult rice weevils were often unable to emerge from grains with husk defects which allowed oviposition, but which were too small to allow their escape.

Bishara et al. (1972) conducted an experiment using granary weevils Sitophilus granarius (L.) and rice weevils on various forms of rice and suggested that coarse grains from which the husk had not been removed were not attacked by either species. More eggs were laid on husked, unpolished grains retaining the embryo than on polished grains from which the embryos were removed. After the hulls have been removed from the rice, some insects that are only minor pests of rough rice became important, e.g., the rice weevil; the saw-toothed grain beetle, Oryzaephilus surinamensis (L.); the red flour beetle, Tribolium castaneum (Herbst); the confused flour beetle, Tribolium confusum (Jacquelin du Val); the cadelle, Tenebroides mauritanicus (L.); the flat grain beetle, Cryptolestes pusillus (Schönherr); the Indian meal moth, Plodia interpunctella (Hübner); the almond moth, Cadra cautella (Walker); the rice moth, Corcyra cephalonica (Stainton); the corn sap bettle, Carpophilus dimidiatus (F.); psocids, and the lesser grain borer (Anonymous, 1964).

Douglas (1941) listed insects found in milled rice in the order of their importance as follows: saw-toothed grain beetle, cadelle, red flour beetle, rice weevil, rice moth, and Indian meal moth.

Prevett (1971) listed the red flour bettle, the long-headed flour beetle (Latheticus oryzae (Waterhouse)), Alphitobius spp., the saw-toothed grain bettle, and the rice moth as species that damage milled rice.

Breese (1964) stated that the greatest losses in milled rice are caused by rice weevils, with lesser grain borers relatively unimportant. He observed that larve of lesser grain borers usually enter milled rice at the softer region of the endosperm against which the scutellum lies in the unmilled grain.

McGaughey (1973) observed that lesser grain borers produced more progeny in brown rice than in milled rice and stated that the appearance of resistance in milled rice suggests that factors other than husk morphology must be involved, although lack of resistance in brown rice may render this factor economically insignificant because the lesser grain borer is primarily a pest of rough and brown rice.

The ability of the Angoumois grain moth to live and breed in rice has been demonstrated, but it does not often appear to be a serious pest in the milled grain. Breese (1964) said that many workers have shown that the preferred oviposition site is a crevice, especially one in which the surfaces are not smooth and it may be that for this reason oviposition does not commonly occur on milled and polished rice.

He stated that the husk, although difficult to perforate, does not provide a better attachment for the entrance of the first instar larva than the smooth exterior of the milled grain.

Only a few studies concerned with the effect of broken kernels on insect development have been done. McGaughey (1964) observed that broken kernels, present in very small quantities, could contribute to progeny production by confused flour beetle, with large quantities having little added effect. The number of beetles developing on reasonably well-milled Bell a Patna rice with 0, 12.5, 25, 37.5, and 50% broken kernels increased slightly as the content of broken kernels increased, but McGaughey also observed that with well-milled and reasonably well-milled rice broken kernels had no effect on progeny production of any of the species tested: Indian meal moth, lesser grain borer, saw-toothed grain beetle, confused flour beetle, rice weevil, almond moth, and cigarette beetle, Lasioderma serricorne (F.), where they were combined with whole kernels at rates of 4 and 25 per cent. In Nato, an increase in broken kernels caused a slight increase in the number of lesser grain borer and cigarette beetle progeny. Saw-toothed grain beetles were unaffected by broken kernels. Prevett (1971) also suggested that broken kernels in milled rice increased susceptibility to infestation, particularly by certain moth species. Also, McGregor (1964) found that red flour beetle exhibited preference for wheat with high dockage (broken kernels, wheat chaff, and wheat dust) content. Turney (1957) said that it is generally accepted that saw-toothed grain beetle cannot live in whole grains of rough rice stored under optimum conditions. He added cracked grains to whole grains to produce mixtures that contained 0, 5, 10, 15, 20, and 100 % cracked grain by weight, and observed that as moisture level was raised, and the amount of cracked grain increased, reproduction increased and that there was an interaction between moisture content (m.c.) and the amount of cracked grain. In 100 % cracked grain reproduction was noticed even at the lower levels of moisture. No reproduction took place on the whole grain rice with m. c. of 12 %. Reddy (1950) reported that female rice weevils showed preference for laying eggs in sound kernels of wheat when given a choice between sound and halved kernels. Sinha (1975) added dockage to clean Manitou wheat which comprised 12 components including wild buckwheat, broken wheat, small wheat kernels, and various weed seeds, observed that both 5 and 10 % dockage at 33 $\pm$ 0.5^{o}C significantly favored the development and reproduction of saw-toothed grain beetle. At 33^{o}C, the red flour beetle, unlike the saw-toothed grain beetle multiplied well on dockage-free wheat. The flour beetle was favorably affected by dockage only at 10 % dockage level.

Effects of Temperature and Humidity on Life Cycle and Number of Progeny

Angoumois Grain Moth (AGM)

Howe (1965) categorized AGM as a cold-hardy species that thrives at moderate temperature. The minimum temperature for development was 16^{o}C with the optimum ranging from 26 - 30^{o}C. Prevett (1971) supported this, suggesting that optimum conditions for its development were 26 - 30°C and 70 % relative humidity (RH). He found that on milled rice, the life cycle was completed in five weeks at 30°C. The minimum RH for development was 30 % (40 % is necessary for the insect to multiply at least double its number annually and to become a pest). The finite rate of increase in four weeks was estimated at 50 per female in optimum conditions.

Boldt (1974) stated that the fecundity of AGM in wheat was greatest at 25 to 30°C. Optimum conditions for development and successful emergence were 30 - 32°C and 65 - 80 % RH.

Rice Weevil (RW)

The RW was classified as a moderately hardy species by Howe (1965) which needs a rather high RH. The minimum temperature required for development was 17°C and the optimum temperature ranging from 27 - 31°C. Birch (1945 c) determined that the maximum and minimum temperatures for survival were 34°C (93.2°F) and 15.2°C (59.36°F), and in another experiment (Birch, 1945 b) found that development from egg to adult was fastest at 29.1°C (84.38°F). Using milled rice as food Qayyum (1964) observed that all the weevils (10 adults in 3" X 1" tube) died at 30°C in combination with 0 % or 33 % RH, and at 52 % RH only 42.5 % died.

The minimum RH for development was 60 % according to Howe (1965, 1952); below 60% egg laying declined rapidly and mortality was high. On sound kernels of paddy in equilibrium with RH of 75, 84.3 and 92.5 % and a constant temperature of 25°C, Breese (1960) observed no adult emergence, and no evidence of feeding at 75 %. Prevett (1971) stated that development was not possible below 40 % RH.

Breese (1964) observed that multiplication of RW on paddy is very limited at a moisture content (m. c.) of 11 % and virtually ceased at 10 %. Birch (1945a) stated that very few eggs were laid in wheat drier than 11 % m. c. The driest grain in which any eggs were laid had a m. c. of 10 %, none being laid at 9.5 %.

According to Howe (1964) the estimate of finite rate of increase in four weeks was 25 per female in optimum conditions. Prevett (1971) observed that up to 150 eggs/female may be laid and the developmental period at optimum conditions of 28^{o}C and 70 % RH was 4 to 5 weeks on rice. Russell (1968) exposed rough rice to 150 randomly-selected adult RW for 4 days and held it at 29^{o}C and 86 $\pm$ 2 % RH; he found that the average emergence time of adults was 41.4 days after the beginning of oviposition.

Lesser Grain Borer (LGB)

Howe (1965) categorized LGB as a moderately hardy species and that it needed moderate RH. The minimum temperature for development was 23^{o}C with the optimum ranging from 32^{o}C - 35^{o}C. Prevett (1971) and Birch (1945a) stated that the optimum temperature was 34^{o}C at which the female can lay up to 415 eggs on wheat and 500 on milled rice. Birch (1945c) suggested that the range of temperatures that permitted development (egg to adult) in wheat of 14 % moisture content, was 18.2^{o}C - 39^{o}C.

The minimum RH required was 30 % (Howe, 1965). Prevett (1971) observed that LGB was able to develop in under-milled rice with a m. c. of 10.3 % and that 12.4 % was the optimum m. c. The driest wheat in which eggs were laid was 8 % m. c. according to Birch (1945a).

The optimum development from egg to adult in milled rice was 4 weeks (Prevett, 1971); on dog biscuits, 42 days (Cline, 1950); and 40 - 44 days on whole meal wheat flour (Howe, 1950). The life cycle occupied about 28 days at 90^{o}F, 40 - 50 at 80^{o}F, and 80 - 100 at 70^{o}F (Mellis, 1945).

Saw-Toothed Grain Beetle (STGB)

Howe (1965) classified the saw-toothed grain beetle as a species needing relatively high temperatures for optimum development, but is cold hardy, and tolerant of low RH. The minimum temperature for development was 21^{o}C and the optimum temperature ranged from 31^{o}C - 34^{o}C. Prevett (1971) found the optimum temperature to be 32.5^{o}C. Thomas (1940) stated that on rolled oats, STGB development was shortest (80.0 days) at 35^{o}C, while the longest mean period occurred at 20^{o}C (69.06 days). Nigam (1969) also found that 35^{o}C was the optimum temperature for development from egg to adult.

According to Howe (1965) the required minimum RH was 10 %. Nigam (1969) stated that at 30^{o}C and 90 % RH, fecundity was greatest, and female longevity and oviposition period were longest.

Prevett (1971) stated that under optimum conditions, up to 300 eggs were laid over a period of about 10 weeks on milled rice and the development from egg to adult was completed in 4 - 5 weeks.

Red Flour Beetle (RFB)

Howe (1965) classified the RFB as a cold susceptible species, suited to relatively high temperature, and tolerant of low RH. The minimum temperature for development was 22°C and the optimum ranged from 32 - 35°C. Prevett (1971) observed that the optimum conditions for development were 35°C and 70 % RH, and indicated that under optimum conditions, larval development on wheat bran was 11 - 16 days and on groundnuts, 18 - 64 days. Qamar et al. (1969) reported the development periods on wheat flour at 25°C and 52 % or 75 % RH were significantly longer than at 30°C and 52 or 75 % RH, i.e., 50.65 vs. 30.75 and 26.42 days, respectively.

The estimate of finite rate of increase in four weeks according to Howe (1965) was 70 per female. Qamar, et al. (1969) observed that the mean number of eggs oviposited on wheat flour at 25°C and 52 or 75 % RH was 29.40 and 35.38, whereas at 30°C and 52 or 75 % RH, it was 40.36 and 48.22, respectively.

Cigarette Beetle (CB)

Howe (1965) classified CB as a species needing high temperatures, was moderately cold hardy, and needed moderate relative humidity. The minimum temperature for development was 22°C with the optimum ranging from 32 - 35°C.

Powell (1937) stated that the optimum temperature was 32°C, and that with yeast as food at temperatures of 75°F, 82°F, or 90°F, the life cycles were not completed in 0, 15, or 30 % RH, and that the optimum RH for the beetle at each temperature used was 75 %. Howe (1965) stated that the minimum RH for development was 30 %.

Powell (1937) reported an average total number of eggs laid per female on tabacco at 32^{o}C and 75 % was 43.57, and that there was wide variation in number of eggs laid by individual beetles (1-93). Howe (1957) said that low humidity inhibited hatching and that from 30^{o}C to 22.5^{o}C, over 75 % of the eggs hatched at 40 % RH. At temperatures above 30^{o}C, the unfavorable effects of low humidity were more marked.

GENERAL METHODS AND MATERIALS

Rice Samples

The rice variety used was NATO, obtained from Seaburg Rice Co., Dayton Texas, in the form of rough rice. Upon receipt, the grain was placed in a freezer for at least two weeks at approximately -16°C to destroy any possible insect infestations, and then stored in a cold room at about 4°C.

Rice was used in 3 forms: rough, brown, and milled. A McGill Sheller MS1 was used to remove husks from rough rice to obtain brown rice.

A one-pass rice whitening and caking machine (made by Satake Engineering Co. Ltd. Tokyo, Japan) was used to obtain milled rice. One pressure plate which was placed on the 3rd mark of the pressure rod was applied during milling to maintain consistency of degree of milling.

A coffee grinder (made by Hobart Mfg. Co.) set-on extra coarse, was used to grind brown and milled rice to obtain cracked kernels. U. S. Standard Sieve Series No. 25 with the openings of .0278 inches was used to separate flour from broken kernels.

Sources of Insect

The test insects were Angoumois grain moth, *Sitrotoga cerealella* (Olivier); rice weevil, *Sitophilus oryzae* (L.); lesser grain borer, *Rhyzopertha dominica* (F.); saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.); red flour beetle, *Tribolium castaneum* (Herbst); and cigarette beetle, *Lasioderma serricorne* (F.). These insects were obtained from stock cultures maintained by the Stored-Product Insects Laboratory, Department of Entomology, Kansas State University.

The cultures were kept in wide-mouthed quart jars. A lid containing kelthane-treated filter paper (for protection against mites) and 60-mesh brass screen was placed in each jar. One pint of red winter wheat at 12.5 to 13.5% moisture content was placed in each jar for rice weevil, lesser grain borer and Angoumois grain moth; and 1 pint of a mixture of rolled oats and dry yearst (95% : 5%) for saw-toothed grain beetle; 1 pint of a mixture of whole wheat flour and dry yeast (95% : 5%) for red flour beetle and cigarette beetle, but with dry dog biscuits added to the surface for cigarette beetles. Fifty unsexed Angoumois grain moths; 5-ml measure of unsexed rice weevils (about 200 to 300); 4-ml measure of unsexed lesser grain borers (about 300 to 400); 200 unsexed adult saw-toothed grain beetles; approximately 1/2 teaspoon measure of unsexed adult red four beetles (about 300 to 400) and approximately 200 unsexed adult cigarette beetles were allowed to oviposit in each jar of the respective medium. The adults of Angoumois grain moth, rice weevil, lesser grain borer and red flour beetle were removed from the medium after 7 days oviposition. Adults of saw-toothed grain beetle and cigarette beetle were not removed from the medium. Adult beetles of 1 to 14 days of age and newly-emerged Angoumois grain moths were used in tests. All the stock insect cultures were kept in a rearing room at 80°F and 67 $\pm$ 3% RH.

Testing Chambers

Test samples were held in six Fisher Low Temperature Incubators at the U.S. Grain Marketing Research Center, Manhattan, Kansas, each with different environmental conditions: 80 or 90 $\pm$ 2°F, and 40, 50, or 70 $\pm$ 5% RH. The 70 and 50 % RH were adjusted by exposing the appropriate amount of surface area of water, and the 40% RH by using saturated solution of $MgCl_2$.

SUSCEPTIBILITY OF WHOLE ROUGH AND BROWN RICE IN DIFFERENT ENVIRONMENTS

Materials and Methods

Each 50-g sample of rice was placed in a pint, wide-mouth mason jar having cap fitted with 60-mesh brass screen and 9 cm filter papers. After exposing the samples for 2 weeks in the environments in which they were to be tested, they were infested with 50 unsexed adults/sample. Five replicate samples were tested for each insect species in each medium and environment. The adults were not removed. Adult counts (dead and alive) were made 8 weeks after infestation. Moisture content of the grain was tested at the day of infestation and at the end of the test using a Motomco Moisture Meter.

RESULTS AND DISCUSSION

The results of the test are summarized in Table 1. A one-way analysis of variance was done using 0.05 significance level. With few exceptions, brown rice was significantly more susceptible than rough rice for each insect tested, and in each environment used.

Table 2 gives moisture contents. Since m.c. in 50% and 40% RH were lower after 8 wk than at the end of the "equilibration" period (time of infestation), it is obvious that 2 wk were not sufficient for complete equilibration, of the samples used.

Susceptibility to AGM

On rough rice at both temperatures, higher humidity favored the development of the moth. In combination with the same RH more progeny were produced at 80°F than at 90°F.

On brown rice in combination with the same RH, more progeny were produced at 80^{o}F than at 90^{o}F. At neither temperature was the effect of humidity consistent.

Susceptibility to RW

On rough rice only at 80^{o}F and 70% RH were rice weevils able to develop, but produced few progeny.

On brown rice, in combination with the same RH (except 70%) temperatures of 90^{o}F and 80^{o}F did not cause significantly different effects. The optimum condition was at 80^{o}F and 70% RH. At neither temperature was the effect of humidity consistent.

Susceptibility to LGB

On rough rice, at both temperatures, higher humidity favored the development of the beetle, although not significantly different at 40% RH. The largest number of progeny was at 90^{o}F and 70% RH.

One brown rice, there were no significant differences in numbers of progeny produced in any of the environments.

Susceptibility to STGB

On rough rice only at 70% RH was the beetle able to produce progeny, then very few.

On brown rice in combination with the same RH except 70%, temperatures of 90^{o}F and 80^{o}F produced no significant differences in the numbers of progeny. The best test conditions for progeny production were at 80^{o}F and 70% RH. The effect of RH was not consistent at either temperature.

Susceptibility to RFB

On rough rice very few progeny were produced.

Except at 70% RH, temperatures of 90^{o}F or 80^{o}F gave no significant differences in the numbers of progeny. The best conditions for progeny production were 90^{o}F and 70% RH, although not significantly different from all other conditions. At neither temperature was the effect of RH consistent.

Susceptibility to CB

On rough rice in combination with the same RH (except 40%), more progeny were produced at 90^{o}F than at 80^{o}F. In most cases higher humidity produced more progeny.

On brown rice, the effects of temperature and RH were not consistent. The conditions which produced the most progeny were 90^{o}F and 40% RH.

In general, the different environments used resulted in significantly different numbers of progeny of each insect in both rough and brown rice, except for LGB on brown rice and STGB on rough rice.

Only AGM, LGB, and CB were able to produce substantial numbers of progeny on rough rice.

Rice weevil, STGB, and RFB produced few or no progeny on rough rice, even at 70% RH where m.c. was 12.32 and 12.54 % at 90^{o} and 80^{o}F, respectively.

Table 1. Average number of adult progeny of 6 species of insects developing in whole rough or brown rice as affected by environment, temperature, and humidity. (Numbers include all dead and alive and parents).

	90^oF			80^oF			
Forms of rice	70 5 RH	50 % RH	40 % RH	70 % RH	50 % RH	40 % RH	Average
			AGM				
RR	122.6 b	67.4 e	50*f	345.8 a	105.8*c	89.4*d	114.41
	(107-136)	(50-83)	(50)	(361-391)	(93-122)	(73-104)	
BR	111 d	85.2 d	286.6*bc	404.6 a	234.2*c	307.6*b	238.2
	(97-120)	(78-96)	(225-321)	(342-489)	(123-381)	(257-365)	
			RW				
RR	50 b	50 b	50*b	65.6*a	50*b	50*b	52.6
	(50)	(50)	(50)	(62-72)	(50)	(50)	
BR	50 c	50 c	1378*b	1570.6*a	120.2*c	1315.2*b	747.30
	(20)	(50)	(1247-1521)	(1449-1694)	(89-162)	(1188-1473)	
			LGB				
RR	673 a	378.6*b	95.4*c	381.8*b	134.6*c	80*c	290.56
	(641-699)	(299-422)	(91-105)	(288-534)	(122-146)	(72-87)	
BR	761.8	689*	761.6*	751.8*	690.4*	690.4*	716.66
	(592-823)	(652-768)	(623-1003)	(412-998)	(625-778)	(663-814)	
			STGB				
RR	51.2*a	50*a	50*a	57.8*a	50*a	50*a	51.5
	(50-54)	(50)	(50)	(50-89)	(50)	(50)	
BR	112.6*c	63.4*d	157.8*b	258.6*a	72.4*d	166.4*b	183.53
	(86-154)	(58-68)	(115-185)	(224-291)	(63-87)	(129-219)	

			<u>RFB</u>				
RR	57.2*a	51.4*b	50*b	53.4*ab	50*b	50*b	52
	(50-70)	(50-57)	(50)	(51-56)	(50)	(50)	
BR	151.4*ab	125.6*b	102.4*cd	95.4*d	115.8*bc	91.4*d	113.66
	(141-162)	(112-135)	(80-126)	(82-108)	(110-122)	(75-112)	
			<u>CB</u>				
RR	301.6*a	180*b	50*c	224.6*b	56.6*c	53.2*c	114.33
	(243-320)	(145-254)	(50)	(148-307)	(50-71)	(50-57)	
BR	430.6*c	279*d	777.0*a	600.6*b	232.4*d	564.2*b	480.93
	(337-517)	(257-310)	(721-829)	(553-643)	(141-317)	(536-649)	

a, b, c, etc. indicates (for each species) significant differences due to environments; numbers not followed by the same letter are significantly different (.05 level).

Table 2. Moisture contents of rough and brown rice at different temperatures and humidities.

Kinds of kernels		90°F			80°F		
		70 % RH	50 % RH	40 % RH	70 % RH	50 % RH	40 % RH
Rough rice							
	I	12.29	11.29	10.82	12.64	11.73	10.94
	II	12.32	10.78	9.51	12.54	11.07	9.86
Brown rice							
(100%	I	13.68	11.19	10.45	14.75	12.91	11.48
whole)	II	12.70	10.24	10.11	15.01	11.56	11.28

I. M.C. after 2 weeks equilibration; day of infestation

II. M.C. 8 weeks after infestation

SUSCEPTIBILITY OF BROWN AND MILLED RICE WITH DIFFERENT PERCENTAGE OF CRACKED KERNELS AND ENVIRONMENT

Materials and Methods

Broken kernels were removed from the samples of brown or milled rice and then cracked kernels added to obtain samples with appropriate percentages of cracked kernels: brown rice with 20%, and milled rice with 100, 60, 20, 2, and none.

Each 50-g sample of rice was placed in a pint, wide-mouth mason jar as in previous tests. After exposure of 5 replicate samples for each insect species and each medium in each of the 6 environments for 2 weeks, they were infested with 50 unsexed adults/sample. All of the parent adults were removed after a 7-day oviposition period.

Observations were made to determine time of emergence of adult progeny so developmental periods could be calculated. These data for brown rice were not included because initial emergents were not detected soon enough. Counting of emerged adults from each replicate sample was done every other day. Observations ceased for each test when no emergence occurred over a period of 7 days. In samples with no insect emergence, observations were halted 8 weeks after infestation.

The emerging adults of each species in each medium and in each environment were collected separately and held in a freezer at approximately -16^{o}C, or in 70% isopropyl alcohol for later measurement. Thirty insects from each of those collections were randomly selected for measurements. Measurements were taken with a Stereo Zoom Microscope

(Bausch & Lomb) with ocular micrometer and with 1x or 5x magnification. The length of the right elytron of each rice weevil, red flour beetle or saw-toothed grain beetle was measured from the base of the elytron to the posterior tip margin (Fig. 1). The elytron of each of lesser grain borer or cigarette beetle was measured (from the lateral aspect) from the point where the right elytron meets the left at the base to the lower point of the posterior tip. The right front wing of each Angoumois grain moth was measured from the base to the tip, excluding the fringe of hairs. All insects measured were unsexed except the Angoumois grain moths.

Moisture contents of separate uninfested samples of the grain were tested (using Motomco Moisture Meter) before equilibration, 2 weeks after equilibration (at the day of infestation), 2 weeks after infestation, and at the end of each test.

RESULTS AND DISCUSSION

The results of the test on the effects of different kinds of kernels and environments on the number of progeny are summarized in Table 3, and on the developmental periods in Table 4. Zeros in the table indicate no adult progeny emergence within 8 weeks after infestation. A one-way analysis of variance was done using 0.05 significance level.

Susceptibility to Angoumois Grain Moth

Effects of temperature, RH, and kind of kernels on the number of progeny. At 80^{O}F and 70 or 50 % RH, AGM were able to produce substantial numbers of progeny on brown rice. The most progeny were produced at 80^{O}F and 70% RH and 80^{O} F and 50% on brown rice; few were on all kinds of kernels tested, produced in any of the other tests.

Effects of temperature, RH, and cracked kernels on the developmental period. Developmental periods in milled media were shorter at 70 than in 50% RH, and shorter in whole kernels than in media with cracked kernels.

Larvae which developed on rice with a high percentage of broken kernels joined the pieces together with silk and lived between them. The optimum conditions for development of 80^{O}F and 70% RH agreed with the findings of Howe (1965) and Prevett (1971).

Susceptibility to Rice Weevils

Effects of temperature, RH, and kind of kernels on the number of progeny. At 90°F on brown rice RW were able to produce a substantial number of adult progeny only at 70% RH. At 80°F, higher humidity generally favored the development of the beatle.

Effects of temperature, RH, and cracked kernels on the developmental period. Developmental periods of the few progeny produced at 90°F were longer than at 80°F. At 80°F, the lower the RH, the longer the developmental period, although differences were not always significant. Effects of broken kernels of milled rice on the developmental period were inconsistent.

Weevils were observed able to develop in broken rice kernels if the pieces were not too small. A temperature of 90°F obviously was above optimum. This supports Birch (1945c), who determined that the maximum temperature for survival was 93.3°F. The low m.c. reduced the number of progeny. Birch (1945a) stated that the driest grain in which any eggs were laid had a m.c. of 10%, with none being laid at 9.5%. Most optimum in the present test were 80°F and 70% on most kinds of kernels; this agreed with Prevett (1971).

Susceptibility to Lesser Grain Borer

Effects of temperature, RH, and kind of kernels on the number of progeny. On brown rice, except at 50% RH, more progeny were produced at 90°F than at 80°F. On milled rice temperature effects were inconsistent. Higher humidity favored progeny production.

Brown rice was much more susceptible than milled. On milled rice at 90°F and 50 or 40% RH, percentages of broken kernels did not produce significant differences in the numbers of progeny; in the other conditions, effects were variable.

Effects of temperature, RH, and cracked kernels on the developmental period. At 90°F and 70% RH, the developmental periods were shortest on all media. They were shorter at 90°F than at 80°F. In most milled rice media, lower RH resulted in longer developmental periods.

The effects of cracked kernels were inconsistent.

LGB were observed able to develop inside broken kernels, which might have resulted in the nonsignificance of the differences in the numbers of progeny from the various milled media, in some environments. At 90°F or 80°F and 40% RH which caused relatively low m.c. of the rice kernels, the borers were still able to develop on some of the kinds of kernels; Prevett (1971) stated that they were able to develop at a m.c. of 10.3%.

Susceptibility to Saw-Toothed Grain Beetle

Effects of temperature, RH, and kind of kernels on the number of progeny. Progeny production was greater at higher RH in most media, at both temperatures. Temperature effects were inconsistent. Milled rice with 2% or with no cracked kernels were least suitable.

Effects of temperature, RH, and cracked kernels on the developmental period. The developmental periods were longer at 80°F than at

$90^{o}F$. In most media, the differences due to RH were small and inconsistent. In milled rice media with cracked kernels there was a tendency for the developmental periods to be longer as percentage of cracked kernels increased.

The beetles were able to develop in all test conditions and media which suggested that STGB can be an important pest of rice as also stated by Douglas (1941). They also develop quite well in 40% RH at either temperature which agreed with Howe (1965) who stated that STGB is tolerant of low RH. The developmental period was shorter at $90^{o}F$ than at $80^{o}F$ which indicated that this species needs a relatively high temperature for optimum development as stated by Howe (1965).

Susceptibility to Red Flour Beetle

Effects of temperature, RH, and kinds of kernels on the number of progeny. In most cases more progeny were produced at $90^{o}F$ than at $80^{o}F$. Effects of RH were inconsistent.

The effects of the kind of kernels were not consistent in any of the environments. At 90 or $80^{o}F$ and 70% RH, brown rice was most susceptible. At $90^{o}F$ and 70 or 40% RH, and $80^{o}F$ and 50% RH, milled rice of 100% whole kernels was the most resistant of the media.

Effects of temperature, RH, and cracked kernels on the developmental period. On any of the kind of kernels, when progeny were produced, developmental periods were shorter at $90^{o}F$ than at $80^{o}F$. In milled rice media with cracked kernels there was a tendency for the developmental periods to be longer as percentage of cracked kernels increased.

Red flour beetles were able to develop to some extent on all media; there were many larvae observed in some media for which zeros are recorded in Table 3 (observations were halted 8 weeks after infestation). Since numerous insects failed to complete development, they were not included in the developmental period data. The RFB is suited to relatively high temperature, as indicated by progeny production and development rate being higher at 90°F than at 80°F.

Susceptibility to Cigarette Beetle

Effects of temperature, RH, and kinds of kernels on the number of progeny. Generally more progeny were produced at 80°F than at 90°F. No progeny were produced at 40% RH except on 100% cracked milled rice. Other RH had inconsistent effects.

Brown rice was much more susceptible than other media. Effects of percentages of broken kernels were inconsistent.

Effects of temperature, RH, and cracked kernels on the developmental period. Developmental periods were longer at 80°F than at 90°F. On milled rice, when progeny were produced, higher humidity usually caused shorter developmental periods. The effects of percentage of cracked kernels were not consistent.

Forty percent RH was detrimental to successful development of the beetle. The beetle needed moderate RH as stated by Howe (1965), and the shorter developmental periods at 90°F indicated that relatively high temperatures favored CB development.

Effects of temperature, RH, and kinds of kernels on the size of the adult insects. The results are summarized in Table 6. The mean size of RW was considerably larger on brown rice than on other kinds of kernels in the environments in which progeny were produced. Wide variations in sizes of all the insects (except RFB) occurred in each medium and environment. Measurements of relative sizes were made as shown in Figure 1. The variations in sizes of the insects are illustrated in Fig. 2-8.

Effects of temperature on sizes of progeny were inconsistent. Higher RH tended to produce larger progeny adults although not consistently. Sizes of progeny of all species on most media tended to be smaller when the developmental periods were longer.

Table 3. Averages and ranges in numbers of adult progeny produced in brown or milled rice with different percentages of broken kernels and in different environments. (50 percent adults/ 50g. samples; ranges in parentheses).

Kinds of kernels	90°F 70 % RH	90°F 50 % RH	90°F 40 % RH	80°F 70 % RH	80°F 50 % RH	80°F 40 % RH
			Angoumois Grain Moth			
Brown Rice						
20% cracked + 80% whole	v 32.2 b (11-16)	v 3.2 b (1-7)	0 b 0	v 280.8 a (230-343)	v 279.2 a (179-373)	v 69.8 b (40-104)
Milled Rice						
100% cracked	w 0 b (0)	w 0 b (0)	0 b (0)	x 6.2 a (4-10)	w 0 b (0)	w 0 b (0)
60% cracked	w 1.6 c (0-4)	w 0.8 c (0-2)	0 c (0)	wx 20.8 a (14-34)	w 9 b (5-10)	w 2 c (0-3)
20% cracked + 80% whole	w 0.6 c (0-2)	w 0 c (0)	0 c (0)	w 30.4 a (25-39)	w 8.4 b (5-18)	w 1.4 c (0-3)
2% cracked + 98% whole	w 0 b (0)	w 0 b (0)	0 b (0)	wx 7.4 a (4-11)	w 2 b (0-6)	w 0.6 b (0-2)
100% whole	w 0 c (0)	w 0 c (0)	0 c (0)	x 5.8 a (4-7)	w 2.2 b (0-5)	w 0.4 c (0-2)

			Rice Weevil			
Brown Rice						
20% cracked + 80% whole	v 135.6 b (81-198)	0 c (0)	0 c (0)	v 733.4 a (577-827)	v 174 b (137-221)	x 0 c (0)
Milled Rice						
100% cracked	w 0 b (0)	0 b (0)	0 b (0)	y 13.6 a (8-16)	x 1.8 b (0-3)	x 0 b (0)
60% cracked + 40% whole	w 0 c (0)	0 c (0)	0 c (0)	y 67.4 b (47-81)	v 155 a (87-197)	x 1.2 c (0-3)
20% cracked + 80% whole	w 3.6 c (0-12)	0 c (0)	0 c (0)	w 343.2 a (287-390)	v 136.6 b (74-196)	w 10.2 c (2-18)
2% cracked + 98% whole	w 0 c (0)	0 c (0)	0 c (0)	x 192.8 a (159-234)	v 157 b (104-227)	v 17.4 c (6-31)
100% whole	w 0 c (0)	0 c (0)	0 c (0)	y 68.5 b (54-82)	w 79.8 a (68-89)	wx 5.4 c (2-12)
			Lesser Grain Borer			
Brown Rice						
20% cracked + 80% whole	v 1346.4 a (1217-1438)	v 733.2 c (555-884)	v 649.8 c (498-754)	v 967.6 b (886-1074)	v 624 c (483-713)	v 424.4 d (400-443)

Milled Rice						
100% cracked	y 32 b (27-38)	w 26.8 b (24-28)	w 7.8 c (4-12)	y 50 a (42-61)	x 29 b (20-36)	x 0 d (0)
60% cracked + 40% whole	wx 112.6 (79-126)	w 103.6 b (92-128)	w 17.4 c (14-22)	wx 119.4 a (77-142)	w 128.4 a (122-136)	x 0 c (0)
20% cracked + 80% whole	w 158.2 a (142-170)	w 63.4 b (54-72)	w 44.2 c (35-58)	w 144.4 a (114-171)	x 53.3 bc (42-66)	x 0 d (0)
2% cracked + 98% whole	xy 60.6 b (54-100)	w 68.6 b (58-86)	w 5 d (2-8)	wx 123.4 a (114-136)	x 56.4 bc (31-82)	w 30.4 cd (24-42)
100% whole	xy 60 b (50-74)	w 53.2 b (28-82)	w 2.2 d (1-4)	xy 89.2 a (64-98)	x 23 c (19-26)	x 1 d (0-2)
			Saw-toothed Grain Beetle			
Brown Rice						
20% cracked + 80% whole	w 191 b (119-233)	vw 63.8 c (47-80)	x 5.6 d (2-9)	v 269.6 a (218-369)	x 86.2 c (40-138)	x 45.8 cd (37-53)
Milled Rice						
100% cracked	x 107.8 c (94-125)	x 46.6 b (35-71)	w 21 c (12-29)	y 55.6 b (41-77)	y 18.2 c (13-27)	y 20.6c (11-27)

60% cracked 40% whole	x 117.2 a (96-133)	v 75.8 b (53-100)	v 42.8 bc (32-53)	x 119.2 a (84-154)	w 126.2 a (60-174)	x 39.4 c (19-71)
20% cracked + 80% whole	v 263.8 a (247-293)	v 68.d (58-78)	v 47.8 e (33-60)	w 200.2 b (171-222)	v 209.6 b (194-226)	v 112.6 c (95-129)
2% cracked + 98% whole	y 57.2 b (40-81)	v 67 b (55-86)	w 21.2 c (12-30)	w 196.2 a (178-211)	x 75.2 b (62-112)	w 64.4 b (44-86)
100% whole	x 95.6 d (80-115)	wx 49.4 b (45-56)	w 22.2 c (14-28)	y 48.5 b (37-60)	y 19 c (7-31)	y 14.8 c (8-23)
Red Flour Beetle						
Brown Rice						
20% cracked + 80% whole	v 219.4 a (210-245)	v 106.6 bc (90-121)	v 92.6 cd (82-104)	v 113 b (103-125)	v 84 d (72-95)	v 49.2 b (37-60)
Milled Rice						
100% cracked	x 53.8 a (44-63)	w 38.8 b (34-42)	y 19.4 d (15-26)	z 0 e (0)	x 40 b (32-47)	v 30.2 c (25-38)
60% cracked + 40% whole	x 61 c (51-74)	v 90.8 a (81-105)	w 48.2 d (36-55)	y 21.8 e (5-33)	v 79.8 b (70-85)	w 0 f (0)
20% cracked + 80% whole	w 90.4 a (79-118)	v 75.8 a (86-113)	v 89.6 a (68-104)	w 64.2 a (48-76)	v 88.8 a (83-94)	w 0 b (0)

2% cracked 98% whole	w 89.8 a (76-99)	v 87 a (66-98)	x 31.6 d (22-40)	x 39.2 cd (32-53)	w 59.8 b (39-80)	y 48.8 bc (42-57)
100% whole	y 31.4 a (22-38)	w 23.6 b (15-29)	z 8.4 c (6-13)	z 10.6 c (5-16)	y 0 d (0)	w 0 d (0)
			Cigarette Beetle			
Brown Rice						
20% cracked + 80% whole	v 236.4 a (152-343)	v 116.6 b (82-151)	w 0 c (0)	v 267 a (234-300)	v 291.6 a (254-318)	0 c (0)
Milled Rice						
100% cracked	wxy 43 b (7-85)	x 37.8 bc (7-56)	v 18.6 cd (5-26)	x 59.6 b (41-75)	w 99.6 a (59-119)	0 d (0)
60% cracked + 40% whole	wx 64.6 b (44-100)	v 104 a (79-142)	w 0 c (0)	x 54.6 b (26-87)	x 71.6 b (61-103)	0 c (0)
20% cracked + 80% whole	w 91.2 ab (56-138)	w 77.6 b (48-108)	w 0 c (0)	w 123.8 a (61-184)	y 0 c (0)	0 c (0)
2% cracked + 98% whole	y 13 d (1-29)	wx 59.8 b (43-87)	w 0 d (0)	x 73.8 a (56-87)	y 21.4 c (9-27)	0 d (0)
100% whole	xy 19.8 b (4-38)	y 12.2 bc (8-15)	w 0 c (0)	wx 93.6 a (50-135)	y 0 c (0)	0 c (0)

Small leters (a to f) behind numbers indicate significant differences (0.05 level) due to the effect of environment.

Small letters (v to z) above numbers indicate significant differences (0.05 level) due to kind of kernels.

Table 4. Averages and ranges in developmental periods (mid oviposition period to adult emergence ± 3 days) of insects reared in milled rice with different percentages of cracked kernels and in different environments. (50 percent adults/ 50 g. samples; ranges in parentheses)

Kinds of kernels	90°F			80°F		
	70 % RH	50 % RH	40 % RH	70 % RH	50 % RH	40 % RH
			Angoumois Grain Moth			
Milled Rice						
100% cracked	-	-	-	60.80	-	-
	-	-	-	(48-70)	-	-
60% cracked + 40% whole	49.16 b	48 b	-	57.60 a	61.92 a	58.58 a
	(46-56)	(46-50)	-	(46-76)	(47-77)	(56-62)
20% cracked + 80% whole	46 c	-	-	52.80 b	56.64 ab	58.44 a
	(42-48)	-	-	(42-68)	(46-68)	(58-66)
2% cracked + 98% whole	-	-	-	45.27 a	49 a	49 a
	-	-	-	(39-55)	(48-54)	(49)
100% whole	-	-	-	41.64 b	43.46 ab	48 a
	-	-	-	(34-50)	(42-48)	(48)

Rice Weevil

Milled Rice						
100% cracked	-	-	-	39.59 b	44.90 a	-
	-	-	-	(36-48)	(44-48)	-
60% cracked	-	-	-	43.11 b	44.40 b	49.22 a
	-	-	-	(33-55)	(33-59)	(45-51)
20% cracked + 80% whole	46.58 a	-	-	40.71 c	48.00 a	48.38 a
	(45-53)	-	-	(30-62)	(60-66)	(46-52)
2% cracked 98% whole	-	-	-	40.35 c	46.71 b	51.23 a
	-	-	-	(29-59)	(36-60)	(47-63)
100% whole	-	-	-	44.20 b	45.89 b	51.31 a
	-	-	-	(35-63)	(35-65)	(47-51)

			Lesser Grain Borer			
Milled Rice						
100% cracked	38.93 d	43.62 c	48.94 b	49.46 b	56.68 a	-
	(37-43)	(42-50)	(40-58)	(43-59)	(53-65)	-
60% cracked + 40% whole	33.52 d	37.27 c	41.77 b	54.50 a	56.38 a	-
	(28-48)	(31-51)	(38-48)	(48-70)	(45-77)	-
20% cracked + 80% whole	31.27 e	37.60 d	41.08 c	52.86 b	60.34 a	-
	(25-43)	(34-48)	(36-54)	(45-71)	(52-74)	-
2% cracked + 98% whole	33.04 e	35.02 d	50.12 c	50.21 c	60.39 b	63.39 a
	(29-45)	(31-45)	(48-62)	(41-71)	(52-70)	(51-79)
100% whole	31.16 e	36.07 d	46.4 c	52.00 a	49.02 b	48 b
	(26-42)	(29-49)	(44-52)	(41-70)	(42-54)	(47-49)
			Saw-toothed Grain Beetle			
Milled Rice						
100% cracked	26.81 b	25.63 bc	23.94 c	30.85 a	29.14 a	29.65a
	(20-34)	(20-38)	(20-32)	(26-42)	(26-30)	(28-34)
60% cracked + 40% whole	25.78 c	20.31 d	20.64 d	30.59 a	30.88 a	29.63 b
	(18-34)	(18-24)	(18-24)	(25-43)	(25-41)	(27-33)

20% cracked 80% whole	21.43 b	21.79 b	20.75 b	31.04 a	30.58a	29.37 a
	(15-31)	(16-30)	(18-24)	(25-37)	(24-38)	(26-34)
2% cracked 98% whole	21.47 e	22.04 e	24.13 d	28.34 c	30.87 a	29.45 b
	(17-29)	(17-31)	(22-28)	(23-37)	(25-35)	(25-33)
100% whole	21.93 d	20.58 e	23.78 c	26.83 b	29.56 a	29.40 a
	(16-30)	(16-32)	(21-29)	(23-33)	(26-32)	(26-32)
			Red Flour Beetle			
Milled Rice						
100% cracked	34.04 d	41.50 c	47.37 b	-	75.13 a	72.84 a
	(24-56)	(26-64)	(28-68)	-	(51-95)	(51-94)
60% cracked 40% whole	33.54 d	35.18 d	38.63 c	62.90 b	65.82 a	-
	(24-48)	(24-56)	(24-54)	(50-78)	(45-91)	-
20% cracked + 80% whole	29.86 c	33.92 b	36.14 b	63.59 a	61.45 a	-
	(21-47)	(26-48)	(27-49)	(48-80)	(49-79)	-
2% cracked 98% whole	28.17 f	33.02 e	36.93 d	55.30 c	59.21 b	67.34a
	(21-45)	(25-51)	(28-48)	(41-79)	(48-82)	(51-85)
100% whole	31.74 c	34.15 c	43.89 b	56.54 a	-	-
	(23-51)	(23-51)	(34-58)	(41-70)	-	-

Cigarette Beetle

Milled Rice						
100% cracked	34.53 e	40.78 d	52.54 b	47.17 c	54.57 a	-
	(30-46)	(34.48)	(45.59)	(36-60)	(47-69)	-
60% cracked + 40% whole	37.30 c	37.69 c	-	50.91 b	52.21 a	-
	(30-52)	(33-47)	-	(45-59)	(43-63)	-
20% cracked + 80% whole	34.44 c	40.22 b	-	56.11 a	-	-
	(23-49)	(34-52)	-	(45-77)	-	-
2% cracked + 98% whole	33.78 d	35.77 c	-	49.64 b	51.77 a	-
	(31-39)	(31-45)	-	(35-61)	(44-60)	-
100% whole	33.28 c	38.53 b	-	50.16 a	-	-
	(26-42)	(35-47)	-	(40-64)	-	-

Small letters (a to f) behind numbers indicate significant difference (at 0.05 level) due to the effect of environment.

Table 5. Moisture contents of different kinds of kernels at different temperatures and humidities.

	90^oF			80^oF		
Kinds of kernels	70 % RH	50 % RH	40 % RH	70 % RH	50 % RH	40 % RH
Brown Rice						
(80% sound + 20% cracked) I.	13.77	11.81	8.36	13.56	12.85	10.09
II.			Not recorded			
III.	12.98	10.77	7.80	13.73	12.67	9.99
Milled Rice						
(100% cracked)						
Initial Moisture Content 14.30 I.	11.38	11.35	9.16	13.17	11.75	10.52
II.	11.26	10.62	9.22	13.19	11.11	9.53
III.	12.04	10.40	9.13	12.76	11.25	10.26
60% cracked + 40% sound						
Initial M.C. 12.59						
I.	13.25	12.32	11.08	13.03	12.52	11.32
II.	13.19	11.94	9.89	13.31	12.74	11.27
III.	12.72	11.94	9.38	13.00	12.16	10.52
20% cracked + 80% sound Initial M.C. 12.43						
I.	12.56	11.39	10.84	13.29	12.28	11.25
II.	12.84	11.13	10.36	13.33	11.85	10.90
III.	13.21	11.61	9.44	13.21	11.79	10.64

2% cracked + 98% sound Initial M.C. 12.72						
I.	13.33	12.10	11.33	12.54	12.58	12.72
II.	12.92	11.71	10.28	13.19	12.16	11.43
III.	13.33	11.28	9.36	13.27	12.30	10.18
100% sound Initial M.C. 11.97						
I.	13.17	12.18	10.44	12.93	12.46	11.69
II.	13.23	11.57	9.36	13.46	12.28	10.82
III.	13.14	10.61	9.19	12.99	11.43	9.97

I. M. C. 2 weeks after equilibration (= at the day of infestation).

II. M. C. 2 weeks after infestation.

III. M. C. 8 weeks after infestation.

Table 6. Averages and ranges in size (mm) of insects reared in brown and milled rice with different percentages of broken kernels and in different environments (20 adults/samples, except as indicated in parentheses).

Kinds of kernels		90°F			80°F		
		70 % RH	50 % RH	40 % RH	70 % RH	50 % RH	40 % RH
				Angoumois Grain Moth (Male)			
Brown Rice							
20% cracked + 80% whole	Av.	3.63 (10)	4.16 (10)	-	3.80 (10)	3.95 (10)	4.10 (10)
	Range	3.3-3.9	3.1-4.8		3.5-4.1	3.5-4.6	3.8-4.7
Milled Rice							
100% cracked	Av.	-	-	-	4.23 (10)	-	-
	Range	-	-	-	3.7-4.7	-	-
60% cracked + 40% whole	Av.	4.15 (4)	4.05 (2)	-	4.11 (10)	4.19 (10)	4.47 (4)
	Range	3.2-4.7	4.0-4.1	-	3.8-4.3	3.6-4.7	4.2-4.8
20% cracked	Av.	3.55	-	-	4.44 (10)	4.10 (10)	4.37 (4)
	Range	3.4-3.7	-	-	4.2-4.8	3.8-4.8	3.6-4.9
2% cracked + 98% whole	Av.	-	-	-	4.78 (10)	4.45 (6)	4.36 (3)
	Range	-	-	-	4.4-5.1	5.2-5.1	4.0-4.7
100% whole	Av.	-	-	-	4.53 (10)	4.55 (8)	-
	Range	-	-	-	3.9-5.0	4.0-5.1	-

				Angoumois Grain Moth (Female)			
Brown Rice							
20% cracked + 80% while	Av.	4.28 (10)	4.71 (10)	-	4.41 (10)	4.85 (10)	4.82 (10)
	Range	3.9-4.6	4.2-5.1	-	4.0-4.6	4.4-5.0	4.5-5.2
Milled Rice							
100% cracked	Av.	-	-	-	4.84 (10)	-	-
	Range	-	-	-	4.1-5.4	-	-
60% cracked + 40% whole	Av.	3.87 (4)	4.05 (2)	-	4.67 (10)	4.85 (10)	4.71 (6)
	Range	3.3-4.8	3.6-4.5	-	4.3-5.0	4.5-5.1	4.4-5.0
20% cracked + 80% whole	Av.	4.2 (1)	-	-	4.93 (10)	4.73 (10)	4.4 (3)
	Range	4.2	-	-	4.4-5.3	4.3-5.1	4.1-4.8
2% cracked + 98% whole	Av.	-	-	-	5.65 (10)	5.125 (4)	-
	Range	-	-	-	5.5-5.8	4.5-5.5	-
100% whole	Av.	-	-	-	5.33 (10)	4.96 (3)	4.85 (2)
	Range	-	-	-	4.9-5.7	4.7-5.2	4.8-4.9
				Rice Weevil			
Brown Rice							
20% cracked + 80% whole	Av.	1.311	-	-	1.425	1.360	-
	Range	1.22-1.52	-	-	1.12-160	1.06-1.54	-
Milled Rice							
100% cracked	Av.	-	-	-	1.098	1.131 (9)	-
	Range	-	-	-	1.04-1.22	1.04-1.18	-

60% cracked + 40% whole	Av.	-	-	-	1.212	1.242	1.210
	Range	-	-	-	1.04-1.30	1.12-1.40	1.04-1.30
20% cracked + 80% whole	Av.	1.18	-	-	1.279	1.231	1.272
	Range	1.14-1.24	-	-	1.06-1.46	1.10-1.38	1.16-1.40
2% cracked + 98% whole	Av.	-	-	-	1.239	1.224	1.240
	Range	-	-	-	1.04-1.40	1.06-1.36	1.04-1.38
100% whole	Av.	-	-	-	1.123	1.139	1.125
	Range	-	-	-	1.02-1.26	1.04-1.28	1.00-1.22

Lesser Grain Borer

Brown Rice

20% cracked + 80% sound	Av.	1.659	1.585	1.578	1.703	1.646	1.570
	Range	1.56-1.78	1.44-1.78	1.38-1.76	1.58-1.86	1.54-1.84	1.34-1.76

Milled Rice

100% cracked	Av.	1.751	1.655	1.554	1.749	1.692	-
	Range	1.56-1.94	1.48-1.80	1.38-1.64	1.48-1.98	1.54-1.82	-
60% cracked + 40% sound	Av.	1.697	1.617	1.596	1.641	1.634	-
	Range	1.54-1.92	1.48-1.84	1.42-1.78	1.50-1.82	1.52-1.78	-
20% cracked + 80% sound	Av.	1.629	1.579	1.465	1.710	1.556	-
	Range	1.52-1.80	1.40-1.68	1.32-1.68	1.52-1.80	1.40-1.66	-
2% cracked + 98% sound	Av.	1.677	1.617	1.433	1.630	1.661	1.548
	Range	1.48-1.86	1.50-1.76	1.34-1.58	1.46-1.78	1.46-1.86	1.78-1.40

100% sound	Av.	1.659	1.552	1.570 (11)	1.607	1.640	1.648 (5)
	Range	1.48-1.82	1.34-1.76	1.42-1.76	1.42-1.82	1.46-1.80	1.44-1.80
				Saw-toothed Grain Beetle			
Brown Rice							
20% cracked + 80% sound	Av.	1.216	1.208	1.217	1.314	1.288	1.250
	Range	1.12-1.34	1.08-1.42	1.10-1.30	1.18-1.48	1.12-1.36	1.04-1.48
Milled Rice							
100% cracked	Av.	1.186	1.202	1.231	1.205	1.215	1.209
	Range	1.04-1.34	1.16-1.26	1.12-1.32	1.06-1.32	1.16-1.30	1.08-1.34
60% cracked + 40% sound	Av.	1.174	1.191	1.254	1.313	1.271	1.276
	Range	1.06-1.24	1.04-1.38	1.08-1.38	1.16-1.38	1.14-1.40	1.14-1.42
20% cracked + 80% sound	Av.	1.308	1.236	1.261	1.288	1.295	1.319
	Range	1.16-1.38	1.18-1.34	1.16-1.34	1.14-1.36	1.22-1.42	1.26-1.42
2% cracked + 98% sound	Av.	1.279	1.268	1.256	1.332	1.277	1.258
	Range	1.16-1.38	1.14-1.36	1.14-1.38	1.18-1.44	1.18-1.38	1.20-1.32
100% Sound	Av.	1.226	1.276	1.225	1.172	1.259	1.258
	Range	1.08-1.34	1.20-1.36	1.08-1.32	1.06-1.24	1.06-1.36	1.14-1.38
				Red Flour Beetle			
Brown Rice							
20% cracked + 80% sound	Av.	1.970	1.960	1.936	1.905	1.900	1.930
	Range	1.8-2.2	1.8-2.2	1.8-2.2	1.8-2.2	1.8-2.2	1.8-2.1

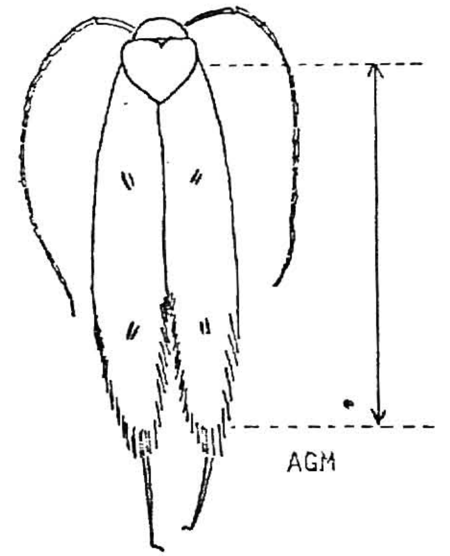
Milled Rice							
100% cracked	Av.	1.975	1.945	1.890	-	1.990	1.920
	Range	1.7-2.3	1.8-2.2	1.7-2.1	-	1.8-2.2	1.7-2.1
60% cracked + 40% sound	Av.	2.035	2.015	1.945	2.065	1.935	-
	Range	1.9-2.2	1.8-2.1	1.7-2.2	1.9-2.2	1.7-2.1	-
20% cracked + 80% sound	Av.	1.990	1.905	1.925	1.930	1.870	-
	Range	1.8-2.1	1.7-2.1	1.8-2.1	1.8-2.1	1.7-2.1	-
2% cracked + 98% sound	Av.	1.865	1.880	1.860	1.870	1.895	1.845
	Range	1.7-2.0	1.7-2.1	1.7-2.0	1.7-2.0	1.7-2.1	1.7-2.1
100% sound	Av.	1.950	1.900	1.870	1.950	-	-
	Range	1.9-2.1	1.7-2.1	1.7-2.0	1.8-2.1	-	-
				Cigarette Beetle			
Brown Rice							
20% cracked + 80% sound	Av.	1.780	1.685	-	2.050	1.885	-
	Range	1.4-2.3	1.4-1.9	-	1.8-2.3	1.7-2.1	-
Milled Rice							
100% cracked	Av.	1.695	1.655	1.630	1.700	1.745	-
	Range	1.5-2.0	1.4-1.9	1.4-1.8	1.5-2.0	1.5-2.0	-
60% cracked + 40% sound	Av.	1.800	1.675	-	1.875	1.840	-
	Range	1.4-2.0	1.4-1.9	-	1.7-2.0	1.5-2.1	-

20% cracked + 80% sound	Av.	1.785	1.645	-	1.840	-	-
	Range	1.5-2.0	1.4-1.9	-	1.6-2.1	-	-
2% cracked + 98% sound	Av.	1.730	1.560	-	1.745	1.750	-
	Range	1.4-2.0	1.4-1.8	-	1.5-2.0	1.5-2.0	-
100% sound	Av.	1.860	1.625	-	1.88	-	-
	Range	1.5-2.1	1.4-1.9	-	1.7-2.1	-	-

EXPLANATION OF PLATE I

Fig. 1. Measuring of the insects (as indicated by arrows).

PLATE I



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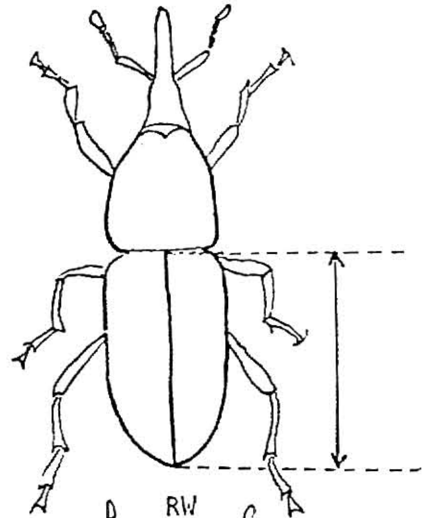

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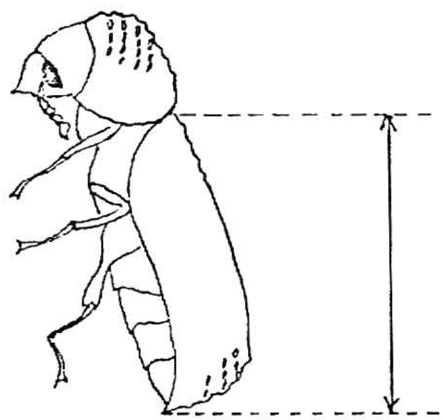

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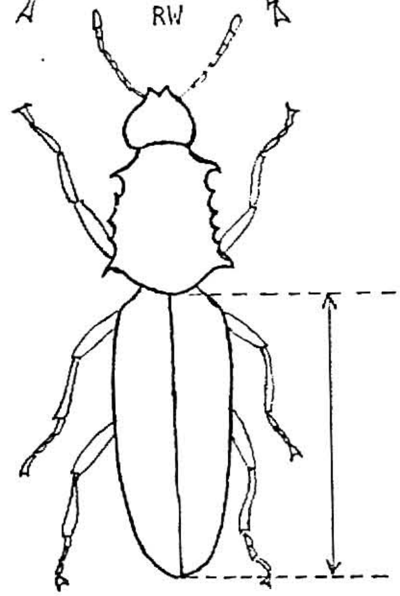

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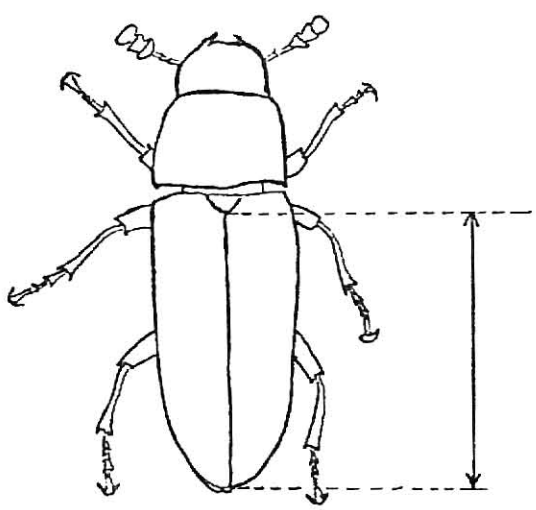

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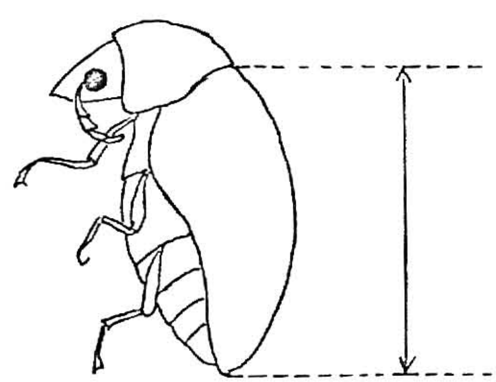

CB

EXPLANATION OF PLATE II

Size Variation of the Insects

Fig. 2. Angoumois Grain Moth (Male)

Medium: Brown rice with 20% cracked + 80% whole kernels
Environment: 90°F and 50% RH
Range: 3.1 - 4.8 mm.

Fig. 3. Angoumois Grain Moth (Female)

Medium: Brown rice with 20% cracked + 80% whole kernels
Environment: 90°F and 50% RH
Range: 4.2 - 5.1 mm.

PLATE II

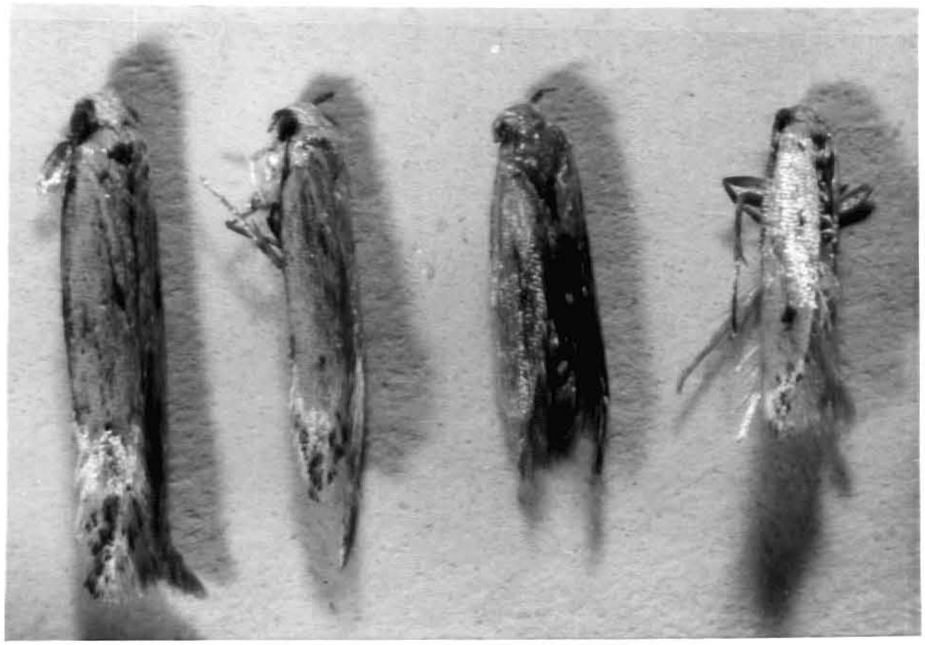

Fig. 2

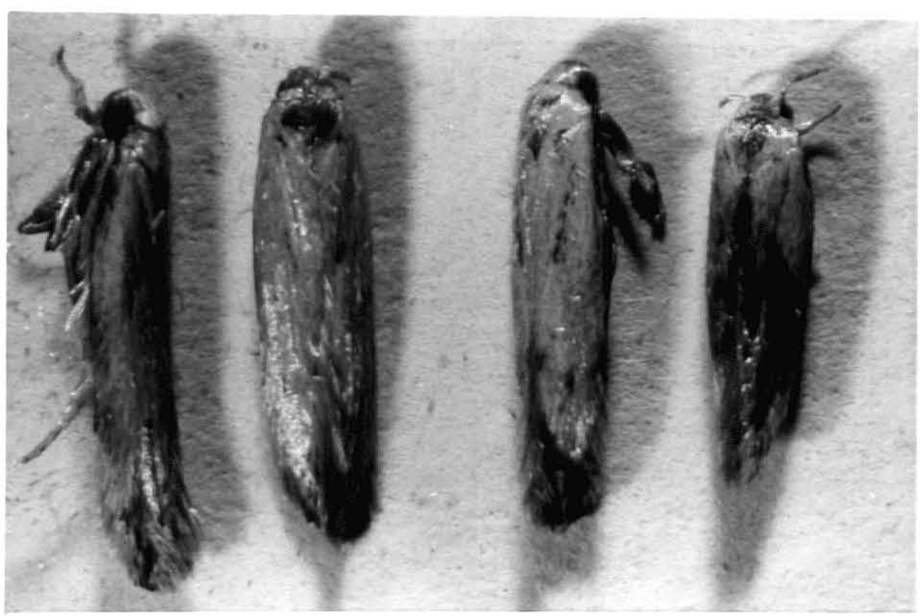

Fig. 3

EXPLANATION OF PLATE III

Size Variation of the Insects

Fig. 4. Rice Weevil

Medium: Milled rice with 2% cracked + 98% whole kernels
Environment: $80^{o}F$ and 50% RH
Range: 1.06 - 1.36 mm

Fig. 5. Lesser Grain Borer

Medium: Milled rice of 20% cracked + 80% whole kernels
Environment: $90^{o}F$ and 40% RH
Range: 1.32 - 1.68 mm.

PLATE III

Fig. 4

Fig. 5

EXPLANATION OF PLATE IV

Size Variation of the Insects

Fig. 6. Saw-Toothed Grain Beetle

Medium: Milled rice with 60% cracked + 40% whole kernels
Environment: 90°F and 70% Rh
Range: 1.06 - 1.24 mm.

Fig. 7. Red Flour Beetle

Medium: Milled rice of 100% cracked kernels
Environment: 80°F and 70% RH
Range: 1.8 - 2.2

PLATE IV

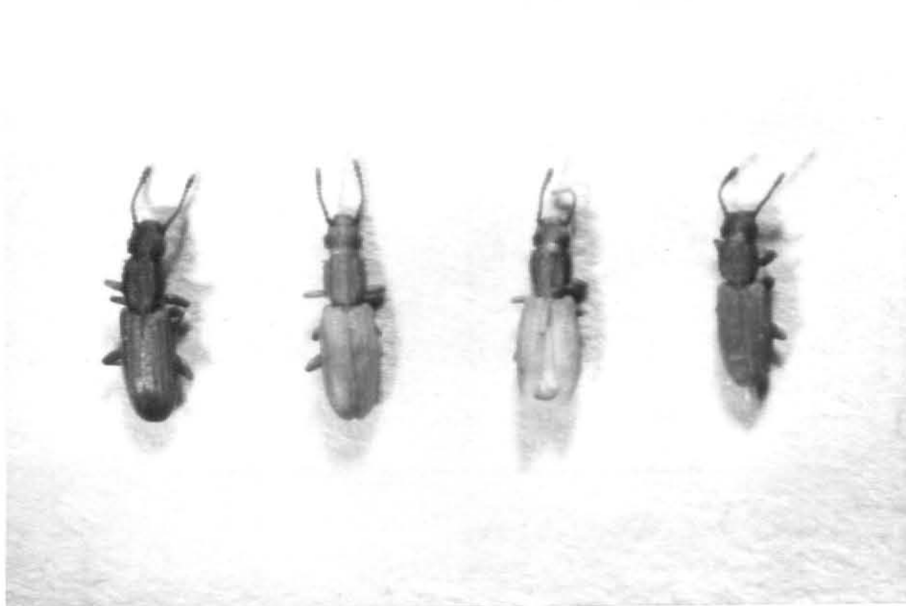

Fig. 6

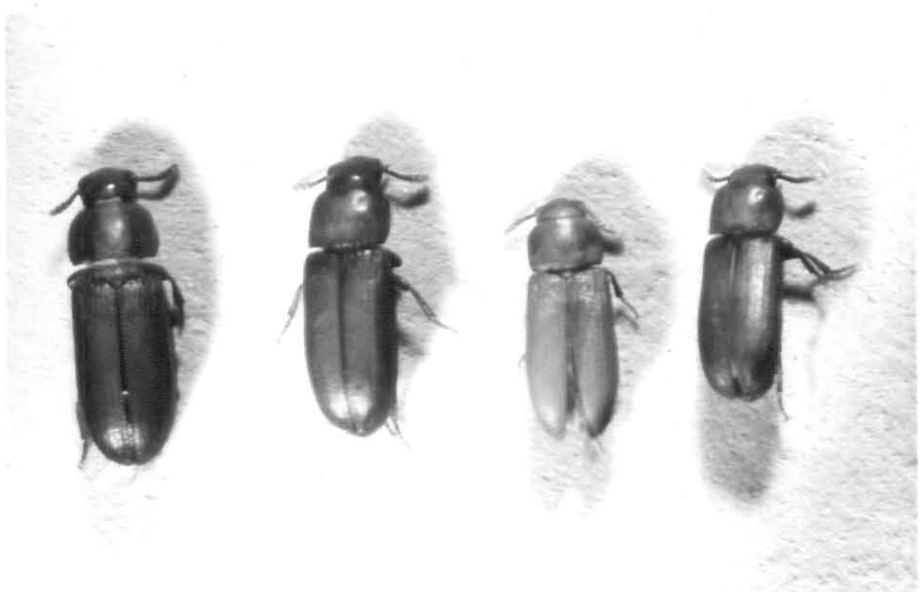

Fig. 7

EXPLANATION OF PLATE V

Size Variation of the Insects

Fig. 8. Cigarette Beetle

Medium: Milled rice of 100% whole kernels
Environment: 80°F and 70% RH
Range: 1.7 - 2.1 mm.

PLATE V

Fig. 8

SUMMARY

The primary objectives of this study were to test the susceptibility of forms (rough, brown, and milled) and of broken kernels of unparboiled NATO rice to six species of stored-product insects in six different environments.

The test insects were Angoumois grain moth, (AGM) Sitotroga cerealella (Oliv.); rice weevil, (RW) Sitophilus oryzae (L.); lesser grain borer, (LGB) Rhyzopertha dominica (F.); saw-toothed grain beetle, (STGB) Oryzaephilus surinamensis (L.); red flour beetle, (RFB) Tribolium castaneum (Herbst.); and cigarette beetle, (CB) Lasioderma serricorne (F.).

The six environment conditions were 80 or 90 $\pm$ 2^{O}F, and 40, 50, or 70 $\pm$ 5% RH.

The first test was to determine the susceptibility of whole rough and brown rice in the six environments. Five replicate samples (each consisted of 50 g of rice placed in a pint, wide-mouth mason jar) were tested for each insect species in each medium and environment. Infestations with 50 unsexed adults/samples were done after exposing the samples for 2 weeks in the environments in which they were tested. The adults were not removed. Adult counts (dead and alive) were made 8 weeks after infestation.

Only AGM, LGB, and CB were able to produce substantial numbers of progeny on rough rice. At both temperatures, higher humidity favored the development of the AGM, LGB (at 80^{O}F not significantly different

between 50 and 40% RH), and CB (except at 80^{O}F and 50% RH which was only slightly different from 80^{O}F and 40% RH). In combination with the same RH more progeny of AGM were produced at 80^{O}F than at 90^{O}F; CB produced fewer at 80^{O}F.

On brown rice, except at 70% RH, the two temperatures produced no significant differences in the number of progeny of RW, STGB, and RFB. AGM produced more progeny at 80^{O}F than at 90^{O}F. There were no significant differences in the numbers of progeny of LGB produced in any of the environments. The effects of temperature on the number of progeny of CB were not consistent.

The second test was to determine the susceptibility of brown and milled rice with different percentages of cracked kernels and in the same six environments. The kinds of kernels tested were: brown rice with 20% cracked kernels and milled rice with 100, 60, 20, 2, or no cracked kernels. At 90^{O}F, only on brown rice at 70% RH were AGM and RW able to produce substantial numbers of progeny. No, or few progeny were produced in the other environments, and other media. In most conditions, RFB produced more progeny at 90^{O}F than at 80^{O}F. In no other environments or kinds of media were the effects of temperature consistent for any insect species.

With few exceptions, AGM, RW, LGB, and STGB produced more progeny at higher RH. Results for RFB and CB were inconsistent.

With few exceptions, brown rice was more susceptible than other media to AGM, RW, LGB, and CB. At 70% RH (both 90 and 80^{O}F), brown rice was more susceptible to STGB than other media, except 20%

cracked and 80% whole kernels (milled); effects of media on other environments were inconsistent. Brown rice was, in most cases, more susceptible to RFB, although not always significant.

Effects of cracked kernels in the milled rice media varied with the insect species. There were too few AGM progeny to draw conclusions. With few exceptions, fewer RW and LGB progeny were produced in 100% cracked kernels than in media including whole kernels. Effects of cracked kernels on STGB progeny production were inconsistent. For RFB, media including cracked kernels produced inconsistent results, but more progeny than all whole kernel medium. Results were similar for CB, except for the large number of progeny from whole kernels at 80^{O}F and 70% RH.

In combination with the same RH, developmental periods of AGM and CB (whenever progeny were produced), LGB, STGB, and RFB were shorter at 90^{O}F than at 80^{O}F on all of the media.

With few exceptions higher RH shortened the developmental periods of all insect species on all of the media, although the differences were not always significant.

Developmental periods seemed to be longer on milled rice with higher percentages of cracked kernels for the AGM at 80^{O}F and 70% RH, and for RFB at 80^{O}F and 50% RH. Effects of cracked kernels on other environments and on other species of insects were inconsistent.

All species in all of the environments showed wide variation of size of the adult progeny in all media (except RFB which showed less variation). RW were considerably larger in brown rice than in other kinds of kernels. Effects of temperature on size were inconsistent. Longer developmental periods appeared to be related to smaller size of adult progeny.

Results suggest that rice stored in the rough form will be less susceptible than brown rice to RW, RFB, or STGB but not to AGM, LGB, or CB. Storage in the form of brown rice should be avoided. Storing milled rice with less percentage of broken kernels is advisable, especially against RFB and CB. All kinds of rice should be stored at relatively low RH. The different forms of rice were less susceptible to AGM and RW at $90^{o}F$ than $80^{o}F$.

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SUSCEPTIBILITY OF ROUGH, BROWN, MILLED, AND BROKEN RICE KERNELS IN DIFFERENT ENVIRONMENTS TO SIX SPECIES OF STORED-PRODUCT INSECTS

by

OETOYO ATMOSUDIRDJO

B. S., Gadjah Mada University, Indonesia, 1964

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Entomology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

The susceptibility of rough, brown, milled, and of cracked kernels of unparboiled NATO rice was tested using Angoumois grain moth, (AGM) Sitotroga cerealella (Oliv.); rice weevil, (RW) Sitophilus oryzae (L.); lesser grain borer, (LGB) Rhyzopertha dominica (F.); saw-toothed grain beetle, (STGB) Oryzaephilus surinamensis (L.); red flour beetle, (RFB) Tribolium castaneum (Herbst.); and cigarette beetle, (CB) Lasioderma serricorne (F.), in six different environments: 80 or 90 ± 2°F, and 40, 50, or 70 ± 5% RH. To determine the effects of cracked kernels, the following were used: brown rice with 20% cracked, and milled rice with 100%, 60%, 20%, 2%, or no cracked kernels.

The different environments used resulted in significantly different numbers of progeny (0.05 level) of each insect in either whole rough or whole brown rice, except for LGB on brown rice and STGB on rough rice. Only AGM, LGB, and CB were able to produce substantial numbers of progeny on rough rice.

At 90°F AGM and RW were able to produce substantial numbers of progeny only on brown rice with 20% cracked kernels at 70% RH.

In combination with the same RH, in brown rice with 20% cracked kernels, milled rice with 60% cracked + 40% whole, and 100% whole kernels, more progeny of RFB were produced at 90°F than at 80°F. In no other environments or kind of media were the effects of temperature consistent for any insect species.

The higher RH favored the development of all of the insects on some media at either temperatures.

Effects of cracked kernels in the milled rice media varied with the insect species, but generally were beneficial for the external feeders.

Developmental periods of AGM, CB, LGB, STGB, and RFB were shorter at 90^{o}F than at 80^{o}F on all media.

Higher RH shortened the developmental periods of RW, LGB, STGB, and RFB on some of the kinds of media at either temperature. On milled rice, the higher percentage of cracked kernels caused longer developmental periods of AGM at 80^{o}F and 70% RH, and of RFB at 80^{o}F and 50% RH. Effects of the percentages of cracked kernels on other environments and on other species of insects were inconsistent.

Variations in size of all insects occurred in all of the environments and kinds of kernels. Effects of temperature on size were inconsistent. Longer developmental periods appeared to be related to smaller size of adult progeny.