BIBLIOGRAPHIC DATA SHEET

1. CONTROL NUMBER: PN-AAJ-498

2. SUBJECT CLASSIFICATION (695): AF30-0150-0000

3. TITLE AND SUBTITLE (240)

Rice grain properties and resistance to storage insects: a review

4. PERSONAL AUTHORS (100)

Juliano, B. O.

5. CORPORATE AUTHORS (101)

IRRI

6. DOCUMENT DATE (110): 1981

7. NUMBER OF PAGES (120): 9p.

8. ARC NUMBER (170): 633.18.J94c

9. REFERENCE ORGANIZATION (130)

IRRI

10. SUPPLEMENTARY NOTES (500)

(In IRRI res. paper ser., no. 56)

11. ABSTRACT (950)

12. DESCRIPTORS (920)

Rice
Rice research
Plant physiology
Plant diseases
Plant protection
Insect control
Storage
Resistance

13. PROJECT NUMBER (150): 497019800

14. CONTRACT NO.(140): AID/492-1310-T

15. CONTRACT TYPE (140)

16. TYPE OF DOCUMENT (160)

AID 590-7 (10-79)

633.18
J94c

PN-AAJ-461

IRRI RESEARCH PAPER SERIES
Number 56 January 1981

Rice grain properties and resistance to storage insects: A review

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Rice Grain Properties and Resistance to Storage Insects: A Review[1]

ABSTRACT

The physicochemical factors contributing to rice resistance to stored-grain insects include tight hull, degree of milling, grain hardness, high amylose content and high gelatinization temperature of endosperm starch, and low moisture content. Little work has been done on attractants and repellants in bran from rices with resistance to storage insects. Insects residing in grains prefer larger, heavier-grained rice varieties.

High amylose content and, to some extent, high gelatinization temperature contribute to low grain equilibrium moisture content at relative humidities above 75%. They also contribute to poorer digestibility of raw starch granules to insect α-amylase.

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Based on the paper delivered 13 June 1980, at the Training Course on Pests of Stored Products, BIOTROP (Seameo Regional Center for Tropical Biology), Bogor, Indonesia. Submitted to the IRRI Research Paper Series Committee 14 January 1981.

Rice Grain Properties and Resistance to Storage Insects: A Review

Recent reviews (Bhatia 1976, Russell and Cogburn 1976) reflect little systematic study that correlates varietal resistance of rice to storage insect pests with physicochemical properties of the grain. Most studies have used regional samples, which represent only a fraction of the range of rice grain properties.

Comparison of insect resistance data on rice is complicated by the use of different bioassay techniques by various entomologists (Russell and Cogburn 1976). In addition, physicochemical properties of the rice varieties seldom have been analyzed simultaneously in the studies. Susceptibility indexes include developmental time of insects, number of F_1 progeny, oviposition preference, weight and length of F_1 progeny, weight loss of rice grain, and milling loss. Less variable results were achieved when eggs rather than adults were used for screening varieties (Russell 1976).

It has been estimated that infestation in commercially grown U.S. long-grain rice could be reduced to <50% if currently existing resistant rice varieties were grown (Russell and Cogburn 1976).

COVERING STRUCTURES OF RICE GRAIN

The grain of rough rice consists of the covering structures (hull or husk) and the fruit or caryopsis (brown rice).

Hull

The hull comprises 18 to 25% of the rough rice. Breese (1960) found that an intact, tight hull contributed to resistance to the rice weevil *Sitophilus oryzae* (L.) and the lesser grain borer *Rhizopertha dominica* (F.). Cohen and Russell (1970) noted that varieties with imperfect hulls had more damage by Angoumois grain moth *Sitotroga cerealella* (Olivier). Imperfect glumes contributed to susceptibility of rough rices to rice weevils (Russell 1968). Cogburn (1974) confirmed hull intactness as a resistance factor to the lesser grain borer and the Angoumois grain moth, but recognized the existence of other factors (Table 1). Hull thickness did not significantly correlate with mean percentage of damage to rough rice by the Angoumois grain moth ($r = 0.10, n = 9$) (Abraham and Thomas 1969).

Bran layers

The brown rice consists of the starchy endosperm and embryo enclosed by thick-walled bran layers of the pericarp, seed coat, nucellus, and aleurone layer (Juliano 1980). Milling removes the embryo (1-2 % of brown rice) and the bran layers. A 10% (by weight) bran-polish removal gives a well-milled endosperm (milled rice).

Brown rice and hand-pounded rice are infested by the rice weevil *Sitophilus oryzae* (L.) to a greater extent during storage than milled rice or milled parboiled rice (Bishara et al 1972, Pingale et al 1957). In addition to the rice weevil, the lesser grain borer, the confused flour beetle *Tribolium confusum* Jacquelin du Val, and the Indian mill moth *Plodia interpunctella* (Huebner) all tend to decrease in numbers with an increasing degree of milling in three rice varieties (McGaughey 1970). Similar results were obtained with four other insect species (McGaughey 1974). McGaughey (1973) reported greater progeny development of the lesser grain borer on brown rice than on rough rice or milled rice of four rice varieties.

Differences in relative susceptibilities of Egyptian rough and brown rices to rice weevils have been reported (Bishara

Table 1. Apparent susceptibility of rough rice to three insects, and rough rice and milled rice properties of six U.S. varieties.

Variety	Progeny on rough rice[b] (no.)			Rough rice			Milled rice analysis[c]		
	Rice weevil	Lesser grain borer	Angoumois grain moth	Imperfect glumes[b] (%)	Length-width[c] ratio	1000-grain wt[c] (g)	Amylose (%)	Final gel. temp. (°C)	Alkali spreading value
Calrose	21 b	146a	280a	21a	2.5	25	19	65	7.0
Nato	31a	76 cd	204 b	18ab	2.6	23	15	67	6.3
Belle Patna	48a	95 bc	168 c	14 b	3.9	22	24	73	3.6
Colusa	7 c	65 de	225 b	13 bc	2.1	30	18	66	6.5
Bluebelle	14 bc	109 b	167 c	10 c	3.9	24	24	74	3.7
Dawn	5 c	42 e	110 d	2 d	3.9	22	25	73	3.9

[a]Source: Cogburn 1974, Webb 1975. [b]Data in the same column followed by a common letter are not significantly different at the 1% level (Cogburn 1974). [c]Source: Webb 1975.

et al 1972, Koura et al 1967). Cogburn (1974) reported a similar number of F progeny on brown rice of six varieties in no-choice experiments with rice weevil, lesser grain borer, and Angoumois grain moth where rough rices showed differential responses. More progeny of the lesser grain borer developed on brown rice than on rough rice or milled rice, and the Dawn variety was more resistant than three other U.S. varieties in rough rice and milled rice forms (McGaughey 1973). Presumably the resistance factor or factors other than hull tightness do not affect oviposition rate or larval mortality but work against the young larvae before they penetrate the seed (Cogburn 1974).

The red flour beetle and the almond moth *Ephestia cautella* (Walker) are common pests of rice bran. The beetle survived on rice bran with oil contents of 0, 2.5, 5, 7.5, and 10% but mortality was greatest at 0% (Golob and Ashman 1974). The almond moth failed to survive on rice bran with 0 or 2.5% oil content and growth was retarded at 5 and 7.5% oil content. The results may reflect the insect's metabolic requirement for an external source of fat.

ENDOSPERM PROPERTIES

Dimensions and hardness

For insects, such as the rice weevil and the lesser grain borer, whose larvae inhabit the endosperm, varietal susceptibility seems to be related to grain width and weight. Sikder (1965) reported that the Angoumois grain moths reared on large-grain rice varieties were bigger than those reared on small-grain varieties. Abraham and Thomas (1969) found a positive, but not significant, correlation ($r = 0.43, n = 9$) between fineness (length-breadth ratio) and mean percentage of damage to rough rice by the same moth. Brown-rice width and weight correlated positively with the index of susceptibility (Dobie 1974) to rice weevil *Sitophilus zeamais* Motsch. (Morallo-Rejesus et al 1980) (Table 2). Seshagiri Rao (1953) found over a 6-month period that, although initially the coarse brown rice was most preferred, fine-grain milled rice was more attractive for rice weevil breeding than medium- and coarse-grain brown rices.

Grain crushing hardness of brown rice correlated positively with brown-rice resistance to rice weevil based on mean developmental period, progeny number, and progeny weight (Rout et al 1976) (Table 3). Brown-rice hardness, based on resistance to grinding (wt percentage >0.177 mm after grinding in a Wig-L-Bug amalgamator), correlated negatively with index of susceptibility (Dobie 1974) and progeny adult weight of the rice weevil (Morallo-Rejesus et al 1981) (Table 2).

Parboiling or heating wet grain at ≥100°C to gelatinize the starch without much grain expansion is known to improve milling quality and to increase grain hardness (Raghavendra Rao and Juliano 1970). McGaughey (1974) reported that parboiled milled rice was less suitable than raw milled rice (of one variety) for progeny production by seven insects including rice weevil. However, longer-term storage by Pingale et al (1957) did not show any advantage of parboiled milled rice over raw milled rice in susceptibility to infestation by rice weevil.

Starch amylose content

Milled rice consists of 90% starch and 8% protein, dry basis. Starch granules, which occur as 3-9 μm compound granules, are confined mainly to the endosperm of the mature rice grain (Juliano 1980). Starch consists of two major fractions — a branched fraction, amylopectin, and a linear fraction, amylose.

Milled rice is classified into amylose types waxy (glutinous, 0-2% amylose, dry basis) and nonwaxy (nonglutinous). The latter is further classified into low (8-20%),

Table 2. Range of properties of rice grain and susceptibility of brown rice samples to the rice weevil and their correlation coefficients.[a]

Susceptibility or grain property	Range of values	Correlation coefficients[b] with			
		Index of suscept-ibility[c]	Progeny adult Length	Progeny adult Weight	Grain loss (wt %)
Index of susceptibility[c]	10.4-15.0	1.00	0.68**	0.63*	0.47
Progeny adult length (mm)	3.8- 4.6		1.00	0.42	0.46
Progeny adult wt (mg)	1.0- 1.5			1.00	0.16
Grain loss (wt %)	1.6- 5.9				1.00
Brown rice					
Width (mm)	2.0- 2.8	0.59*	0.52	0.41	0.34
Weight (mg)	14.4-25.0	0.59*	0.74**	0.34	0.63*
Hardness (% >0.177 mm)	32.0-47.5	−0.62*	−0.41	−0.79**	−0.32
Milled rice					
Amylose content (%)	1.6-29.1	−0.38	−0.56*	−0.34	−0.12
Alkali spreading value	2.0- 7.0	−0.37	−0.03	−0.40	0.09
Protein content (%)	5.0-13.4	−0.28	−0.10	0.03	−0.01

[a]Source: Morallo-Rejesus et al 1981. [b]Significant r values: 5% = 0.514; 1% = 0.641.
[c] $\frac{\ln(\text{progeny no.})}{\text{Mean dev. period}} \times 100$ (Dobie 1974).

Table 3. Relationship between susceptibility of brown rice to the rice weevil and grain hardness and alkali spreading value of eight rice varieties.[a]

Variety	Susceptibility based on: Mean developmental period (days)	Progeny No.	Progeny Wt (mg)	Index of susceptibility[b]	Grain hardness (kg/cm²)	Alkali spreading value
Rajeswari	39.7	19.0	1.58	7.42	4.7	7.0
Padma	40.1	17.5	1.48	7.14	4.8	7.0
Hema	41.8	12.5	1.45	6.04	4.9	7.0
Kumar	42.3	11.0	1.41	5.67	5.4	6.6
Ratna	42.8	8.5	1.35	5.00	5.7	6.2 (5.6)[c]
IR8	42.4	8.5	1.34	5.05	5.8	5.1 (7.0)[c]
OR-10-26	43.3	6.0	1.34	4.14	6.2	4.5
Vijaya	43.6	4.5	1.32	3.45	7.1	4.5 (6.2)[c]
S.e. of mean	0.90	1.40	0.017		0.03	0.10

[a]Source: Rout et al 1976.
[b] $\frac{\text{ln (progeny no.)}}{\text{Mean dev. period}} \cdot 100$ (Dobie 1974).
[c]Values at IRRI for different samples of the same variety (Juliano and Pascual 1980).

intermediate (20-25%), and high (25-32%). Amylose content is related inversely to tenderness and stickiness scores of cooked milled rice (Juliano 1979).

Abraham et al (1972) reported the absence of any relationship between amylose content and infestation of rough rice by the Angoumois grain moth, but the most susceptible variety, Tainan 3, had the lowest amylose content. Chatterji et al (1977) also did not find any significant relationship between the extent of damage to rough rice by the Angoumois grain moth and amylose content, although the amylose values of the rice they used were lower than reported for high-amylose Indian varieties (Juliano and Pascual 1980). Morallo-Rejesus et al (1981) found a negative but not significant correlation between amylose content and the index of susceptibility of 15 brown rices to the rice weevil. Waxy starch granules have a lower density than nonwaxy starch granules (Juliano 1980). Verma et al (1979) reported that among six IRRI rices tested, milled rice of the low-amylose (16%) variety IR24 had a shorter developmental period, higher percentage of adult emergence, and heavier adults of the almond moth compared to five high-amylose (26-28%) IRRI rices (Table 4).

Although no absolute resistance to insects has been reported, Vohra et al (1979) found that red flour beetle larvae grew better on diets with waxy cereal starch or California milled rice flour as carbohydrate source. With a set of 16 brown rice samples, final larval weight correlated negatively with the amylose content of rice (Vohra et al 1980) (Fig. 1). A similar correlation was observed for milled rice but growth was faster on milled than on brown rice. Larval weights were highest for waxy and low-amylose rices. The data reflect the relative digestibility of raw starch granules to α-amylase (Evers and Juliano 1976).

Table 4. Relative susceptibility of brown and milled rice of IRRI varieties to almond moth[a] and their amylose and alkali spreading value.[b]

Variety name	Susceptibility based on: Mean developmental period (days)	Adult emergence (%)	Wt of adult (mg)	IRRI data[b]: Amylose content (%)	Alkali spreading value[c]
IR24	28.4	57.8	2.38	16	7 (L)
IR36	31.0	46.7	1.67	28	5 (I)
IR8	32.1	48.9	2.17	28	7 (L)
IR30	35.5	33.3	1.95	26	4 (I)
IR26	35.8	48.9	2.00	28	7 (L)
IR20	48.2	17.8	1.90	27	4 (I)
C.D. (5%)	0.38	2.04	0.077		

[a]Source: Verma et al 1979. [b]Source: Juliano and Pascual 1980. [c]Letters in parentheses are gelatinization type: L = low; I = intermediate.

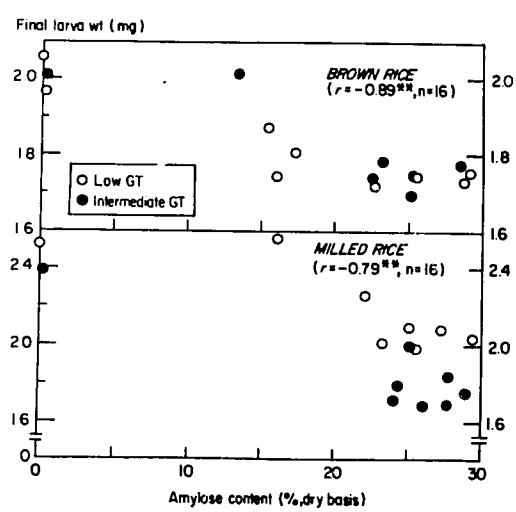

Fig. 1. Red flour beetle larvae fed rice-based diets were heavier when starch had low amylose content for both brown and milled rices (Vohra et al 1980). Growth was also faster on low-gelatinization-temperature (GT) milled rices among high-amylose samples.

Starch gelatinization temperature

Another property of starch important to grain quality is final gelatinization temperature (Juliano 1979). It represents

the temperature at which more than 95% of the starch granules have swollen irreversibly in hot water. This property varies from 55° to 80°C in rice (Juliano 1979).

Gelatinization temperature is measured in the IRRI breeding program by the alkali spreading values of Little et al (1958): low 6-7, intermediate 4-5, high-intermediate 3, and high 1-2. Alkali spreading values have been reported to correlate negatively with developmental period, progeny number, and progeny weight of rice weevil on eight brown rices (Rout et al 1976) (Table 3). But, the reported alkali values differed from data from other samples of the same varieties (Juliano and Pascual 1980) (Table 3). Alkali spreading values correlated negatively with cracking hardness of eight rices (Rout et al 1976), but contrasting correlations were obtained with different sets of samples (IRRI 1976).

Relative importance of amylose content and gelatinization temperature

In Vohra et al's study (1980), the red flour beetle larvae were fed rice as a carbohydrate source. The larvae tended to be heavier when fed intermediate- and high-amylose rices (>20%) with alkali spreading values of 6-7, than when fed similar amylose-content rices with lower alkali spreading values (Fig. 1). Although the simple correlation coefficient was not significant, partial correlation coefficient of larval weight with alkali spreading value, independent of amylose content, was 0.69** (n = 16). The correlation between alkali spreading value and index of susceptibility of 15 brown rices to rice weevils also was not significant (Morallo-Rejesus 1981). Although both factors directly affect the rate and extent of corrosion of starch granules by HCl (Maningat and Juliano 1979), amylose seems to be a more important factor affecting digestibility of rice starch granules than gelatinization temperature (Morallo-Rejesus et al 1981).

Kruerklai (1979) reported no significant correlation between indexes of susceptibility (according to Dobie 1974) of 19 Indonesian milled rices to the rice weevil and the lesser grain borer and grain properties — weight, length, width, amylose, alkali spreading value, gel consistency, and protein. Indexes of susceptibility to the two insects were not correlated. However, among 5 IRRI high-amylose varieties and Taichung Native 1, susceptibility tended to correlate with alkali spreading value of 6 to 7, except in IR26 (Table 5).

Interpretation of storage insect resistance data of U.S. varieties is complicated by the relationship between specific grain types with amylose content and gelatinization temperature. The medium-grain variety Nato (~15% amylose, gel. temp. 67°C) is more susceptible than the long-grain variety Dawn (~25% amylose, gel. temp. 73°C) in rough rice form to Angoumois grain moth (Cogburn 1974, Russell 1976), rice weevil (Cogburn 1974, 1977a), and lesser grain borer (Cogburn 1974) (Table 1); and in milled form to the confused flour beetle, the lesser grain borer, and rice weevil (McGaughey 1974). The other long-grain varieties such as Belle Patna and Bluebelle, however, were not as resistant as Dawn (Table 1).

The importance of amylose content and alkali spreading value on susceptibility of rough rice to Angoumois grain moth is also suggested by the insect data of Russell (1976) and published data on the U.S., French, and Asian rices he tested (Juliano and Pascual 1980, Suzuki and Juliano 1975, Webb 1975) (Table 6). Low-amylose rices, except Cesariot, were more susceptible to the moth than intermediate- and high-amylose rices. Varieties with alkali spreading values of 3.5-4.0, except Delta, were more resistant to the moth than those with alkali spreading values of 6.2-7.0 (low gelatinization temperature). Among the three high-amylose rices, IR8 (alkali spreading value of 7.0) was more susceptible than IR5 and Peta (alkali spreading value of 4.0).

Moisture content

High moisture content brought about by high relative humidity favors the development of high infestations of rough rice by rice weevil and lesser grain borer (Breese 1960). At >75% relative humidities, waxy rice has higher equilibrium moisture content than nonwaxy rice (Antonio and Juliano 1973, Juliano 1964). In addition, intermediate to high gelatinization temperature of starch granules con-

Table 5. Varietal resistance of milled rice to rice weevil and red flour beetle[a] and properties of the milled rice.[a,b]

Variety	Index of suceptibility[c]		100-grain wt (g)	Grain width (mm)	Milled rice analysis[b]		
	Rice weevil	Red flour beetle			Amylose (%)	Alkali spreading value	Protein (%)
IR34	11.3a	6.5ab	1.64	2.19	~28	7.0	~8
Taichung (Native) 1	8.9 bc	7.4a	1.56	2.59	28.1	6.7	6.6
IR20	8.6 bc	5.9 b	1.38	2.47	~26	~5	~9
IR36	7.5 bc	1.6 d	1.56	2.21	~28	~5	~8
IR26	6.7 c	4.4 c	1.49	2.50	~28	7.0	~8
IR32	3.7 d	1.3 d	1.47	2.18	~28	~5	~8

[a]Source: Kruerklai 1979. [b]Source: Juliano and Pascual 1980. [c]Values in the same column followed by the same letter are not significantly different from each other at 1% level by the F-test (Kruerklai 1979).

Table 6. Susceptibility of rough rice of commercial varieties to Angoumois grain moth and their milled rice properties.

Variety	Moth progeny[a] (no.)	Milled rice property		
		Amylose content (%)	Alkali spreading value	Source of data
Saturn	156a	15	6.2	Webb 1975
Eurıbe	153a	18	7.0	Juliano and Pascual 1980
Nato	146a	15	6.3	Webb 1975
IR8	121 b	28	7.0	Juliano and Pascual 1980, Suzuki and Juliano 1975
Delta	119 b	24	3.9	Webb 1975
Balilla	83 c	22	7.0	Juliano and Pascual 1980
Cesariot	80 c	18	7.0	Juliano and Pascual 1980
Labelle	67 c	25	3.5	Webb 1975
IR5	65 c	28	4.0	Juliano and Pascual 1980, Suzuki and Juliano 1975
Dawn	38 d	25	3.9	Webb 1975
Peta	27 d	29	4.0	Juliano and Pascual 1980, Suzuki and Juliano 1975

[a]Values followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test (Russell 1976).

tributes to lower equilibrium water content of steeped grains among high-amylose rices (IRRI 1980) and among intermediate-amylose and waxy rices (Merca 1980). Values range from 31 to 48% wet basis for milled rice and from 29 to 39% for brown rice.

Protein content

Protein exists in the rice endosperm in the form of single-membraned 0.5-4 μm particles called protein bodies (Juliano 1980). Protein content is higher in the bran layer than in the endosperm, but an increase in protein content is mainly an increase in the number of endosperm protein bodies. Protein bodies of the aleurone layer are morphologically different from those of the endosperm and contain globoid (phytate) inclusions. Protein content was reported to be unrelated to resistance of brown rice to rice weevil (Morallo-Rejesus et al 1981, Rout et al 1976) and of rough rice to the Angoumois grain moth (Abraham and Thomas 1969, Abraham et al 1972). By contrast, low protein content was observed to contribute to resistance of rough rice to the Angoumois grain moth but the relationship is not distinct (Chatterji et al 1977). Protein may not be a limiting nutritional factor to insect infestation and growth on rice grain.

Unlike wheat, rice does not contain an α-amylase inhibitor (IRRI 1980, Kneen and Sandstedt 1946). The rice grain, particularly the bran and embryo, however, contains protease inhibitors, which are either proteinaceous (Toshiro and Maki 1978) or phytate (Kanaya et al 1976). The presence of polyphenols in pigmented rices has not been fully investigated.

OTHER FACTORS

Cogburn (1974) found a definite nonpreference for the U.S. variety Dawn over five other varieties by the rice weevil, the lesser grain borer, and the Angoumois grain moth, which was not directly related to percentage of imperfect glumes (Table 1). Survival rates of Angoumois grain moth F_1 progeny on rough rice of 780 varieties from the United States Department of Agriculture world collection ranged from 1% to more than 82% (mean 33%) and showed a bimodal distribution pointing to the existence of more than one resistance factor (Russell and Cogburn 1976). X-ray examination and grain dissection indicated that whatever factors were operating were still affecting the young larvae before they entered the seeds. Further screening of 111 resistant varieties suggested that 37 of them showed strong indication of resistance (Cogburn 1977b). The Angoumois grain moth was reported to have varietal preference for rough rice both in the field and during laboratory storage for 2 years among 67 varieties (Kittur and Patel 1972).

Further studies on the nonpreference factors in Dawn by Cogburn (cited in Russell and Cogburn 1977) suggested that:

- brown-rice flour and rough-rice flours have significant varietal effects on larval development,
- larval survival rates are affected significantly by rough-rice flours, and
- flours of several varieties, whether rough rice or brown rice, adversely affect both development and survival.

On the other hand, Russell (cited in Russell and Cogburn 1976) using a modified Chamberlain olfactometer (Honda et al 1969a) and the Angoumois grain moth, noted that:

- rough rice arrests significantly fewer larvae than brown rice,
- varietal effects are significant whether brown or rough rice is used, and
- varietal differences are accentuated in brown rice as compared to rough rice.

With diets contributing 10% protein from yeast-soybean protein mixture, Vohra et al (1970) found slower growth of

red flour beetle on brown rice than on milled rice.

An attractant to rice weevil *S. zeamais* has been isolated from rice hull, which is acidic in nature (Honda et al 1969a,b). Subsequent studies on diethyl ether extracts of maize and rice grain showed that the attractants are present in brown and milled rice (Yamamoto et al 1976). Maize and rice bran oils also contain the attractants. Maize contains a stronger attractancy than rice probably because of its larger embryo and higher oil content. The attractants are readily extracted with diethyl ether and are present in the acidic and neutral fractions. Later studies on maize confirmed that hexanoic acid presented the major contribution to the attractancy as a single compound but γ-nonalactone and 2-phenyl ethanol had the strongest specific attraction (Yamamoto et al 1980 [?]).

Strong aroma also has been reported to be related to resistance of rough rice to the Angoumois grain moth (Chatterji et al 1977), but aroma tended to be confined to superfine-grain Indian varieties like Badshabhog and T. 412. Thus, resistance may be related to the narrow grain of the aromatic varieties rather than to aroma *per se*.

IMPLICATIONS OF RESEARCH

Storage losses are becoming more serious as more countries achieve self-sufficiency in rice production. Varietal resistance to rice storage insects is a potential means of reducing postharvest losses of the rice crop.

The importance of tight hull as a resistance factor for rough rice needs to be verified and possibly included as a breeding objective. A tight hull probably also minimizes microbial population inside the hull (brown rice surface) and improves parboiling quality of rough rice by preventing the overexpansion of the gelatinized grain. However, the contribution of tight hull to the difficulty of dehulling the grain needs to be established.

The contribution of grain hardness to varietal resistance of milled rice to storage insects is understandable. Grain hardness contributes also to higher total and head-rice yield (Juliano 1979) but hardness is difficult to measure. Additional research to fully determine the interrelationship among grain hardness, grain quality factors now routinely screened in the rice breeding program — protein and amylose contents, alkali spreading value, and gel consistency —and varietal resistance to major storage insects is needed. Such study will lead to a better appreciation of how these grain properties affect the physical properties of the endosperm, including grain hardness.

Detailed studies on the resistance factors to storage insects should preferably use pairs of sister lines differing mainly in the particular property being studied to make the results definitive.

REFERENCES CITED

Abraham, C. C., and M.J. Thomas. 1969. The relation between some grain characters and insect infestation in stored rice. Agric. Res. J. Kerala 7:130-131.

Abraham, C. C., B. Thomas, K. Karunakaran, and R. Gopalakrishnan. 1972. Relative susceptibility of different varieties of paddy to infestation by the Angoumois grain moth *Sitotroga cerealella* Olivier (Gelechiidae: Lepidoptera), as influenced by the amylose content of the endosperm. Bull. Grain Technol. 10:263-266.

Antonio, A. A., and B. O. Juliano. 1973. Amylose content and puffed volume of parboiled rice. J. Food Sci. 38:915-916.

Bhatia, S. K. 1976. Resistance to insects in stored grains. Trop. Stored Prod. Inf. 31:21-35.

Bishara, S. I., and A. Koura, and M. A. El-Halfawy. 1972. Oviposition preference of the granary and the rice weevils of the Egyptian rice varieties and recommendations for grain protection. Bull. Soc. Entomol. Egypte 56:145-150.

Breese, M. H. 1960. The infestibility of stored paddy by *Sitophilus sasakii* (Tak.) and *Rhyzopertha dominica* (F.). Bull. Entomol. Res. 51:599-630.

Chatterji, S. M., R. C. Dani, and S. Govindaswami. 1977. Evaluation of rice varieties for resistance to *Sitotroga cerealella* Oliv. (Lepidoptera:Gelechiidae). J. Entomol. Res. 1:74-77.

Cogburn, R. R. 1974. Domestic rice varieties: apparent resistance to rice weevils, lesser grain borers, and Angoumois grain moths. Environ. Entomol. 3:681-685.

Cogburn, R. R. 1977a. Susceptibility of varieties of stored rough rice to losses caused by storage insects. J. Stored Prod. Res. 13:29-34.

Cogburn, R. R. 1977b. Resistance to the Angoumois grain moth in some varieties of rough rice from the USDA world collection. J. Econ. Entomol. 70:753-754.

Cohen, L. M., and M. P. Russell. 1970. Some effects of rice varieties on the biology of the Angoumois grain moth, *Sitotroga cerealella*. Ann. Entomol. Soc. Am. 42:621-622.

Dobie, P. 1974. The laboratory assessment of the inherent susceptibility of maize varieties to post-harvest infestation by *Sitophilus zeamais* Motsch. (Coleoptera, Curculionidae). J. Stored Prod. Res. 10:183-197

Evers, A. D., and B. O. Juliano. 1976. Varietal differences in surface ultrastructure of endosperm cells and starch granules of rice. Staerke 28:160-166.

Golob, P., and F. Ashman. 1974. The effect of oil content and insecticides on insects attacking rice bran. J. Stored Prod. Res. 10:93-103.

Honda, H., I. Yamamoto, and R. Yamamoto. 1969a. Attractant for rice weevil, *Sitophilus zeamis* Motschulsky (Coleoptera: Rhynchophoridae) from rice grains. I. Bioassay method for the attractancy of rice grains to weevils. Appl. Entomol. Zool. 4:23-31.

Honda, H., I. Yamamoto, and R. Yamamoto. 1969b. Attractant for rice weevil, *Sitophilus zeamais* Motschulsky (Coleoptera:

Rhynchophoridae) from rice grains. II. Fractionation of rice grains and nature of the crude attractive fraction. Appl. Entomol. Zool. 4:32-41.

IRRI (International Rice Research Institute). 1966. Annual report 1965. Los Banos, Philippines. p. 69-77.

IRRI (International Rice Research Institute). 1980. Annual report for 1979. Los Banos, Laguna, Philippines. (in press)

Juliano, B. O. 1964. Hygroscopic equilibria of rough rice. Cereal Chem. 41:191-197.

Juliano, B. O. 1979. The chemical basis of rice grain quality. Pages 69-90 *in* International Rice Research Institute. Proceedings of the workshop on chemical aspects of rice grain quality. Los Banos, Philippines

Juliano, B. O. 1980. Properties of the rice caryopsis. Pages 403-438 *in* B. S. Luh, ed. Rice: production and utilization. Avi. Publ. Co., Inc., Westport, Connecticut.

Juliano, B. O., and C. G. Pascual. 1980. Quality characteristics of milled rice grown in different countries. IRRI Res. Pap. Ser. 48. 25 p.

Kanaya, K., K. Yasumoto, and H. Mitsuda. 1976. Pepsin inhibition by phytate contained in rice bran. Eiyo To Shokuryo 29: 341-346.

Kittur, S. U., and K. K. Patel. 1972. Preference of *Sitotroga cerealella* Oliv. to rice varieties during storage. Indian J. Agric. Sci. 42:621-622.

Kneen, E., and R. M. Sandstedt. 1946. Distribution and general properties of an amylase inhibitor in cereals. Arch. Biochem. 9:235-249.

Koura, A., M. El-Halfawy, and S. A. El-Askalany. 1967. The susceptibility of certain varieties of Egyptian rough rice *Oryza sativa* (L.) to infestation with *Sitophilus oryzae* (L.), *S. granarius* (L.) and *Rhizopertha dominica* (F.). Agric. Res. Rev. (U.A.R.) 45:67-69.

Kruerklai, W. 1979. Varietal resistance of milled rice to *Sitophilus zaemais* and *Tribolium castaneum*. Report to BIOTROP, Bogor, Indonesia.

Little, R. R., G. B. Hilder, and E. H. Dawson. 1958. Differential effect of dilute alkali on 25 varieties of milled white rice. Cereal Chem. 35:111-126.

McGaughey, W. H. 1970. Effect of degree of milling and rice variety on insect development in milled rice. J. Econ. Entomol. 63:1375-1376.

McGaughey, W. H. 1973. Resistance to the lesser grain borer in 'Dawn' and 'Labelle' varieties of rice. J. Econ. Entomol. 66:1005.

McGaughey, W. H. 1974. Insect development in milled rice: effects of variety, degree of milling, parboiling and broken kernels. J. Stored Prod. Res. 10:81-86.

Maningat, C.C., and B.O. Juliano. 1979. Properties of lintnerized starch granules from rices differing in amylose content and gelatinization temperature. Staerke 31:5-10.

Merca, F. E. 1980. Physico-chemical properties of Philippine waxy and intermediate amylose rices. Ph D dissertation, University of the Philippines at Los Banos.

Morallo-Rejesus, B., P. A. Javier, and B. O. Juliano. 1981. Properties of brown rice and varietal resistance to storage insects. J. Stored Prod. Res. (submitted for publication)

Pingale, S. V., S. B. Kadkol, M. Narayana Rao, M. Swaminathan, and V. Subrahmanyan. 1957. Effect of insect infestation on stored grain. II. Studies on husked, hand-pounded and milled raw rice, and parboiled milled rice. J. Sci. Food Agric. 8:512-516.

Raghavendra Rao, S. N., and B. O. Juliano. 1970. Effect of parboiling on some physicochemical properties of rice. J. Agric. Food Chem. 18:289-294.

Rout, G., G. Senapati, and T. Ahmed. 1976. Studies on relative susceptibility of some high yielding varieties of rice to the rice weevil, *Sitophilus oryzae* L. (Curculionidae:Coleoptera). Bull. Grain Technol. 14:34-38.

Russell, M. P. 1968. Influence of rice variety on oviposition and development of the rice weevil. *Sitophilus oryzae*, and the maize weevil, *S. zeamais*. Ann. Entomol. Soc. Am. 61:1335-1336.

Russell, M. P. 1976. Resistance of commercial rice varieties to *Sitotroga cerealella* (Olivier) (Lepidoptera:Gelechiidae). J. Stored Prod. Res. 12:105-109.

Russell M. P., and R. R. Cogburn. 1976. Host resistance to stored-products insects — I. Proc. Joint U.S. - Japan Seminar on Stored Products Insects 1976:68-76.

Russell, M. P., and R. R. Cogburn. 1977. World collection rice varieties: resistance to seed penetration by *Sitotroga cerealella* (Olivier) (Lepidoptera:Gelechiidae). J. Stored Prod. Res. 13:103-108.

Seshagiri Rao, D. 1953. The breeding of *Sitophilus oryzae* (L.) in rice. Indian J. Entomol. 15:157-159.

Sikder, H. P. 1965. Varied growth of stored-grain moth (*Sitotroga cerealella* Oliv.) as a preliminary index for using it as a test organism in estimating the quality of rice. Indian J. Agric. Sci. 35:206-209.

Suzuki, H., and B. O. Juliano. 1975. Alkaliviscogram and other properties of starch of tropical rice. Agric. Biol. Chem. 39:811-817.

Toshiro, M., and Z. Maki. 1978. Partial purification and some properties of a trypsin inhibitor from rice bran. Agric. Biol. Chem. 42:1119-1124.

Verma, S. K., G. C. Sachan, Y.S. Rathore, and M. N. Lal. 1979. Relative susceptibility of various rice varieties to almond moth, *Ephestia cautella* (Walker). Bull. Grain Technol. 17:141-143.

Vohra, P., G. Shariff, D. W. Robinson, and C. O. Qualset. 1979. Nutritional evaluation of starches, rice flours and carbohydrates using *Tribolium castaneum* larvae and chickens. Nutr. Rep. Int. 19:101-109.

Vohra, P., G. Shariff, and B. O. Juliano. 1980. Relative nutritional value of some rices for growth of *Tribolium castaneum* larvae. Qual. Plant. Plant Foods Hum. Nutr. (in press)

Webb, B. D. 1975. Cooking, processing and milling qualities of rice. Texas Agric. Exp. Stn. Res. Monogr. 4 (Six decades of rice research in Texas):97-106.

Yamamoto, I., Ohsawa, H. Honda, S. Kato, and R. Yamamoto. 1976. Attractants of rice weevil, *Sitophilus zeamais* Motschulsky, in rice and corn. Proc. U.S.-Japan Seminar on Stored Products Insects 1976:88-103.

Yamamoto, R., K. Ohsawa, H. Honda, and I. Yamamoto. 1980(?). Attractants for rice weevil, *Sitophilus zeamais* Motschulsky, isolated from corn grains. (Typescript)

The International Rice Research Institute
P.O. Box 933, Manila, Philippines

ISSN 0115-3862

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BIBLIOGRAPHIC DATA SHEET

1. CONTROL NUMBER: PN-AAJ-498

2. SUBJECT CLASSIFICATION (695): AF30-0150-0000

3. TITLE AND SUBTITLE (240)

Rice grain properties and resistance to storage insects: a review

4. PERSONAL AUTHORS (100)

Juliano, B. O.

5. CORPORATE AUTHORS (101)

IRRI

6. DOCUMENT DATE (110): 1981

7. NUMBER OF PAGES (120): 9p.

8. ARC NUMBER (170): 633.18.J94c

9. REFERENCE ORGANIZATION (130)

IRRI

10. SUPPLEMENTARY NOTES (500)

(In IRRI res. paper ser., no. 56)

11. ABSTRACT (950)

12. DESCRIPTORS (920)

Rice
Rice research
Plant physiology
Plant diseases
Plant protection
Insect control
Storage
Resistance

13. PROJECT NUMBER (150): 497019800

14. CONTRACT NO.(140): AID/492-1310-T

15. CONTRACT TYPE (140)

16. TYPE OF DOCUMENT (160)

AID 590-7 (10-79)

633.18
J94c

PN-AAJ-461

IRRI RESEARCH PAPER SERIES
Number 56 January 1981

Rice grain properties and resistance to storage insects: A review

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Rice Grain Properties and Resistance to Storage Insects: A Review[1]

ABSTRACT

The physicochemical factors contributing to rice resistance to stored-grain insects include tight hull, degree of milling, grain hardness, high amylose content and high gelatinization temperature of endosperm starch, and low moisture content. Little work has been done on attractants and repellants in bran from rices with resistance to storage insects. Insects residing in grains prefer larger, heavier-grained rice varieties.

High amylose content and, to some extent, high gelatinization temperature contribute to low grain equilibrium moisture content at relative humidities above 75%. They also contribute to poorer digestibility of raw starch granules to insect α-amylase.

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Based on the paper delivered 13 June 1980, at the Training Course on Pests of Stored Products, BIOTROP (Seameo Regional Center for Tropical Biology), Bogor, Indonesia. Submitted to the IRRI Research Paper Series Committee 14 January 1981.

Rice Grain Properties and Resistance to Storage Insects: A Review

Recent reviews (Bhatia 1976, Russell and Cogburn 1976) reflect little systematic study that correlates varietal resistance of rice to storage insect pests with physicochemical properties of the grain. Most studies have used regional samples, which represent only a fraction of the range of rice grain properties.

Comparison of insect resistance data on rice is complicated by the use of different bioassay techniques by various entomologists (Russell and Cogburn 1976). In addition, physicochemical properties of the rice varieties seldom have been analyzed simultaneously in the studies. Susceptibility indexes include developmental time of insects, number of F_1 progeny, oviposition preference, weight and length of F_1 progeny, weight loss of rice grain, and milling loss. Less variable results were achieved when eggs rather than adults were used for screening varieties (Russell 1976).

It has been estimated that infestation in commercially grown U.S. long-grain rice could be reduced to <50% if currently existing resistant rice varieties were grown (Russell and Cogburn 1976).

COVERING STRUCTURES OF RICE GRAIN

The grain of rough rice consists of the covering structures (hull or husk) and the fruit or caryopsis (brown rice).

Hull

The hull comprises 18 to 25% of the rough rice. Breese (1960) found that an intact, tight hull contributed to resistance to the rice weevil *Sitophilus oryzae* (L.) and the lesser grain borer *Rhizopertha dominica* (F.). Cohen and Russell (1970) noted that varieties with imperfect hulls had more damage by Angoumois grain moth *Sitotroga cerealella* (Olivier). Imperfect glumes contributed to susceptibility of rough rices to rice weevils (Russell 1968). Cogburn (1974) confirmed hull intactness as a resistance factor to the lesser grain borer and the Angoumois grain moth, but recognized the existence of other factors (Table 1). Hull thickness did not significantly correlate with mean percentage of damage to rough rice by the Angoumois grain moth ($r = 0.10, n = 9$) (Abraham and Thomas 1969).

Bran layers

The brown rice consists of the starchy endosperm and embryo enclosed by thick-walled bran layers of the pericarp, seed coat, nucellus, and aleurone layer (Juliano 1980). Milling removes the embryo (1-2 % of brown rice) and the bran layers. A 10% (by weight) bran-polish removal gives a well-milled endosperm (milled rice).

Brown rice and hand-pounded rice are infested by the rice weevil *Sitophilus oryzae* (L.) to a greater extent during storage than milled rice or milled parboiled rice (Bishara et al 1972, Pingale et al 1957). In addition to the rice weevil, the lesser grain borer, the confused flour beetle *Tribolium confusum* Jacquelin du Val, and the Indian mill moth *Plodia interpunctella* (Huebner) all tend to decrease in numbers with an increasing degree of milling in three rice varieties (McGaughey 1970). Similar results were obtained with four other insect species (McGaughey 1974). McGaughey (1973) reported greater progeny development of the lesser grain borer on brown rice than on rough rice or milled rice of four rice varieties.

Differences in relative susceptibilities of Egyptian rough and brown rices to rice weevils have been reported (Bishara

Table 1. Apparent susceptibility of rough rice to three insects, and rough rice and milled rice properties of six U.S. varieties.

Variety	Progeny on rough rice[b] (no.)			Rough rice			Milled rice analysis[c]		
	Rice weevil	Lesser grain borer	Angoumois grain moth	Imperfect glumes[b] (%)	Length-width[c] ratio	1000-grain wt[c] (g)	Amylose (%)	Final gel. temp. (°C)	Alkali spreading value
Calrose	21 b	146a	280a	21a	2.5	25	19	65	7.0
Nato	31a	76 cd	204 b	18ab	2.6	23	15	67	6.3
Belle Patna	48a	95 bc	168 c	14 b	3.9	22	24	73	3.6
Colusa	7 c	65 de	225 b	13 bc	2.1	30	18	66	6.5
Bluebelle	14 bc	109 b	167 c	10 c	3.9	24	24	74	3.7
Dawn	5 c	42 e	110 d	2 d	3.9	22	25	73	3.9

[a]Source: Cogburn 1974, Webb 1975. [b]Data in the same column followed by a common letter are not significantly different at the 1% level (Cogburn 1974). [c]Source: Webb 1975.

et al 1972, Koura et al 1967). Cogburn (1974) reported a similar number of F progeny on brown rice of six varieties in no-choice experiments with rice weevil, lesser grain borer, and Angoumois grain moth where rough rices showed differential responses. More progeny of the lesser grain borer developed on brown rice than on rough rice or milled rice, and the Dawn variety was more resistant than three other U.S. varieties in rough rice and milled rice forms (McGaughey 1973). Presumably the resistance factor or factors other than hull tightness do not affect oviposition rate or larval mortality but work against the young larvae before they penetrate the seed (Cogburn 1974).

The red flour beetle and the almond moth *Ephestia cautella* (Walker) are common pests of rice bran. The beetle survived on rice bran with oil contents of 0, 2.5, 5, 7.5, and 10% but mortality was greatest at 0% (Golob and Ashman 1974). The almond moth failed to survive on rice bran with 0 or 2.5% oil content and growth was retarded at 5 and 7.5% oil content. The results may reflect the insect's metabolic requirement for an external source of fat.

ENDOSPERM PROPERTIES

Dimensions and hardness

For insects, such as the rice weevil and the lesser grain borer, whose larvae inhabit the endosperm, varietal susceptibility seems to be related to grain width and weight. Sikder (1965) reported that the Angoumois grain moths reared on large-grain rice varieties were bigger than those reared on small-grain varieties. Abraham and Thomas (1969) found a positive, but not significant, correlation ($r = 0.43, n = 9$) between fineness (length-breadth ratio) and mean percentage of damage to rough rice by the same moth. Brown-rice width and weight correlated positively with the index of susceptibility (Dobie 1974) to rice weevil *Sitophilus zeamais* Motsch. (Morallo-Rejesus et al 1980) (Table 2). Seshagiri Rao (1953) found over a 6-month period that, although initially the coarse brown rice was most preferred, fine-grain milled rice was more attractive for rice weevil breeding than medium- and coarse-grain brown rices.

Grain crushing hardness of brown rice correlated positively with brown-rice resistance to rice weevil based on mean developmental period, progeny number, and progeny weight (Rout et al 1976) (Table 3). Brown-rice hardness, based on resistance to grinding (wt percentage >0.177 mm after grinding in a Wig-L-Bug amalgamator), correlated negatively with index of susceptibility (Dobie 1974) and progeny adult weight of the rice weevil (Morallo-Rejesus et al 1981) (Table 2).

Parboiling or heating wet grain at ≥100°C to gelatinize the starch without much grain expansion is known to improve milling quality and to increase grain hardness (Raghavendra Rao and Juliano 1970). McGaughey (1974) reported that parboiled milled rice was less suitable than raw milled rice (of one variety) for progeny production by seven insects including rice weevil. However, longer-term storage by Pingale et al (1957) did not show any advantage of parboiled milled rice over raw milled rice in susceptibility to infestation by rice weevil.

Starch amylose content

Milled rice consists of 90% starch and 8% protein, dry basis. Starch granules, which occur as 3-9 μm compound granules, are confined mainly to the endosperm of the mature rice grain (Juliano 1980). Starch consists of two major fractions — a branched fraction, amylopectin, and a linear fraction, amylose.

Milled rice is classified into amylose types waxy (glutinous, 0-2% amylose, dry basis) and nonwaxy (nonglutinous). The latter is further classified into low (8-20%),

Table 2. Range of properties of rice grain and susceptibility of brown rice samples to the rice weevil and their correlation coefficients.[a]

Susceptibility or grain property	Range of values	Correlation coefficients[b] with			
		Index of suscept-ibility[c]	Progeny adult Length	Progeny adult Weight	Grain loss (wt %)
Index of susceptibility[c]	10.4-15.0	1.00	0.68**	0.63*	0.47
Progeny adult length (mm)	3.8- 4.6		1.00	0.42	0.46
Progeny adult wt (mg)	1.0- 1.5			1.00	0.16
Grain loss (wt %)	1.6- 5.9				1.00
Brown rice					
Width (mm)	2.0- 2.8	0.59*	0.52	0.41	0.34
Weight (mg)	14.4-25.0	0.59*	0.74**	0.34	0.63*
Hardness (% >0.177 mm)	32.0-47.5	−0.62*	−0.41	−0.79**	−0.32
Milled rice					
Amylose content (%)	1.6-29.1	−0.38	−0.56*	−0.34	−0.12
Alkali spreading value	2.0- 7.0	−0.37	−0.03	−0.40	0.09
Protein content (%)	5.0-13.4	−0.28	−0.10	0.03	−0.01

[a]Source: Morallo-Rejesus et al 1981. [b]Significant r values: 5% = 0.514; 1% = 0.641.
[c] $\frac{\ln(\text{progeny no.})}{\text{Mean dev. period}} \times 100$ (Dobie 1974).

Table 3. Relationship between susceptibility of brown rice to the rice weevil and grain hardness and alkali spreading value of eight rice varieties.[a]

Variety	Susceptibility based on: Mean developmental period (days)	Progeny No.	Progeny Wt (mg)	Index of susceptibility[b]	Grain hardness (kg/cm²)	Alkali spreading value
Rajeswari	39.7	19.0	1.58	7.42	4.7	7.0
Padma	40.1	17.5	1.48	7.14	4.8	7.0
Hema	41.8	12.5	1.45	6.04	4.9	7.0
Kumar	42.3	11.0	1.41	5.67	5.4	6.6
Ratna	42.8	8.5	1.35	5.00	5.7	6.2 (5.6)[c]
IR8	42.4	8.5	1.34	5.05	5.8	5.1 (7.0)[c]
OR-10-26	43.3	6.0	1.34	4.14	6.2	4.5
Vijaya	43.6	4.5	1.32	3.45	7.1	4.5 (6.2)[c]
S.e. of mean	0.90	1.40	0.017		0.03	0.10

[a]Source: Rout et al 1976.
[b] $\frac{\text{ln (progeny no.)}}{\text{Mean dev. period}} \cdot 100$ (Dobie 1974).
[c]Values at IRRI for different samples of the same variety (Juliano and Pascual 1980).

intermediate (20-25%), and high (25-32%). Amylose content is related inversely to tenderness and stickiness scores of cooked milled rice (Juliano 1979).

Abraham et al (1972) reported the absence of any relationship between amylose content and infestation of rough rice by the Angoumois grain moth, but the most susceptible variety, Tainan 3, had the lowest amylose content. Chatterji et al (1977) also did not find any significant relationship between the extent of damage to rough rice by the Angoumois grain moth and amylose content, although the amylose values of the rice they used were lower than reported for high-amylose Indian varieties (Juliano and Pascual 1980). Morallo-Rejesus et al (1981) found a negative but not significant correlation between amylose content and the index of susceptibility of 15 brown rices to the rice weevil. Waxy starch granules have a lower density than nonwaxy starch granules (Juliano 1980). Verma et al (1979) reported that among six IRRI rices tested, milled rice of the low-amylose (16%) variety IR24 had a shorter developmental period, higher percentage of adult emergence, and heavier adults of the almond moth compared to five high-amylose (26-28%) IRRI rices (Table 4).

Although no absolute resistance to insects has been reported, Vohra et al (1979) found that red flour beetle larvae grew better on diets with waxy cereal starch or California milled rice flour as carbohydrate source. With a set of 16 brown rice samples, final larval weight correlated negatively with the amylose content of rice (Vohra et al 1980) (Fig. 1). A similar correlation was observed for milled rice but growth was faster on milled than on brown rice. Larval weights were highest for waxy and low-amylose rices. The data reflect the relative digestibility of raw starch granules to α-amylase (Evers and Juliano 1976).

Starch gelatinization temperature

Another property of starch important to grain quality is final gelatinization temperature (Juliano 1979). It represents

Table 4. Relative susceptibility of brown and milled rice of IRRI varieties to almond moth[a] and their amylose and alkali spreading value.[b]

Variety name	Susceptibility based on: Mean developmental period (days)	Adult emergence (%)	Wt of adult (mg)	IRRI data[b]: Amylose content (%)	Alkali spreading value[c]
IR24	28.4	57.8	2.38	16	7 (L)
IR36	31.0	46.7	1.67	28	5 (I)
IR8	32.1	48.9	2.17	28	7 (L)
IR30	35.5	33.3	1.95	26	4 (I)
IR26	35.8	48.9	2.00	28	7 (L)
IR20	48.2	17.8	1.90	27	4 (I)
C.D. (5%)	0.38	2.04	0.077		

[a]Source: Verma et al 1979. [b]Source: Juliano and Pascual 1980. [c]Letters in parentheses are gelatinization type: L = low; I = intermediate.

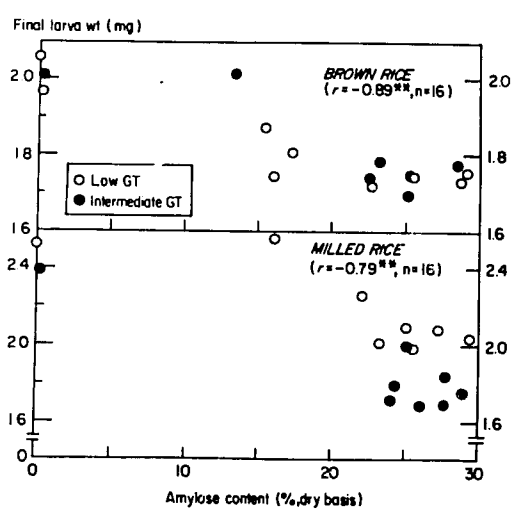

Fig. 1. Red flour beetle larvae fed rice-based diets were heavier when starch had low amylose content for both brown and milled rices (Vohra et al 1980). Growth was also faster on low-gelatinization-temperature (GT) milled rices among high-amylose samples.

the temperature at which more than 95% of the starch granules have swollen irreversibly in hot water. This property varies from 55° to 80°C in rice (Juliano 1979).

Gelatinization temperature is measured in the IRRI breeding program by the alkali spreading values of Little et al (1958): low 6-7, intermediate 4-5, high-intermediate 3, and high 1-2. Alkali spreading values have been reported to correlate negatively with developmental period, progeny number, and progeny weight of rice weevil on eight brown rices (Rout et al 1976) (Table 3). But, the reported alkali values differed from data from other samples of the same varieties (Juliano and Pascual 1980) (Table 3). Alkali spreading values correlated negatively with cracking hardness of eight rices (Rout et al 1976), but contrasting correlations were obtained with different sets of samples (IRRI 1976).

Relative importance of amylose content and gelatinization temperature

In Vohra et al's study (1980), the red flour beetle larvae were fed rice as a carbohydrate source. The larvae tended to be heavier when fed intermediate- and high-amylose rices (>20%) with alkali spreading values of 6-7, than when fed similar amylose-content rices with lower alkali spreading values (Fig. 1). Although the simple correlation coefficient was not significant, partial correlation coefficient of larval weight with alkali spreading value, independent of amylose content, was 0.69** (n = 16). The correlation between alkali spreading value and index of susceptibility of 15 brown rices to rice weevils also was not significant (Morallo-Rejesus 1981). Although both factors directly affect the rate and extent of corrosion of starch granules by HCl (Maningat and Juliano 1979), amylose seems to be a more important factor affecting digestibility of rice starch granules than gelatinization temperature (Morallo-Rejesus et al 1981).

Kruerklai (1979) reported no significant correlation between indexes of susceptibility (according to Dobie 1974) of 19 Indonesian milled rices to the rice weevil and the lesser grain borer and grain properties — weight, length, width, amylose, alkali spreading value, gel consistency, and protein. Indexes of susceptibility to the two insects were not correlated. However, among 5 IRRI high-amylose varieties and Taichung Native 1, susceptibility tended to correlate with alkali spreading value of 6 to 7, except in IR26 (Table 5).

Interpretation of storage insect resistance data of U.S. varieties is complicated by the relationship between specific grain types with amylose content and gelatinization temperature. The medium-grain variety Nato (~15% amylose, gel. temp. 67°C) is more susceptible than the long-grain variety Dawn (~25% amylose, gel. temp. 73°C) in rough rice form to Angoumois grain moth (Cogburn 1974, Russell 1976), rice weevil (Cogburn 1974, 1977a), and lesser grain borer (Cogburn 1974) (Table 1); and in milled form to the confused flour beetle, the lesser grain borer, and rice weevil (McGaughey 1974). The other long-grain varieties such as Belle Patna and Bluebelle, however, were not as resistant as Dawn (Table 1).

The importance of amylose content and alkali spreading value on susceptibility of rough rice to Angoumois grain moth is also suggested by the insect data of Russell (1976) and published data on the U.S., French, and Asian rices he tested (Juliano and Pascual 1980, Suzuki and Juliano 1975, Webb 1975) (Table 6). Low-amylose rices, except Cesariot, were more susceptible to the moth than intermediate- and high-amylose rices. Varieties with alkali spreading values of 3.5-4.0, except Delta, were more resistant to the moth than those with alkali spreading values of 6.2-7.0 (low gelatinization temperature). Among the three high-amylose rices, IR8 (alkali spreading value of 7.0) was more susceptible than IR5 and Peta (alkali spreading value of 4.0).

Moisture content

High moisture content brought about by high relative humidity favors the development of high infestations of rough rice by rice weevil and lesser grain borer (Breese 1960). At >75% relative humidities, waxy rice has higher equilibrium moisture content than nonwaxy rice (Antonio and Juliano 1973, Juliano 1964). In addition, intermediate to high gelatinization temperature of starch granules con-

Table 5. Varietal resistance of milled rice to rice weevil and red flour beetle[a] and properties of the milled rice.[a,b]

Variety	Index of suceptibility[c]		100-grain wt (g)	Grain width (mm)	Milled rice analysis[b]		
	Rice weevil	Red flour beetle			Amylose (%)	Alkali spreading value	Protein (%)
IR34	11.3a	6.5ab	1.64	2.19	~28	7.0	~8
Taichung (Native) 1	8.9 bc	7.4a	1.56	2.59	28.1	6.7	6.6
IR20	8.6 bc	5.9 b	1.38	2.47	~26	~5	~9
IR36	7.5 bc	1.6 d	1.56	2.21	~28	~5	~8
IR26	6.7 c	4.4 c	1.49	2.50	~28	7.0	~8
IR32	3.7 d	1.3 d	1.47	2.18	~28	~5	~8

[a]Source: Kruerklai 1979. [b]Source: Juliano and Pascual 1980. [c]Values in the same column followed by the same letter are not significantly different from each other at 1% level by the F-test (Kruerklai 1979).

Table 6. Susceptibility of rough rice of commercial varieties to Angoumois grain moth and their milled rice properties.

Variety	Moth progeny[a] (no.)	Milled rice property		
		Amylose content (%)	Alkali spreading value	Source of data
Saturn	156a	15	6.2	Webb 1975
Eurıbe	153a	18	7.0	Juliano and Pascual 1980
Nato	146a	15	6.3	Webb 1975
IR8	121 b	28	7.0	Juliano and Pascual 1980, Suzuki and Juliano 1975
Delta	119 b	24	3.9	Webb 1975
Balilla	83 c	22	7.0	Juliano and Pascual 1980
Cesariot	80 c	18	7.0	Juliano and Pascual 1980
Labelle	67 c	25	3.5	Webb 1975
IR5	65 c	28	4.0	Juliano and Pascual 1980, Suzuki and Juliano 1975
Dawn	38 d	25	3.9	Webb 1975
Peta	27 d	29	4.0	Juliano and Pascual 1980, Suzuki and Juliano 1975

[a]Values followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test (Russell 1976).

tributes to lower equilibrium water content of steeped grains among high-amylose rices (IRRI 1980) and among intermediate-amylose and waxy rices (Merca 1980). Values range from 31 to 48% wet basis for milled rice and from 29 to 39% for brown rice.

Protein content

Protein exists in the rice endosperm in the form of single-membraned 0.5-4 μm particles called protein bodies (Juliano 1980). Protein content is higher in the bran layer than in the endosperm, but an increase in protein content is mainly an increase in the number of endosperm protein bodies. Protein bodies of the aleurone layer are morphologically different from those of the endosperm and contain globoid (phytate) inclusions. Protein content was reported to be unrelated to resistance of brown rice to rice weevil (Morallo-Rejesus et al 1981, Rout et al 1976) and of rough rice to the Angoumois grain moth (Abraham and Thomas 1969, Abraham et al 1972). By contrast, low protein content was observed to contribute to resistance of rough rice to the Angoumois grain moth but the relationship is not distinct (Chatterji et al 1977). Protein may not be a limiting nutritional factor to insect infestation and growth on rice grain.

Unlike wheat, rice does not contain an α-amylase inhibitor (IRRI 1980, Kneen and Sandstedt 1946). The rice grain, particularly the bran and embryo, however, contains protease inhibitors, which are either proteinaceous (Toshiro and Maki 1978) or phytate (Kanaya et al 1976). The presence of polyphenols in pigmented rices has not been fully investigated.

OTHER FACTORS

Cogburn (1974) found a definite nonpreference for the U.S. variety Dawn over five other varieties by the rice weevil, the lesser grain borer, and the Angoumois grain moth, which was not directly related to percentage of imperfect glumes (Table 1). Survival rates of Angoumois grain moth F_1 progeny on rough rice of 780 varieties from the United States Department of Agriculture world collection ranged from 1% to more than 82% (mean 33%) and showed a bimodal distribution pointing to the existence of more than one resistance factor (Russell and Cogburn 1976). X-ray examination and grain dissection indicated that whatever factors were operating were still affecting the young larvae before they entered the seeds. Further screening of 111 resistant varieties suggested that 37 of them showed strong indication of resistance (Cogburn 1977b). The Angoumois grain moth was reported to have varietal preference for rough rice both in the field and during laboratory storage for 2 years among 67 varieties (Kittur and Patel 1972).

Further studies on the nonpreference factors in Dawn by Cogburn (cited in Russell and Cogburn 1977) suggested that:

- brown-rice flour and rough-rice flours have significant varietal effects on larval development,
- larval survival rates are affected significantly by rough-rice flours, and
- flours of several varieties, whether rough rice or brown rice, adversely affect both development and survival.

On the other hand, Russell (cited in Russell and Cogburn 1976) using a modified Chamberlain olfactometer (Honda et al 1969a) and the Angoumois grain moth, noted that:

- rough rice arrests significantly fewer larvae than brown rice,
- varietal effects are significant whether brown or rough rice is used, and
- varietal differences are accentuated in brown rice as compared to rough rice.

With diets contributing 10% protein from yeast-soybean protein mixture, Vohra et al (1970) found slower growth of

red flour beetle on brown rice than on milled rice.

An attractant to rice weevil *S. zeamais* has been isolated from rice hull, which is acidic in nature (Honda et al 1969a,b). Subsequent studies on diethyl ether extracts of maize and rice grain showed that the attractants are present in brown and milled rice (Yamamoto et al 1976). Maize and rice bran oils also contain the attractants. Maize contains a stronger attractancy than rice probably because of its larger embryo and higher oil content. The attractants are readily extracted with diethyl ether and are present in the acidic and neutral fractions. Later studies on maize confirmed that hexanoic acid presented the major contribution to the attractancy as a single compound but γ-nonalactone and 2-phenyl ethanol had the strongest specific attraction (Yamamoto et al 1980 [?]).

Strong aroma also has been reported to be related to resistance of rough rice to the Angoumois grain moth (Chatterji et al 1977), but aroma tended to be confined to superfine-grain Indian varieties like Badshabhog and T. 412. Thus, resistance may be related to the narrow grain of the aromatic varieties rather than to aroma *per se*.

IMPLICATIONS OF RESEARCH

Storage losses are becoming more serious as more countries achieve self-sufficiency in rice production. Varietal resistance to rice storage insects is a potential means of reducing postharvest losses of the rice crop.

The importance of tight hull as a resistance factor for rough rice needs to be verified and possibly included as a breeding objective. A tight hull probably also minimizes microbial population inside the hull (brown rice surface) and improves parboiling quality of rough rice by preventing the overexpansion of the gelatinized grain. However, the contribution of tight hull to the difficulty of dehulling the grain needs to be established.

The contribution of grain hardness to varietal resistance of milled rice to storage insects is understandable. Grain hardness contributes also to higher total and head-rice yield (Juliano 1979) but hardness is difficult to measure. Additional research to fully determine the interrelationship among grain hardness, grain quality factors now routinely screened in the rice breeding program — protein and amylose contents, alkali spreading value, and gel consistency —and varietal resistance to major storage insects is needed. Such study will lead to a better appreciation of how these grain properties affect the physical properties of the endosperm, including grain hardness.

Detailed studies on the resistance factors to storage insects should preferably use pairs of sister lines differing mainly in the particular property being studied to make the results definitive.

REFERENCES CITED

Abraham, C. C., and M.J. Thomas. 1969. The relation between some grain characters and insect infestation in stored rice. Agric. Res. J. Kerala 7:130-131.

Abraham, C. C., B. Thomas, K. Karunakaran, and R. Gopalakrishnan. 1972. Relative susceptibility of different varieties of paddy to infestation by the Angoumois grain moth *Sitotroga cerealella* Olivier (Gelechiidae: Lepidoptera), as influenced by the amylose content of the endosperm. Bull. Grain Technol. 10:263-266.

Antonio, A. A., and B. O. Juliano. 1973. Amylose content and puffed volume of parboiled rice. J. Food Sci. 38:915-916.

Bhatia, S. K. 1976. Resistance to insects in stored grains. Trop. Stored Prod. Inf. 31:21-35.

Bishara, S. I., and A. Koura, and M. A. El-Halfawy. 1972. Oviposition preference of the granary and the rice weevils of the Egyptian rice varieties and recommendations for grain protection. Bull. Soc. Entomol. Egypte 56:145-150.

Breese, M. H. 1960. The infestibility of stored paddy by *Sitophilus sasakii* (Tak.) and *Rhyzopertha dominica* (F.). Bull. Entomol. Res. 51:599-630.

Chatterji, S. M., R. C. Dani, and S. Govindaswami. 1977. Evaluation of rice varieties for resistance to *Sitotroga cerealella* Oliv. (Lepidoptera:Gelechiidae). J. Entomol. Res. 1:74-77.

Cogburn, R. R. 1974. Domestic rice varieties: apparent resistance to rice weevils, lesser grain borers, and Angoumois grain moths. Environ. Entomol. 3:681-685.

Cogburn, R. R. 1977a. Susceptibility of varieties of stored rough rice to losses caused by storage insects. J. Stored Prod. Res. 13:29-34.

Cogburn, R. R. 1977b. Resistance to the Angoumois grain moth in some varieties of rough rice from the USDA world collection. J. Econ. Entomol. 70:753-754.

Cohen, L. M., and M. P. Russell. 1970. Some effects of rice varieties on the biology of the Angoumois grain moth, *Sitotroga cerealella*. Ann. Entomol. Soc. Am. 42:621-622.

Dobie, P. 1974. The laboratory assessment of the inherent susceptibility of maize varieties to post-harvest infestation by *Sitophilus zeamais* Motsch. (Coleoptera, Curculionidae). J. Stored Prod. Res. 10:183-197

Evers, A. D., and B. O. Juliano. 1976. Varietal differences in surface ultrastructure of endosperm cells and starch granules of rice. Staerke 28:160-166.

Golob, P., and F. Ashman. 1974. The effect of oil content and insecticides on insects attacking rice bran. J. Stored Prod. Res. 10:93-103.

Honda, H., I. Yamamoto, and R. Yamamoto. 1969a. Attractant for rice weevil, *Sitophilus zeamis* Motschulsky (Coleoptera: Rhynchophoridae) from rice grains. I. Bioassay method for the attractancy of rice grains to weevils. Appl. Entomol. Zool. 4:23-31.

Honda, H., I. Yamamoto, and R. Yamamoto. 1969b. Attractant for rice weevil, *Sitophilus zeamais* Motschulsky (Coleoptera:

Rhynchophoridae) from rice grains. II. Fractionation of rice grains and nature of the crude attractive fraction. Appl. Entomol. Zool. 4:32-41.

IRRI (International Rice Research Institute). 1966. Annual report 1965. Los Banos, Philippines. p. 69-77.

IRRI (International Rice Research Institute). 1980. Annual report for 1979. Los Banos, Laguna, Philippines. (in press)

Juliano, B. O. 1964. Hygroscopic equilibria of rough rice. Cereal Chem. 41:191-197.

Juliano, B. O. 1979. The chemical basis of rice grain quality. Pages 69-90 *in* International Rice Research Institute. Proceedings of the workshop on chemical aspects of rice grain quality. Los Banos, Philippines

Juliano, B. O. 1980. Properties of the rice caryopsis. Pages 403-438 *in* B. S. Luh, ed. Rice: production and utilization. Avi. Publ. Co., Inc., Westport, Connecticut.

Juliano, B. O., and C. G. Pascual. 1980. Quality characteristics of milled rice grown in different countries. IRRI Res. Pap. Ser. 48. 25 p.

Kanaya, K., K. Yasumoto, and H. Mitsuda. 1976. Pepsin inhibition by phytate contained in rice bran. Eiyo To Shokuryo 29: 341-346.

Kittur, S. U., and K. K. Patel. 1972. Preference of *Sitotroga cerealella* Oliv. to rice varieties during storage. Indian J. Agric. Sci. 42:621-622.

Kneen, E., and R. M. Sandstedt. 1946. Distribution and general properties of an amylase inhibitor in cereals. Arch. Biochem. 9:235-249.

Koura, A., M. El-Halfawy, and S. A. El-Askalany. 1967. The susceptibility of certain varieties of Egyptian rough rice *Oryza sativa* (L.) to infestation with *Sitophilus oryzae* (L.), *S. granarius* (L.) and *Rhizopertha dominica* (F.). Agric. Res. Rev. (U.A.R.) 45:67-69.

Kruerklai, W. 1979. Varietal resistance of milled rice to *Sitophilus zaemais* and *Tribolium castaneum*. Report to BIOTROP, Bogor, Indonesia.

Little, R. R., G. B. Hilder, and E. H. Dawson. 1958. Differential effect of dilute alkali on 25 varieties of milled white rice. Cereal Chem. 35:111-126.

McGaughey, W. H. 1970. Effect of degree of milling and rice variety on insect development in milled rice. J. Econ. Entomol. 63:1375-1376.

McGaughey, W. H. 1973. Resistance to the lesser grain borer in 'Dawn' and 'Labelle' varieties of rice. J. Econ. Entomol. 66:1005.

McGaughey, W. H. 1974. Insect development in milled rice: effects of variety, degree of milling, parboiling and broken kernels. J. Stored Prod. Res. 10:81-86.

Maningat, C.C., and B.O. Juliano. 1979. Properties of lintnerized starch granules from rices differing in amylose content and gelatinization temperature. Staerke 31:5-10.

Merca, F. E. 1980. Physico-chemical properties of Philippine waxy and intermediate amylose rices. Ph D dissertation, University of the Philippines at Los Banos.

Morallo-Rejesus, B., P. A. Javier, and B. O. Juliano. 1981. Properties of brown rice and varietal resistance to storage insects. J. Stored Prod. Res. (submitted for publication)

Pingale, S. V., S. B. Kadkol, M. Narayana Rao, M. Swaminathan, and V. Subrahmanyan. 1957. Effect of insect infestation on stored grain. II. Studies on husked, hand-pounded and milled raw rice, and parboiled milled rice. J. Sci. Food Agric. 8:512-516.

Raghavendra Rao, S. N., and B. O. Juliano. 1970. Effect of parboiling on some physicochemical properties of rice. J. Agric. Food Chem. 18:289-294.

Rout, G., G. Senapati, and T. Ahmed. 1976. Studies on relative susceptibility of some high yielding varieties of rice to the rice weevil, *Sitophilus oryzae* L. (Curculionidae:Coleoptera). Bull. Grain Technol. 14:34-38.

Russell, M. P. 1968. Influence of rice variety on oviposition and development of the rice weevil. *Sitophilus oryzae*, and the maize weevil, *S. zeamais*. Ann. Entomol. Soc. Am. 61:1335-1336.

Russell, M. P. 1976. Resistance of commercial rice varieties to *Sitotroga cerealella* (Olivier) (Lepidoptera:Gelechiidae). J. Stored Prod. Res. 12:105-109.

Russell M. P., and R. R. Cogburn. 1976. Host resistance to stored-products insects — I. Proc. Joint U.S. - Japan Seminar on Stored Products Insects 1976:68-76.

Russell, M. P., and R. R. Cogburn. 1977. World collection rice varieties: resistance to seed penetration by *Sitotroga cerealella* (Olivier) (Lepidoptera:Gelechiidae). J. Stored Prod. Res. 13:103-108.

Seshagiri Rao, D. 1953. The breeding of *Sitophilus oryzae* (L.) in rice. Indian J. Entomol. 15:157-159.

Sikder, H. P. 1965. Varied growth of stored-grain moth (*Sitotroga cerealella* Oliv.) as a preliminary index for using it as a test organism in estimating the quality of rice. Indian J. Agric. Sci. 35:206-209.

Suzuki, H., and B. O. Juliano. 1975. Alkaliviscogram and other properties of starch of tropical rice. Agric. Biol. Chem. 39:811-817.

Toshiro, M., and Z. Maki. 1978. Partial purification and some properties of a trypsin inhibitor from rice bran. Agric. Biol. Chem. 42:1119-1124.

Verma, S. K., G. C. Sachan, Y.S. Rathore, and M. N. Lal. 1979. Relative susceptibility of various rice varieties to almond moth, *Ephestia cautella* (Walker). Bull. Grain Technol. 17:141-143.

Vohra, P., G. Shariff, D. W. Robinson, and C. O. Qualset. 1979. Nutritional evaluation of starches, rice flours and carbohydrates using *Tribolium castaneum* larvae and chickens. Nutr. Rep. Int. 19:101-109.

Vohra, P., G. Shariff, and B. O. Juliano. 1980. Relative nutritional value of some rices for growth of *Tribolium castaneum* larvae. Qual. Plant. Plant Foods Hum. Nutr. (in press)

Webb, B. D. 1975. Cooking, processing and milling qualities of rice. Texas Agric. Exp. Stn. Res. Monogr. 4 (Six decades of rice research in Texas):97-106.

Yamamoto, I., Ohsawa, H. Honda, S. Kato, and R. Yamamoto. 1976. Attractants of rice weevil, *Sitophilus zeamais* Motschulsky, in rice and corn. Proc. U.S.-Japan Seminar on Stored Products Insects 1976:88-103.

Yamamoto, R., K. Ohsawa, H. Honda, and I. Yamamoto. 1980(?). Attractants for rice weevil, *Sitophilus zeamais* Motschulsky, isolated from corn grains. (Typescript)

The International Rice Research Institute
P.O. Box 933, Manila, Philippines

ISSN 0115-3862

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