Loss Assessment of Stored Rice Infested by *Sitotroga cerealella* (OLIVIER) (Lepidoptera: Gelechiidae)

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Stored brown and rough rice of 2 high-yield cultivars, Shinpo-38 (Japonica type, S-38) and Nankin 11 (Indica type, N-11), were artificially infested with *Sitotroga cerealella* (OLIVIER). Losses were assessed for 13 weeks at 28°C and 70% R.H. by measuring 6 or 7 loss criteria. The criteria were adult insect number, moisture content of rice, germinability, % kernels stained by the TZ method, fat acidity value (FAV), weight of 1,000 kernels (TGM) and weight of 200-ml volume of kernels (SVW). N-11 cultivar had a thicker and more intact husk than S-38 cultivar. The moth population grew most in the rough rice of S-38 and least in that of N-11. Moisture content and FAV were not sensitive indicators of deterioration losses in the infested rice. Germinability and the TZ test effectively indicated a decline in seed quality due to infestation treatment and aging. In comparison to non-infested controls, TGM decreased by 14.3, 12.4, 6.7 and 7.5% in S-38 rough and brown rice and N-11 rough and brown rice, respectively, over 13 weeks. SVW showed slightly lower loss estimates than TGM. The loss assessment by these criteria indicated resistance of N-11 rough rice to *S. cerealella*. The properties of the loss criteria are discussed.

INTRODUCTION

Rice is stored in various forms, such as rough, brown and milled. During storage, qualitative and quantitative losses are caused by many biological, chemical and physical factors, and particularly by insects (FERKIN, 1970; SINHA, 1973). Reduction of such postharvest losses is the most efficient way to increase food availability (BOXALL, 1986; HARRIS and LINDBLAD, 1978). Establishment of rational and accurate loss assessment methods is indispensable for proper stored-grain management to prevent postharvest losses of grains.

Among the insect pests of stored rice, the Angoumois grain moth, *Sitotroga cerealella* (OLIVIER) is one of the most destructive species, especially in tropical and subtropical areas (SOON et al., 1980; SUKPRAKARN and TAUTHONG, 1981; PRAKASH et al., 1984; LIN, 1985). The grain moth deposits its eggs on grain surfaces and newly hatched larvae enter through slits or cracks in the husk and burrow into the rice kernels. Larval development is completed within the kernel. Pupation also occurs in the burrow. The adult moth emerges through a hole in the pericarp and husk, and does not feed.

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Although there is some information about *S. cerealella* rice damage, only one or 2 criteria, e.g., percentage of infested grains (SHAHJAHAN, 1974, 1975; PRAKASH et al., 1983, 1984) or grain-weight loss (SHAHJAHAN, 1974), were usually measured for loss assessment. COGBURN et al. (1983b), however, measured 6 loss criteria for rough rice infested with *S. cerealella* and *Rhizopertha dominica*. In this study, we describe quantitative and qualitative losses by *S. cerealella* in rough and brown rice of 2 high-yield Japonica and Indica type cultivars, and present several different loss assessment criteria developed in simulated tropical storage conditions.

MATERIALS AND METHODS

Insect strain. *S. cerealella* was collected in a wheat warehouse in Tsukuba and was reared on rough rice at 30°C and 70% R.H. for about one year.

Rice. Rice seeds were high-yield cultivars of a Japonica type *Oryza sativa* (L.) (cv. Shinpo 38, 1983 year crop, abbreviated as S-38) and an Indica type rice (cv. Nankin 11, 1984 year crop, abbreviated as N-11), which were stored as rough rice in a cold room at 10°C for 10 or 22 months after harvest. Half of the seeds was hulled to produce brown rice. The other half was left as rough rice. Both quantities were tempered in a growth chamber (model PR-3, Tabai Mfg. Co. Ltd., Osaka) at $28 \pm 0.3^\circ\text{C}$ and $70 \pm 0.5\%$ R.H. for 2 weeks before use.

Measurement of kernel dimensions. The length, breadth and thickness of brown rice and husk thickness of 50 randomly selected kernels from the 2 cultivars were measured by a dial-micrometer (Makinoseiki Co. Ltd., Tokyo). Three hundred kernel husks of each cultivar were examined for slits and cracks under binoculars.

Loss assessment procedures. Six-hundred ml glass bottles (10 cm dia. $\times$ 10 cm ht.) with screw lids were used. Lids were perforated with a 4 cm dia. hole which was covered with Toyo No. 5 filter paper sealed at the edge with Scotch tape for ventilation. Four groups of 25 bottles were prepared. Bottles from each of the groups were partially filled with 200 g of rough or brown rice of S-38 or N-11. Two hundred gram of S-38 rough and brown rice corresponded to ca. 7,100 and 7,750 kernels, respectively. In N-11 rice, the same quantity corresponded to ca. 7,200 and 8,900 kernels, respectively. Four male-female pairs of newly emerged *S. cerealella* adults were introduced to each of 15 bottles from each group for the moth-infested treatments. The remaining 10 bottles in each group were controls and did not receive insects. All bottles were kept in the growth chamber.

After 3, 6, 9 and 13 weeks, 2 bottles from each of the 4 control series and 3 bottles from each of the 4 treated series were taken out of the chamber, and rice losses were assessed by measuring 6 or 7 criteria. The criteria were adult moth number, moisture content of rice, germinability, % kernels stained by the TZ method, fat acidity value, weight of 1,000 kernels and weight of a 200 ml volume of kernels. These were measured as follows. The adult moths in the bottles were counted after being separated from the grains by aspiration, sieving and hand-sorting. The moisture content of rice (wet weight basis) was determined by sampling 5 g of rice and drying at 130°C for 19 hr in an air oven. For the determination of germinability, 100 randomly selected kernels were surface sterilized in 0.5% sodium hypochlorite and rinsed in distilled water. The kernels were placed on a filter paper moistened with distilled water in a Petri dish. The germinability was determined after one week of incubation at 25°C.

The TZ test (staining of germ with an aqueous 0.8% 2, 3, 5-triphenyl tetrazolium chloride; Food Agency of Japan, 1981) was performed for estimating viability of brown rice seeds. The fat acidity value (FAV) was measured by a modified method of the Food Agency of Japan (1981). For the measurement of the 1,000 kernel weight, 500 kernels were randomly selected using a grain-sampling apparatus (a board with 500 rice kernel shaped pockets) and weighed with an electronic balance (model PE360, Mettler Instrumente, Greifensee). The value was doubled and converted into the kernel weight on a standard moisture basis of 12.5% for rough rice or 14.0% for brown rice: the thousand grain mass (TGM) (BOXALL, 1986). The conversion equation was $W_s = (1 - M_o) \cdot W_o / (1 - M_s)$, where W_s was kernel weight of standard moisture content, W_o was observed kernel weight and M_s and M_o were % standard and observed moisture content divided by 100, respectively. The weight of the 200 ml volume of kernels (Food Agency of Japan, 1981) was also measured by electronic balance and converted to the standard moisture contents: standard volume weight (SVW) (BOXALL, 1986). At the beginning of the experiment, the loss criteria of the rice in each series were also measured. The number of damaged grains (which is sometimes used for a quality standard of rice as in WEBB and STERMER, 1972) was not measured, as the larvae fed inside the grains and the damage was often invisible.

Differences between the means were analyzed by the STUDENT'S *t*-test. Simple correlation analysis was performed to measure the relationships between loss criteria. Transformation of raw data ($\log_{10} n$ for the adult number and $\sin^{-1} \sqrt{p}$ for germination % and viability % by the TZ test) were made before the statistical analyses. Means were given along with S.E.s.

RESULTS

Morphological characters of seeds

The length/breadth ratio of kernels of S-38 (1.59 ± 0.009) was significantly smaller than that of N-11 (2.05 ± 0.013) ($p < 0.01$); the former was classified as short-round type and the latter as medium-bold type, according to the FAO standard (ESMAY et al., 1979). S-38 had larger variability (coefficient of variation) in all measurements of 3 kernel dimensions (length, breadth and thickness) than N-11. The husk thickness of S-38 and N-11 were 79 ± 1.7 and 96 ± 2.3 μm , respectively. The percentage of intact kernels which had no slits and cracks in the husk was 80.0 for S-38 and 96.7 for N-11.

Insect populations

The adult *S. cerealella* population increased after week 3 in all infested treatments. The greatest increase was in S-38 rough rice, in which the mean adult number at week 13 was 512.3 ± 128.1 ; the corresponding figures for N-11 and S-38 brown rice were 324.0 ± 249.5 and 132.6 ± 8.4 , respectively (Fig. 1). The development of the moth population was relatively poor on N-11 rough rice; the mean population at week 13 (10.7 ± 2.1) was significantly smaller than that in rough and brown S-38 rice ($p < 0.01$).

Changes of loss criteria

The moisture content of infested S-38 brown and rough rice increased from those of controls after week 6 (Fig. 2A). At the end of the experiment, moisture contents of

Fig. 1. The mean number of adult *S. cerealella* population on 200 g of Shinpo 38 (S-38) and Nankin 11 (N-11) rough and brown rice, stored at 28°C and 70% R.H. ●—●: S-38 rough rice, ●---●: S-38 brown rice, ▲—▲: N-11 rough rice, ▲---▲: N-11 brown rice.

Fig. 2. The mean moisture content of rice grains in control and moth-infested treatments of Shinpo 38 (A) and Nankin 11 (B) stored at 28°C and 70% R.H. ○—○: control brown rice, ●—●: infested brown rice, ○—○: control rough rice, ●—●: infested rough rice.

infested brown and rough rice were 0.25% and 1.32% higher than those of corresponding controls, respectively, and the increase in rough rice was significant ($p < 0.02$). In contrast, no significant moisture increase was observed in both N-11 brown and rough rice of control and infested groups (Fig. 2B).

The FAV continued to increase gradually during the entire storage period in all treatments (Fig. 3A, B). In control and infested S-38 brown rice the rate of increase was high during the first 3 weeks; thereafter it was gradual. The FAV increased most in S-38 brown rice (ca. 94%) and least in S-38 rough rice (ca. 58%) over 13-week storage, regardless of treatment. Although FAV in all moth-infested treatments was slightly higher than that of the corresponding controls throughout the storage period

Fig. 3. The mean fat acidity value (FAV, mg of KOH per 100 g of dry brown rice) of rice grains in control and moth-infested treatments of Shinpo 38 (A) and Nankin 11 (B) stored at 28°C and 70% R.H. ○ ○: control brown rice, ● ●: infested brown rice, ○—○: control rough rice, ●—●: infested rough rice.

Fig. 4. The mean percentage losses in 2 seed viability criteria; loss in germinability of rough and brown rice in control and moth-infested treatments of Shinpo 38 (A) and Nankin 11 (B); loss in seed viability of brown rice measured by the TZ test in control and moth-infested treatments of Shinpo 38 (C) and Nankin 11 (D). ○ ○: control brown rice, ● ●: infested brown rice, ○—○: control rough rice, ●—●: infested rough rice.

Fig. 5. The mean percentage losses in 2 kernel-weight criteria; loss in weight of 1,000-kernels (TGM) of rough and brown rice in control and moth-infested treatments of Shinpo 38 (A) and Nankin 11 (B); loss in weight of a 200-ml volume of kernels (SVW) of rough and brown rice in control and moth-infested treatments of Shinpo 38 (C) and Nankin 11 (D).
 ○ ○: control brown rice, ● ●: infested brown rice, ○—○: control rough rice, ●—●: infested rough rice.

of weeks 3–13, only the difference between the means in N-11 brown rice at week 13 was significant ($p < 0.05$).

Figure 4 shows the changes in quality losses assessed by 2 seed viability measures. The losses were expressed as reduction percentages in each measurement from the initial value at week 0. The initial mean germinabilities in S-38 rough and brown rice (Fig. 4A) were 93.7 and 92.0%, respectively, and those of N-11 (Fig. 4B) were 91.0 and 90.3%, respectively. The reduction rate in germinability accelerated after week 6 in all treatments including the controls. However, the mean germinabilities of the infested treatments at week 9 and 13 in S-38 rice and those at week 13 in N-11 rice were significantly lower than those of the corresponding controls ($p < 0.01$). The control rice of both cultivars lost about 50% of its initial germinability at the end of experiment. The loss in infested S-38 rough and brown rice and N-11 brown rice was more than 90% at week 13. The reduction of seed viability assessed by the TZ test was also observed in the control and infested brown rice of both cultivars (Fig. 4C, D). Seed viability was evidently reduced more in the infested treatments than in the controls.

Figure 5 shows the changes of 2 criteria which represent quantitative losses of rice. The losses were expressed as reduction percentage from the initial value at week 0. The initial mean TGM in S-38 (Fig. 5A) was 28.4 ± 0.1 g for rough rice and 26.0 ± 0.2 g for brown rice and that in N-11 (Fig. 5B) was 27.2 ± 0.4 g for rough rice and 22.8 ± 0.1 g for brown rice. The TGM dropped significantly ($p < 0.01$) below that of the cor-

responding controls after 9 weeks in all infested treatments, except in N-11 rough rice, in which significant reduction appeared at week 13 (Fig. 5A, B). S-38 rough and brown rice lost 19.9 and 20.8% of the initial kernel weight over 13 weeks, respectively, whereas the loss in TGM in N-11 was 7.2% in rough rice and 13.5% in brown rice. The controls also lost some kernel weight. The initial mean SVWs were 96.9 ± 0.1 and 149.3 ± 2.1 g, in S-38 rough and brown rice, respectively (Fig. 5C), and 110.6 ± 2.0 and 150.9 ± 2.1 g in N-11 rough and brown rice, respectively (Fig. 5D). The SVW loss was negligible in the controls. Much heavier losses occurred in infested S-38 rice than in N-11 rice over 13-week storage.

DISCUSSION

HARUKAWA and KUMASHIRO (1935) reported that the shortest developmental period of this moth on wheat was 23 days at 28°C. Increase of adult population in all infested treatments at week 6 apparently corresponds to the 1st generation. In this study, the moth was allowed to develop at least three generations on the rice in 13 weeks. The reduction or large variation in the moth number in S-38 and N-11 brown rice at week 13 may be due to unsuitableness of brown rice as a medium for the growth of moth population. PRAKASH et al. (1979) reported that *S. cerealella* laid fewer eggs on brown rice than on rough rice of several cultivars, and that no adults emerged from the former.

Increases in moisture content during weeks 0–3 were possibly due to the fact that the 2-week tempering was not enough for the moisture's equilibration. Figure 2 indicates that moth population growth affected the rice moisture content in all infested treatments to a certain degree. With the exception of S-38 rough rice, moisture contents were nevertheless poorly correlated with other measures (Table 2, 3), indicating that changes of moisture content are not always parallel with those of other loss measures, particularly when an insect population density is low. SITTISUANG and IMURA (1987) reported a similar result in rice infested with other stored product insects.

The increase in FAV was dependent not on the moth infestation but on the varietal difference, the presence of husk and the storage period. Therefore the FAV may not be a sensitive indicator of rice deterioration by *S. cerealella* infestation, at least when the adult population density is less than 500 per 200 g rice. Probably, the rise of excessive temperature and/or moisture in grains caused by insect growth is necessary for further increases of FAV in infested rice (COGBURN et al., 1983b; IMURA and SINHA, 1984). The high correlations of FAV with seed viability and kernel weight measures in the controls (Table 1, 2) suggest that the increase in FAV reflects the degradation of rice due to aging.

The reduction in germinability of the control seeds was due to aging which occurred under a relatively high temperature and humidity condition. Feeding by the moth larvae on germ and endosperm of rice was responsible for the drastic loss of germinability in the infested rice. IMURA and SINHA (1984) also reported that wheat seed infested with *S. cerealella* lost almost all of its germinability in 15 weeks at 28°C and 60% R.H. The changes of seed viability loss measured by the TZ test were similar to those of the germinability loss, and these 2 measures were highly correlated with each other in both S-38 and N-11 ($p < 0.01$; Table 2). Therefore, the TZ test must be a reliable measure for simple estimation of seed viability, although it gives slightly smaller

Table 1. Correlation matrices between loss criteria measured in controls and moth-infested treatments for brown rice of Shinpo 38 and Nankin 11

Treatment ^a	Criterion ^b	C1.	C2.	C3.	C4.	C5.	C6.	C7.	Criterion ^b	Treatment ^a
Shinpo 38, Brown rice, Control	C1. Mo.	1.000	-.515*	-.384	.583*	.358	-.464	.557*	C1. Mo.	Shinpo 38, Brown rice, Infested
	C2. Ge.	-.152	1.000	.944**	-.713**	.838**	.918**	-.901**	C2. Ge.	
	C3. Tz.	-.029	.935**	1.000	-.886**	.894**	.921**	.502	C3. Tz.	
	C4. Fa.	.699*	-.700*	-.638*	1.000	-.868**	-.492	.541*	C4. Fa.	
	C5. W1.	-.769**	.568	.405	-.868**	1.000	.701**	-.708**	C5. W1.	
	C6. W2.	-.263	.256	.305	-.197	.218	1.000	-.928**	C6. W2.	
								1.000	C7. In.	
Nankin 11, Brown rice, Control	Criterion ^b	C1.	C2.	C3.	C4.	C5.	C6.	C7.	Criterion ^b	Treatment ^a
	C1. Mo.	1.000	-.079	-.138	.282	-.095	.304	-.046	C1. Mo.	Nankin 11, Brown rice, Infested
	C2. Ge.	-.343	1.000	.971**	-.915**	.972**	.702**	-.865**	C2. Ge.	
	C3. Tz.	-.434	.970**	1.000	-.961**	.974**	.569*	-.787**	C3. Tz.	
	C4. Fa.	.619	-.709*	-.825**	1.000	-.953**	-.464	.756**	C4. Fa.	
	C5. W1.	-.525	.705*	.769**	-.878**	1.000	.660**	-.841**	C5. W1.	
	C6. W2.	-.056	.409*	.349	-.441	.542	1.000	-.717**	C6. W2.	
								1.000	C7. In.	

^a Correlation coefficients under the diagonal line marked by 1.000 correspond to those for controls. Coefficients above this line correspond to moth-infested treatments.

^b Criterion Mo. indicates % moisture content, Ge. % germination, Tz. % kernels stained by the TZ method, Fa. fat acidity value, W1. weight of 1,000 kernels, W2. weight of kernels of 200-ml volume, and In. adult number.

* Significant at 5% level, and ** at 1% level; d.f. is 8, and 13 for controls and moth infestations, respectively.

Table 2. Correlation matrices between criteria measured in controls and moth-infested treatments for rough rice of Shinpo 38 and Nankin 11

Treatment ^a	Criterion ^b	C1.	C2.	C3.	C4.	C5.	C6.	Criterion ^b	Treatment ^a
Shinpo 38, Rough rice, Control,	C1. Mo.	1.000	-.831**	.812**	-.699**	-.772**	.813**	C1. Mo.	Shinpo 38, Rough rice, Infested,
	C2. Ge.	-.250	1.000	-.892**	.837**	.907**	-.942**	C2. Ge.	
	C3. Fa.	.640**	-.858**	1.000	-.813**	-.776*	.809**	C3. Fa.	
	C4. W1.	-.757**	.706*	-.932**	1.000	.605*	-.822**	C4. W1.	
	C5. W2.	-.404	.612	-.651*	.747*	1.000	-.875**	C5. W2.	
							1.000	C6. In.	
Nankin 11, Rough rice, Control	C1. Mo.	1.000	.335	-.250	.164	.002	.040	C1. Mo.	Nankin 11, Rough rice, Infested
	C2. Ge.	-.194	1.000	-.848**	.826**	.748**	-.402	C2. Ge.	
	C3. Fa.	.219	-.804**	1.000	-.799**	-.760**	.603*	C3. Fa.	
	C4. W1.	.092	-.066	.349	1.000	.719**	-.473	C4. W1.	
	C5. W2.	-.087	.333	-.180	-.327	1.000	-.403	C5. W2.	
							1.000	C6. In.	

See Table 1 for footnotes.

loss estimates than germinability. These 2 criteria were also highly correlated with insect number and other quality and quantity loss criteria in the infested rice (Tables 1, 2) indicating these criteria as proper tools for loss assessment.

The marked reduction of TGM of S-38 at week 3 was presumably due to a sampling error; the initial kernel weight at week 0 was possibly overestimated because heavier kernels were trapped on the grain-sampling board (as stated above S-38 has larger variation in kernel size than N-11). Consequently, the subsequent loss estimates for S-38 may be overestimated. To avoid this kind of error, the measured value obtained simultaneously in the control, instead of the initial value, can be used as a baseline for the loss due to insect infestation. The loss in TGM at week 13 measured by this method was 14.3 and 12.4% in S-38 rough and brown rice, respectively and 6.7 and 7.5% in those of N-11, respectively. As in the seed viability criteria, the changes of the losses assessed by the 2 kernel weight criteria (TGM and SVW) were similar, and these criteria had significantly high correlations ($p < 0.01$; Table 1, 2) with each other in most of the infested treatments. The TGM was, however, a more sensitive loss criteria than the SVW, although GOLOB (1981) reported that the former gave consistently lower loss estimates than the latter in the maize damaged by *Sitophilus* species. Moreover the TGM method gave higher loss estimates in brown rice than in rough rice, and the SVW method gave the reverse result. The damaged brown rice grains packed more closely than the undamaged grains, leading to underestimation of the loss. The SVW method is therefore more reliable for assessing losses in rough rice than in brown rice.

Overall, it may be concluded that among criteria measured, moisture content is not a sensitive indicator of damage in rice; FAV is not always a proper standard of loss in rice quality caused by insects; and seed viability criteria and the kernel-weight criteria are effective for detecting losses in the moth-infested rice, although each criteria gives a different degree of loss estimate from others.

The moth population dynamics and the losses assessed by those criteria indicated that the N-11 rough rice was fairly resistant to *S. cerealella* infestation, while that of S-38 was susceptible. Among the 2 cultivars, N-11 had a thicker and more intact husk than S-38. Such husk characteristics must be responsible for the resistance of N-11 to *S. cerealella* infestation (COHEN and RUSSELL, 1970; COGBURN, 1974; COGBURN et al., 1983a), although PRAKASH et al. (1979) stated that the shape of rice grains is also a resistance factor. N-11 rough rice was also almost immune to the infestations by *Ephestia cautella*, *Tribolium castaneum*, *Sitophilus oryzae* and *Rhyzopertha dominica* (SITTISUANG and IMURA, 1987). The breeding and screening of resistant rice cultivars such as N-11 should be effective in preventing postharvest losses from insect infestations.

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