Lethal and Sublethal Effects of Rice Polishing Process on *Sitophilus oryzae* (Coleoptera: Curculionidae)

ÉRIC LUCAS AND JORDI RIUDAVETS

Departament de Protecció Vegetal, Institut de Recerca i Tecnologia Agroalimentàries, Centre de Cabrils, E-08348 Cabrils (Barcelona), Spain

J. Econ. Entomol. 93(6): 1837–1841 (2000)

ABSTRACT The mechanical impact of rice polishing on the rice weevil, *Sitophilus oryzae* (L.), and the subsequent postpolishing effects associated with rice quality were studied. "Brown" rice (not polished), "White (infest then polish)" rice, and "White (polish then infest)" rice were used with different polishing process intensities and different initial weevil densities. Weevil progeny were more numerous in Brown than in White (infest then polish) or White (polish then infest) rice. Polishing corresponding to a weight loss of 11% in rice generated an immediate mortality of ≈40%; the subsequent mortality caused by rice quality was also 40% (total >80%). A polishing process corresponding to 14 and 16% of rice weight loss generated a drastic mortality in the weevil population (>95%). The progeny per adult weevil was similar with high and low initial weevil densities. The development of weevil progeny was also delayed by about 1 wk in White (infest then polish) rice compared with Brown rice. Furthermore, weevil adults of the progeny were significantly heavier in Brown than in White (infest then polish) or White (polish then infest) rice.

KEY WORDS *Sitophilus oryzae*, rice polishing, whitening, mechanical action, rice weevil

DURING THE CONVENTIONAL polishing process, rice should lose at least 10% of its initial weight (International Organization for Standardization 1984), although in practice losses are higher. Kernels are rubbed, lose their pericarp layer, and become white. White rice thus differs from brown rice both morphologically (kernel dimensions, proportions of broken kernels) and biochemically (elimination of germ and pericarp layer), and consequently in its sensibility to insect pests.

The rice weevil, *Sitophilus oryzae* (L.) is one of the major coleopteran pest of stored white and brown rice (Beckett et al. 1994). Adult weevils feed on rice and females lay their eggs inside rice kernels, where the larva develops to the adult stage (Arbogast 1991). Several studies have shown the effects of the rice polishing on its subsequent susceptibility to the rice weevil. In choice tests, weevils showed a feeding and ovipositing preference for brown over white rice (Pingale et al. 1957, Ryoo and Cho 1992). Reproductivity was also higher and the developmental period was shorter in brown rice (McGaughey 1974, Singh 1981, Cho et al. 1988) and an increase in polishing reduced rice suitability to the weevil (McGaughey 1974). Moreover, mortality decreased in the presence of mixed white and brown rice compared with only white rice, specifically during the first instar (Ryoo and Cho 1992, Haryadi and Fleurat-Lessard 1994). Finally, as shown in *Triticum* spp., by removing germ and pericarp layers, polishing made the grain less attractive for the weevils (Trematerra et al. 1999). Despite exhaustive studies on postpolishing effects, the direct impact of polishing on rice weevils already present in the grain is poorly known. Eggs of the weevils are laid near the grain surface (Steffan 1963, Estellé 1998) and would thus be especially vulnerable to polishing. This study aims to evaluate the mechanical impact of rice polishing on rice weevils and the subsequent postpolishing effects associated with rice quality.

Materials and Methods

Insects were originally collected from storage areas around Barcelona (Spain). *S. oryzae* was reared on polished rice from 1997 at 25 ± 1°C, 70 ± 10% RH, and a photoperiod of 16:8 (L:D) h. The experiments were conducted in a climatic chamber in the same conditions. The experimental arenas were ventilated, 0.5-liter glass jars containing 83 g of rice (mixed cultivar 'Senia' and cultivar 'Bahia') (≈3,260 kernels). Adults weevils (1,280 adults per kilogram unless otherwise stated) were added and allowed to ovoposit for 7 d. They were then removed with a 2.0-mm sieve. When required, rice was polished using a laboratory polisher (Universal Brevetto 65378, vertical type, A. Guid'etti, Italy).

Three experiments were carried out according to rice type, duration of polishing process, and degree of weevil infestation. In the first, three types of rice were used: "Brown" (not polished), "White (infest then polish)" (weevil infestation before polishing, weight loss of 11%), and "White (polish then infest)" (commercial white rice polished before weevil infestation,

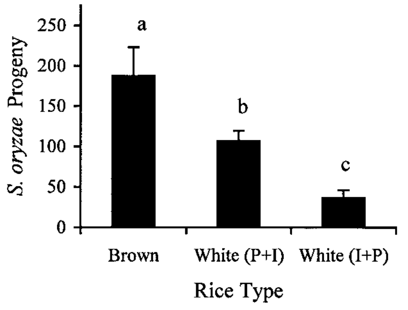

Fig. 1. Total *S. oryzae* progeny emerged from "Brown," "White (P+I)" (polish then infest) and "White (I+P)" (infest then polish) rice. Different letters indicate a significant difference between treatments (Tukey, $n = 12$, $P < 0.05$).

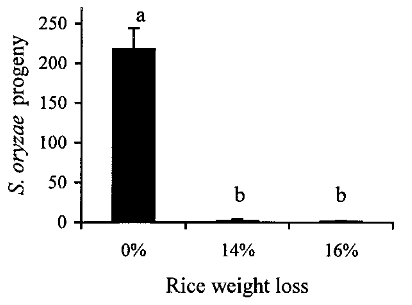

Fig. 2. Total *S. oryzae* progeny emerged during 9 wk in relation to rice weight loss during polishing process. Different letters indicate a significant difference between treatments (Tukey, $n = 15$, $P < 0.05$).

weight loss of >10%). Emerging weevil progeny were counted and removed weekly for 6 wk (4-9 wk after weevil introduction). Twelve replicates were carried out. The total weevil progeny were compared using one-way analysis of variance (ANOVA) and subsequent posthoc Tukey tests (SAS Institute 1996). A Bartlett test was applied to the results, to test variance homogeneity, and data were log-transformed when necessary (Sokal and Rohlf 1981). During 5 wk, three samples of emerging weevils from each treatment were weighed and individual weights were also compared using one-way ANOVA.

The second experiment included three treatments corresponding to different polishing intensities: a rice weight loss of 0% (Brown rice), of 14% (11.6 g), and of 16% (13.6 g). Weevil progeny were counted and removed as in the previous experiment. Fifteen replicates were carried out, and the total weevil progeny were compared using one-way ANOVA.

The third experiment included two initial weevil density, a low (410 adults per kilogram) and a high (1,280 adults per kilogram), and two rice types, Brown and White (infest then polish) (corresponding to 11% of rice weight lost). Weevil progeny were also counted and removed weekly as in the previous experiments. The development of weevil progeny occurring during the 9 wk was compared, according to rice type and initial weevil density. Twelve to 15 replicates were performed for each treatment.

Results

Effect of the Polishing Process on Weevil Progeny Density. Weevil progeny collected from White (infest then polish), White (polish then infest), and Brown rice differed significantly ($F = 181.39$; df = 3, 33; $P < 0.0001$) (Fig. 1). The polishing of the infested white rice ("White" [infest then polish]) produced a drastic decrease of >80% in *S. oryzae* survival. Weevil populations in the White (polish then infest) grain, which did not suffer the mechanical effects of polishing, showed a decrease of >40%. Then, comparing White (infest then polish) and White (polish then infest) weevil populations, the mechanical effect of polishing was ≈40%.

Sitophilus oryzae progeny mortality increased significantly with the intensity of the polishing ($F = 461.43$; df = 2, 41; $P < 0.0001$) (Fig. 2). A mean of 218.00 *S. oryzae* emerged from Brown rice (0% of rice weight lost). With 14% of rice weight lost, 98.9% of the weevils were killed and 13% of the samples ($n = 2/15$) of 83 g did not contain any *S. oryzae.* With 16% of rice weight lost, 99.5% of the weevils were killed and 40% of the samples ($n = 6/15$) did not contain any weevil.

The final weevil progeny density was higher in the high-initial weevil density treatment (389.9 ± 57.4 adults per 83 g) than in the low-initial density (112.0 ± 81.1 adults per 83 g) ($F = 104.11$; df = 1, 25; $P < 0.0001$). However, the numbers of emerged weevils per initial adult were not statistically different between high (0.91 ± 0.05 emerging adult/initial adult) and low-density treatments (1.08 ± 0.08 emerging adult/initial adult) ($F = 3.75$; df = 1, 25; $P = 0.0641$).

Effect of the Polishing Process on Weevil Development. Both low and high density experiments demonstrated a delay in *S. oryzae* development in White (infest then polish) rice compared with Brown (Fig. 3). The emergence of *S. oryzae* occurred from 1 to 2 wk later in White (infest then polish) rice. Furthermore, the emergence appeared to be more concentrated in Brown rice (≈90% of emergence in 2 wk) than in White (infest then polish).

Effect of the Polishing Process on Weevil Weight. Weevils emerging from Brown rice (1.93 mg ± 0.06) were heavier (>25%) than those emerging from White (polish then infest) (1.50 mg ± 0.04) and White (infest then polish) (1.49 mg ± 0.05) ($F = 20.45$; df = 2, 25; $P < 0.0001$) (Fig. 4). No difference was observed between weevils that were introduced before polishing, "White (infest then polish)," and those introduced after, "White (polish then infest)."

Discussion

In our study, the polishing process and the subsequent postpolishing effects had drastic lethal and sublethal effects on *S. oryzae.* Polishing was applied when most weevils were at the egg phase of development. As eggs are very close to the kernel surface (Estellé 1998), they were very vulnerable. The vulnerability of

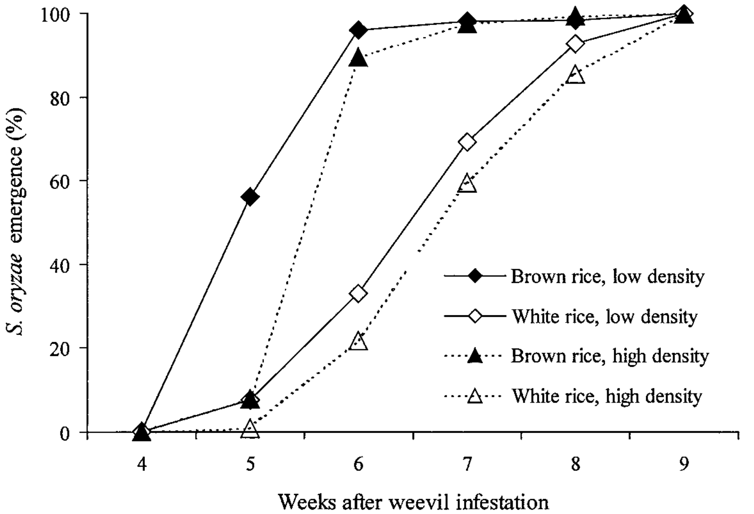

Fig. 3. Cumulative emergence of *S. oryzae* collected weekly from "Brown" and "White" (infest then polish) rice in relation to initial weevil density (low density, 410 adults per kilogram; high density, 1,280 adults per kilogram) (n = 12-15).

adult weevils was not investigated, but should also be very high, according to the principle of the technique. Although it was not evaluated, the larva may be less susceptible because it lives inside the kernels. Then, in a practical point of view, the polishing process will have a maximum impact if it occurs before egg hatch (before 6-7 d at 25°C, Hill 1990).

The subsequent postpolishing effect on weevil development confirms the previous results in the literature concerning the poor suitability of white rice for the weevil (McGaughey 1970, 1974; Ryoo and Cho 1992; Haryadi and Fleurat-Lessard 1994). According to our results, the polishing effect itself killed ≈40% of weevil individuals, and the subsequent postpolishing process another 40%. Furthermore, surviving weevils suffered a significant weight loss, which should reduce fecundity (Hespenheide 1973, Scriber and Slansky 1981). The impact of polishing on progeny production per initial adult was similar at low and high initial weevil density. This means that at high density, the

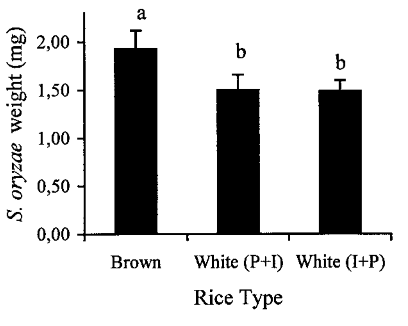

Fig. 4. Individual weight of *S. oryzae* progeny collected from "Brown," "White (P+I)" (polish then infest) and "White (I+P)" (infest then polish) rice. Different letters indicate a significant difference between treatments (Tukey, $n = 15, P < 0.05$).

mortality caused by the polishing process was not associated with competitive factors.

Because the main method of control of the rice weevil is based on methyl bromide fumigation, which should be abandoned to preserve the ozone layer (Banks 1994), it is important to investigate alternative methods. The polishing process conducted in this study was similar to those used in the industry (International Organization for Standarization 1984). Hence, it may be interesting to evaluate the effects of higher and lower intensities of polishing on weevils fitness and the associated costs to select an optimal level of pest control and economical gain. Nevertheless, this mechanical control could not be applied to brown rice, or to "golden rice," because the rice weight loss during its polishing process is only 1 % (Tainsh and Bursey 1982), which would be insufficient to destroy most of the weevil eggs.

Given the great reproductive power of a *Sitophilus* female (Hill 1990) and the low tolerance in industry for insect infestation, the mechanical control of the polishing process should be used in association with another means of control. The process appears to be compatible with most other control techniques, except previous biological control, because natural enemies also suffer from the polishing process. The potential of pre- and postpolishing biological control is currently being investigated in our laboratory, using two pteromalid parasitoids, *Anisopteromalus calandrae* (Howard) and *Lariophagus distinguendus* (Förster) (Riudavets and Lucas 2000). The female of the weevil chews a hole in the kernel, lays the egg inside, and then seals the hole with a gelatinous secretion (Arbogast 1991). This hardened secretion protects the egg. As the polishing process rubs the rice kernels, it should damage or destroy this protection, and consequently change the susceptibility to parasitism. Also, as the polishing process slows the weevil development, it should extend the period of weevil larval suitability to parasitism.

The polishing process may also affect other pest species. The maize weevil, *S. zeamais* Motsch. and the granary weevil, *S. granarius* (L.), have a very similar bioecology to *S. oryzae* and thus should be similarly affected. The mechanical process should particularly affect adult pests and other external-feeding stages. Further studies should evaluate the susceptibility of other pest species, especially those with intra-kernel stages. Besides physically destroying the eggs, by turning the grain the process can also disturb the pest. Other mechanical control methods, including the simple turning of the grain or the "Entoleter" (centrifugation and mechanical shocks) killed a high percentage of insects including weevils inside cereal kernels (Steffan 1963, Fields and Muir 1996).

Although rice polishing is detrimental for weevils, it reduces the susceptibility of rice to the pyralids *Plodia interpunctella* (Hübner) and *Ephestia (Cadra) cautella* (Walker), the anobiid *Lasioderma serricorne* (F.), the tenebrionids *Tribolium confusum* Jacquelin duVal and *T. castaneum* (Herbst), the bostrichid *Rhyzopertha dominica* (F.) and the silvanid *Oryzaephilus surinamensis* (L.) (McGaughey 1970, 1974).

Finally, the type of polishing process (cone or cylinder, horizontal or vertical), the duration, and the variety of rice used may also influence the polishing and postpolishing susceptibility of pests. Kernel pre- and postpolishing size and proportion of broken kernels affect the grain attraction and susceptibility to pest infestation (Steffan 1963, McGaughey 1974, Stejskal and Kucerova 1996, Trematerra et al. 1999). As an example, female weevils select intact wheat kernels for laying eggs when facing a mixture of intact and damaged ones because an irruption outside of the grain during the digging process of the larva could lead to its death (Steffan 1963).

Acknowledgments

We thank R. Gabarra and J. Arnó for their helpful suggestions and M. P. Hernández, V. Muñoz, and M. Montero for their technical assistance. This research was financially supported by SE Carburos Metalicos S.A. and by postdoc scholarships from the Comissionat per a Universitats i Recerca of the Generalitat de Catalunya and from the Fonds pour la Formation de Chercheurs et l'Aide à la Recherche du Québec to É.L.

References Cited

Arbogast, R. T. 1991. Beetles: Coleoptera, pp. 131-176. *In* J. R. Gorham [ed.], Ecology and management of food-industry pests. Association of Official Analytical Chemists, Arlington, VA.

Banks, H. J. 1994. Fumigation—an endangered technology? pp. 2-6. *In* E. Highley, E. J. Wright, H. J. Banks and B. R. Champ [ed.], Proceedings, 6th International Workshop and Conference on Stored-Product Protection. CAB, Wallingford, UK.

Beckett, S. J., B. C. Longstaff, and D. E. Evans. 1994. A comparison of the demography of four major stored grain coleopteran pest species and its implications for pest management, pp. 491-497. *In* E. Highley, E. J. Wright, H. J. Banks and B. R. Champ [eds.], Proceedings, 6th International Workshop and Conference on Stored-Product Protection. CAB, Wallingford, UK.

Cho, K. J., M. I. Ryoo, and S. Y. Kim. 1988. Life table statistics of the rice weevil (Coleoptera: Curculionidae) in relation to the preference for rough, brown and polished rice. Korean J. Entomol. 18: 1-6.

Estellé E. 1998. Estudi de la supervivancia dels ous del coleopter plaga *Sitophilus oryzae* als processos industrials de blanquejat de l'arros i d'obtencio de farines de cereals. T.F.C. Universitat de Vic, Vic, Spain.

Fields, P. G., and W. E. Muir. 1996. Physical Control, pp. 195-222. *In* B. Subramanyam and D. W. Hagstrum [eds.], Integrated management of insects in stored products. Marcel Dekker, New York.

Haryadi, Y., and F. Fleurat-Lessard. 1994. factors affecting survival and development of *Sitophilus oryzae* (L.) in rice grain pericarp layers, pp. 525-527. *In* E. Highley, E. J. Wright, H. J. Banks and B. R. Champ [eds.], Proceedings, 6th International Workshop and Conference on Stored-Product Protection. CAB, Wallingford, UK.

Hespenheide, H. A. 1973. Ecological inferences from morphological data. Annu. Rev. Ecol. Syst. 4: 213-229.

Hill, D. S. 1990. Pests of stored products and their control. CRC, Boston, MA.

International Organization for Standardization. 1984. Rice determination of the yield of husked rice and milled rice 1-3. ISO6646. ISO, Geneva, Switzerland.

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. 1974. Insect development in milled rice: effect of variety, degree of milling, parboiling and split kernels. J. Stored Prod. Res. 10: 81-88.

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

Riudavets, J., and É. Lucas. 2000 Biological control of *Sitophilus oryzae* (Coleoptera: Curculionidae) and combined effect with polishing process. Bulletin of the International Organization for Biological and Integrated Control of Noxious Animals and Plants, West Palaeartic Regional Section 22, Gheut, Belgium (in press).

Ryoo, M. I., and Cho H.W. 1992. Feeding and oviposition preferences and demography of rice weevil (Coleoptera: Curculionidae) reared on mixtures of brown, polished and rough rice. Environ. Entomol. 21: 549-555.

SAS Institute. 1996. JMP In, version 3.2. SAS Institute, Cary, NC.

Scriber, J. M., and F. Slansky, Jr. 1981. The nutritional ecology of immature insects. Annu. Rev. Entomol. 26: 183-211.

Singh, K. 1981. Influence of milled rice on insect infestation: II- Developmental period and productivity of *Sitophilus oryzae* Linn. and *Tribolium castaneum* Herbst in milled rice. Z. Angew. Entomol. 92: 472-477.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry: the principles and practice of statistics in biological research, 2nd ed. Freeman, New York.

Steffan, J. R. 1963. Les calandres des grains (Sitophilus), pp. 1070-1099. *In* A. S. Balachowsky [ed.], Entomologie appliquée à l'agriculture, Tome 1, vol. 2. Masson et Comp, Paris.

Stejskal, V., and Z. Kucerova. 1996. The effect of grain size on the biology of *Sitophilus granarius* L. (Col., Curculionidae). I. Oviposition, distribution of eggs and adult emergence. J. Appl. Entomol. 120: 143-146.

Tainsh, J.A.R., and E. C. Bursey. 1982. Golden rice, the mean between brown and white rice. World Crops 34: 68-69.

Trematerra, P., F. Fontana, M. Mancini, and A. Sciarretta. 1999. Influence of intact and damaged cereal kernels on the behaviour of rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). J. Stored Prod. Res. 35: 265-276.

Received for publication 6 January 2000; accepted 30 July 2000.