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Feeding Preference and Development of *Sitophilus oryzae* L. on Organic and Inorganic Rice Cultivation

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ABSTRACT

This study examined the preferences and development of *Sitophilus oryzae* on different organic and inorganic rice varieties by free-choice and no-choice tests. Feeding preference was assessed by the total adult present, no. of female adult present, and the percentage of weight loss. The development was assessed by the numbers of eggs, larvae, pupae, and adults, the period of eggs, larvae, and pupae, the total development time, larval growth index, growth index, and biotic potential. The free-choice test showed that the total adult present, female present, and the percentage of weight loss were higher on inorganic rice than on organic rice of either the Shinta Nur or IR-64 variety. The no-choice test showed that the numbers of eggs, larvae, pupae, and adults were higher on inorganic rice than on both varieties of organic rice. The period of eggs, larvae, and pupae and the total development time were shorter on inorganic rice than on organic rice. The larval growth index, growth index, and biotic potential were higher on inorganic rice than on organic rice varieties. Organic rice had high levels of phenolic, amylose, and carbohydrates, but smaller seed size and lower protein levels and ash was preferred less compared with inorganic rice of both varieties.

INTRODUCTION

Rice (*Oryza sativa*) is the most important staple food in Indonesia. Post-harvest rice is stored as paddy, brown, or polished rice. During storage, rice can be infested by several insect pests, such as *Sitophilus oryzae, S. zeamais, Sitotroga cerealella, Rhyzopertha dominica, Tribolium castaneum,* and *Oryzaephilus surinamensis* (Astuti, Mudjiono, Rasminah, & Rahardjo, 2013b; Devi, Thomas, Rebijith, & Ramamurthy, 2017; Hagstrum, Flinn, & Howard, 1995; Mansoor-ul-Hasan et al., 2017; Trematerra, 2009). According to the Head of Logistic Bureu (Bulog) of East Java, Indonesia, annual grain loss caused by insect infestation during storage is approximately 10%–25% (Astuti, Mudjiono, Rasminah, & Rahardjo, 2013b). In developing countries, product loss is approximately 10% (Buzby, Wells, & Hyman, 2014) and grain loss is between 20% and 50% (Adam, Phillips, & Flinn, 2006; Phillips & Throne, 2010). Infestation of *S. oryzae* reduces the quantity and quality through weight loss, broken grain, dust, and increases in free fatty acids, and facilitates the establishment of secondary stored product pathogens (Trematerra, Valente, Athanassiou, & Kavallieratos, 2007).

S. oryzae is the most destructive species that is widely spread in warm, tropical, and sub-tropical zones (Antunes et al., 2016; Devi, Thomas, Rebijith, & Ramamurthy, 2017; Hagstrum, Flinn, & Howard, 1995; Mansoor-ul-Hasan et al., 2017). It grows and develops on rice, maize, wheat, and sorghum (Athié & de Paulo, 2002; Rossetto, 1969). Athanassiou et al. (2008) reported that the name does not mean that rice is the most suitable host for development. Barbhuiya & Kar (2002) reported differences in the preferences of *S. oryzae* for rice, wheat, maize, and sorghum. The different preferences are associated with the physical and biochemical characteristics of the grain (Astuti, Mudjiono, Rasminah, & Rahardjo, 2013a; 2013b; Khan & Halder, 2012; Antunes et al., 2016). Physical characteristics include kernel hardness and the width of the grain. Biochemical

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characteristics include high phenol, amylose, and carbohydrate contents and lower starch, ash, and protein contents (Antunes et al., 2016; Astuti, Mudjiono, Rasminah, & Rahardjo, 2013a; 2013b).

Given consumer demands for healthy food free of chemical and pesticide residues, some researchers have developed varieties of rice that are resistant to insect attacks using organic fertilizer and no pesticide applied as an organic system. Jennings, Coffman, & Kauffman (1979) reported that rice quality can be influenced genetic and environmental conditions and processing techniques. Pest management on stored grain can be accomplished by modifying the biotic factor component through genetic development and cultivation methods to modify the physical and chemical characteristics of the grain (Nadeem, Hamed, & Shafique, 2011; da Silva Costa et al., 2016; Su, Adam, Arthur, Lusk, & Meullenet, 2019). This study examined the preferences and development of *S. Oryzae* on some method of cultivation, i.e. organic and inorganic, using two rice varieties and free-choice and no-choice tests.

MATERIALS AND METHODS

The experiment was conducted in the Plant Pest Laboratory of the Department of Plant Pests and Diseases, Agriculture Faculty, Universitas Brawijaya, Malang, Indonesia from September 2014 to January 2015. The temperature of laboratory was kept at 27 ± 2 ℃ with a relative humidity of 60 ± 5% humidity. The study was conducting using free-choice and no-choice tests.

The feeding preference (free-choice) test involved inorganic and organic rice in two varieties, i.e., Shinta Nur and IR-64. Treatment was arranged by a randomized complete-block design that was replicated five times. The experiment was carried out by placing 30 g of rice on each treatment into a chamber-of-preference cage, after which 30 mating pairs of *S. oryzae* aged between 1 and 2 weeks were placed into the cage. Insect infestation was accomplished by releasing the insects into the center of the preference cage to provide an equal chance for each treatment to be chosen as a host by *S. oryzae*. Adult *S. oryzae* were removed from the preference cage 1 week after infestation. Rice infested with *S. oryzae* eggs on each treatment combination were transferred into glass tubes (7 cm tall, Ø 4.5 cm) and wrapped in gauze until F1 progeny emerged. The observed variables were the total number of adult insects (male and female) present and the number of female adult insects present 1 week after infestation. The percentage of weight loss was observed at the end of the experiment.

The second experiment (no-choice test) used two different cultivations of inorganic and organic rice as in the first experiment. The no-choice test was carried out by filling each glass jar (7 cm tall, Ø 4.5 cm) with 30 g of each rice variety according to the treatment. Each jar was infested by 15 mating pairs of adult *S. oryzae* between 1 and 2 weeks old and wrapped in gauze. Sterilization and water content of the rice, and *S. oryzae* insects used in this experiment were the same as in the first experiment. This experiment used a completely randomized design repeated five times. Adult insects of *S. oryzae* were removed after 1 week of infestation. Eggs on the infested rice were incubated until F1 progeny emerged. The observed variables were the numbers of insect eggs, larvae, pupae, and F1 progeny that emerged, and the life cycle of *S. oryzae*. The number of adult insects was calculated after all F1 progeny had emerged.

The formula of larval growth index (LGI) was determined by Itoyama, Kawahira, Murata, & Tojo (1999), and Pretorius (1976); the growth index (GI) by Howe (1971), Kumawat (2007), and Shires (1979); and the biotic potential (BP) by Din, Ashraf, Hussain, Iqbal, & Hussain (2018).

$$LGI = \frac{l_x}{L} \quad \text{...(1)}$$

where l_x is survival rate of larvae and L is larvae period

$$GI = \frac{\text{Log } f}{D} \times 100 \quad \text{..(2)}$$

where Log f is the percentage of adult insect emerged and D is developing time from egg to adult insect

$$BP = \frac{\text{Log Fecundity}}{\text{Log Development Time}} \quad \text{.............................(3)}$$

where development time is larvae duration and pupae duration.

The recorded data were analyzed by analysis of variance and the treatment means were compared by least significant difference at a 5% significance level. The correlation analyses on various variables between the variables of *S. oryzae* preference and biochemical characteristics were examined using the Pearson correlation coefficient (Steel & Torrie, 1980).

RESULTS AND DISCUSSION

Based on the free-choice test, there was a significant difference between the two different varieties of rice tested in the total number (male and female) of adult insects present, the number of female adult insects present, and the percentage of weight loss (Table 1). The total number of adult insects present was higher on inorganic rice than on organic rice of either the Shinta Nur or IR-64 variety. The total number of adult insects present was higher on Shinta Nur inorganic rice (24.60 individuals) than on Shinta Nur organic rice (11.00 individuals). The total number of adult insects present on inorganic IR-64 rice was 17.80 individuals compared with 6.60 individual on the organic IR-64 rice. The presence of female indicated that inorganic Shinta Nur rice was more attractive (5.60 individuals) compared with organic Shinta Nur rice. Furthermore, the number of females present on inorganic IR-64 rice was higher (4.22 individuals) compared with organic IR-64 rice (1.5 individuals). The preference of *S. oryzae* can also be seen in the percentage of weight loss, which was higher for Shinta Nur inorganic rice (11.8%) compared with organic Shinta Nur rice (5.60%). The percentage of weight loss was also higher for inorganic IR-64 rice (8.80%) compared with the organic variety (3.60%).

In the no-choice test, the numbers of eggs laid, larvae, pupae, and F1 progeny showed a significant different between inorganic and organic cultivations on the two different varieties tested. Table 2 shows that the number of eggs on inorganic Shinta Nur rice was higher (123 eggs) than on organic Shinta Nur rice (86.4 eggs). Similarly, the number of eggs on inorganic IR-64 rice was higher (96.80 eggs) than on organic IR-64 rice (54.40 eggs). Furthermore, the numbers of larvae, pupae, and F1 progeny that emerged on inorganic rice were higher than those for organic cultivations of either the Shinta Nur or IR-64 variety.

The development period of eggs, larvae, and pupae, and the total duration of development (egg to adult) were shorter on inorganic cultivations of either Shinta Nur or IR-64 varieties (Table 3). The period of eggs on inorganic Shinta Nur rice was shorter (2.80 days) than on organic rice (3.60 days). The period of larvae on inorganic IR-64 rice was also shorter (3.40 days) than on organic rice (4.20 days). The pupae period on inorganic Shinta Nur varieties was also shorter (7.60 days) compared with organic cultivation (8.20 days). The pupae period on inorganic IR-64 varieties was shorter (6.40 days) than on organic cultivation (8.80 days). The total duration of *S. oryzae* development on inorganic Shinta Nur varieties was shorter (25.80 days) than organic cultivation (29.60 days). A similar result showed the total duration of development for inorganic IR-64 rice was shorter (27.20 days) than for the organic variety (31.40 days).

Table 1. Mean number of total adult insects (male and female) present ($\bar{X} \pm SE$), number of female adult insects present ($\bar{X} \pm SE$), and the percentage of weight loss ($\bar{X} \pm SE$) of two rice varieties with different cultivations in a free-choice test

Variables	Shinta Nur Varieties		IR-64 Varieties	
	Inorganic	Organic	Inorganic	Organic
Adult Insect Total (No)	24.60 ± 0.51a	11.00 ± 0.71c	17.80 ± 0.58b	6.60 ± 0.51d
Female Adult Insect (No)	5.60 ± 0.31a	3.80 ± 0.83b	4.22 ± 0.73b	1.50 ± 0.84c
Weight Loss (%)	11.80 ± 0.80a	5.60 ± 0.40c	8.80 ± 0.37b	3.60 ± 0.40d

Remarks: The mean at the same row followed by the same letters are not significantly different ($p < 0.05$)

Table 2. Mean number of eggs ($\bar{X} \pm SE$), number of larvae ($\bar{X} \pm SE$), number of pupae ($\bar{X} \pm SE$), and number of F1 progeny ($\bar{X} \pm SE$) of *S. oryzae* of two varieties with different cultivations in a no-choice test

Variables	Shinta Nur varieties		IR-64 varieties	
	Inorganic	Organic	Inorganic	Organic
Number of eggs	123.00 ± 1.14a	86.40 ± 0.93c	96.80 ± 0.80b	54.40 ± 0.93d
Number of larvae	78.20 ± 0.86a	59.60 ± 0.93c	64.60 ± 0.75b	36.20 ± 0.73d
Number of pupae	74.40 ± 0.60a	57.20 ± 1.24c	62.60 ± 0.93b	34.00 ± 0.71d
Number of F1 progeny	55.20 ± 0.66a	44.60 ± 0.75c	48.20 ± 0.73b	28.40 ± 0.75d

Remarks: The mean at the same row followed by the same letters are not significantly different ($p < 0.05$)

Table 3. Mean of eggs period ($\bar{X} \pm SE$), larvae period ($\bar{X} \pm SE$), pupae period ($\bar{X} \pm SE$), and total duration of development ($\bar{X} \pm SE$) of *S. oryzae* on two varieties with different cultivation in the no-choice test

Variables	Shinta Nur varieties		IR-64 varieties	
	Inorganic	Organic	Inorganic	Organic
Egg period	2.80 ± 0.37b	3.60 ± 0.24b	3.40 ± 0.24b	4.20 ± 0.37a
Larvae	14.20 ± 0.66b	17.80 ± 0.49a	17.00 ± 0.45a	18.40 ± 0.24a
Pupae	6.40 ± 0.24c	8.20 ± 0.20a	7.60 ± 0.24b	8.80 ± 0.37a
Total duration (egg to adult)	25.80 ± 0.37d	29.60 ± 0.24b	27.20 ± 0.37c	31.40 ± 0.40a

Remarks: The means at the same row followed by the same letters are not significantly different ($p < 0.05$)

Table 4. Mean of larvae growth index ($\bar{X} \pm SE$), growth index ($\bar{X} \pm SE$), and biotic potential ($\bar{X} \pm SE$) of *S. oryzae* on two varieties with different cultivations on the no-choice test

Variables	Shinta Nur varieties		IR-64 varieties	
	Inorganic	Organic	Inorganic	Organic
Larvae growth index	0.045 ± 0.001c	0.038 ± 0.0003b	0.038 ± 0.0002b	0.034 ± 0.001a
Growth index	0.063 ± 0.0008a	0.057 ± 0.0005b	0.061 ± 0.0007a	0.054 ± 0.0005c
Biotic potential	1.57 ± 0.016a	1.36 ± 0.008b	1.44 ± 0.010a	1.20 ± 0.007c

Remarks: The mean at the same row followed by the same letters is not significantly different ($p < 0.05$)

Table 4 shows that the LGI, GI, and BP of *S. oryzae* on inorganic rice were higher than on organic Shinta Nur and IR-64 varieties. The LGI on inorganic Shinta Nur rice (0.045) was also higher than on the organic variety (0.038). Similarly, the LGI on inorganic IR-64 cultivation (0.038) was higher than on organic rice (0.04). Furthermore, the GI on inorganic Shinta Nur rice (0.063) was higher than on organic cultivation (0.057). The GI on inorganic cultivation (0.061) was similarly higher than on organic cultivation (0.054).

Results for the BP of *S. oryzae* were similar to those for LGI and GI. The BP of the two varieties tested on inorganic cultivation was higher than those tested on organic rive. These results demonstrate that *S. oryzae* preferred inorganic rice to organic, and inorganic rice was more susceptible to *S. oryzae* than was organic rice.

The results of the free-choice test shows a significant different between treatments on the total number (male and female) insects present, the number of females present, and the percentage of weight loss. *S. oryzae* preferred inorganic rice to organic rice of either Shinta Nur or IR-64 varieties. The results of the no-choice test also showed a high and significant number of eggs, larvae, pupae, and F1 progeny in inorganic rice compared with organic rice, either on Shinta Nur or IR-64 varieties. However, the period of eggs, larvae, and pupae, and the total duration (egg to adult insect) on inorganic rice was significantly lower than for organic cultivation, either on Shinta Nur or IR-64 varieties. Furthermore, the LGI, GI, and BP results show that the growth of *S. oryzae* was faster on inorganic rice than on organic rice in the case of both Shinta Nur and IR-64 varieties. Those results demonstrate that *S. oryzae* develops faster on inorganic than organic rice of both Shinta Nur and IR-64 varieties.

This revealed different physical and biochemical characteristics of inorganic and organic cultivation and rice varieties. Some of the physical and biochemical properties of inorganic and organic rice of Shinta Nur and IR-64 varieties are presented in Table 5. Inorganic kernels are softer than those of organic rice, and the inorganic seed (measured by a thousand of kernel weight) is larger than the seed of organic rice in both Shinta Nur and IR-64 varieties. The phenol, amylose, and carbohydrate contents are lower in inorganic rice than in organic rice of varieties tested. However, the ash and protein content of inorganic rice is higher than those of organic rice for both varieties. Those results are in line with Bagchi et al. (2016), Gangmei & George (2017), Gharieb, Metwally, Abou-Khadrah, Glela, & El Sabagh (2017), and Paule, Gomez, Juliano, & Coffman (1979), as inorganic rice has a softer kernel and lower phenol and carbohydrate content, while organic rice has lower ash and protein contents. Ingver, Tamm, & Tamm (2008) reported that inorganic barley and wheat have larger seeds and higher protein contents compared with organic grains.

This study found a negative correlation between the physical properties of grain, such as kernel hardness, and insect preference, as measured by weight loss percentage (r = −0.785), number of F1 emerged (r = −0.773), LGI (r = −0.708), GI (r = −0.729), and BP (r = −0.731). These results mean that softer kernels were preferred by *S. oryzae*. However, a positive correlation was found between the size of kernels and *S. oryzae* preference: larger kernels were preferred to smaller ones. A positive correlation between the size of rice kernel and susceptibility parameter due to the attacking of *Sitophilus* sp. was also reported by Akhter, Sultana, Akter, & Begum (2018), and Stejskal, Kučerová, & Lukáš (2004), who concluded that weevils prefer larger seeds for oviposition purposes. The larger seed was more parasitized and contained more eggs. This results are also in line with those of Nadeem, Hamed, & Shafique (2011), who reported a significant positive correlation between rice kernel size and susceptibility parameters due to attacks of *R. dominica.* Kernel hardness and susceptibility of wheat show a significant negative correlation (Shafique, Ahmad, & Chaudry, 2006). According to Antunes et al. (2016), damage in the husks of rice was correlated with lower hardness, making it more attractive to *S. oryzae* compared with undamaged husks. Furthermore, the same authors reported that paddy kernels with undamaged husks of rice were resistant to weevil attack. Astuti, Mudjiono, Rasminah, & Rahardjo (2013a), (2013b), Demissie, Swaminathan, Ameta, Jain, & Saharan (2015), and Khan & Halder (2012) reported that the susceptibility of rice against stored pests can be affected by a combination of the physical and biochemical properties of rice.

A correlation analysis between the biochemical properties and preference (susceptibility) parameters of percentage of weight loss, number of F1 progeny emerged, LGI, GI, and BP showed that variables including phenol, amylase, and carbohydrate contents have a significant negative correlation (Table 6).

Table 5. Grain characteristics of Shinta Nur and IR-64 rice varieties in inorganic and organic cultivations

Characteristics	Shinta Nur varieties		IR-64 varieties	
	Organic	Inorganic	Organic	Inorganic
Hardness	126.465 ±1.035	122.225 ± 0.805	149.165 ±1.065	141.95 ± 0.62
Thousand of kernel weight (g)	26.05 ± 0.15	27.00 ± 0.20	25.30 ± 0.10	26.80 ± 0.10
Phenol content	13.50 ± 0.40	11.75 ± 0.55	19.70 ± 0.70	17.85 ± 0.85
Protein content	6.425 ± 0.175	7.5 ± 0.3	6.625 ± 0.125	7.065 ± 0.135
Carbohydrate content	77.85 ± 0.35	75.80 ± 0.70	79.25 ± 0.05	77.50 ± 0.30
Amylase content	18.60 ± 0.10	17.85 ± 0.25	25.75 ± 0.25	24.35 ± 0.15
Ash content	0.53 ± 0.02	0.7 ± 0.05	0.38 ± 0.03	0.535 ± 0.035

Table 6. The matrix of correlation coefficient between physicochemical characteristics of rice and the percentage of weight loss, F1 progeny emerged, total development time, larval growth index (LGI), growth index (GI), and biotic potential (BP) of S. *oryzae***.**

Physicochemical characteristics	Percentage of weight loss	F1 progeny emerged	Total development time	Larvae growth index	Growth index	Biotic potential
Hardness	−0.785*	−0.773*	0.734*	−0.708*	−0.729*	−0.731*
Thousand of kernel weight (g)	0.898*	0.897*	−0.934*	0.802*	0.823*	0.934*
Phenol content	−0.773*	−0.737*	−0.789	−0.779*	−0.786*	−0.718*
Protein content	0.733*	0.787*	−0.467	0.895*	0.582	0.806*
Carbohydrate content	−0.951*	−0.946*	0.907*	−0.817*	−0.859*	−0.940*
Amylose content	−0.714*	−0.793*	0.443	−0.764*	−0.744*	−0.748*
Ash content	0.911*	0.910*	−0.774	0.883*	0.802*	0.914*

Remarks: * show significances

However, protein and ash contents showed a significant positive correlation with percentage of weight loss, F1 progeny emerged, LGI, GI, and BP. These results are consistent with those of several previous studies (Nadeem, Hamed, & Shafique, 2011; da Silva Costa et al., 2016) that found negative correlations between phenolic, carbohydrate, and amylase content and susceptibility of rice. Reports by Astuti, Mudjiono, Rasminah, & Rahardjo (2013a), (2013b), Demissie, Swaminathan, Ameta, Jain, & Saharan (2015), and Yadu, Saxena, & Dubey (2000) show that susceptibility of rice is positively correlated with ash and protein content.

CONCLUSION

Organic rice was preferred less than inorganic rice of either Shinta Nur or IR-64 varieties. Physical properties such as hardness and kernel seed size, and biochemical properties such as phenol, ash, protein, carbohydrate, and amylose contents have an effect on the preference of *S. oryzae*. Negative correlations are evident between hardness, phenol, carbohydrate, and amylose contents and the preference of *S. oryzae* as measured by percentage of weight loss, F1 progeny emerged, LGI, GI, and BP. However, these physical and biochemical properties are positively correlated with total development times of *S. oryzae.* Seed size as indicated by the weight of a thousand kernel and protein and ash contents are positively correlated with those preference parameters, with the exception of development time, which shows a negative correlation.

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