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Original Article

Susceptibility of aromatic rice (*Oryza sativa* L.) varieties to *Sitophilus oryzae* L. (Coleoptera: Curculionidae)

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Abstract

Aromatic rice varieties and grain types differ in their susceptibility to a *Sitophilus oryzae* attack during storage. Nine aromatic rice varieties (RD 6, RD 105, Chai Nat 2, RD 15, Dok Pa-yom, Nhang Mon S-4, Hom Ubon 80, RD 12, and R 258) were evaluated for their relative susceptibility to *S. oryzae*. ANOVA analysis of the results revealed that varieties R 258, Nhang Mon S-4, and RD 12 have a higher tolerance to *S. oryzae* infestation, while RD 6, RD 15, and Dok Pa-yom possess intermediate tolerance. Varieties RD 105, Hom Ubon 80, and Chai Nat 2 demonstrated less tolerance to *S. oryzae*. Egg oviposition, emerged adults, seed weight loss, damage incidence, and susceptibility index were significantly ($p \leq 0.05$) lower (9.71, 27.77, 4.23 g, 0.61, and 4.97, respectively) in R 258. The longest developmental period, 28.38 days was also found in R 258. Standardized multiple regression coefficients analysis showed that varietal susceptibility strongly dependent on the number of eggs laid and the developmental period. Interspecific crossing of R 258 to RD 12 and Nhang Mon S-4 is recommended to improve their resistance. High storage protection will be required for RD 105, Hom Ubon 80, and Chai Nat 2 to preserve grain quality.

Keywords: aromatic rice, insect pest infestation, *Sitophilus oryzae*, susceptibility, resistance

1. Introduction

Thai aromatic rice (*Oryza sativa*) locally known as *Hom Mali* rice forms the parental line of the most distributed glutinous and non-glutinous rice varieties across the country (Bureau of Rice Research and Development, 2010). Aromatic rice has gained global popularity among consumers due to its fragrance taste and high market price (Bhattacharjee, Singhal, & Kulkami, 2002; Qiu, & Zhang, 2003). Thailand dominates the world in the production and export of aromatic rice. Statistically, Thailand exports over 8,000 m tonnes of rice annually (Prasertsri, 2012), which makes rice the major agricultural crop in the country. Rice quality is specified on characteristics, such as grain size, as well as chemical and physicochemical properties (Soontrunnarudrungsri, Chambers, Oupadissakoon, & Chambers, 2014), which influences the marketability and price. Therefore, the quality of rice both in the field and after harvest is very important. But most Hom Mali rice varieties generally grown are said to have less to no resistance to biotic stresses (Pusadee, Jamjod, Chiang, Rerkasem, & Schaal, 2009; Soontrunnarudrungsri *et al.*, 2014). This prompted the Bureau of Rice Research and Development to release new varieties (RD 6, RD 105, Chai Nat 2, RD 15, Dok Pa-yom, Nhang Mon S-4, Hom Ubon 80, RD 12, and R 258) after interspecific crossing with other varieties to combine useful traits for stress tolerance. At present, over 400,000 ha of these new varieties are under production nationwide. Neighbouring countries like Laos, Cambodia, and Myanmar have adopted some of these varieties for production as well.

Most of these new genotypes are claimed to have a disease and pest resistance, tolerate drought and weed

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competition with higher grain yield over their *O. sativa* parents (Govindaraj, Vetriventhan and Srinivasan, 2015; Pusadee *et al*., 2009; Pusadee, Oupkaew, Rerkasem, Jamjod, & Schaal, 2014). Notwithstanding, the sustainable cultivation of these varieties in the agro-ecologies of Thailand is still hampered by storage insect pest infestation.

According to Ashamo (2006), about 800 species of insects infest rice both on the field and at storage. Insect pests such as *Sitophilus oryzae*, *S. zeamais*, *Rhizopertha dominica*, and *Sitotroga cereallela* infest rice grains at storage and in distribution. Predominantly, *S. oryzae* causes severe economic damages through quantitative and qualitative losses, and seed viability loss (Ashamo, 2006; Prasertsri, 2012). The invasion of milled rice threatens the rice food chain and leads to huge losses as eight months of infestation makes the grains unfit for human consumption (Prakash, Rao, Pasalu and Mathur, 1987). *S. oryzae* often invades the seeds in the field before it is harvested, and can multiply rapidly, causing serious damages and loss by directly feeding on grains, and also stimulating fungi contamination. Shivakoti and Manandhar (2000) reported a lifetime daily grain consumption and waste product production of 0.49 mg and 11-12 mg for this insect. Banerjee and Nazimuddin (1985) mentioned that a single *S. oryzae* insect can cause 57% grain damage loss, while Joshi, Karmacharya and Khadge (1991) reported 15% yearly storage grain loss. To worsen the situation, external infesters which under normal conditions cannot infest sound seeds can do so due to the damages caused by *S. oryzae* larva. The control of this insect pest is essential to save seed viability, food energy, nutritional value, and produce marketability at future dates. However, though chemical control measures such as fumigants and protectants exist for this insect pest, due to the associated health and environmental risks coupled with their high price and product scarcity on local markets, the approach is unsustainable (Astuti, 2019; Wangspa, Chanbang, & Vearasilp, 2015). The search for resistant/tolerant rice varieties against *S. oryzae* has become necessary due to the need to decrease the over-dependence on chemical pesticides. Previous efforts to assess these varieties to *S. oryzae* infestation were focused at the field level. Since the aim of most rice breeding programs is on grain quality protecting the quality after harvest is very crucial to reduce post-harvest losses (Juliano, & Duff, 1991).

Thailand is one of the most significant and unique countries for aromatic rice genetic resources and diversity (Harakotr, Prompoh, Boonyuen, Suriham, & Lertrat, 2019; Londo, Chiang, Hung, Chiang, & Schaal, 2006), hence the characterization of local varieties and landrace collections are critical for efficient resources utilization. Varieties and grain types differ in their susceptibility to attack by stored product pests (Bamaiyi, Dike, & Amd, 2007; Bostan, & Naeem, 2002; Landang, Ngamo, Ngassoum, Mapongmestsem, & Hance, 2008). The assessment of these varieties will provide an opportunity for rice breeders to select and improve new cultivars for *S. oryzae* tolerance. In light of this, the study aims to investigate the relative susceptibility of nine aromatic rice varieties to *S. oryzae* infestation and damage.

2. Materials and Methods

2.1 Experimental location and materials

The study was performed at the Udon Thani Rice Research Center, Thailand, located at 17.3673° N, 102.5830° E. Seeds of nine different aromatic rice varieties were sourced from the Seed Department while Adult *S. oryzae* parental stock was obtained from the Entomology Department. Table 1 gives a detailed description of the nine varieties. Seeds were oven sterilized at 70 ºC for 1 hr in glass jars to kill any available pathogen. The temperature used was in line with Qaisrania and Banks (2000) who proposed the prospects of heat disinfestations of *S. oryzae*, *R. Dominica*, and *S. cereallela* for grains. The seeds were afterwards calibrated to room temperature and stored for the test. Grain length, grain width, amylose content, alkali spreading value, and 1,000 seed-weight were measure for each variety. Grain length and width were measured with a vernier caliper. Amylose content was determined by the spectrophotometry method (Avaro, Pan, Yoshida, & Wada, 2011) and the alkali spreading value was determined by spreading rice in an alkali solution (Tuaño, Ricafort and del Rosario, 2018). A thousand seeds were randomly counted and weighed for each variety as 1,000 seed-weight.

2.2 Rearing of test insects

Choice and non-choice test weevils were produced. The non-choice production method was adopted (Swella, & Mushobozy, 2009). The parental *S. oryzae* adults were mass bred in a growth chamber on 1,500 g rice seeds under an ambient temperature and relative humidity of 28 ± 2 °C and 75 ± 5%, respectively. Fifty pairs of the emerged F1 progenies

Table 1. Description of test varieties

Varieties	Type	Grain length (mm)	Grain width (mm)	Paddy color	Amylose content (%)	Alkali spreading value	1,000 seed-weight (g)
RD 6	Glutinous	7.0	3.1	Brown	15.0	6.4	22.0
RD 105	Non-glutinous	7.3	3.4	Brown	29.1	6.5	29.0
Chai Nat 2	Non-glutinous	7.9	3.6	Straw	28.5	6.7	28.8
RD 15	Non-glutinous	6.8	3.3	Brown	27.2	6.6	28.5
Dok Pa-yom	Non-glutinous	7.3	3.4	Dark brown	22.5	6.5	28.0
Nhang Mon S-4	Non-glutinous	7.6	3.2	Straw	20.3	6.6	33.0
Hom Ubon 80	Non-glutinous	7.5	3.6	Straw	17.5	6.5	28.0
RD 12	Glutinous	7.1	3.4	Brown	15.5	6.4	28.0
R 258	Glutinous	6.9	2.2	Straw	17.1	6.4	34.0

were transferred onto 200 g seeds of each test variety in a well- ventilated covered jar. The purpose of using samples of the various test varieties from this stage was to precondition the pest to the host materials to prevent any later behavioural changes due to the host material (Dobie, 1974). Mating and oviposition were allowed for four continuous days. Afterward, the parental F1 adults were removed from the seeds, and seeds on which eggs were laid were transferred with a pooter into a new kilned jar containing 20 g of fresh seeds. The jar was well covered with a white cotton cloth, fastened in place by a rubber band. The newly emerged F2 offspring were set as the parental stock for the choice experiment.

2.3 Experimental design and procedure

The test was conducted from June to October because Caswell (1980) reported this as the peak activity period for *S. oryzae*. According to Caswell (1980), any rice variety that performs well against *S. oryzae* at this period possesses good resistance. The experiment consisted of nine aromatic rice varieties, replicated four in completely randomized design (CRD). Varieties were RD 6, RD 105, Chai Nat 2, RD 15, Dok Pa-yom, Nhang Mon S-4, Hom Ubon 80, RD 12, and R 258. R 258 was set as the control as it is locally known to have good resistance to *S. oryzae*. One hundred and fifty grams of sterilized seeds of the test varieties were measured into a 20 ml kilned jar. Swella and Mushobozy (2009) procedure was gain adopted for the choice experiment. The moisture content of the seeds was 12**%** and was measured with a moisture meter (FARMEX model, Delhi, India). With the help of a pooter, twelve pairs of the emerged F2 offspring were placed onto the seeds (sex determination was done by examining the thickness and length of the rostrum and 6° abdominal sternite aspect (Dinuta *et al*., 2009) and the jars were well covered and placed undisturbed for five days in an incubator under the condition described above, for mating and oviposition (Figure 1). On the 6^{th} day, the insects were removed from the setup and data collection began. Data collection lasted for 30 days and the weight of the final seeds was measured for each variety.

2.4 Experimental data

Emphasis was given to the number of eggs laid on seeds, the number of eggs laid in the entire container, developmental period, adult emergence, seed weight loss, damage incidence, and susceptibility index. The method of Lambert, Gale, Amason and Philogene (1985) was adopted to count the eggs laid on seeds and container walls of each treatment setup. Counting was done on the 6^{th} day with the help of an egg plug under an illuminated magnifier (Asante, & Mensah, 2007). Newly emerged *S. oryzae* adults were counted daily for each treatment setup with the help of a daily chart. Adults count lasted for 30 days and the adult emergence percentage was computed. The number of days taken for the insect to develop from the egg phase to fully grown adults was counted and recorded as a developmental period. Seed weight loss measurement was done per the method of Jackai and Asante (2003). Weight loss was computed as the difference between the initial seeds weight and final seeds weight while weight loss percentage was calculated by Equation 1 at about 11.8% moisture content.

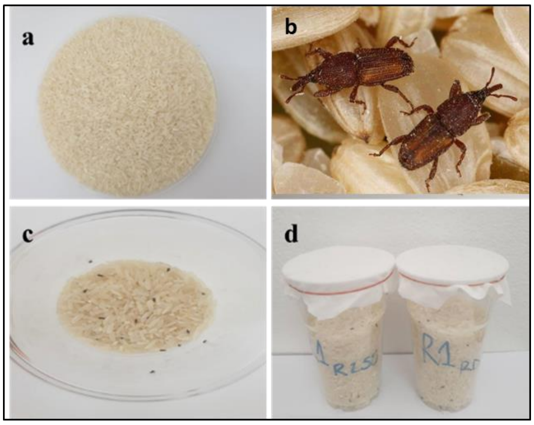

Figure 1. a. Dried sterilized rice; b. *S. oryzae*; c. rice infested with *S. oryzae*; d. treatment setup

$$\text{Weight loss (\%)} = \frac{\text{Initial seed weight} - \text{Final seed weight}}{\text{Initial seed weight}} \times 100 \qquad (1)$$

Seed damage incidence was measured by the number of damaged holes created by adults *S. oryzae* on the various whole grains. Grain damage incidence in percentage was calculated as Equation 2.

$$\text{Damage incidence} = \frac{\text{Number of damages grains}}{\text{Total number of grains}} \times 100 \qquad (2)$$

The formula of Dobie (1977) was followed to calculate the susceptibility index (Equation 3).

$$\text{Susceptibility index} = \frac{F\iota}{D} \times 100 \qquad (3)$$

where $F\iota$ is the number of emergent adults and D is the developmental period (days).

2.5 Statistical analysis

Numerical and percentage data were square root and arcsine transformed. The data were analysed by Fisher's method of Analysis of Variance (ANOVA) using the Statistical Package for Social Sciences, version 21. Critical differences were compared at $p \leq 0.05$ wherever the F value was significant (Panse, & Sukhatme, 1985). Duncan's Multiple Range Test (Duncan, 1955) analysis was performed and the results are shown in tabular alphabets with 'a' indicating the highest value. The standard multiple regression coefficient analysis was conducted to illustrate the relationship between measured variables and their contributions to varietal susceptibility.

3. Results and Discussion

3.1 Oviposition and *S. oryzae* development

Results obtained for egg oviposition and *S. oryzae* development are shown in Table 2. The average number of eggs laid on the seeds was significantly ($p \leq 0.05$) different

Table 2. Egg oviposition and *S. oryzae* development

Varieties	Average number of eggs laid on seeds	Average number of eggs laid in the entire container	Average developmental period (days)	Average number of adults	Adult emergence (%)
RD 6	13.89 ± 0.10[e]	36.95 ± 2.32	24.53 ± 0.33[c]	29.75 ± 3.01[abc]	80.76 ± 3.01
RD 105	15.59 ± 0.48[d]	35.63 ± 3.05	23.15 ± 0.34[e]	31.18 ± 2.23[ab]	88.14 ± 2.23
Chai Nat 2	16.66 ± 0.30[b]	35.20 ± 2.89	23.78 ± 0.13[d]	31.71 ± 2.62[ab]	90.09 ± 2.62
RD 15	13.45 ± 0.36[f]	37.50 ± 5.78	23.23 ± 0.19[e]	29.67 ± 2.36[abc]	79.12 ± 2.35
Dok Pa-yom	16.16 ± 0.11[c]	36.43 ± 3.35	25.15 ± 0.24[b]	32.17 ± 2.41[a]	88.31 ± 2.41
Nhang Mon S-4	12.97 ± 0.20[g]	34.83 ± 2.22	23.90 ± 0.22[d]	27.70 ± 2.32[cd]	79.60 ± 2.32
Hom Ubon 80	17.31 ± 0.33[a]	36.40 ± 1.35	24.55 ± 0.17[c]	32.84 ± 2.10[a]	90.48 ± 2.10
RD 12	13.30 ± 0.33[fg]	36.78 ± 2.16	23.35 ± 0.13[e]	28.53 ± 1.40[bcd]	77.50 ± 1.40
R 258	9.71 ± 0.12[h]	33.63 ± 175	28.35 ± 0.13[a]	25.77 ± 1.86[d]	76.73 ± 1.86
CD @ 5%	0.42	ns	0.32	3.33	ns

Note: Data are shown as average ± SD. Column averages followed by similar superscript letters [a,b,c,d,e,f,g] are not significant at p > 0.05, sample size n=4; SD=standard deviation; CD=critical difference between averages; n=non-significant.

among the varieties and were in the range of 9.71 in R 258 (control) to 17.31 in Hom Ubon 80. Eggs laid on the seeds were lowest in the order R 258<Nhang Mon S-4<RD 12<RD 15<RD 6<RD 105<Dok Pa-yom<Chai Nat 2<Hom Ubon 80. However, that of RD 12 and RD 15 as well as Nhang Mon S-4 and RD 15 were comparable. It is worth mentioning that some eggs were found on the walls of the storage container, although this insect does not usually oviposit outside the seed. When the number of eggs deposited on the walls of the container was summed up with those on the seeds, no significant difference was observed among the varieties. In R 258, Nhang Mon S-4, and RD 12, the insects preferred to oviposit on the walls of the container as compared to the seeds. The physical characteristics of rice have been reported to influence the oviposition site reference of *S. oryzae* (Campbell 2002; Keteku *et al.*, 2020; Oguntola, Odeyemi, Eniola, & Oagbola, 2019). The size, thickness, and texture of the grains affect their suitability as an oviposition site (Enobakhere *et al*., 1996). Stejskal and Kučerová (1996) further added that *S. oryzae* prefer larger grains for oviposition than smaller ones. Coincidentally, the varieties RD 15, RD 6, RD 105, Dok Pa-yom, Chai Nat 2, and Hom Ubon 80 which had larger grains were much preferred by the insect for oviposition compared to R 258 and RD 12. The fewer eggs number found on R 258, Nhang Mon S-4, and RD 12 can also be explained by the grain quality of these varieties. Previous work reported that *S. oryzae* takes a long time to accept poor quality seeds for oviposition, and intends to lay fewer eggs when held in low quality and small size substrate (Campbell 2002; Keteku, Badii, & Sowley, 2020). This statement concurs with our findings, as R 258 had the smallest grain size and was, therefore, the least preferred variety for oviposition. Physical characteristics that contributed to resistance include grain texture, size, and thickness. A positive correlation was found between the rice grain characteristics and the number of eggs laid on the seeds. Notably, the grain width correlated the most ($R^2 = 0.788$) to eggs laid (Figure 2). The larger the grain length ($R^2 = 0.392$), width and amylose content ($R^2 = 0.154$), the higher the number of eggs deposited.

The developmental period and the number of emerged adults for the various setups are presented in Table 2. The developmental period (days from eggs to adult) was significantly different among the varieties and was in the range of 23.15 in RD 105 to 28.35 in R 258. Thus, the average number of days taken for the insect to develop from eggs stage to adult stage was significantly longest in (R 258 and Dok Pa-yom), intermediate in (Hom Ubon 80, RD 6 and Nhang Mon S-4), and shortest in (RD105, RD 15, RD 12 and Chai Nat 2). Correspondingly, the average number of emerged adults were also significantly low (25.77, 27.70, and 28.53) in R258, Nhang Mon S-4 and RD 12, respectively but high (32.84, 32.17, 31.71, 29.75 and 29.67) in Hom Ubon 80, Dok Pa-yom, Chai Nat 2, RD 105, RD 6 and RD 15, respectively. The pattern of adult emergence may be attributed to the number of eggs and the soft nature of the grains of each variety. For development time R 258 recorded the longest and this may be due to the inability of *S. oryzae* to get adequate nutrients to feed on and the resistant status of the variety. The number of emerged adults correlates to the number of eggs laid per variety; the higher the eggs, the greater the number of emerged adults. According to Campbell (2002), large-quality seeds can host more seeds and also provide more nutrition and favourable growth conditions for the developing larvae survival compared to smaller seeds. To buttress this point results from a sorghum experiment revealed a positive relationship between seed hardness and *S. oryzae* infestation, thus relatively hard sorghum cultivars restricted adult emergence while soft seeds hosted as much as 2-6 times more eggs (Russell and Rink 1965). R 258 turned the lowest in terms of adult emergence which may be due to the small size of its kernel. This observation, however, disagrees with

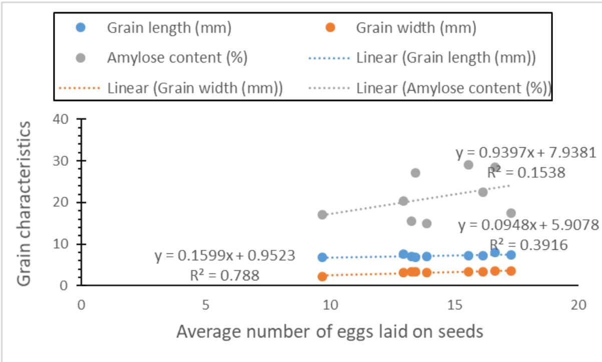

Figure 2. Relationship between grain characteristics and average number of eggs laid on seeds

Stejskal and Kučerová (1996) who counted fewer adults from larger grains as compared to smaller grains.

3.2 Grain damage and susceptibility index

Table 3 depicts the damaging effects recorded on the various aromatic rice varieties due to *S. oryzae* infestation. A significant variation ($p \leq 0.05$) was found in the weight of the seeds after 30 days of infestation. Weight loss was highest (8.45 g) in Chai Nat 2 and lowest (4.23 g) in R 258. The weight loss in the R 258 was significantly lower than in all the other varieties. No significant difference was found in weight loss (5.25 g) of Nhang Mon S-4 and 5.38 g of RD 12. Other varieties; RD 15, RD 6, and RD 105 showed moderate resistance and were significant apart, while Chai Nat 2, Dok Pa-yom, and Hom Ubon 80 had no significant difference between them. The percentage of weight losses corresponded to the weight loss of each variety. During the observation, we realized that *S. oryzae* bred less on varieties that had small size hard seeds with less amylase content. This indicates a varietal resistant trait among the varieties in their resistance to *S. oryzae*. The damage incidence as recorded for the various varieties is also shown in Table 3. It ranged significantly from 0.61 in R 258 to 0.89 in Hom Ubon 80. The damage incidence of R 258, Nhang Mon S-4, and RD 12 was lower when compared to the other varieties. Chai Nat 2, Dok Pa-yom, and Hom Ubon 80 recorded the greatest weight loss and damage incidence, this may be due to their less resistance to *S. oryzae* activity. These findings concur with Mbata (1993) whose work strongly correlated seed weight loss to susceptibility. The higher the amount of emerged adults and damaged grains per variety, the greater the weight loss. Mohammad, Waseem and Azam (1988) similarly emphasized this by stating that grain weight loss was dependent on the number of emerged adults and the number of damaged seeds. Likewise, Singh, Singh and Adjadi (1984) revealed that seeds that permitted rapid *S. oryzae* development and higher levels of adult emergence had extensively damaged holes. RD 105 recorded the highest susceptibility index of 6.47 and was mainly due to its shortest developmental period (23.15 days). It was however not significant from those of RD 15, Chai Nat 2, RD 12, and Hom Ubon 80. The lowest susceptibility index (4.97) was noticed in R 258 and was followed by Dok Pa-yom, RD 6, and Nhang Mon S-4. Varieties that restricted early insect development with fewer emerged adults recorded the least susceptibility. Painter (1951) categorized plants' resistance mechanisms to insect infestation into three: non-preference, antibiosis, and tolerance. Antixenotic resistance was observed in this study as certain seed morphological characters such as size, hardiness, and less amylase content may have hindered *S. oryzae* colonization. Also, Pixley (1997) reported that high insect mortality rates and significant differences between average developmental periods among genotypes suggest antibiosis as a resistant mechanism.

3.3 Relationship between variables and their contributions to varietal susceptibility

The relationship between measured variables and their contribution to varietal susceptibility was analysed by multiple regression (standardized multiple regression coefficients) as in Table 4. The number of eggs laid on seeds correlated positively to the number of emerged adults, weight loss, damage incidence, and susceptibility index with (r = 0.978, 0.956, 0.932, and 0.705, $p \leq 0.05$), respectively. This implies that if more eggs are laid on seeds, more *S. oryzae* adults will emerge and damage may be severe. The relationship between the number of eggs laid in the entire container to other variables was not strong enough to reach a significant level. Insect developmental period correlated negatively to the other measured variables and was strongly negative with susceptibility index ($r = -0.972$, $p \leq 0.01$). This, however, is consistent with Mohammad *et al*. (1988) who similarly reported a negative correlation between developmental period and susceptibility index for rice weevil. This indicates that as the development time increases, the susceptibility index decreases, and vice versa, as observed in R 258, Dok Pa-yom, and RD 6. Also, the number of emerged adults correlated positively to weight loss, damage incidence, and susceptibility index. A similar situation was found between weight loss and damage incidence. Our results showed a strong dependence of varietal susceptibility on developmental period ($r = -0.972$, $p \leq 0.01$), number of eggs ($r = 0.705$, $p \leq 0.05$), number of emerged adults ($r = 0.658$), damage incidence ($r = 0.575$) and weight loss ($r = 0.558$).

Nonetheless, when the variables were ranked in a scale of 1-9 with 1 representing least susceptible and 9 indicating most susceptible (Table 5), the varieties performed in the order of R 258 > Nhang Mon S-4 > RD 12 > RD 6 > RD 15 > Dok Pa-yom > RD 105 > Hom Ubon 80 > Chai Nat

Table 3. Weight Loss, Seed damage and Susceptibility Index of varieties to *S. Oryzae*.

Varieties	Average weight loss (g)	Weight loss (%)	Damage incidence	Susceptibility index
RD 6	6.55 ± 0.26^{c}	4.36 ± 0.26^{c}	0.74 ± 0.05^{d}	6.02 ± 0.10^{cd}
RD 105	7.15 ± 0.19^{b}	4.73 ± 0.19^{b}	0.81 ± 0.03^{bc}	6.47 ± 0.18^{a}
Chai Nat 2	8.45 ± 0.39^{a}	5.68 ± 0.39^{a}	0.85 ± 0.03^{ab}	6.31 ± 0.22^{abc}
RD 15	6.10 ± 0.22^{d}	4.07 ± 0.22^{d}	0.77 ± 0.01^{cd}	6.35 ± 0.18^{ab}
Dok Pa-yom	8.30 ± 0.45^{a}	5.53 ± 0.45^{a}	0.87 ± 0.05^{a}	5.96 ± 0.07^{d}
Nhang Mon S-4	5.25 ± 0.21^{e}	3.53 ± 0.21^{e}	0.64 ± 0.03^{ef}	6.04 ± 0.06^{bcd}
Hom Ubon 80	8.25 ± 0.34^{a}	5.53 ± 0.34^{a}	0.89 ± 0.02^{a}	6.16 ± 0.05^{abcd}
RD 12	5.38 ± 0.13^{e}	3.61 ± 0.13^{e}	0.69 ± 0.03^{e}	6.22 ± 0.10^{abcd}
R 258	4.23 ± 0.13^{f}	2.83 ± 0.13^{f}	0.61 ± 0.03^{f}	4.97 ± 0.46^{e}
CD @ 5%	0.40	0.281	0.049	0.33

Note: Data are shown as average ± SD. Column averages followed by similar superscript letters (^{a,b,c,d,e,f,}) are not significant at $p > 0.05$ ($n = 4$); SD = standard deviation; CD = critical difference between averages.

Table 4. Relationship between variables and their contributions to varietal susceptibility

Variables	Average number of eggs laid on seeds	Average number of eggs laid in the entire container	Average developmental period	Adults emergence (%)	Percentage progeny emergence	Average weight loss (g)	Weight loss (%)	Damage incidence	Suscep-tibility index
Average number of eggs laid on seeds	1.000								
Average number of eggs laid in the entire container	0.420	1.000							
Average developmental period	-0.549	-0.628	1.000						
Average number of adults	0.978*	0.497	-0.477	1.000					
Adults emergence (%)	0.912*	0.085	-0.256	0.900*	1.000				
Average weight loss (g)	0.956*	0.347	-0.369	0.979**	0.941*	1.000			
Weight loss (%)	0.961**	0.343	-0.366	0.974**	0.943*	0.996**	1.000		
Damage incidence	0.932*	0.458	-0.378	0.982**	0.901*	0.969*	0.964**	1.000	
Susceptibility index	0.705*	0.642	-0.972**	0.658	0.452	0.558	0.543	0.575	1.000

Note: * indicates significant at p ≥ 0.05 and 0.01, respectively (2-tailed)

Table 5. Aromatic rice varieties ranked in order of relative susceptibilities to *S .oryzae* infestation and damage.

Varieties	Average number of eggs laid on seeds	Average number of eggs laid in the entire container	Average develop-mental period	Average number of adults	Adult emergence (%)	Average weight loss (g)	Weight loss (%)	Damage incidence	Suscep-tibility index	Rank total	Rank position
RD 6	5	8	4	5	5	5	5	4	3	44	4
RD 105	6	4	9	6	6	6	6	6	9	58	7
Chai Nat 2	8	3	6	7	8	9	9	7	7	64	9
RD 15	4	9	8	4	3	4	4	5	8	49	5
Dok Pa-yom	7	6	2	8	7	8	8	8	2	56	6
Nhang Mon S-4	2	2	5	2	4	2	2	2	4	25	2
Hom Ubon 80	9	5	3	9	9	7	7	9	5	63	8
RD 12	3	7	7	3	2	3	3	3	6	37	3
R 258	1	1	1	1	1	1	1	1	1	9	1

Ranking scale (1- 9); 1 implies the least susceptible; 9 implies most susceptible.

2. Therefore, R 258, Nhang Mon S-4, and RD 12 can be said to have more tolerance to *S. oryzae* infestation and damage, while RD 6, RD 15, and Dok Pa-yom possess intermediate tolerance to *S. oryzae*. The varieties RD 105, Hom Ubon 80, and Chai Nat 2 demonstrated less tolerance to *S. oryzae* infestation and damage.

4. Conclusions

The findings revealed a variability among the varieties with regards to the number of eggs laid on seeds, developmental period, number of emerged adults, seeds weight loss, damage incidence, and susceptibility index. These factors collectively reflect the inherent capacity of a particular variety to resist *S. oryzae* infestation. Averagely, the varieties R 258, Nhang Mon S-4, and RD 12 showed high tolerance to *S. oryzae* infestation and damage, while RD 6, RD 15, and Dok Pa-yom possess intermediate tolerance to *S. oryzae*. Varieties RD 105, Hom Ubon 80, and Chai Nat 2 demonstrated less tolerance to *S. oryzae* infestation and damage. Based on our results, we recommend interspecific crossing of R 258 and RD 12 to improve the RD 12 variety since they are of the same type. The Nhang Mon S-4 variety has good grain quality in terms of grain size, weight, and amylase content, as such an upgrade of this variety through the transfer of resistant traits from R 258 will improve its shelf-life, market competitiveness and help minimize the high grain losses incurred by farmers during storage. Dok Pa-yam also showed a high level of resistance to *S. oryzae* development, such traits can also be incorporated into future breeding programs. Lastly, high storage protection will be required for RD 105, Hom Ubon 80, and Chai Nat 2 to preserve grain quality.

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