Damage Potential, Effect on Germination, and Development of *Sitophilus oryzae* (Coleoptera: Curculionidae) on Wheat Grains in Northwestern Himalayas

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Abstract

The present investigation was carried out to study the biological parameters and orientation of *Sitophilus oryzae* (L.) toward wheat cultivar HPW-236 and mixed grains of different cultivars (HPW-155, HPW-236, HPW-249, HPW-349, HPW-360, HS-490, and VL-892). The incubation period, larval period, pupal period, and total life cycle period of *S. oryzae* was longer when fed on mixed grains as compared to HPW-236. Also, the weevils were more oriented toward HPW-236 and lower germination rates were observed from HPW-236 than mixed cultivars when exposed to *S. oryzae*. We also evaluated quantitative losses caused by *S. oryzae* in different cultivars of wheat recommended in the northwestern Himalayas under free-choice conditions. The weevil inflicted greater damage and weight loss in grains of HPW-236 while it was negligible in the case of HPW-360 and HPW-249. HPW-236 which is the most cultivated variety of wheat in northwestern Himalayas proved to be highly susceptible to the weevil and provided a more suitable environment for weevil’s development. Therefore, this particular cultivar can be avoided for prolong storage and the farmers should prefer cultivars such as HPW-360 and HPW-249, which proved to be least affected the weevil.

Key words: biology, germination, *Sitophilus oryzae*, susceptibility index, wheat

The postharvest losses surpass 12–16 million metric tons/year of food grain in India (Singh 2010). Rice weevil, *Sitophilus oryzae* (L.), is cosmopolitan and one of the most damaging insect-pest causing about 10–65% damage under moderate storage conditions, while it accounts for 80% under prolonged storage conditions (Park et al. 2004). A dozen of pests affect wheat seeds in storage, out of which *S. oryzae* is one of the most economically important one. Wheat is an important food grain crop in India and across the world. The present production and productivity of wheat in India is 98.61 million tons and 33.18 q/ha, respectively, which is obtained from an area of 29.72 million hectares (IIWBR 2018). Wheat production in India is projected around 140 million tons by 2050 considering its increasing demand for domestic and international trade, several processed products, and excessive consumption (IIWBR 2015). In order to achieve this target, sole reliance on enhancing productivity or increasing the area under wheat will not be sufficient and a sincere focus is required toward minimizing huge postharvest/storage losses, right from the harvesting of the crop to the actual period of storage in different storage structures/warehouses, etc.

Agricultural chemicals are considered as ‘Miracle Weapons’ in the frontline of management of stored grain pests; however, a lot of drawbacks are being faced in the present scenario. Solitary reliance on a particular or a range of chemicals has led to complications like residual hazards, resistance, pollution, and control failures (Mehta and Kumar 2020). Stored grain insect-pests exhibit a phenomenon of antixenosis/antibiosis, when fed on the grains of different crops and cultivars of same cereals, which leads to decreased or no feeding, altered oviposition, and varied development of a particular insect-pest (Sarin and Sharma 1983). In places where storage facilities are inadequate, stored grain resistance/susceptibility might be used solely or as a combination of other protective methods for the efficient management of the insect-pests (Badri et al. 2013). The damage potential of rice weevil is a subject of considerable research, mainly on the relative preference in different stored products and the varieties of the same product. In recent years, the laboratory studies established that many varieties have shown some resistance against *S. oryzae* (Swamynarayana et al. 2014). The growing awareness of environment hazards due to synthetic insecticides has attracted attention toward the use of plant and animal origin products which are biodegradable and also toward resistant cultivars which are environment-friendly and safe for human health (Yadav et al. 2018).
In Himachal Pradesh state of India (including a major portion of northwestern Himalayas), wheat is a very important cereal crop. It is cultivated in 0.35 million hectares with an overall production of 0.68 MT and productivity of 1,968 kg/ha (MAFW 2016). Although a lot of modern storage facilities are available, farmers in the state of Himachal Pradesh (India) still depend upon traditional techniques of storage of grains due to unfamiliarity and lack of extension facilities in the hinterland, thereby making the grains more prone to the infestations of insect-pests during storage (Aslam et al. 2004). The techniques followed by researchers will remain remote if it is not scientifically and widely accepted by farming community. Devising methods of storage and assessing the susceptibility of a particular cultivar to a pest requires the study of the life cycle of the pest. HPW-236 is a cultivar which is most widely and commonly grown by farmers of northwestern Himalayas and no doubt, it has performed well as far as yield is concerned and can be grown easily where such type of climatic conditions prevails. However, there is a little information regarding the response of this cultivar toward S. oryzae under storage conditions. As farmers in hilly areas of the country have no specific restrictions on the use of a particular cultivar and most of the time they go for grain mixtures, i.e., sowing and storage of wheat grains of different cultivars together. Therefore, the present study was carried out to investigate differences in biology, germination, and orientation of rice weevil between stored grains of cultivar HPW-236 and mixed grains of different cultivars recommended under mid-hill conditions of the country. We also evaluated the damage and weight loss caused by this weevil in different recommended wheat cultivars in northwestern Himalayas. Furthermore, it is also necessary to publicize these varietal differences in the present trend and to keep pace with our future requirements (which would be higher) and overcome the problem of storage.

Materials and Methods

Commodity

The present study was conducted in the Department of Entomology, CSK Himachal Pradesh Agricultural University, Palampur, India. The healthy, genetically pure, insect- and disease-free seeds of HPW-155, HPW-236, HPW-249, HPW-349, HPW-360, HS-490, and VL-892 were obtained from Rice and Wheat Research Centre, Malan (India) and Department of Seed Science and Technology, CSK Himachal Pradesh Agricultural University, Palampur, India (Table 1).

| Cultivars | Sowing time | Type of grain | Area |
|-----------|-------------|---------------|------|
| HPW-236   | Timely sown | Large-sized and moderately hard grains | Unirrigated and low, mid-, and high hills areas of India |
| HPW-155   | Timely sown | Large-sized and hard grains | High altitude and hill regions of Jammu and Kashmir (except district Jammu and Kathua), Himachal Pradesh (except district Una), and Uttarakhand states of India |
| HPW-249   | Timely sown | Large-sized and hard grains | Mid-hills areas of India |
| HPW-349   | Timely sown | Small-sized grain | High altitude and hill regions of Jammu and Kashmir (except district Jammu and Kathua), Himachal Pradesh (except district Una), and Uttarakhand states of India |
| HPW-360   | Early sown  | Medium thick or hard and white gold grains | Low and mid-hills areas of India |
| HS-490    | Late sown   | Large-sized and moderately hard grains | High altitude and hill regions of Jammu and Kashmir (except district Jammu and Kathua), Himachal Pradesh (except district Una), and Uttarakhand states of India |
| VL-892    | Late sown   | Medium bold grains | Irrigated hills of Himachal Pradesh and Uttarakhand states of India |

Test Insect

S钜thillus oryzae was obtained from the infested stocks with local farmers and was maintained on uninfested wheat grains in 2 kg capacity plastic jars covered with a clean sterile muslin cloth. Different biological parameters of S. oryzae were studied on HPW-236 and a mixture of different cultivars (the grains of abovementioned seven cultivars when stored by intermixing their grains) recommended in mid-hill conditions of the state (Table 1). For this purpose, 20 (2 d old, fifth generation) newly emerged adults (10 pairs) from the culture were released in plastic boxes containing 100-g grains in five replications at 25 ± 2°C and 65 ± 5% RH. Wheat cultivars were first sieved and cleaned carefully to remove foreign particle, if any. They were then sterilized for 4 h at 65 ± 5°C to remove any type of infection and maintain similar moisture level (which was checked after removing from the oven). The grains of different cultivars were mixed in equal amounts to make the final weight of 100 g. For releasing the weevils in pairs in the experiments, the males and females were sorted out, being easily detected by the form of rostrum. In male rostrum was relatively short and wide, punctures along rostrum were large and irregular, not in rows and often touching each other. In female rostrum was relatively long and narrow, punctures along rostrum were in regular rows and not touching each other (Sharifi 1972). Data on incubation period, larval period, pupal period, total life cycle, adult emergence, and susceptibility index were recorded by daily observing the grains under a stereo zoom microscope (Nikon SMZ 1000T). Each grain was dissected carefully using sharp forces and needle to observe different stages of the weevil inside the grain. The susceptibility index of each variety was calculated using the below-mentioned formula (Dobie 1977):

\[
\text{Susceptibility index} = \frac{\text{Natural log } F}{D} \times 100
\]

where \( F \) = no. of adults emerged; \( D \) = developmental period.

Orientation Studies

Twenty-gram grains of HPW-236 and mixed cultivars (a single variant containing mixture of grains of foresaid cultivars) were kept in small boxes (6 × 4.5 × 4.5 cm) which were further placed circularly in a large plastic box (18 × 18 × 5.5 cm) in three replications at 25 ± 2°C and 65 ± 5% RH. One hundred adults of S. oryzae were
released in the center of the trough and minute holes were made with a sharp needle on the lid for aeration. The number of adults oriented toward each treatment was counted after 24, 48, and 72 h after the release of weevils.

Germination Test
For evaluating the effect of rice weevil's damage on germination, 100 g of grains of HPW-236 and mixed cultivars were kept in a plastic box with 10 pairs (20) of 5-d-old adults in 10 replications. After completion of a single generation of weevil (30–35 d), 100 randomly selected seeds were evaluated using the paper towel method as recommended by ISTA and percent germination was calculated. The shortened life cycle may be attributed due to more preference and easy development of the weevil on a single cultivar rather than the mixed ones. In an investigation conducted by Barbhuiya (2002) who reported that the incubation period of S. oryzae ranged from 4 to 6 d with an average of 5.10 d at a temperature ranging from 15 to 34°C and 58–89% RH in maize and 5–7 d in rice, respectively. This variation may be due to the preference of weevil toward a particular seed morphology or biochemical factor and therefore needs further investigation in terms of softness, protein content, etc., which may influence the egg-laying behavior of adults. Optimality models generally predict that large numbers of eggs were laid in high-quality hosts because they can support more progeny (Godfray et al. 1991). In the case of larval period, the present findings are conflicting with the results of Bhuiyah et al. (1990). They reported a larval period of 16–20 d on maize seeds. However, Bheemanna (1986) reported 25–34 d of larval period on grains of CSH-5 genotype of sorghum, while Yervo (2003) reported larval and the pupal period as 27.25 and 8–9 d on maize seeds, supporting our findings. Our findings are also in line with Bhuiyah et al. (1990) who reported 8–9 d of pupal period at a temperature range of 23–30°C and 78–87% RH, Sharifi and Mills (1971) who reported a pupal period of 6.3 d on wheat grains by radiographic method, and Lopez-Cristobal (1953) who reported it as 6–16 d. However, Kumar et al. (2016) reported a pupal period of 6.75–7.08 d with a mean of 6.93 d, which slightly differed from the current results.

Discussion
Our results indicated that weevil completed its life cycle on HPW-236 as well as mixed grains of different cultivars. Our findings on the egg period are in agreement with Swamyvaranayana et al. (2014) and Barbhuiya (2002) who reported that the incubation period of S. oryzae ranged from 4 to 6 d with an average of 5.10 d at a temperature ranging from 15 to 34°C and 58–89% RH in maize and 5–7 d in rice, respectively. This variation may be due to the preference of weevil toward a particular seed morphology or biochemical factor and therefore needs further investigation in terms of softness, protein content, etc., which may influence the egg-laying behavior of adults. Optimality models generally predict that large numbers of eggs were laid in high-quality hosts because they can support more progeny (Godfray et al. 1991). In the case of larval period, the present findings are conflicting with the results of Bhuiyah et al. (1990). They reported a larval period of 16–20 d on maize seeds. However, Bheemanna (1986) reported 25–34 d of larval period on grains of CSH-5 genotype of sorghum, while Yervo (2003) reported larval and the pupal period as 27.25 and 8–9 d on maize seeds, supporting our findings. Our findings are also in line with Bhuiyah et al. (1990) who reported 8–9 d of pupal period at a temperature range of 23–30°C and 78–87% RH, Sharifi and Mills (1971) who reported a pupal period of 6.3 d on wheat grains by radiographic method, and Lopez-Cristobal (1953) who reported it as 6–16 d. However, Kumar et al. (2016) reported a pupal period of 6.75–7.08 d with a mean of 6.93 d, which slightly differed from the current results.

Results
The egg period of rice weevil on wheat varied significantly in HPW-236 and mixed grains of different cultivars. It lasted for more time in the case of mixed cultivars (6.4 ± 0.37 d) as compared to HPW-236 (4.8 ± 0.24 d). Larva was short, apodous, stout, yellowish-white in color with brown-colored head, and developed inside the grain (Fig. 1). Larval period was longer in case of mixed cultivars (27.4 ± 1.07 d) than HPW-236 (24.33 ± 0.88 d). Pupation of the larva was observed inside the grains. The pupal period followed a similar trend as the larval period, i.e., being longer in mixed cultivars and shorter in HPW-236 (7.60 ± 0.57 and 5.80 ± 0.37 d, respectively). The total life cycle of the weevil fed on the grains of HPW-236 was 32.4 ± 0.74 d with $X^2(27, N = 20)$ chi-square value $= 46.66$, $P = 0.11$, while in the case of mixed grains of different cultivars it was 41.4 ± 0.67 with $X^2(27, N = 20)$ chi-square value $= 52.00$, $P = 0.03$ (Fig. 2).
Similar observations on the life cycle of rice weevil were also reported by Howe (1952) and Bheemanna (1986) which support our findings. We also calculated the susceptibility index, based on the adult emergence and developmental period of the weevil. A similar study was conducted by Mehta and Kumar (2021) on wheat grains. They reported that the susceptibility index varied from 7.19 to 13.55 in different wheat genotypes which are commonly cultivated in the northwestern Himalayan region, while Bhanderi et al. (2015) screened 12 maize genotypes and reported that the susceptibility index varied from 9.00 to 15.33 in different genotypes.

Another important aspect of this study was to know about the effect of weevil damage on the germination of grains. Earlier, many researchers have studied the effect of *S. oryzae* on the germination of different cultivars of wheat and other cereals. Jha et al. (2014) reported losses in the germination of wheat cultivars due to rice weevil infestation, while Singh et al. (1975) observed that variety S-308 showed higher germination after weevil infestation and PV-18, Kalyan Sona, and S-307 had the lowest values. Jadhav (2006) observed that *S. oryzae* affected the viability of seeds after 180 d of storage, while Chauhan et al. (2005) observed that variety DL803-3 had the least adult emergence, grain damage, and orientation of adults.

There were significant differences in the orientation of weevil toward HPW-236 and mixed grains of different cultivars evaluated in the present investigation. This may be due to the grain characteristics rendering the weevil more toward a particular wheat cultivar. Similar to our work, Tiwari (2016) conducted
a free-choice test and observed a minimum orientation toward Sujata variety and maximum orientation toward LOK-1. Patel et al. (2002) conducted a free-choice test and observed minimum orientation toward cultivar HUW-552 (3.1) and maximum toward HD-2285 (13.6). In the case of stored sorghum seeds, Reddy et al. (2002) screened a total of 35 genotypes and observed maximum oviposition and orientation toward DJ-6514, 2077 B, and IS 11758.

In the free-choice test conducted by us, HPW-236 was most preferred while HPW-360 and HPW-249 were the least preferred cultivar by S. oryzae. A similar investigation was carried out by Mehta (2020) to know about the differences in certain biological parameters of lesser grain borer (Rhyzopertha dominica (F.)), feeding on different wheat cultivars. Out of all seven cultivars screened, HPW-155 had maximum damage and weight loss, adult emergence, susceptibility index, orientation, and shortest developmental period, while HPW-349 had minimum damage and weight loss, adult emergence, susceptibility index, orientation preference, and longest developmental period and the rest cultivars had mediocre values. The borer completed its life cycle on all the cultivars; however, HPW-349 was found to be the least susceptible one and should be preferred over others for long storage purposes. Certain mechanisms in insect-pests may be induced due to some biochemical attributes which in turn modifies behavioral responses of insects (antixenosis) or can affect their development (antibiosis) and thus plays a role in varietal susceptibility to a particular insect-pest (Throne et al. 2000, Arve et al. 2014). All these kinds of studies depict the behavior of the weevil like orientation, population buildup, ease of development, losses in a particular cultivar, and effect on germination of grains. Although the cultivars evaluated in the present investigation were not analyzed for their biochemical parameters, the reason for the preference of weevil may be found after advanced studies concerning biology and behavior of the weevil with respect to ecological, morphological, and biochemical factors. Thus, concluding our study, it is clear that none of the cultivars was found to be resistant and the weevil successfully completed its life cycle on all the tested cultivars. HPW-236 was the most preferred host with higher damage and had greater orientation and lower germination of grains after a single generation of S. oryzae. HPW-236 is the most commonly grown and famous cultivar is common in India, but the cultivars with similar seed characteristics and locations similar to mid-hill (subhumid) conditions of India can implement our findings and go for less susceptible cultivar for long storage purpose.

**Table 2.** Free-choice study after 1 mo of storage against *Sitophilus oryzae*

| Cultivars | Weight of 100 grains (g) | Grain damage (%) | Weight loss (%) |
|-----------|--------------------------|------------------|-----------------|
| HPW-236   | 4.99                     | 27.16 ± 10.31a   | 14.82 ± 0.38a   |
| VL-892    | 3.94                     | 23.43 ± 6.63a    | 9.33 ± 0.28a    |
| HPW-155   | 3.82                     | 21.69 ± 10.42c   | 9.00 ± 0.26bc   |
| HS-490    | 4.46                     | 21.56 ± 9.62d    | 9.48 ± 0.08b    |
| HPW-349   | 3.49                     | 17.80 ± 9.42d    | 7.56 ± 0.22d    |
| HPW-249   | 4.17                     | 14.08 ± 8.04^e   | 5.44 ± 0.31^d   |
| HPW-360   | 4.55                     | 9.92 ± 4.85^f    | 2.66 ± 0.53^f   |

Values represent mean of three replicates; ± values are SE; means followed by the same letter do not differ significantly at P = 0.05 according to Tukey’s HSD test.

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