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Increasing Rice Yield Loss Associated with Pecky Rice Incidence and Population Growth of *Eysarcoris ventralis* (Westwood, 1837) in Paddy Fields

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ABSTRACT

Acceptable limits of quantitative/qualitative damages in rice yield induced by stink bugs have recently become more stringent worldwide. Here, population growth, phenology, and yield loss caused by *Eysarcoris ventralis* were examined in paddy fields (Eshkik village, Guilan). The same-aged eggs were clip-caged, and the life history was recorded. The collected adults of the first spring generation were transferred under mesh cages, and phenological experiments continued until harvesting of ratoon. Furthermore, different pest densities were released on rice plants. After harvesting, the total, empty, filled, and pecky kernels were counted. The head (perfect) and broken rice were also recorded after milling process. The developmental time was 24.24±0.20 days, and fecundity was 65.60±10.84 eggs laid on the flag leaf, kernel surface, and awns. The intrinsic rate of increase (*r*) was 0.0904±0.006 day^{-1}. The phenological survey showed that the first spring generation completed three other generations, then the fourth-generation adults overwintered. Based on damage assessment, the mean number of pecky rice ranged from 6.67±0.88 to 25.00±2.81 kernels per panicle in control and infestation with nine pests, respectively. The lowest number of non-pecky kernels was 78.36±1.33 kernels in an infestation of nine pests. The mean weight of head rice was inversely related to pest density. Due to a higher number of pecky rice inducing grain breakage, the lowest milling efficiency for head rice was 36.99±0.63% in an infestation with nine pests. Evaluated potential for population increase, together with yield loss even at low pest density, would justify the economic importance of *E. ventralis*.

Keywords: Damage symptom, Demography, Empty kernel, Loss quantification, Phenology.

INTRODUCTION

Piercing-sucking stink bugs (Pentatomidae) have recently been recognized as major pests of rice, whit their late-season infestations causing economic losses worldwide. Recent global warming has resulted in the outbreak of pentatomids due to stimulating the reproduction of overwintered adults. Indeed, the higher temperatures in late winter and early spring might lead to an even one-month earlier appearance of overwintered adults. Moreover, a 2°C temperature rise in areas with a mean annual

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temperature of 15°C would increase the number of pentatomid generations by 1.02 per year. Consequently, the major pest fauna of paddy fields in Japan has gradually changed from stem borers during 1945–1959 to rice bugs since 1995 (Kiritani, 2006).

The white-spotted stink bug, *Eysarcoris ventralis* (Westwood, 1837) (Hemiptera: Pentatomidae), has been considered a serious threat among pentatomids on cereals (Rashid *et al.*, 2006; Nasiruddin and Roy, 2012; Gonzalez-Fernandez *et al.*, 2015; Mariey *et al.*, 2023). This species was collected from weeds, wheat, alfalfa as well as grape in Iran (Linnavuori, 2008); however, its damage had not been documented. Nonetheless, Jalaeian *et al.* (2019) revealed that *E. ventralis* caused damage to rice panicle as a first report in Iran. Few studies have been carried out on the bio-ecology of *E. ventralis* (Noda and Ishii, 1981; Arias *et al.*, 1998). Numata and Nakamura (2002) demonstrated that *E. ventralis* had the type A life cycle, where the pest completed two generations and the third generation overwintered. Indeed, environmental factors in central Japan provided type A life cycle for *E. ventralis*, where unsuitable conditions (e.g., lack of food or high lethal temperatures for nymphs) did not usually occur for summer diapause. Based on sampling, *E. ventralis* was monitored from May to October in Egyptian paddy fields (Hegazy *et al.*, 2021).

Feeding of rice stink bugs mainly on panicles has been known to cause direct and indirect damages. Direct damage to panicles has resulted in the qualitative and quantitative losses. However, pentatomids were responsible for indirect damage through the transmission of pathogens or facilitating their entry (Tumanyan *et al.*, 2024 a). The direct damages by stink bugs, causing quantitative and qualitative crop losses, have been more considerable. In quantitative loss, the rice panicles were found to remain erect because pest feeding activity during booting to the milky stage of rice reproductive-ripening phases produced more empty grains (due to complete content removal of grains) and also restricted further grain development, reducing the weight of grains (atrophied grains due to partial removal of contents) (Patel *et al.*, 2006). On the other hand, the feeding damage of rice stink bugs during the dough stage (later stages of grain maturity) has been found to impair grain quality, resulting in the qualitative loss. The qualitative rice loss was evident when stink bugs injected enzymes into the grains at the dough stage and left the discolored areas around the points of stylet entry. Damaged grains with chalky discoloration and structural weaknesses (pecky rice) were frequently broken during milling process or had black or brown spots, which led to serious quality issues for marketability and rice export industries (Brorsen *et al.*, 1988; Wang *et al.*, 2002; Yamashita *et al.*, 2016). Based on Fryar *et al.* (1986), rice samples with lower than 1 or 2% pecky rice were qualified as grade 1 or 2, respectively, in the USA. However, newly defined grades of rice have even limited the pecky grains as low as 0.5% in the USA (USDA, 2009). The effect of pentatomid *Oebalus* *pugnax* (F.) on rice yield showed that the percentage of empty kernels increased to 33.1% at a density of 18 *O. pugnax* per m^2 (Awuni *et al.*, 2015). Krinski and Foerster (2017) demonstrated that the feeding activity of four adults of *O. poecilus* (Dallas) on rice panicles during anthesis/caryopsis stages decreased the total grain weight by one-sixth of the control treatment.

Few studies have verified the relationship between the occurrence of *Eysarcoris* sp. and rice yield loss. According to Ito *et al.* (1992), *E. ventralis* was a common ear-sucking pest among five collected bug species in Malaysia, and the number of pecky rice per 500 samples ranged from 19.7 to 114.7 grains. Moreover, the percentage of pecky grains due to *E. ventralis* infestation on three rice varieties varied 0.30–0.47% (Prakash and Rao, 2001). The samples of milled rice showed 4–6% pecky rice in Australia, where *E. trimaculatus* (Distant) constituted 9% of the collected rice stink bugs (Stevens *et al.*, 2008). Furthermore, the feeding activity of *E. aeneus* (Scopoli) at the milky rice stage caused 10.2% pecky grains in Korea (Lee *et al.*, 2009).

Owing to the increasing attention stink bugs are receiving in the rice-producing countries and the limitation of a recent comprehensive resource on biological as well as ecological characteristics of the white-spotted stink bug, the current study was conducted to develop a sustainable management program against *E. ventralis* based on detailed population ecology, life history and quantitative/qualitative damage risk in rice yield.

MATERIALS AND METHODS

Experimental Conditions

The study was carried out in a paddy field (5400 m^2) located in Eshkik village (Guilan, Iran, 37.365182 N and 49.624245 E) in 2022–2023. First, rice seedlings (Hashemi variety) were transplanted at 4–5 leaf stage in paddy field. The manual transplanting was considered at 25×25 cm space. The ordinary cultural practices were applied as per the existing technical recommendations by RRII (Rice Research Institute of Iran).

Insect Rearing

As soon as the rice panicle emerged in June (2023), the collected mating adults were transferred to the laboratory. The adults were kept in plastic oviposition containers (20×12×8 cm) and provided with fresh rice panicles daily. After oviposition, freshly laid eggs were transferred to paddy fields. The eggs were clip-caged (plastic containers 10×8×2.5 cm) on rice panicles, and after hatching, newly emerged nymphs were individually transferred to clip-cages.

Body Length Measurements and Adult Sex Differentiation

The nymphs were daily checked, and their exuviae in clip-cages were used to discriminate the nymphal instars (Govindan and Hutchison, 2020). After molting, different nymphal instars (10 replicates) were transferred to the laboratory for longitudinal body size assays. After adult emergence, twenty adults were transferred to the plastic containers for mating. Then, mated adults were individually kept in oviposition containers and provided with rice panicles. The adults in the boxes containing eggs were considered as females. Therefore, females and males were separately checked for morphological characteristics.

Two-Sex Life Table Study

A total of 116 same-aged eggs (< 12 h) were used to initiate demographic study under field conditions. The eggs were separately transferred to clip-cages (10×8×2.5 cm) on rice panicles. The clip-cages were checked daily and the life history data were recorded. After adult emergence, the pairs were separately placed in the oviposition containers on rice panicles. The number of laid eggs was daily recorded until the death of all adults. Furthermore, environmental data were obtained from the Meteorological Station at Rasht Airport.

Number of Generations

The mesh cages (60×60×150 cm) were placed on rice plants (each containing one rice plant) simultaneously with the first observation of overwintered adults on weeds around the experimental paddy field in 2023. Then, the collected adults (10 pairs) of first spring generation (observed in June) were transferred under mesh cages. The cages were checked daily and the process of oviposition and nymphal development was monitored until adult emergence. After adult emergence of each generation, 10 pairs of adults were separately transferred to new mesh cages on rice plants. This experiment continued until the end of the rice growing season (harvesting of ratoon in late November).

Quantitative and Qualitative Crop Loss Assessment

First, a number of mesh cages (60×60×150 cm) were separately placed on rice plants in the paddy field. Then, different densities of 0, 1, 3, 6, and 9 adults were released under the mesh cages from the reproductive to ripening phases of rice plants (three replications). The cages were monitored daily, and dead adults were replaced. The experiment was conducted from July 27 to August 22, 2022, and then the panicles were manually harvested after grain maturation. Then, the kernels were manually separated from panicles, and the total kernels, the number of empty, filled, and pecky kernels were counted. After that, the kernels were dried and milled using the rice milling machine. Finally, the head (perfect) and broken rice grains were separated. Therefore, milling efficiency (percentage of milled rice weight to total kernel weight), and the weight of head and broken rice were evaluated.

Data Analysis

The mean body length of different nymphal instars and adults was evaluated using SPSS software (ver.22). To evaluate the demographic parameters, the recorded raw life history data were analyzed by the age-stage, two-sex life table approach (Chi and Liu, 1985; Chi, 1988) using the computer program TWOSEX-MSChart (Chi, 2022). The means as well as standard errors of population growth parameters were estimated with 100,000 bootstrap samples (Chi, 2022). For crop loss assessment, the number of kernels per panicle, number of empty, filled, and pecky kernels induced by different densities of *E. ventralis*, and also the weight of head and broken rice were analyzed by one-way analysis of variance ANOVA (SPSS ver.22), and the means were compared using Tukey test (p< 0.05).

RESULTS

Body Length and Adult Sexual Dimorphism

The body length (mm) of different nymphal instars and adults was presented in Table 1. Moreover, females and males were distinguished based on the last abdominal segment (visible to the naked eye). Indeed, two morphological characteristics in the ventral surface of the last abdominal segment led to distinguishing the sex of adults. In the last abdominal sternite of females, the hairs were arranged in a coherent longitudinal tuft, prolonging in the middle of the ventral surface. Furthermore, the posterior margin of the last abdominal segment was rounded or oval in females. On the other hand, the hairs in the ventral surface of the last abdominal segment of males were arranged in a scattered pattern. Moreover, the posterior margin of the last abdominal segment was bilobed (distinctly bent down in the middle) in males (Figure 1). These findings facilitated easy identification of females and males during the demographic surveys in the paddy field.

Life History, Survival Rate, and Fecundity

Meteorological data during the experiment in the paddy field were shown in Figure 2. Moreover, developmental times as well as adult longevities were summarized in Table 2. According to the results, eggs laid on the 12th of July started to hatch after July 18, 2023, when the mean daily temperature and humidity ranged 22.9–26.2°C and 78–98%, respectively. The nymphs had five instars and needed 17.92±0.21 days to complete the nymphal period at the a.m. conditions. Male and female *E. ventralis* had similar immature development duration (24.24±0.20 days) without any significant differences (p= 0.12). The total lifespan from egg to adult death did not differ between females and males (p= 0.14).

The data on oviposition periods and fecundity were presented in Table 3. The adult pre-oviposition period (APOP) was 4.46±0.30 days. The present results revealed that females laid eggs on various sites of rice plants under cages. Although some eggs were observed on the flag leaf and panicle base (neck), females preferred the surface of kernels and their awn. Furthermore, the mean fecundity was evaluated to be 65.60±10.84 eggs per female. Some egg masses were observed in two rows on the flag leaf, whereas the egg masses on the kernel surface and especially on awns were laid in one row.

The detailed age-stage survival rate (s_{xj}) was plotted in Figure 3. The female and male emerging pattern showed that males had lower survival rate than females at day 21 (Figure 3). The survival rate of *E. ventralis* (ignoring stage) indicated a gradual increase rate of mortality during the experiment, where the value of l_x at first reproduction (day 25) was 67.2%. The highest mean daily fecundity (9.33 eggs) occurred at day 57. Despite the high fecundity during the ages of 47–58 days, the maternity (l_xm_x) decreased due to increasing adult mortality (Figure 4). The curve of reproductive value (v_{xj}) revealed that females at ages of 29–38 and also 54–57 days had the highest contribution to future population growth (Figure 5), when the mean daily temperature ranged 25.4–29.3°C on 10–19 August and 26.1–26.9°C on 4–7 September 2023, respectively. The life expectancy (e_{xj}) of females and males at the first day of emergence (age of 21 days) was 17.3 and 16.3 days, respectively, and then gradually decreased. Although the decreasing trend continued up to age of 52 days, life expectancy slightly increased during age of 54–60 days (4 to 10 September 2023) in paddy field and then the expected decline in the life expectancy resumed (Figure 6).

Life Table Parameters

The net reproductive rate (R_0) was 22.620±4.703 offspring/individual. Moreover, the intrinsic rate of increase (r) of *E. ventralis* was 0.0904±0.006 day^{-1}. According to the results, the finite rate of increase (λ) was 1.0946±0.006 day^{-1} under paddy field conditions (Table 3).

Number of Generations

Based on field survey in 2023, the overwintered adults started their feeding, mating and oviposition activities on weeds especially *Echinochloa crus-galli* (L.) and *Paspalum distichum* L. adjacent to the experimental paddy field. The results showed that *E. ventralis* completed the first spring generation on host plants species other than rice in June. After transferring the first-generation adults under mesh cages, the pest completed three other generations during rice growing season and then adults of fourth generation overwintered.

Quantitative and Qualitative Damages

The damages caused by different densities of *E. ventralis* on the number of kernel and grain weight per panicle were shown in Table 4 and 5, respectively. It should be considered that since the adults of *E. ventralis* were released under mesh cages after flowering stage (anthesis) and initial ripening phase (early milky stage) based on the rice phenology, the total number of kernels per panicle was not significantly affected by different adult densities (p= 0.97). Therefore, the total number of kernels per panicle were 120.00±2.88 and 118.33±2.43 kernels in control and for panicles infested with nine *E. ventralis* adults, respectively. Moreover, there were no significant differences in the mean number of empty kernels per panicle induced by different pest densities (p= 0.13). Although a significant difference was not detected in the total number of kernels, the mean number of undamaged (non-pecky) filled kernels showed a significant reduction after infestation at different densities of *E. ventralis* (p< 0.0001). Therefore, the mean number of undamaged (non-pecky) filled kernels per panicle decreased from 105.33±2.60 in control to 78.36±1.33 kernels with infestation of nine stink bugs. Oppositely, the mean number of pecky kernels significantly increased and varied from 6.67±0.88 to 25.00±2.81 kernels in the control treatment and at the density of nine pests, respectively (p< 0.0001) (Table 4).

There was no significant difference in total grain weight per panicle at different pest densities (p= 0.17). However, the quality of rice grain during the milling process was affected by infestation density, where the breakage level increased. The higher pest densities resulted in lower weight of head (perfect) rice grains per panicle after milling. Indeed, the weight of head (perfect) rice showed a significant reduction when rice plant was infested even with one *E. ventralis* (p< 0.0001). Furthermore, the highest weight of broken grains (0.97±0.04 g) was observed at infestation of nine stink bugs (p< 0.0001) (Table 5). The percentage of milling recovery was significantly affected by different pest densities. Therefore, the percentage of milling recovery for head (perfect) rice significantly decreased from 52.33±0.96% to 36.99±0.63% in control treatment and infestation of nine *E. ventralis,* respectively (p< 0.0001) (Table 5).

DISCUSSION

Little effort has been made to understand the bio-ecology and damages of *E. ventralis* in rice-producing countries (Ito *et al.*, 1992; Jalaeian *et al.*, 2019). Recent increasing reports have shown a high preference of *E. ventralis* for paddy fields, especially during the rice reproductive and ripening stages (Prakash and Rao, 2001; Jalaeian *et al.*, 2019). Therefore, concerns about the quantitative and qualitative damages caused by the feeding activities of *E. ventralis*, as a late-season pest of rice, have become more serious.

The age-stage, two-sex life table approach has provided more accurate estimates of population growth parameters under given conditions (Chi and Liu, 1985; Huang and Chi, 2012). To assay detailed demographic parameters of *E. ventralis*, the described adult sexual differentiation in the current research provided convenient conditions for the age-stage two-sex life table survey in the paddy field. According to the life history results, the adult feeding activities of *E. ventralis* before oviposition were necessary and unavoidable. Similarly, Rashid *et al.* (2005) reported that newly emerged adults of *O. pugnax* started oviposition after feeding for 5 days on panicles of weeds or cultivated crops at reproductive phase. Furthermore, Barrigossi *et al.* (2017) stated that the pre-oviposition period of a pentatomid species (*Cyptocephala alvarengai* Rolston) ranged from 4 to 15 days on rice panicle in Brazil. Recently, concern has risen about the damage of *Halyomorpha halys* (Stal) (Pentatomidae) on rice, especially in Europe, due to the first evidence of adult feeding activities on panicles reported from Italy (Lupi *et al.*, 2017). It should be noted that further studies on the female ovary and pre-oviposition behavior might provide more accurate information to understand the importance of feeding during the pre-oviposition period for *E. ventralis*.

The current findings showed that the eggs were laid singly or in row-shaped masses, and the number of eggs ranged between 2 to 40 eggs per mass. Although some egg masses were found on flag leaves and the base of panicles (usually in two rows), the females preferred the surface of kernels and their awns for oviposition (in one row). Our field survey revealed that *E. crus-galli* and *P. distichum* (both belong to Poaceae) were also host plants for *E. ventralis* feeding and oviposition activities. In Crimea, *E. ventralis* was observed on *Poa bulbosa* L. and *Glyceria aquatic* (L.) (Hemala *et al.*, 2014). Based on the present research, no mortality occurred during the incubation period, and all eggs hatched successfully. Barrigossi *et al.* (2017) demonstrated that the egg hatch rate of other pentatomid species (*C. alvarengai*) varied from 35% to 100%, depending on egg deposition time during the female oviposition period.

Our results showed that the highest mortality occurred in the second nymphal instar. Similarly, the mortality rate was reported to be the highest in the second nymphal instar of *C. alvarengai* on rice panicles (Barrigossi *et al.*, 2017) and also overwintering and summer generation of *H. halys* in western Slovenia (Rot *et al.*, 2022). According to researchers, first instars of different pentatomids did not feed and then started their feeding activities after molting to the second instar (Bowling, 1979; Bhavanam *et al.*, 2021). The high mortality rate of the second nymphal instar might be due to the inability to find suitable feeding sites for penetration of the stylet on host plants. However, additional studies would be necessary to explain the reported high mortality rate in the second nymphal instar.

Although the life expectancy (e_{xj}) of newly emerged adults of *E. ventralis* gradually decreased throughout the age in the current research, the female and male expectancy curves unexpectedly began to increase during the age of 54 to 60 days when the mean daily temperatures ranged 22.6–26.9°C on 4 to 10 September 2023 under paddy field conditions. Furthermore, the maximum daily temperatures during these 7 days (4 to 10 September 2023) ranged from 25.8 to 30.8°C. It seems that the recorded higher life expectancy (e_{xj}) might be justifiable by the lower maximum temperatures during 4–10 September 2023, wherein the mean daily temperatures were < 31°C. Previously, Numata and Nakamura (2002) revealed that the high summer temperature was an important mortality factor of stink bugs that had at least three generations per year, such as *E. ventralis* (type A).

According to the literature, so far research has not been conducted regarding the population growth parameters of *E. ventralis*, limiting the comparison of life table parameters. However, the intrinsic rate of increase (*r*) evaluated for other rice bug species might provide valuable information for justification of the importance of *E. ventralis* in paddy fields as a new pest of concern on rice panicle. For *Leptocorisa acuta* (Thunb.) (Alydidae) feeding on panicles in India, the *r* value was evaluated to be 0.020 and 0.012 day^{-1} on rice panicles and non-rice weeds, respectively (Dutta and Roy, 2016). Govindan and Hutchison (2020) stated that the highest *r* values for *H. halys* (recently recorded on rice) were 0.0876 and 0.0794 day^{-1} at 27 and 30°C, respectively. Considering the higher *r* value (0.0904±0.006 day^{-1}) evaluated for *E. ventralis* in the present study, the pest outbreak and also its damage risks have become serious under paddy field conditions.

The monitoring of *E. ventralis* on caged rice plants revealed the pest completed three generations under paddy field conditions, where overwintered adults had previously produced the first spring generation on weeds near paddy fields. The adults of the fourth generation under cages were found to overwinter on rice stubble and remained at the base of harvested rice plants. Since paddy fields in Guilan province (Iran) are usually tilled in winter and also flooded due to high precipitation, it would be expected that a large number of overwintering adults that remained at the base of rice plants were unable to survive. Indeed, only those adults overwintering on the weeds near the paddy fields might successfully survive to produce the next generation in the following year.

Based on the current life history findings, *E. ventralis* spent 30–32 days (more than 75% of lifespan, except egg and first nymphal instar) feeding on rice panicles, which resulted in considerable loss of rice yield. The kind and intensity of damage caused by nymphs as well as adults have been found to be varied based on rice phenology, cultivars and also pest density (Ferreira and Barrigossi, 2006). The quantitative loss due to decreases in the numbers of filled grains and grain weights caused by feeding injuries of rice bugs on kernels from anthesis to the milky stage of rice plants resulted in empty or atrophied grains. Here, it should be noted that since different densities of *E. ventralis* were induced on rice plants after the panicle emergence stage (early ripening phase), the number of panicles per examined plant and the total number of kernels per panicle were not affected by *E. ventralis* density. Therefore, the comparisons were made based on the number and weight of grains per panicle in the present research. Similarly, the total number of kernels (empty + partially/completely filled grains) per panicle did not have significant differences in different infestation densities of *O. poecilus* at any phenological stages of panicle development (Krinski and Foerster, 2017). Indeed, Krinski and Foerster (2017) believed that the number of kernels per panicle was related to plant genetic factors, and also the fact that pest infestations were usually carried out after liberating panicles in rice plants. Our results revealed that the total number of kernels, as well as the number of empty kernels, did not significantly vary with pest density due to the time of pest establishment. Previously, Ito *et al.* (1992) concluded that the number of empty kernels in the anthesis stage was more affected than in the milky and dough stages of grain maturity by pest density of *L. oratorius* (Fabricius). In a similar trend, an increase in the number of empty kernels was evident in relation to *O. poecilus* density, especially in the caryopsis stage of rice (Awuni *et al.*, 2015). Tumanyan *et al.* (2024 b) stated that the percentage of empty kernels at densities of one and three rice bugs (*Nezara viridula* L.) on a day after the flowering stage was ≈ 25% and 55%, respectively, compared to 2–5% in control treatment. Due to an insignificant difference in the number of empty kernels in the present study, further research on various growth stages of rice plants infested by different densities of *E. ventralis* should be undertaken to clarify the relative importance of infestation time or pest density during the grain maturity process.

Although the number of empty kernels did not increase with the density of *E. ventralis,* undamaged (non-pecky) filled kernels showed significant reductions at higher pest densities. The mean number of pecky rice increased four-fold at infestation with nine adults, resulting in the significant reduction of undamaged (non-pecky) filled kernels per panicle. Krinski and Foerster (2017) found that feeding activities of four *O. poecilus* in rice milky stages reduced the number of undamaged grains from 111.23 kernels in control to 66.73 kernels per panicle.

Several papers on different rice bug species other than *E. ventralis* showed that the qualitative losses (pecky rice and broken grain) were evident due to pest feeding during later stages of grain development, where higher pest density increased the qualitative rice losses (Ito, 2004; Bhavanam *et al.*, 2021). Based on Patel *et al.* (2006), the percentage of pecky rice was higher at infestation of two rice bugs compared to one *O. pugnax* adult. In a similar trend, three adults of *N. viridula* produced

28% pecky rice compared to 1.2% pecky rice in the control treatment (Tumanyan *et al.*, 2024 b). In contrast, Sugiura *et al.* (2022) detected no correlation between the number of *L. chinensis* Dallas (Alydidae) and pecky rice incidence. According to SEM images of cross-sections of the palea, the small width of hook openness in kernels of some rice genotypes and also preferred sites for stylet insertion by *L. chinensis* (gap of the hooking portion) might be critical factors inducing rice resistance against this bug species. Since *L. chinensis* has been known as hooking-attacking stink bugs, a smaller width of the hook openness in kernels would inhibit the penetration of the stylet (Sugiura *et al.*, 2022). Therefore, the comprehensive studies on morphological characteristics of panicle in different rice varieties, as well as the preferred feeding sites (site of stylet penetration) on kernels, might explain these contradictory results reported for different rice bugs.

The presence of peck symptoms on rice kernels has led to an increase in the probability of grain breakage during the milling process, resulting in the reduction of the number of whole (head) rice grains and also the commercial value of rice. In the current study, the highest number of pecky rice grain was detected at infestation with nine *E. ventralis* adults, indicating the important role of this pest in qualitative yield loss. It should be considered that the restrictions on the percentage of pecky grains in the rice trade has recently increased, where the damaged grains have been expected to be < 0.5% (USDA, 2009).

Other than the number of kernels per panicle, grain weight characteristics have been considered for quantitative and qualitative damages, where the weight of head (perfect) rice has been evaluated for rice milling efficiency. The present survey on weight characteristics showed that the weight of broken rice grains was ≈ twice as high at a density of nine *E. ventralis.* Therefore, the mean weight of head (perfect) rice was inversely related to pest density. It should be noted that the higher pecky rice incidence led to lower milling efficiency, which coincided with a reduction in head rice weight. Tumanyan *et al.* (2024 a) demonstrated that the increased percentage of grain damage (2.0–3.0% pecky rice) decreased the milling yield even up to 12–13% for some rice varieties.

CONCLUSIONS

Owing to the yield loss risk, more precise monitoring is required for the recent *E. ventralis* outbreak in paddy fields. The favorable climatic conditions resulted in the development of four generations per year where fourth generation adults overwintered at the base of examined harvested rice plants. Moreover, the risk assessment of damage revealed that rice yield qualitatively decreased at higher pest infestation densities. Thereby, the weight of head rice and milling efficiency significantly decreased after infestation with only one *E. ventralis.* The current findings of ecological and phenological characteristics along with yield loss assessment would be useful to determine the specific economic threshold for this rice stink bug in paddy fields. However, further research focused on the timing of pest infestation (different rice phenological stages), rice varieties, and infestation of different nymphal instars as well as adults (male and female separately) would provide detailed information for the efficient management of *E. ventralis*.

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Table 1. Body length of different nymphal instars and adults of *Eysarcoris ventralis*.

		Min	Max	Mean±SE
Nymphal instar				
	First	0.64	0.75	0.72±0.02
	Second	1.08	1.18	1.16±0.001
	Third	1.72	2.26	1.90±0.06
	Fourth	2.37	3.99	2.80±0.12
	Fifth	4.32	5.40	4.90±0.08
Adult				
	Male	4.50	5.44	5.10±0.07
	Female	5.30	6.00	5.80±0.12

Means (±SE) were evaluated based on 10 replications for different nymphal instars and mated adults.

Table 2. Developmental time and adult longevity (mean±SE) of *Eysarcoris ventralis* under paddy field conditions.

	Male	Female	*p*	Male+Female	Mortality%[a] (Alive number)[b]
Egg	6.34±0.09 a	6.30±0.07 a	0.71	6.31±0.04	0 (116)
First instar	3.03±0.13 a	3.00±0.11 a	0.87	2.93±0.07	9.48 (105)
Second instar	2.77±0.19 a	2.75±0.17 a	0.93	2.84±0.12	13.33 (91)
Third instar	4.49±0.26 a	4.10±0.22 a	0.25	4.21±0.16	7.69 (84)
Fourth instar	3.20±0.16 a	3.12±0.15 a	0.73	3.21±0.11	4.76 (80)
Fifth instar	4.74±0.16 a	4.67±0.14 a	0.75	4.71±0.10	6.25 (75)
Nymphal stage	18.23±0.33 a	17.65±0.25 a	0.11	17.92±0.21	35.34 (75)
Total developmental time	24.57±0.33 a	23.95±0.23 a	0.12	24.24±0.20	–
Adult longevity	14.11±1.81 a	15.47±1.76 a	0.59	14.84±1.19	–
Life span	38.69±10.19 a	39.42±1.65 a	0.14	39.08±1.19	–

[a] Mortality percentage occurred in stage *j*. [b] The number of individuals in stage *j* survived to stage *j*+1. Standard errors were estimated by using 100,000 bootstraps. Means within rows followed by the same letters are not significantly different between male and female ($p< 0.05$).

Table 3. Adult pre-oviposition period, total pre-oviposition period, fecundity and life table parameters of *Eysarcoris ventralis* under paddy field conditions.

Parameter	Min	Max	Mean±SE
Adult pre-oviposition period, APOP (day)	1	7	4.46±0.30
Total pre-oviposition period, TPOP (day)	25	31	27.69±0.34
Oviposition period (day)	3	15	6.92±0.86
Fecundity (egg/female)	19	259	65.60±10.84
Net reproduction rate, R_0 (offspring/individual)	4.741	45.853	22.620±4.703
Intrinsic rate of increase, r (day^{-1})	0.047	0.112	0.0904±0.006
Finite rate of increase, (day^{-1})	1.048	1.118	1.0946±0.006
Mean generation time, T (day)	30.528	38.685	34.508±0.720

Standard errors were estimated by using 100,000 bootstraps.

Table 4. Mean number of kernels, undamaged (non-pecky) filled kernels, empty kernels and pecky rice per panicle after infestation with different densities of *Eysarcoris ventralis* under paddy field conditions.

Pest density	Total kernels	Undamaged filled kernels	Pecky rice	Empty kernels
0 (control)	120.00±2.88 a	105.33±2.60 a	6.67±0.88 d	8.00±1.15 a
1	117.34±3.92 a	96.67±1.64 ab	10.66±1.33 cd	10.01±1.53 a
3	118.67±3.18 a	90.66±0.67 bc	16.33±1.85 bc	11.67±1.67 a
6	118.66±2.02 a	86.00±3.05 cd	20.46±0.67 ab	12.01±1.32 a
9	118.33±2.43 a	78.36±1.33 d	25.00±2.81 a	14.23±1.25 a
p	0.9769	< 0.0001	< 0.0001	0.1313

Means within columns followed by the same letters are not significantly different ($p < 0.05$).

Table 5. Mean weight of rice grains, head (perfect) rice, broken rice and rice milling efficiency (%) per panicle after infestation with different densities of *Eysarcoris ventralis* under paddy field conditions.

Pest density	Mean weight (g)			Milling efficiency (%)		
	Total grains	Head rice	Broken rice	Total grains	Head rice	Broken rice
0 (control)	2.71±0.07 a	2.14±0.08 a	0.56±0.01 d	66.13±0.64 a	52.33±0.96 a	13.81±0.38 d
1	2.56±0.06 a	1.86±0.03 b	0.69±0.04 cd	64.23±0.86 ab	46.74±0.32 b	17.49±0.73 c
3	2.55±0.04 a	1.79±0.01 bc	0.76±0.03 bc	62.86±0.49 bc	44.14±0.16 c	18.73±0.58 bc
6	2.54±0.08 a	1.65±0.03 cd	0.88±0.05 ab	61.92±0.40 bc	40.39±0.31 d	21.53±0.71 ab
9	2.47±0.02 a	1.50±0.02 d	0.97±0.04 a	60.80±0.43 c	36.99±0.63 e	23.81±0.93 a
p	0.1664	< 0.0001	0.0001	0.0007	<0.0001	< 0.0001

Means within columns followed by the same letters are not significantly different ($p < 0.05$).

Figure 1. Morphological characteristics of the last abdominal segment in female and male of *Eysarcoris ventralis* (visible to the naked eye). **Female:** hair arrangement in a coherent longitudinal tuft prolonging in the middle of the last abdominal sternite, the posterior margin of the last abdominal segment is rounded/oval. **Male:** irregularly scattered hairs in the last abdominal sternite, the posterior margin of the last abdominal segment is bilobed.

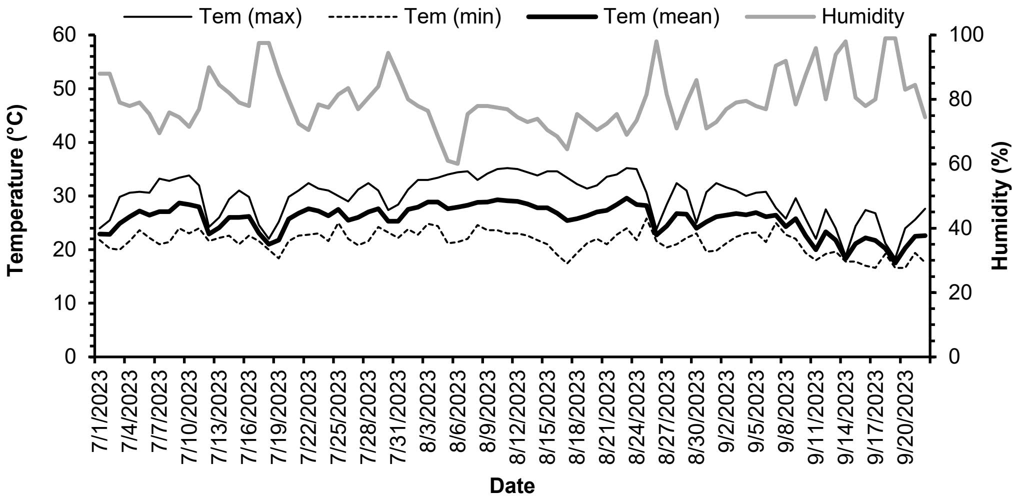

Figure 2. Meteorological data during the demographic experiment of *Eysarcoris ventralis* under paddy field conditions.

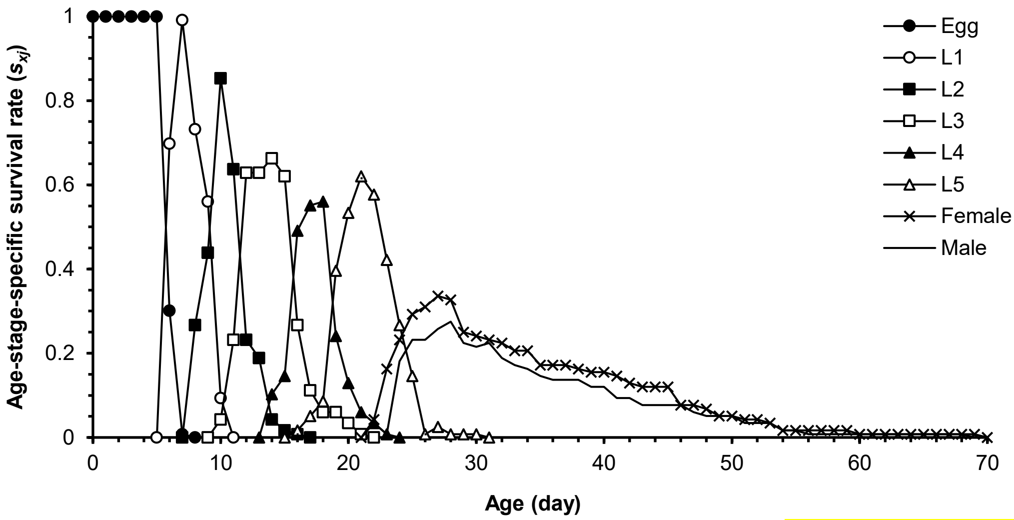

Figure 3. Age-stage-specific survival rate (s_{xj}) of *Eysarcoris ventralis*, which is the proportion of initial cohort population (116 eggs) surviving to age x and stage j when reared on the rice panicles under paddy field conditions.

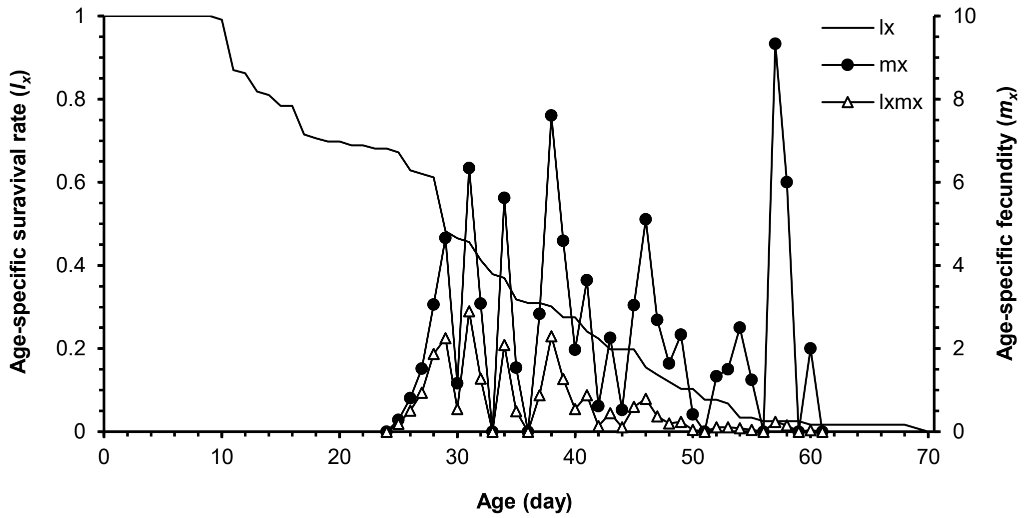

Figure 4. Age-specific survival rate (l_x), age-specific fecundity (m_x) and age-specific maternity (l_xm_x) of *Eysarcoris ventralis* under paddy field conditions.

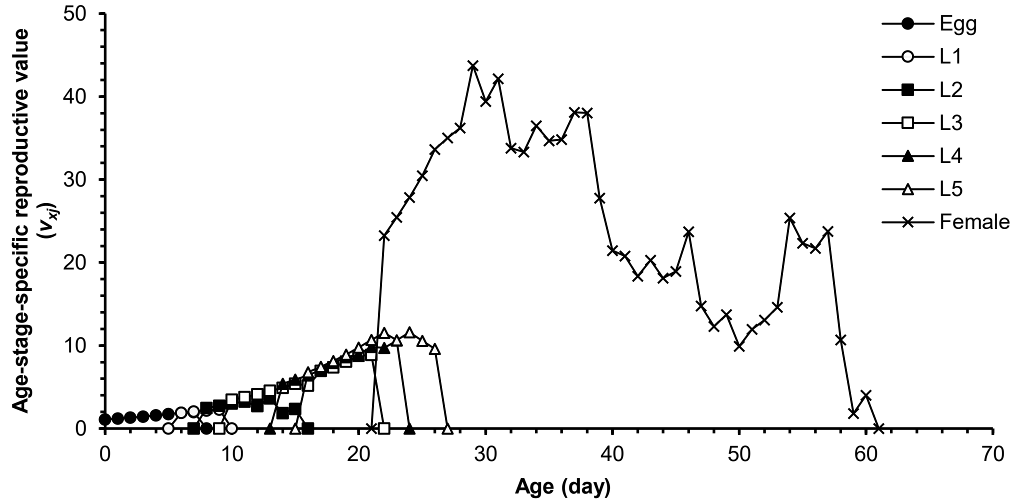

Figure 5. Age-stage-specific reproductive values (v_{xj}) of *Eysarcoris ventralis* under paddy field conditions.

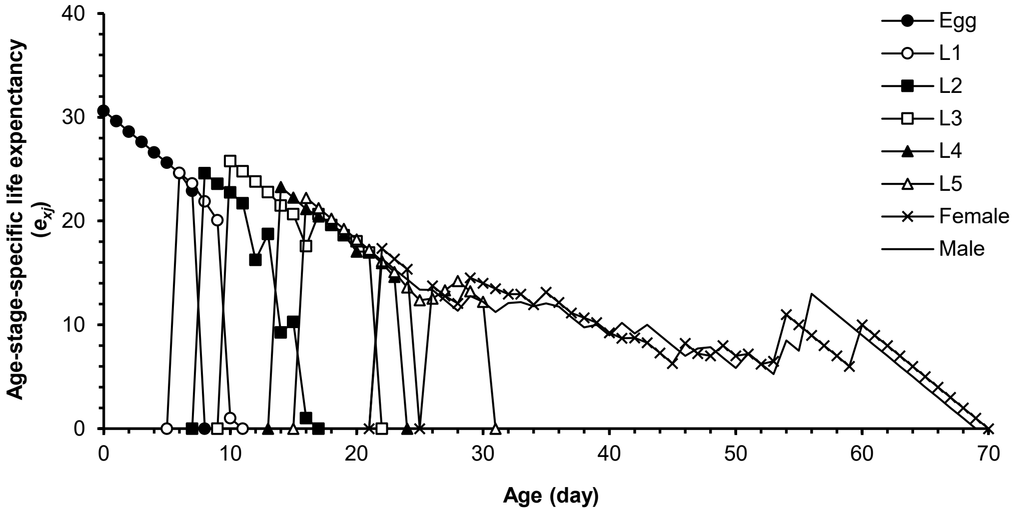

Figure 6. Age-stage-specific life expectancy (e_{xj}) of *Eysarcoris ventralis* under paddy field conditions.

کاهش فزاینده عملکرد برنج مرتبط با بروز دانه نیش‌خورده و رشد جمعیت سن *Eysarcoris ventralis* (Westwood, 1837) در مزارع برنج

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چکیده

سطح قابل قبول خسارت کمی و کیفی که توسط سن‌های بدبو در عملکرد برنج ایجاد می‌شود، اخیرا به‌صورت سختگیرانه‌تری در سراسر جهان اعمال می‌شود. در این پژوهش، پتانسیل رشد جمعیت، فنولوژی و کاهش عملکرد ناشی از آفت سن *Eysarcoris ventralis* در مزارع برنج (منطقه اشکیک، گیلان) مورد بررسی قرار گرفت. ابتدا تخم‌های همسن در قفس برگی قرار گرفتند و دوره زندگی آن‌ها ثبت شد. همچنین حشرات بالغ نسل اول بهاره، جمع‌آوری شده و به زیر قفس توری منتقل شدند و آزمایش فنولوژی تا زمان برداشت برنج رتون ادامه یافت. علاوه بر این، تراکم‌های مختلف آفت سن بدبو روی گیاه برنج رهاسازی شدند. پس از برداشت برنج، تعداد کل دانه‌ها، دانه‌های پوک، دانه‌های پر و نیز دانه‌های نیش‌خورده شمارش شدند. همچنین دانه‌های سالم (کامل) و نیز دانه‌های شکسته پس از فرایند سفیدکردن ثبت شدند. نتایج نشان داد طول دوره رشدی آفت 24/24±0/20 روز بود و میزان باروری معادل 65/60±10/84 تخم بود که روی برگ پرچم، پوست دانه و نیز سیخک‌ها گذاشته شده بودند. نرخ ذاتی افزایش جمعیت (r) 0/0904±0/006 بر روز بود. بررسی فنولوژی آفت نشان داد که نسل اول بهاره آفت توانست سه نسل دیگر را تکمیل کند و سپس حشرات بالغ نسل چهارم شروع به زمستان‌گذرانی کردند. بر اساس نتایج ارزیابی خسارت، تعداد دانه‌های نیش‌خورده بین 6/67±0/88 تا 25/00±2/81 عدد دانه به ازای هر خوشه، به‌ترتیب در تیمار شاهد و تراکم نه عدد آفت سن بدبو متغیر بود. کم‌ترین تعداد دانه‌های سالم بدون علایم نیش‌خوردگی، به میزان 78/36±1/33 عدد در تراکم نه عدد آفت سن بدبو مشاهده شد. میانگین وزن دانه‌های برنج کامل با تراکم آفت رابطه معکوس داشت. به دلیل تعداد بیش‌تر دانه‌های نیش‌خورده که منجر به شکستگی برنج می‌شد، کم‌ترین کارایی فرایند سفید کردن برنج به میزان 36/99±0/63 درصد بود که در تراکم نه عدد آفت سن بدبو به‌دست آمد. برآورد پتانسیل افزایش جمعیت این آفت، همراه با کاهش عملکرد برنج حتی در تراکم پایین آفت، اهمیت اقتصادی آفت سن بدبوی *E. ventralis* را توجیه می‌کند.