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Host-Specific Biotic Potential of Small Brown Planthopper, *Loadelphax striatellus* (Hemiptera: Delphacidae); Life Table Analysis

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Small brown planthopper, Fecundity, Developmental time, Population projection, Insect-plant interaction

ABSTRACT

The small brown planthopper (SBPH), *Laodelphax striatellus* Fallén (Hemiptera: Delphacidae), is a very destructive insect pest that feeds on a variety of cereal crops, notably rice. We investigated the demographic parameters of SBPH by feeding on maize (*Zea mays*), wheat (*Triticum estivum*), and rice (*Oryza sativa*) from the Poaceae family using age-stage, two sex life table analysis. The first three nymphal instars of SBPH developed more quickly when fed on rice (2.1-3.2 days) than on maize (2.6-4.4 days) and wheat (2.3-3.7 days). The 4th nymphal instar's developmental period was not differed significantly ($P > 0.05$) across the host plants. The developmental period of the last nymphal instar was prolonged (3.95 days) when fed on maize in comparison to rice (3.33 days) and wheat (3.17 days). The longest average adult life span was recorded on wheat (21.1 days), followed by maize (18.6 days) and rice (18.7 days). The fecundity rate of SBPH females was 199.2 eggs/female on rice, while the fecundity rate was reduced to 143.7 eggs/female on maize and 133.4 eggs/female on wheat. Further, age-stage-specific data indicates that fertility, life expectancy, and survival rate was reduced when SBPH fed on maize and wheat compared to rice. When SBPH fed on maize and wheat as compared to rice, population parameters such as the intrinsic and finite rate of increase were likewise lower. Despite having a lower biotic potential on wheat and maize, SBPH can survive and reproduce successfully on these crops in the absence of its primary host, rice. This information would be helpful to better understand the interaction of SBPH with host plants and to develop an integrated pest management plan for this destructive pest.

INTRODUCTION

Rice, *Oryza sativa* L. (Poales: Poaceae), holds the second position as a cash crop in Pakistan (Bibi *et al*., 2020). Moreover, it is extensively cultivated in numerous countries globally, including Australia, China, Southeast Asia, Latin America, and the USA (Redfern *et al*., 2012; FAO, 2021). The detrimental impact on the quality and quantity of rice is substantial when insect pests feed on different stages of its growth. Among these pests, several planthopper species, including the brown planthopper (BPH), *Nilaparvata lugens* (Hemiptera: Delphacidae), and the white-backed planthopper (WBPH), *Sogatella furcifera*, pose severe risks to rice crops, especially in Asian countries (Sun *et al*., 2015; Hullio *et al*., 2018; Hereward *et al*., 2020). Due to feeding of these planthoppers, signs of chlorosis and hopper burn show on the plant surface, which ultimately result in total crop failure (Atta *et al*., 2020). During 2017–18 growing season, rice planthoppers in Pakistan's Punjab province resulted in an average loss of 10 mounds per acre (Atta *et al*., 2020). Additionally, the planthoppers are a major threat to rice in different countries including China, which lost 2.5 million tons of rice in 2005, Thailand, which suffered losses of $52 million in 2010, and Vietnam, which lost about 1 million tons of rice.

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Small brown planthopper (SBPH) *Laodelphax striatellus* Fallén, has a widespread distribution around the world and has recently been reported in Pakistani rice fields as well (Rizwan *et al*., 2020). This specific insect poses a serious threat to crop productivity since it mostly infests basmati rice during the flowering and milking stages. All five nymphal instars of SBPH have the potential to damage rice fields (Bottrell and Schoenly, 2012). Beyond the direct damage by its feeding, SBPH also acts as a vector for many plant viruses that cause serious diseases to plants (Moya Fernández *et al*., 2021). Since these viruses are linked to serious diseases, they pose a significant threat to agricultural production. In East Asian nations like China, rice stripe virus alone has been shown to impair rice production by 30–50% (Sun and Jiang, 2006). Due to its distinctive traits, such as its potential for dispersal, host range, and the plant viruses it carries and transmits, SBPH stands out as more damaging than other planthopper species (Iqbal *et al*., 2022).

The extensive range of plant-feeding insects is widely recognized to be heavily influenced by the interactions with their host plants (Nakadai and Kawakita, 2016). Despite the identification of various alternative host plants for the SBPH (Rizwan *et al*., 2020), there is less information available on the demography of this pest for alternative hosts concerning its primary host, rice. Understanding how insect pests can survive on other host plants is crucial, as these plants may serve as reservoirs for pests that later infest other economically important crops (Clementine *et al*., 2005). To mitigate economic losses caused by significant insect pests, it is necessary to consider parameters such as the availability, diversity, density, and categorization of alternate hosts (Rizwan *et al*., 2020). The survival of the SBPH in the absence of rice crops remains uncertain. This study aims to enhance our understanding of how the SBPH spreads among alternative hosts in the Basmati Zone (Kallar tract) of Punjab, Pakistan.

The life-table study is a thorough scientific methodology used to assess an insect's fitness, such as survival, and reproduction (Arshad *et al*., 2021). According to several studies, it provides insightful information about the fitness of a plant species with respect to the insect under study and its implications for integrated pest management (IPM) tactics (Gabre *et al*., 2005; Yang *et al*., 2015). The age-stage two-sex life table is especially valuable when investigating aspects of fitness, as it considers both male and female insects (Ahn and Choi, 2022). It has become common practice to evaluate an insect's fitness at different life stages and how it responds to environmental variables like temperature, humidity, pesticides, and insect-plant interaction (Yang *et al*., 2015; Li *et al*., 2015; Saska *et al*., 2016). Consequently, this research can significantly contribute to determining the fitness level of an insect and identifying its true hosts. Investigating the alternate host plants of SBPH that can serve as habitats for the primary pests and sources of infestation is of utmost importance. We investigated the biotic potential of SBPH feeding on maize, wheat, and rice using age-stage, two-sex life table analysis.

MATERIALS AND METHODS

Field monitoring

Net sweeping were done on monthly basis on following host plants; *Trifolium alexandrinum* L. (Barseem), *Medicago polymorpha* (Burclover), *Cynodon dactylon* (Khabbal grass), *Leptochloa chinensis* (Ghora grass), *Zea mays* (maize), *Sorghum bicolor* (Sorghum) and *Helianthus annuus* (Sunflower) to check the presence of SBPH. A killing bottle (6.5cm in height and 2.5cm in diameter) containing potassium cyanide was used to instantly kill the captured insects. With the use of a stereoscope, the specimens were subsequently identified using morphological and taxonomic traits (de Remes Lenicov and Virla, 1993).

Insect rearing

The SBPH populations were collected from rice plants at the Rice Research Institute in Kala Shah Kaku, Pakistan. The adult SBPH samples were used for mass rearing, primarily on rice (TN1 variety), in a greenhouse. The newly established seedlings utilized for rearing the SBPH population were replaced at intervals of approximately 3 to 5 days. The SBPH population was raised for two generations before experimentation.

Plant material

Three grass species; maize (*Zea mays*), rice (*Oryza sativa*), and wheat (*Triticum aestivum*) were chosen for SBPH development after sample collection. Wheat and maize seeds were grown in plastic jars (15×15×20cm) after sterilization. The wheat and maize seeds received sterilization before the trial. When the plants height was 4-6 inches, they were used in the experiment. To aid SBPH development, the plant material was replaced every 3-5 days with new seedlings, depending on their vigor. Kissan Basmati rice was used, and it was planted in pots (19×13×15cm). The seedlings of 5-7 cm in length were used in the bioassay.

Life table studies

Total ten gravid females were placed in plastic containers with the target plant species. The females were taken out after a day, and the containers were checked twice a day at 9:00 AM and 9:00 PM. The freshly hatched nymphs were then moved to separate containers with the respective host plant seedlings. To study a life table of SBPH, the number of eggs was taken to be equal to the number of emerging nymphs. The developmental period of nymphs and adults were recorded. The seedlings and adult insects were segregated into separate containers. Adult insects from the larger culture were introduced into the containers as per the required male and female ratios, enabling the measurement of adult longevity and fecundity. To track the number of eggs laid until the death of each pair, newly formed pairs were transferred daily to fresh containers with new seedlings. In case of the death of a male or female in the experimental containers, a new individual of the corresponding sex was introduced, and data were recorded regarding the male's lifespan if a female died. Similar data on female fertility and longevity were collected as well.

Life table analysis

The life history data of SBPH were analyzed using the age-stage, two-sex life table method (Chi, 1988) using the computer program TWO SEX-MS Chart (Chi and Liu, 1985; Chi *et al*., 2020). Various population parameters were calculated, including the age-stage specific fecundity (f_{xj}), the age-specific survival rate (l_x), the age-specific fecundity (m_x), age-stage life expectancy (e_{xj}). To estimate the standard errors of all life table parameters, including intrinsic (r) and finite (λ) rates of increase, net reproduction rate (R_0), mean generation time (T), adult longevity, and fecundity, the bootstrap method with 100,000 replications were utilized (Efron and Tibshirani, 1993).

Population projection

The timing-MS chart program was used to compute the population increase and age-stage distribution of SBPH that was cultivated on three distinct host plants throughout subsequent generations using the information from the two-sex life table. The simulation's runtime of 60 days and the initial population of 10 eggs for each host plant were used for the comparative analysis.

RESULTS

The development time for the egg stage was significantly longer on wheat (5.37d) than on rice (5.50d) and maize (6.56d). The first three nymphal instars were significantly developed faster (2.1-3.2 d) when they fed on rice plants compared to maize (2.6-4.4 d) and wheat 2.3-3.7 d). No significant difference (P > 0.05) in the developmental time of the 4th nymphal instar was recorded. The last nymphal instar developed longer on maize (3.95d) than on rice (3.33 d) and wheat (3.17 d). Adult longevity was recorded highest on wheat (21.1 d) than on maize (18.6 d) and rice (18.7 d). The longevity of female adults was significantly higher on rice (20.5 d) than on maize (19.4 d) and wheat (18.3 d). While male adults survived longer on maize (17.5 d) than on rice (16.3 d) and wheat (11.2 d). The proportion of females in the total population was highest when they fed on rice (0.34 d) as compared to maize (0.26 d) and rice (0.20 d) (Table I).

Table I. Developmental period (days) of small brown planthopper on different host plants.

Stage	Developmental time (Mean ± SE)					
	n^b	Rice	n^b	Maize	n^b	Wheat
Egg	100	5.50±0.05a	90	6.56±0.05a	70	5.37±0.06b
N1	100	3.16±0.04c	90	4.44±0.05a	70	3.71±0.05b
N2	82	2.12±0.03c	62	3.40±0.06a	40	2.65±0.07b
N3	74	2.30±0.05b	54	2.63±0.06a	28	2.36±0.09a
N4	66	3.58±0.06a	46	3.50±0.07a	24	3.58±0.10a
N5	60	3.33±0.06b	40	3.95±0.15a	24	3.17±0.25b
Adult longevity	60	18.7±0.70b	40	18.6±0.55b	24	21.1±0.26a
Female	34	20.5±0.97a	23	19.4±0.77b	14	18.3±0.86b
Male	26	16.3±0.81b	17	17.5±0.72a	10	11.2±0.15c
Nf/N		0.34±0.05a		0.25±0.04a		0.20±0.04b

L1-L4 indicate the larval instar, means sharing similar letters in each row are not significantly different at $P > 0.05$, n = Numbers of individual *C. septumpunctata* that completed a stage.

No significant (P > 0.05) difference in the oviposition period was observed in the case of three host plants. The fecundity rate of individual females was significantly higher on rice (199.24eggs/female) followed by maize (143.7eggs/female) and wheat (133.4eggs/female). The net reproductive rate (R_0) was highest on rice (67.72 offspring/individual) followed by maize (36.70 offspring/individual) and wheat (26.68 offspring/individual). Mean generation time was highest when SBPH fed on maize (34.53 d) than on rice (30.51 d) and wheat (30.23 d). The intrinsic rate of increase (r) was recorded highest on rice (0.1378 d^{-1}) than on wheat (0.107d^{-1}) and maize (0.103d^{-1}). A similar trend was recorded in the case of finite rate of increase (λ) (1.1477d^{-1} on rice, 1.1137 d^{-1}on wheat, and 1.0719d^{-1} on maize) (Table II).

The age-stage specific survival rate (s_{xj}) of SBPH on three host plants is shown in Figure 1. The male and female adults emerged at the 22nd d when immature fed on maize followed by the 18th day on wheat and rice. The survival rate of males and females was higher when they fed on rice as compared to maize and wheat (Fig. 1).

Table II. Comparison of life table parameters (mean ± SE) of small brown planthopper on different host plants.

Parameters	Rice	Maize	Wheat
APOP	2.65±0.08a	2.09±0.08b	2.29±0.13b
TPOP	22.4±0.21b	26.5±1.08a	23.3±0.44a
Oviposition days	10.4±0.65a	9.78±0.24a	9.14±0.27a
Fecundity (eggs/female)	199.2±11.1a	143.7±7.31b	133.4±6.12b
R_0 (offspring individual^{-1})	67.72±10.1a	36.70±6.86b	26.68±6.49c
T (d)	30.51±0.31b	34.53±0.27a	30.23±0.60b
r (d^{-1})	0.137±0.01a	0.103±0.01b	0.107±0.01b
λ (d^{-1})	1.147±0.02a	1.071±0.01b	1.113±0.01b

Whereas APOP, TPOP, T, r, λ, and Ro represents an adult pre-oviposition period (days), total pre-oviposition period (days), mean generation time (days), intrinsic rate of increase (d^{-1}), and finite rate of increase (d^{-1}), net reproductive rate (offspring) respectively, means sharing similar letters in each row are not significantly different at $P > 0.05$.

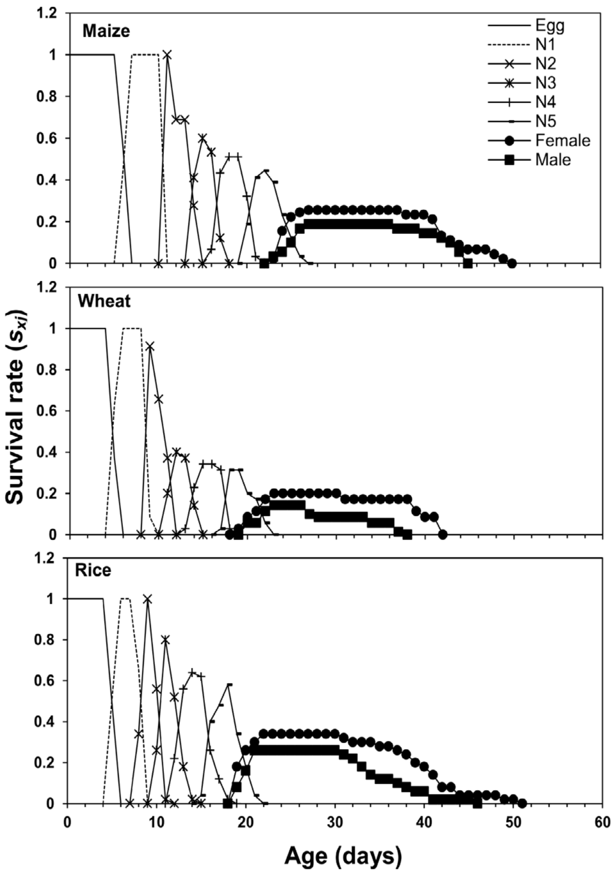

Fig. 1. Age stage-specific survival rate (s_{xj}) of small brown planthopper fed on different host plants.

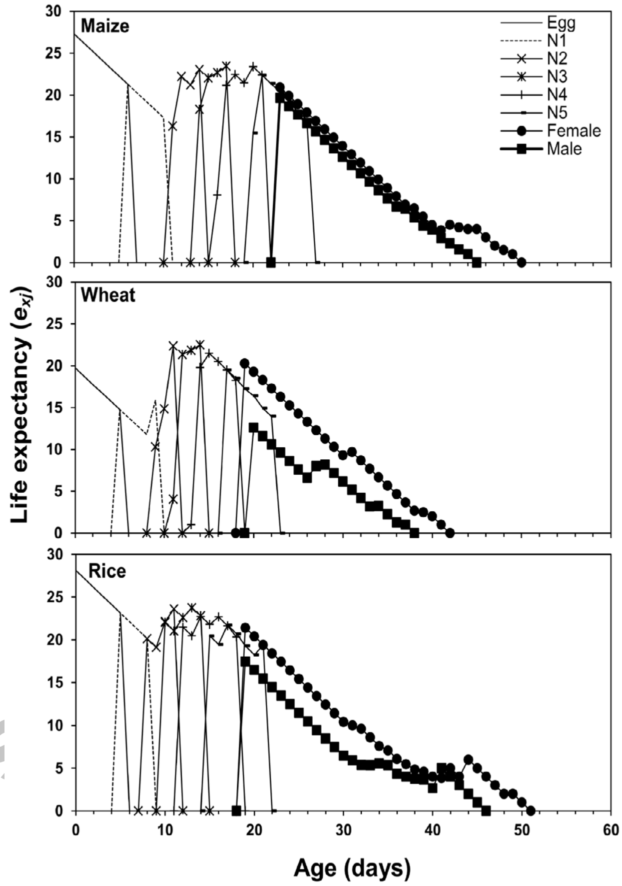

Fig. 2. Age stage-specific life expectancy (*exj*) of small brown planthopper fed on different host plants.

The e_{xj} curves of nymphs and adults of SBPH were lower on wheat as compared to rice and maize. The e_{xj} of female SBPH was 21.1 on 19th day on rice, 20.2 on 19th d on wheat, and 20.9 on 23rd d on maize (Fig. 2). The highest age-stage reproductive value (v_{xj}) value of females was observed in the case of rice at age 25th d ($v_{25,7}$ = 77.96d^{-1}). However, v_{xj} value was highest ($v_{24,7}$ = 62.39 d^{-1}) at 24th d on wheat and in the case of maize, the higher peak of v_{xj} was recorded as $v_{28,7}$ = 66.72 d^{-1} at 28th d (Fig. 3). The age-specific survival rate (l_x), age-stage specific fecundity (f_{xj}), age-specific fecundity (m_x) and age-specific maternity ($l_x m_x$) of SBPH on three host plants are shown in Figure 4. The fecundity rate of SBPH female appeared at 20th d on rice and wheat, and at 24th d on maize. Overall, the maternity rate of SBPH was highest (24.5) on the 47th d in rice, while the rate was 10.1 at 38th d in wheat and 12.6 on 46th and 48th d in maize (Fig. 4).

The population developed from 10 eggs stage size and growth rate is given in Figure 5 for 60 days. The highest stage size eggs, N1, N2, N3, N4, N5, female, and male

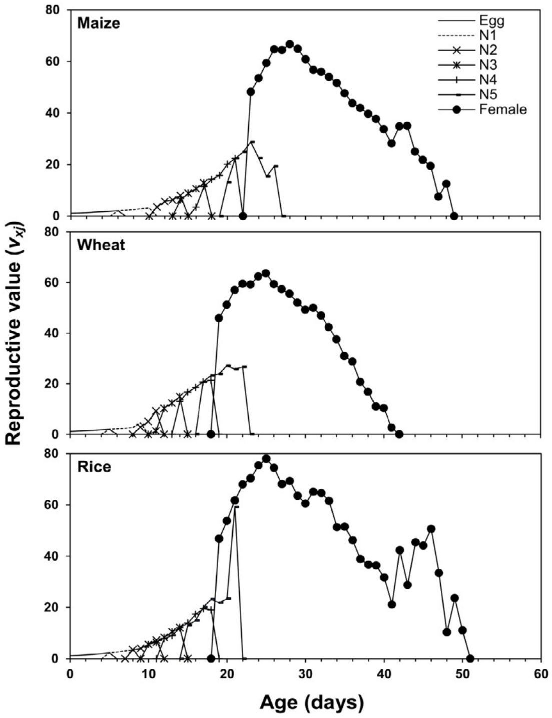

Fig. 3. Age-specific survival rate (*lx*), age stage-specific fecundity (f_{xj}), age-specific fecundity (m_x), and age-specific maternity ($l_x m_x$) of small brown planthopper fed on different host plants.

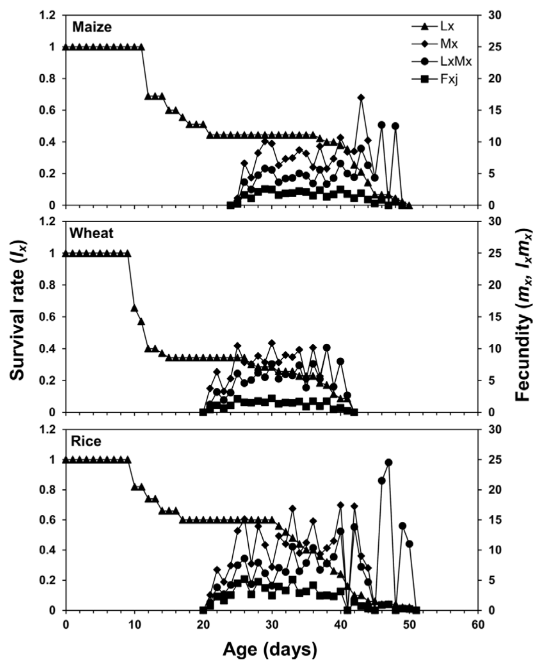

Fig. 4. Age stage-specific reproductive rate (v_{xj}) of small brown planthopper fed on different host plants.

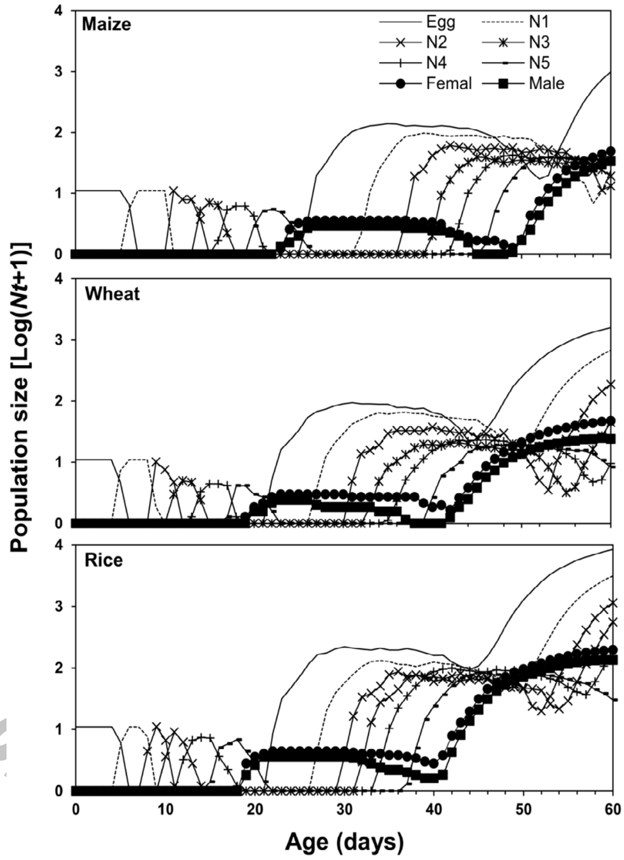

Fig. 5. Population projection of small brown planthopper showing the changes in the age-stage structure fed on different host plants.

population was recorded on rice (8470, 3107, 1139, 552, 192, 29, 195, and 133, respectively) followed by wheat (1588, 678, 186, 43, 8,7, 46, and 23, respectively), and maize (993, 23, 12, 18, 33, 33, 48, and 32, respectively). The emergence of different stages in rice is much earlier as compared to wheat and maize. The SBPH has produced more generations on rice (3.96) and wheat (3.20) as compared to maize (3.00) in 60 days (Fig. 5).

DISCUSSION

The population growth of an insect pest in specific agroecology is primarily influenced by the ecological fitness potential of the insect (Skendžić *et al*., 2021). Despite belonging to the Poaceae family, maize, and wheat, may be optimal hosts for SBPH. These crops serve as hosts for SBPH in tropical and neotropical regions depending on the season (Dupo and Barrion, 2009). The availability of suitable host plants throughout the year is a significant factor influencing the population densities and dynamics of insect pests (Richter and Hirthe, 2014; Askoul *et al.*, 2019). Different plant species have been shown to have a substantial impact on insect growth, fecundity, egg-laying, reproductive period, female survival, and lifespan (Gomes *et al*., 2017; Altaf *et al*., 2022). However, the suitability of host plants for SBPH in terms of its biotic potential on other hosts has not been studied yet. Therefore, we determined whether two other Poaceae species would be more or less suitable than rice for the survival and reproduction of SBPH. The results of our study revealed that rice, followed by wheat, exhibited faster development during the first three and final nymphal instars of SBPH. There was no significant difference in the developmental period of fourth instar larvae when they fed on three host plants. Individuals that consumed wheat during their immature stages had a longer adult lifespan, while no noticeable variation in adult lifespan was observed between rice and maize plants. The number of ovipositional days among SBPH individuals feeding on the three different plant types remained unchanged. These findings indicate that SBPH is capable of growing and surviving on wheat and maize plants in the absence of rice plants. Consequently, in the absence of rice plants, the SBPH population can easily spread to other hosts such as wheat and maize. The quality of the host plant plays a significant role in the population growth of planthoppers, impacting their efficiency and survival. Herbivores feeding on host plants with more nutritional components displayed increased survival rates (Huberty and Denno, 2006; Lu and Heong, 2009), larger body sizes (Jauset *et al*., 2000; Huberty and Denno, 2006), shorter development times (Fischer and Fiedler, 2000), and higher fecundity rates (Rashid *et al*., 2016). Each host plant species comprises a diverse array of nutritional compounds as well as secondary metabolic compounds that possess distinct defensive mechanisms, including tolerance, antibiosis, and antixenosis (Smith, 2005). Host plants serve as both food and habitat for insects, providing a suitable environment essential for their survival. In order to enhance their chances of survival and reproduction, insects must continually enhance their adaptability to host plants (Jiang *et al*., 2022).

Food availability generally, the relative distribution of various food types, and the apparent risk associated with each food source, such as the presence of poisonous chemicals or secondary metabolites, all have an impact on food preferences (Wink, 2018). Herbivorous insect development, survival, and reproductive success are significantly influenced by host plants (Ali *et al*., 2021; Altaf *et al*., 2022). Population factors shed light on a plant's tolerance and resistance to a particular insect pest. The physiological capacity of an organism to multiply on a specific host plant is characterized by the intrinsic rate of increase (r) (Razmjou *et al*., 2006). The effectiveness and suitability of insect pests on a host plant can therefore be assessed using this measure (Southwood, 2000; Zhang *et al*., 2007). In this study, we found that SBPH individuals feeding on wheat and maize had lower values of r, λ, R_0, age-stage specific survival rate, life expectancy, and reproductive rate than those feeding on rice.

Nevertheless, these alternative hosts exhibited sufficient potential for the growth of SBPH. The observed variations in fitness and survival patterns may be attributed to nutritional differences among the host plants (Kazemi *et al*., 2001). It is important to note that these characteristics often vary depending on the specific host plant species and regional environmental factors (Ozgokce *et al*., 2018; Xie *et al*., 2019). In the absence of rice, SBPH populations may seek shelter in wheat and maize. In Pakistan, where farmers commonly cultivate wheat crops after harvesting rice, wheat can serve as an alternative host for SBPH establishment and reproduction. As a result, if the primary rice crop is unavailable, SBPH can readily switch to maize and wheat as viable alternatives.

Our findings indicate that SBPH can utilize maize and wheat for shelter and survival, although with varying levels of success. Understanding the life history parameters of SBPH on different host plants can be helpful to develop more targeted and effective IPM strategies. For example, farmers can implement cultural control measures such as crop rotation or intercropping with less preferred hosts to reduce SBPH populations. These results align with previous research that has also observed performance variations of the same insect species on different host plants. Yang *et al*. (2010) worked on potato psyllids and found that eggplant and bell pepper exhibited different survival rates from egg to adult stage, with adults emerging approximately two days earlier when eggs were laid on eggplant. The pre-oviposition phase was unaffected by the host plant, and females began oviposition around 8 to 9 days after emergence. In our study, we successfully demonstrated SBPH establishment on both wheat and rice. However, it is important to note that SBPH may utilize these plants as temporary shelters during unfavorable conditions or for short periods.

CONCLUSION

These findings provide important information regarding the interaction between SBPH and host plants, aiding in the development of integrated pest management (IPM) strategies for mitigating the damage caused by this pest. Moreover, there is a need to check the presence of any virus associated with this vector affecting major host rice as well as other alternate hosts.

DECLARATIONS

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IRB approval

The study was approved by Director of Beekeeping and Hill Fruit Pests Research Station, Rawalpindi, Pakistan.

Ethical statement

The study have been conducted in accordance with the ethical standards and protocols related to site visits and data collection.

Statement of conflict of interest

The authors have declared no conflict of interest.

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