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Analysis of Mortality Factors Affecting Brown Planthopper, *Nilaparvata lugens* (Stål, 1854) Population as Rice Field Life Tables

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ABSTRACT

Nilaparvata lugens (Stål) is a significant insect pest of rice and its population under field conditions is regulated by natural factors. Ecological or field life table analysis is an effective tool for estimating the mortality caused by these factors. In the present study, cohort based ecological life tables were constructed to evaluate the mortality caused by abiotic and biotic factors across three rice phenological stages: active tillering, panicle bearing-grain filling and grain maturity. Egg sterility, high temperature, predation, parasitism and incomplete moulting were identified as the major mortality factors, with early nymphal instars (1-3) being the most susceptible. The key mortality factor was predation by arthropods such as spiders, coccinellids and bugs. This study provides quantitative, stage-specific insights into mortality dynamics, highlighting the dominant role of predation and the vulnerability of early nymphal stages in regulating *N. lugens* populations under field conditions.

Keywords: cohort, population dynamics, ecological regulation, natural mortality, spiders, coccinellids.

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INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops in the world, as nearly 3 billion people depend on it for their daily sustenance (Jeevanandham et al*.,* 2023). Various biotic stresses, such as diseases and insect pests, significantly limit rice production (Prahalada et al*.,* 2017). Among insect pests, *Nilaparvata lugens* (Stål), brown planthopper (BPH) is recognized as one of the most destructive pests of rice (Kumar et al., 2018). Both nymphs and adults of BPH feed by extracting phloem sap in the initial stages of rice plants leading to a condition known as 'hopper burn'. Additionally, BPH serves as a vector for several viral diseases such as wilted stunt (Chen & Chiu, 1989), ragged stunt (Ling, 1978) and grassy stunt (Rivera, 1966) which collectively contribute to a yield reduction exceeding 60% (Chitra, Subhash, Sinha, & Palta, 2009; Kumar, Managanvii, & Tiwari, 2012).

The brown planthopper (BPH) has traditionally been managed through the application of chemical insecticides (Bottrell & Schoenly, 2012). However, several workers have reported that extensive use of insecticides leads to early occurrences of pest resurgence in planthoppers, specifically in BPH (Gao, Gu, Bei, & Wang*,* 1988; Azzam, Wang, Wu, Shen, & Wang, 2009). Such resurgence is often associated with the disruption of natural enemy populations and the induction of physiological changes that enhance planthopper fecundity (Zhou et al., 2024). Therefore, to mitigate the prospective effects of pesticides on humans and the environment, there is a need to develop alternative pest control approaches (Kinuthia, Ayuya, & Nyaanga*,* 2019). This results in the acceptance of another pest management technique known as "Integrated Pest Management (IPM)" on a global scale. IPM offers an ecologically sound approach that combines cultural, biological, and chemical control measures to maintain pest populations below economic threshold levels while conserving natural enemies (Heong et al., 2015). Natural enemies, including spiders, coccinellids, mirid bugs, and parasitoids, play a crucial role in regulating planthopper populations in rice ecosystems, often providing effective biological control and reducing reliance on chemical insecticides (Ali et al., 2023). Conservation of natural enemies plays a central role in sustainable pest management. Ecological engineering approaches in rice systems focus on enhancing ecosystem services by conserving and promoting natural enemies through habitat manipulation, thereby improving pest suppression and reducing pesticide use (Zhu et al., 2022). Field studies have demonstrated that ecological engineering practices, such as bund planting with flowering crops, significantly enhance predator activity and reduce planthopper populations in rice fields (Yele et al., 2024).

The developmental stage of an insect that experiences the highest mortality is referred to as the critical age interval, while the environmental factors responsible for that mortality are identified as the key mortality factors (Fidelis et al., 2018). Life table analysis serves as an important tool in ecological studies, providing insight into the relevance and significance of various mortality factors regulating pest populations (Rodrigues et al., 2017; Silva et al*.,* 2017). Understanding crop phenological stages

in relation to pest population is essential because damage thresholds vary with crop growth stages and determine the degree to which pest severity is associated with yield (Kaur, Sarao, & Singh, 2022). Therefore, the present study was conducted to identify natural mortality factors and quantify their contributions to the regulation of *N. lugens* populations using life table analysis across three rice phenological stages - active tillering, panicle bearing - grain filling and grain maturity under field conditions. While previous studies have documented the role of natural enemies in regulating *N. lugens*, quantitative information on stage-specific mortality and the relative contributions of different mortality factors under field conditions remains limited, particularly in this agroecosystem. Accordingly, this study constructs a stage-specific life table, estimates k-values, and identifies key mortality factors operating at different developmental stages, thereby providing a more precise understanding of population regulation.

MATERIAL AND METHODS

Study site and period

The present study was carried out at the Rice Research Area, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana using rice variety PR-121. Life tables were constructed using data collected from three phenological stages of rice: active tillering (IV week of July - III week of August), panicle bearing-grain filling (IV week of August - III week of October) and grain maturity stage (IV week of October - IV week of November) during the wet (*kharif*) seasons of 2021 and 2022.

Cohort establishment

The cohort was established by collecting twenty pairs of newly emerged adults of *N. lugens* from laboratory reared colonies maintained at 28 ± 2 °C, 75 ± 5% relative humidity (RH) and 14:10 h light:dark (L:D) photoperiod for each rice phenological stage. Cohorts from these laboratory colonies represent field genotypes. Three independent sets, each comprising twenty pairs, were maintained for each rice phenological stage, representing three replicate cages per stage. The collected adults were confined in *Mylar* cages (25×10 cm) containing 50-day-old rice plants at a density of two pairs per cage for oviposition. To obtain eggs of the uniform age, the adults were removed after 3-day oviposition period. Upon hatching, first instar nymphs were collected and transferred onto fresh PR-121 plants. The plants were replaced every two days. The number of eggs laid was determined by destructively sampling the leaf sheaths used for oviposition.

Determination of mortality factors

The observations on the causes of BPH mortality were recorded at three-day intervals during each crop phenological stage, starting from the establishment of the BPH cohort and continuing until the adults entered the reproductive phase. Rice variety PR-121 was cultivated in a plot of 1500 m^2 divided into 60 blocks, following recommended agronomic practices but without the application of any plant protection measures. From each block, five hills were randomly selected to ensure unbiased

sampling. From these sampling units, individuals representing discrete stages of *N. lugens* population- eggs, early (1-3) and late (4-5) instar nymphs and adults were collected. The identification and classification of developmental stages were based on criteria established through laboratory cohort observations. For life-table parameter estimation, observations of all developmental stages collected across blocks were pooled for each sampling event, and parameters were calculated using aggregated dataset. The blocks were used to improve spatial representativeness of the field population and were not treated as independent replicates. To assess parasitism at various stages, direct sampling of nymphs and adults was conducted in the field. Since eggs and egg parasitoids were not visible to the naked eye, tillers bearing oviposition scars were collected from each block and brought to the laboratory for further examination. Similarly, predators were collected from the rice field and starved for 24 hours prior to experimentation. Individual predators were then confined in separate plastic vials with five, seven, and ten fifth-instar *N. lugens* nymphs to determine predation-induced mortality. After 24 and 48 hours, the number of nymphs killed or consumed was recorded to evaluate the feeding efficiency of individual predators.

Analyses of life tables

Determination of marginal mortality (MM)

Life tables of *N. lugens* were constructed following the methodology described by Southwood & Henderson (1960). MM is the marginal mortality and was derived from Naranjo & Ellsworth (2005) and is estimated as MB = dB/(1-dA). Here, MB is the marginal rate of mortality factor B, dB is the apparent rate of mortality from factor B and dA is the apparent rate of mortality added for all mortality factors that can overcome factor.

Key-factor analysis

For key-factor analysis, the method of Varley & Gradwell (1960) was used. Data were transformed to natural logarithms and was calculated as $k=-\log10(1 - MMx \div 100)$, where MMx is the marginal mortality (percentage) for a given factor at a given stage of development. Statistical analysis was performed using one-way analysis of variance (ANOVA) to assess differences in mortality parameters among phenological stages.

RESULTS AND DISCUSSION

Level of *N. lugens* mortality

In this study, life tables were used to measure the effects of various mortality factors of *N. lugens* in rice under field conditions. During the construction of ecological life tables, the most valuable information is recorded in the marginal mortality rates of each factor in each stage (Jing et al., 2022). These rates are converted into k-values to calculate total generational mortality by calculating stage-specific mortality over all factors and factor-specific mortality over all stages (Naranjo & Ellsworth, 2017). During active tillering stage of crop growth, the mortality of *N. lugens* was 83.62%

(Table 1). Out of total 524.00 (±13.57) eggs, 120.67 (±5.04) reached the adult stage. During advanced crop growth stage i.e. during panicle bearing-grain filling stage, the percentage mortality was 51.27%. During this stage, a total of 2004.33 (±47.27) eggs were obtained out of which 931.00 (±35.69) were able to emerge as adults. As the crop advances towards maturity i.e. during grain maturity stage 77.98% mortality was observed. A total of 1676.00 (±6.27) eggs were obtained among which 370.33 (±2.12) adults emerged. It was observed that the trend index was positive during active tillering stage. This positive trend index indicated that mortality factors operating during this stage were not effective in suppressing BPH population in succeeding generations. During panicle bearing-grain filling and grain maturity stages, the trend index was negative (less than one) which revealed that key mortality factors operating during these stages were effective in causing population decline. Prasad (2022) also explained a number of factors are operational in fields, which affect the growth and metabolism of insects ultimately influencing their population.

Table 1. Ecological life table for *Nilaparvata lugens* population during active tillering stage of rice (values are mean ± SE).

Stage/Mortality Factor	Factor (l x)	Stage (d x)	Factor (d x)	Real mortality		Apparent mortality		Marginal mortality	k-value
				Stage/ (dx/l0)	Mortality Factor	Stage (q x)	Factor (q x)		
Egg	524.00±13.57	254.67±5.96		0.49		0.49			
Sterility			257.00		0.49		0.49	0.49	0.67
Early instar (1-3)	251.33±19.74	145.67±2.84		0.28		0.54			0.92
High temperature			49.00		0.09		0.18	0.18	0.20
Predation			82.00		0.16		0.31	0.48	0.65
Incomplete moulting			14.00		0.03		0.05	0.07	0.07
Late instar (4-5)	120.67±5.04	37.00±2.82		0.07		0.30			0.37
High temperature			14.00		0.03		0.11	0.11	0.12
Predation			17.00		0.03		0.14	0.17	0.18
Incomplete moulting			6.00		0.01		0.05	0.07	0.07
Adults	86.00±2.88			0.00					
Generational mortality					0.84			1.56	1.96
Total mortality= 83.62 %									

Sample size **(n)** equals individuals entering each stage (l_x). **l_x:** initial population; **d_x:** deaths per stage; **factor d_x:** cause-specific deaths; **q_x:** mortality rate; **marginal mortality:** independent contribution of each factor; **k-value:** log-transformed mortality. Total cohort mortality = **83.62%.**

Key-factor analysis

During all the three crop stages, egg sterility was the major cause of mortality as presented in table 1, table 2 and table 3. Sterility may be caused by the plethora of abiotic and biotic threats to which eggs are exposed (Hilker, Salem, & Fatouros, 2023). Normal eggs of *N. lugens* undergo distinct morphological changes during embryogenesis such as color transition and visible embryo formation, whereas parasitized eggs exhibit characteristic discoloration (darkening or color change), internal parasitoid development, and eventual emergence. In contrast, sterile (non-viable) eggs fail to show embryonic differentiation and lack any signs of parasitoid development, allowing

clear separation of these categories based on morphological and developmental criteria. Similar observations and diagnostic criteria for distinguishing normal, parasitized, and non-viable eggs have been reported in previous studies (Zhang et al., 2020; Ye et al., 2022). Among abiotic factors, temperature is the most important factor exerting such direct effects (Vasudeva et al*.,* 2019). We also observed that high temperature (threshold of ≥ 35 °C) was an important mortality factor among *N. lugens* during all the rice phenological stages for both early and later instar nymphs (Table 1, 2 and 3). Mortality attributed to high temperature was diagnosed based on characteristic physiological and morphological symptoms observed in the absence of biotic factors (predation or parasitism). Individuals classified under this category exhibited signs such as desiccation, body shrinkage, discoloration, and sudden mortality coinciding with elevated ambient temperature conditions recorded during the sampling interval. No evidence of feeding damage, parasitoid development, or moulting failure was present in such cases, and mortality was temporally associated with periods of high field temperature. Several previous studies also indicated the remarkable influence imposed by temperature on population dynamics of BPH (Sharma, Raju, & Jaiswal, 2018; Horgan, Arida, Ardestani, & Almazan, 2021). We recorded that incomplete molting was another factor causing mortality in nymphal instars. This may be due to the fact that attack by *N. lugens* modifies the plant defence response by affecting the production of ecdysteroid. Mortality due to incomplete moulting was identified when nymphs were observed partially emerged from the exuviae, trapped within the old cuticle or showing deformities such as twisted appendages or incomplete sclerotization. These individuals typically died during the moulting process and were clearly distinguishable from other mortality factors due to the presence of retained exuviae and unsuccessful ecdysis. Hincapié et al*.* (2011) also explained that ecdysteroid in plants serves a similar purpose to ecdysteroid in insects and insect ecdysis can be encouraged at low levels, which could disrupt their typical growth and development that leads to incomplete molting. Also, heat stress has been shown to interfere with endocrine regulation of moulting, leading to developmental abnormalities and failure of nymphs to successfully moult to subsequent instars (Yang et al., 2021). To minimize observer bias, these diagnostic criteria were standardized based on observations from laboratory-reared cohorts, where normal and abnormal moulting processes and temperature-induced stress symptoms were documented under controlled conditions. In agricultural ecosystems, various arthropod predators like spiders, ladybugs, green lacewings, syrphid flies, and others naturally inhabit the environment and act as biological control agents (Nadeem et al*.* 2023). In our study, among biotic factors spiders, coleopterans and hemipterans were recorded as key mortality factors as they impart significant mortalities in *N. lugens*. Within each *N. lugens* developmental stage, the greater k-values were contributed by mortality caused by predators at all the rice developmental stages (Table 1, 2 and 3).

Table 2. Ecological life table for *Nilaparvata lugens* population during panicle bearing-grain filling stage (values are mean ± SE).

Stage/Mortality Factor	Factor (l x)	Stage (d x)	Factor (d x)	Real mortality		Apparent mortality		Marginal mortality	k-value
				Stage/ (dx/l0)	Mortality Factor	Stage (q x)	Factor (q x)		
Egg	2004.33±47.27	322.66±15.82		0.161		0.16			0.17
Sterility			177.00		0.08		0.08	0.08	0.09
			148.00		0.07		0.07	0.08	0.08
Early instar (1-3)	1648.66±21.71	563.33±26.29		0.277		0.33			0.42
High temperature			155.00		0.07		0.09	0.09	0.09
Predation			216.00		0.10		0.12	0.16	0.17
Parasitiods			81.00		0.04		0.04	0.06	0.06
Incomplete moulting			105.00		0.05		0.06	0.08	0.08
Late instar (4-5)	1141.33±25.57	153.00±6.01		0.075		0.13			0.15
High temperature			46.00		0.02		0.04	0.04	0.04
Predation			80.00		0.04		0.07	0.08	0.09
Incomplete moulting			24.00		0.01		0.02	0.02	0.02
Adults	931.00±35.69			0.000	0.00				0.00
Generational mortality					0.51			0.72	0.76
	Total mortality= 51.27 %								

Sample size **(n)** equals individuals entering each stage (l_x). **l_x:** initial population; **d_x:** deaths per stage; **factor d_x:** cause-specific deaths; **q_x:** mortality rate; **marginal mortality:** independent contribution of each factor; **k-value:** log-transformed mortality. Total cohort mortality = **51.27%.**

Table 3. Ecological life table for *Nilaparvata lugens* population during grain maturity stage (values are mean ± SE).

Stage/Mortality Factor	Factor (l x)	Stage (d x)	Factor (d x)	Real mortality		Apparent mortality		Marginal mortality	k-value
				Stage/ (dx/l0)	Mortality Factor	Stage (q x)	Factor (q x)		
Egg	1676.00±6.27	683.00±8.01		0.41		0.41			0.52
Sterility			407.00		0.24		0.24	0.24	0.27
			276.00		0.16		0.16	0.22	0.24
Early instar (1-3)	943.67±23.20	434.67±12.91		0.26		0.44			0.65
High temperature			98.00		0.06		0.10	0.10	0.10
Predation			211.00		0.13		0.21	0.27	0.32
Parasitiods			88.00		0.05		0.09	0.14	0.15
Incomplete moulting			43.00		0.03		0.04	0.07	0.07
Late instar (4-5)	552.67±23.87	182.00±7.13		0.11		0.34			0.42
High temperature			92.00		0.05		0.17	0.17	0.18
Predation			74.00		0.04		0.13	0.17	0.18
Incomplete moulting			21.00		0.01		0.04	0.05	0.06
Adults	370.33±2.12								
Generational mortality					0.78			1.78	2.21
	Total mortality= 77.98 %								

Sample size **(n)** equals individuals entering each stage (l_x). **l_x:** initial population; **d_x:** deaths per stage; **factor d_x:** cause-specific deaths; **q_x:** mortality rate; **marginal mortality:** independent contribution of each factor; **k-value:** log-transformed mortality. Total cohort mortality = **77.98%.**

Natural enemy species

In this study, twelve spider species belonging to nine different families were observed. The major predatory spiders are *Araneus sp., Ostearius melanopygius* (Araneae), *Atypena formosana* (Oi), *Tetragnatha nitens* (Audouin), *Neoscona theisi* (Walckenaer), *Oxyopes hindostanicus* (Pocock), *Pardosa pseudoannulata* (Bösenberg & Strand), *Clubiona sp.*, *Plexippus paykulli* (Audouin), *Bianor angulosus* (Karsch), *Theridion sp.* and *Thomisus sp.* Various species of coleopterans such as *Menochilus sexmaculatus* (Fabricius), *Coccinella transversalis* (Fabricius), *Coccinella septempunctata* (Linnaeus), *Micraspis discolor* (Fabricius), *Brumoides suturalis* (Fabricius), *Ophionea nigrofasciata and Paederus fuscipes* (Curtis) form a very prolific group and are observed as ubiquitous obligate carnivores in imparting mortalities in *N. lugens.* Apart from spiders and coleopterans, a few species of hemipteran such as *Cyrtorhinus lividipennis* (Reuter), *Microvelia douglasi* (Scott) and *Geocoris sp.* were observed as significant *N. lugens* predators. The laboratory feeding trials conducted in the present study were designed to estimate the potential feeding capacity of individual predators under standardized conditions, rather than to directly quantify field-level predation. We recognize that actual predation rates in the field are influenced by multiple ecological factors, including functional response, prey density, spatial heterogeneity, search efficiency, and prey stage preference. In particular, predators may exhibit stage-specific preferences, and their encounter rates with prey in the field are constrained by habitat structure and mobility, which are not replicated in confined laboratory conditions. Therefore, the predation rates obtained in this study should be interpreted as relative estimates of predation potential, useful for comparing predator efficiency across species, rather than absolute measures of field predation intensity. In fact, these arthropods are well documented predators and feed voraciously on *N. lugens* (Joseph & Premila, 2016; Shanker et al., 2018).

Whereas, during advanced stages of crop growth in addition to above mortality factors, parasitoids also impart significant mortalities in all the nymphal instars. In our study, parasitoid wasps (*Pseudogonatopus sp.*) were identified as an important mortality factor for *N. lugens*, with various stages of parasitism, including host attack, larval development, and adult emergence. Predatory wasps prefer to feed on plants that have been injured by insects rather than on unharmed plants and wasps may also mark plants or leaves to aid in locating prey (Geitzenauer & Bernays, 1996).

Critical mortality stage

At all three crop growth stages, mortality at egg and all the nymphal stages had a positive and significant correlation with total mortality (Table 4). Simple linear regression analysis was performed to assess the contribution of each factor within the key mortality factor. Significant R^2 values at all the *N. lugens* developmental stages indicated the role played by mortality factors in maintaining population. Among various *N. lugens* growth stages, highest k-values were observed for early instar nymphs (1-3) as 0.92, 0.429 and 0.65 at active tillering, panicle bearing-grain filling and grain maturity stage of rice, respectively. Therefore, the critical mortality stage of the *N. lugens* was early

nymphal instars and these early instars were most vulnerable stage. In this study, the food and space are assumed as unlimited resources at early stages of the *N. lugens,* the quality of host plant was the most important factor affecting population development. Previous studies also reported several mechanisms enhancing the resistance of rice plants to insects (Pati et al*.,* 2023). However, ANOVA indicated that mortality parameters did not differ significantly among phenological stages ($F_{2,6}$ = 0.002; $P > 0.05$). The very low F-value and high P-value suggest that variation in mortality across stages was negligible compared to within-stage variability.

Table 4. Correlation coefficients (r), regression equations, and coefficients of determination (R^2) to identify the critical mortality stage of *Nilaparvata lugens* population.

Stage	Correlation (r)	Regression equation	Coefficient of determination (r^2)
Egg	0.817194	y = 1.3563x + 0.5961	R^2 = 0.752
Early instar (1-3)	0.862697	y = 1.9868x + 0.6603	R^2 = 0.6605
Late instar (4-5)	0.774098	y = 7.9939x + 0.4415	R^2 = 0.5992

Higher r and R^2 values indicate stages where mortality contributes more significantly to variations in population decline.

This study demonstrates that natural control factors play an important role in regulating *N. lugens* populations in rice fields. The early nymphal instars (1-3) are most critical phase of *N. lugens* life cycle. Predators emerged as the most significant mortality factor, making them fundamental to the natural management of *N. lugens*. Although the importance of predators in regulating *N. lugens* populations has been previously reported, the present study provides quantitative, stage-specific estimates of mortality (k-values), enabling identification of the most influential mortality factors at each developmental stage under field conditions. These findings highlight the ecological importance of natural enemies in influencing *N. lugens* population dynamics under field conditions. Conservation of these natural enemies through reduced reliance on broad-spectrum insecticides and adoption of ecologically based pest management strategies may enhance natural suppression. The identification of early nymphal instars as the most vulnerable stage suggests that timely monitoring and intervention during this phase could improve management efficiency. Further studies are required to establish quantitative relationships between natural enemy abundance and pest reduction.

REFERENCES

Ali, M.P., Clemente-Orta, G., Kabir, M.M.M., Haque, S.S., Biswas, M., & Landis, D.A. (2023). Landscape structure influences natural pest suppression in a rice agroecosystem. *Scientific Reports,* 13, 15726. https://doi.org/10.1038/s41598-023-41786-y

Azzam, S., Wang, F., Wu, J.C., Shen, J., & Wang, L.P. (2009). Comparisons of stimulatory effects of a series of concentrations of four insecticides on reproduction in the rice brown planthopper *Nilaparvata lugens* Stål (Hemiptera: Delphacidae). *International Journal of Pest Management*, 55, 347-358. https://doi.org/10.1080/09670870902934872

Bottrell, D. G. & Schoenly, K. G. (2012). Resurrecting the ghost of green revolutions past: The brown planthopper as a recurring threat to high-yielding rice production in tropical Asia. *Journal of Asia-Pacific Entomology*, 15(1), 122-140. https://doi.org/10.1016/j.aspen.2011.09.004

Chen, C.C. & Chiu, R.J. (1989). Transmission of rice wilted stunt virus by brown planthopper (*Nilaparvata lugens* Stål). *Bulletins of Taichung District Agricultural Improvement Station*, 23, 3-10.

Chitra, S., Subhash, C., Sinha, S.R., & Palta, R.K. (2009). Toxicity of various insecticides against Delhi and Palla population of brown planthopper (*Nilaparvata lugens*). *Indian Journal of Agricultural Sciences*, 79(12), 1003-1006. https://epubs.icar.org.in/index.php/IJAgS/article/view/2564

Fidelis, E.G., Santos, A.A., Sousa, F.F., Silva, R.S.D., Dângelo, R.A.C., & Picanço, M.C. (2018). Predation is the key mortality factor for *Brevicoryne brassicae* in cabbage crops. *Biocontrol Science and Technology*, 28(12), 1164-1177. https://doi.org/10.1080/09583157.2018.1516735

Gao, C.X., Gu, X.H., Bei, Y.W., & Wang, R.M. (1988). Approach of causes on brown planthopper resurgence. *Acta Ecologica Sinica*, 8, 155-163.

Geitzenauer, H.L. & Bernays, E.A. (1996). Plant effects on prey choice by a vespid wasp, *Polistes arizonensis*. *Ecological Entomology*, 21(3), 227-234. https://doi.org/10.1046/j.1365-2311.1996.t01-1-00006.x

Heong, K.L., Escalada, M.M., Huan, N.H., & Mai, V. (2015). Sustainable rice pest management through ecological engineering and IPM. *Rice Science,* 22, 173-183. https://doi.org/10.1016/j.rsci.2015.04.002

Hilker, M., Salem, H., & Fatouros, N.E. (2023). Adaptive plasticity of insect eggs in response to environmental challenges. *Annual Review of Entomology*, 68, 451-469. https://doi.org/10.1146/annurev-ento-120120-100746

Hincapié, L.C.A., Monsalve, F.Z., Parada, K., Lamilla, C., Alarcón, J., Céspedes, A.C.L., & Seigler, D. (2011). Insect growth regulatory activity of *Blechnum chilense*. *Natural Product Communications*, 6, 1085-1088.

Horgan, F.G., Arida, A., Ardestani, G., & Almazan, M.L.P. (2021). Positive and negative interspecific interactions between coexisting rice planthoppers neutralise the effects of elevated temperatures. *Functional Ecology*, 35(1), 181-192. https://doi.org/10.1111/1365-2435.13683

Jeevanandham, N., Raman, R., Ramaiah, D., Senthilvel, V., Mookaiah, S., & Jegadeesan, R. (2023). Rice: *Nilaparvata lugens* Stål interaction—current status and future prospects of brown planthopper management. *Journal of Plant Diseases and Protection*, 130(1), 125-141. https://doi.org/10.1007/s41348-022-00672-x

Jing, T.X., Qi, C.C., Jiao, A., Liu, X.Q., Zhang, S., Su, H.H., & Yang, Y.Z. (2022). Life table construction under different temperatures and insecticide susceptibility analysis of *Uroleucon formosanum* (Hemiptera: Aphididae). *Insects*, 13(8), 693. https://doi.org/10.3390/insects13080693

Joseph, R. & Premila, K.S. (2016). A study on the richness of spider fauna in rice ecosystem. *Journal of Entomology and Zoology Studies*, 4(2), 425-430.

Kaur, G., Sarao, P.S., & Singh, P. (2022). Effect of weather variabilities on dispersion pattern of *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae) in paddy field. *Journal of Agrometeorology*, 24(4), 403-408. https://doi.org/10.54386/jam.v24i4.1726

Kinuthia, C.W., Ayuya, O.I., & Nyaanga, J.G. (2019). Determinants of intensity of uptake of alternative pest control methods: a case of small-scale tomato farmers in Kenya. *Journal of Development and Agricultural Economics*, 11(5), 110-121. https://doi.org/10.5897/JDAE2018.1004

Kumar, K., Sarao, P.S., Bhatia, D., Neelam, K., Kaur, A., Mangat, G.S., Brar, D.S., & Singh, K. (2018). High-resolution genetic mapping of a novel brown planthopper resistance locus, *Bph34* in *Oryza sativa* L. × *Oryza nivara* (Shastry) derived interspecific F_2 population. *Theoretical and Applied Genetics*, 131, 1163-1171. https://doi.org/10.1007/s00122-018-3069-7

Kumar, R., Managanvi, K., & Tiwari, S.N. (2012). Screening of rice varieties resistant against brown planthopper, *Nilaparvata lugens* (Stål). *Bioinfolet*, 9(1), 730-731. https://doi.org/10.1556/CRC.40.2012.0001

Ling, K.C., Tiongco, E.R., & Aguiero, V.M. (1978). Rice ragged stunt, a new virus disease. *Plant Disease Reporter*, 62, 701-705. https://doi.org/10.21769%2FBioProtoc.3060

Nadeem, A., Tahir, H.M., Khan, A.A., Bano, N., Hassan, Z., & Khan, A.M. (2023). Species composition, seasonal abundance and population dynamics of predatory spiders from cotton field plots of irrigated and semi-arid regions of Punjab, Pakistan. *Saudi Journal of Biological Sciences*, 30(7), 103686. https://doi.org/10.1016/j.sjbs.2023.103686

Naranjo, S.E. & Ellsworth, P.C. (2005). Mortality dynamics and population regulation in *Bemisia tabaci*. *Entomologia Experimentalis et Applicata*, 116(2), 93-108. https://doi.org/10.1111/j.1570-7458.2005.00297.x

Naranjo, S.E. & Ellsworth, P.C. (2017). Methodology for developing life tables for sessile insects in the field using the whitefly, *Bemisia tabaci*, in cotton as a model system. *Journal of Visualized Experiments*, 129, e56150. https://doi.org/10.3791/56150

Pati, P., Jena, M., Bhattacharya, S., Behera, S.K., Pal, S., Shivappa, R., & Dhar, T. (2023). Biochemical defense responses in red rice genotypes possessing differential resistance to brown planthopper, *Nilaparvata lugens* (Stål). *Insects*, 14(7), 632. https://doi.org/10.3390/insects14070632

Prahalada, G.D., Shivakumar, N., Lohithaswa, H.C., SiddeGowda, D.K., Ramkumar, G., Kim, S.R., & Jena, K.K. (2017). Identification and fine mapping of a new gene, *BPH31* conferring resistance to brown planthopper biotype 4 of India to improve rice, *Oryza sativa* L. *Rice*, 10(1), 41. https://doi.org/10.1186/s12284-017-0178-x

Prasad, K.H. (2022). Factors affecting growth and metabolism of insects. In *Insect Ecology: Concepts to Management* (pp. 23-35). Springer Nature, Singapore.

Rivera, C.T., Ou, S.H., & Lida, T.T. (1966). Grassy stunt disease of rice and its transmission by the planthopper *Nilaparvata lugens* Stål. *Plant Disease Reporter*, 7, 453-456.

Rodrigues-Silva, N., de Oliveira Campos, S., de Sá Farias, E., de Souza, T.C., Martins, J.C., & Picanço, M.C. (2017). Relative importance of natural enemies and abiotic factors as sources of regulation of mealybugs (Hemiptera: Pseudococcidae) in Brazilian coffee plantations. *Annals of Applied Biology*, 171(3), 303-315. https://doi.org/10.1111/aab.12373

Shanker, C., Sampathkumar, M., Sunil, V., Amudhan, S., Sravanthi, G., Jhansirani, B., Poorani, J., & Katti, G. (2018). Biodiversity and predatory potential of coccinellids of rice ecosystems. *Journal of Biological Control*, 13, 25-30. https://doi.org/10.18311/jbc/2018/17912

Sharma, K.R., Raju, S.V., & Jaiswal, D.K. (2018). Influence of environmental effect on the population dynamics of brown planthopper, *Nilaparvata lugens* (Stål) and white-backed planthopper, *Sogatella furcifera* (Horváth) in Varanasi region. *Journal of Entomological Research*, 42(3), 339-342. https://doi.org/10.5958/0974-4576.2018.00056.7

Silva, É.M., da Silva, R.S., Rodrigues-Silva, N., Milagres, C.C., Bacci, L., & Picanço, M.C. (2017). Assessment of the natural control of *Neoleucinodes elegantalis* in tomato cultivation using ecological life tables. *Biocontrol Science and Technology*, 27(4), 525-538. https://doi.org/10.1080/09583157.2017.1319911

Southwood, T.R.E. & Henderson, P.A. (1960). *Ecological Methods*. (3rd ed.). Blackwell Science, Oxford

Varley, G.C. & Gradwell, G.R. (1960). Key factors in population studies. *Journal of Animal Ecology,* 29, 399-401. https://doi.org/10.2307/2296

Vasudeva, R., Sutter, A., Sales, K., Dickinson, M.E., Lumley, A.J., & Gage, M.J.G. (2019). Adaptive thermal plasticity enhances sperm and egg performance in a model insect. eLife, 8, e49452. https://doi.org/10.7554/eLife.49452

Yang, L., Huang, L.F., Wang, W.L., Zhang, Y., Li, J., & Chen, H. (2021). Effects of temperature on growth and development of *Nilaparvata lugens*. *Environmental Entomology,* 50, 1-11. https://doi.org/10.1093/ee/nvaa168

Ye, Z., Yu, X., Xia, L., Zhang, J., Chen, J., Li, Y., Wang, H., Liu, X., & Zhang, Y. (2022). Genome and biological characteristics of the egg parasitoid *Anagrus nilaparvatae. BMC Genomics,* 23, 1-15. https://doi.org/10.1186/s12864-022-08656-9

Yele, Y., Chander, S., Suroshe, S.S., Nebapure, S., Tenguri, P., & Pattathanam, S.A. (2023). Ecological engineering in lowland rice for brown planthopper, *Nilaparvata lugens* (Stål) management. *PeerJ*, 11, e15531. https://doi.org/10.7717/peerj.15531

Zhang, X., Liu, X., Ma, X., Chen, J., Wang, H., & Li, Y. (2020). Embryonic development of the brown planthopper, *Nilaparvata lugens*. *Frontiers in Physiology,* 11, 106. https://doi.org/10.3389/fphys.2020.00106

Zhou, Q., Zhang, Y., Liu, Z., Li, X., Wang, H., & Chen, J. (2024). Sublethal effects of emamectin benzoate induce fecundity enhancement and resurgence potential in *Nilaparvata lugens*. *Ecotoxicology,* 33, 155-168. https://doi.org/10.1007/s10646-023-02749-3

Zhu, P., Zheng, X., Johnson, A.C., Chen, G., Xu, H., Zhang, F., Yao, X., Heong, K.L., Lu, Z., & Gurr, G.M. (2022). Ecological engineering for rice pest suppression in China. A review. *Agronomy for Sustainable Development,* 42, 69. https://doi.org/10.1007/s13593-022-00800-9