Enfoque UTE
ISSN: 1390-6542
enfoque@ute.edu.ec
Universidad Tecnológica Equinoccial
Ecuador

Afzal, Muhammad; Rizwan, Muhammad; Arshad, Muhammad; Rizwan, Misbah;
Mubeen, Noshaba; Muhammad Raza, Abu Bakar; Atta, Bilal; Sabir, Arshed Makhdoom
Susceptibility of six chemical insecticides against brown planthopper, Nilaparvata lugens (Hemiptera: Delphacidae) in Kallar tract of Punjab, Pakistan; 2015-2019
Enfoque UTE, vol. 13, núm. 4, 2022, Octubre-Diciembre, pp. 39-46
Universidad Tecnológica Equinoccial
Ecuador

DOI: https://doi.org/10.29019/enfoqueute.867

Enfoque UTE, V.13-N.4, Oct. 2022, pp. 39-46
http://ingenieria.ute.edu.ec/enfoqueute/
e-ISSN: 1390-6542

Received: 2022/07/27
Accepted: 2022/08/05
Online: 2022/08/05
Published: 2022/10/01
https://doi.org/10.29019/enfoqueute.867

Susceptibility of six chemical insecticides against brown planthopper, *Nilaparvata lugens* (Hemiptera: Delphacidae) in Kallar tract of Punjab, Pakistan; 2015-2019

Susceptibilidad de seis insecticidas químicos contra el saltamontes marrón, Nilaparvata lugens *(Hemiptera: Delphacidae) en el tracto Kallar de Punjab, Pakistán; 2015-2019*

Muhammad Afzal[1], Muhammad Rizwan[2], Muhammad Arshad[3], Misbah Rizwan[4], Noshaba Mubeen[5], Abu Bakar Muhammad Raza[6], Bilal Atta[7], Arshed Makhdoom Sabir[8]

Abstract

Brown planthopper (BPH), Nilaparvata lugens (Stål) (Hemiptera: Delphacidae) is an economically important insect pest of rice crop worldwide including Pakistan. The use of chemicals insecticides to control the BPH population has been considered an effective strategy. However, long-term and intensive use of insecticides has resulted in resistance against this pest. In this study, six recommended insecticides were tested against BPH over the period of 2015-2019 to determine the susceptibility level. From 2015-19, susceptibility of BPH was reduced to all tested insecticides. Increasing trend of LC_{50} values was recorded in fipronil (18.23-35.11 mg/L), imidacloprid (64.22-128.8 mg/L), buprofezin (185.01-315.0 mg/L), chlorantranilipyrole (199.2-263.3 mg/L), pymetrozine (248.2-315.5 mg/L), and nitenpyram (21.07-34.3 mg/L) respectively from 2015 to 2019. Correlation coefficient values indicated a significant relation (P < 0.05) between fipronil, imidacloprid, and buprofezin. The study will be helpful for resistance management strategies to prevent the resistance development in BPH against insecticides.

Keywords

Insecticide resistance, Kallar tract, Chemical control, Basmati rice, Brown planthopper

Resumen

El saltamontes marrón (BPH), *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae), es una plaga de insectos económicamente importante del cultivo de arroz en todo el mundo, incluido Pakistán. El uso de insecticidas químicos para controlarla ha constituido una estrategia eficaz; sin embargo, utilizarlos de forma prolongada e intensiva ha ocasionado que la plaga se vuelva resistente a dichos pesticidas.

En este estudio se probaron seis insecticidas recomendados contra la BPH durante el periodo 2015-2019 para determinar el nivel de susceptibilidad. De 2015 a 2019, la susceptibilidad a la BPH se redujo a todos los insecticidas probados. Se registró una tendencia creciente de los valores de LC50 en fipronil (18.23-35.11 mg/l), imidacloprid (64.22-128.8 mg/l), buprofezina (185.01-315.0 mg/l), clorantranilipirol (199.2-263.3 mg/l), pimetrozina (248.2-315.5 mg/l) y nitenpiram (21.07-34.3 mg/l) respectivamente de 2015 a 2019. Los valores del coeficiente de correlación indicaron una relación significativa (P < 0.05) entre fipronil, imidacloprid y buprofezin.

El estudio será útil tanto para llevar a cabo estrategias de manejo de la resistencia como para prevenir el desarrollo dicha resistencia de la BPH hacia los insecticidas.

Palabras clave

Resistencia a insecticidas, tracto Kallar, control químico, arroz basmati, chicharrita parda

1 Hill Fruit Research Station, Sunny Bank, Murree, Punjab – Pakistan [mafzal834@gmail.com, https://orcid.org/0000-0001-6620-1399].
2 Beekeeping and Hill Fruit Pests Research Station, Rawalpindi, Punjab – Pakistan [ranarizwanjabbar@yahoo.com, https://orcid.org/0000-0002-6103-4330].
3 Department of Entomology, University of Sargodha – Pakistan [makuaf@gmail.com, https://orcid.org/0000-0002-5442-0380].
4 Beekeeping and Hill Fruit Pests Research Station, Rawalpindi, Punjab – Pakistan [misbahrizwanjabbar@gmail.com, https://orcid.org/0000-0001-5843-7975].
5 Department of Entomology, University of Sargodha – Pakistan [noshabamubeen@gmail.com, https://orcid.org/0000-0002-1371-6759].
6 Department of Entomology, University of Sargodha – Pakistan [abu.bakar@uos.edu.pk, https://orcid.org/0000-0003-2197-5088].
7 Rice Research Institute, Kala Shah Kaku, Punajb – Pakistan [bilal.atta@aari.punjab.gov.pk, https://orcid.org/0000-0002-8000-0005].
8 Rice Research Institute, Kala Shah Kaku, Punajb – Pakistan [amsabir@yahoo.co.uk, https://orcid.org/0000-0003-1803-2396].

1. Introduction

Rice, *Oryza sativa* L. (Graminales: Poaceae), is one of the most important cereal crop and a staple food for over half of the world's population (Heong et al., 2015). Asia is a major rice-producing continent including China, India, Bangladesh, and Pakistan. Pakistan is among the top ten rice-producing countries in the world (Khan et al., 2022). After cotton, rice is the 2nd most important cash crop of Pakistan which is grown on 11% of the total cropped área of the country. In Pakistan, Kallar tract (i.e., Gujranwala, Sialkot, Sheikhupura, Narowal, Lahore, Hafizabad, Nankana) is famous for the cultivation of aromatic rice (Khan et al., 2022). Pakistan is the 4th largest rice exporter, earning $2.05 billion in foreign exchange annually (Pakistan Economic Survey, 2020-21). With a rapidly growing world population, it is imperative to increase the production of rice in the world including in Pakistan (Miao et al., 2011). Unfortunately, this crop is facing major threats such as climate change and the attack of various insect pests and diseases. The brown planthopper (BPH), *Nilaparvata lugens* (Stål), (Homoptera: Delphacidae) is one of the most serious insect pest of rice crop in all rice-growing countries including Pakistan (Rizwan et al., 2019; Sabir et al., 2019). Both nymphs and adults are damaging and cause severe economic losses to the rice crop. They suck the cell sap from the plant material and lead to the situation known as "hopper burn" (Liu et al., 2008, Normile, 2008, Horgan, 2009, Vanitha et al., 2011, Atta et al., 2019). Adults are Macroptreous due to which they migrate over a mile causing more damage to crops and also transmitting various kinds of diseases (Heong and Hardy, 2009).

It is estimated that 10-30% of yield loss in rice crop is attributable to the BPH attack (Harris and Trisyono, 2019). The control strategy of BPH has predominantly relied upon synthetic chemicals (Garrood et al., 2016). Chemical insecticides of major clases such as carbamate, organophosphorus, and neonicotinoids are widely used against this pest (Wang, Gao, Zhu, et al., 2008, Liu et al., 2015, Matsumura et al., 2017). BPH has been reported to develop resistance to many insecticides (Wang, Gao, Xu, et al., 2008, Wen et al., 2009, Punyawattoe et al., 2013). The development of resistance in BPH to insecticides has been attributed to the extensive use of chemicals including organophosphates, carbamates, pyrethroids, neonicotinoids, insect growth regulators (IGRs), and phenylpyrazoles (Punyawattoe et al., 2013, Zhang et al., 2016).

The use of synthetic chemical insecticides has been increased to suppress the population of rice insect pests in Pakistan. Monitoring the insecticide resistance in BPH is an essential part of the integrated pest management. It is necessary to evaluate the susceptibility of this pest regularly to estimate the effectiveness of recommended chemicals for its control. This insect has developed resistance to almost 33 different active ingredients of insecticides with 421 reported cases throughout the world (Mota-Sanchez and Wise, 2022). Thus, monitoring of resistance is a crucial part to comprehend the current status of susceptibility of the BPH population to various insecticides in the field. Little is known about the status of insecticide resistance in BPH in Pakistan. Thus, our main objective of the study was to determine the susceptibility of commonly used insecticides against BPH.

2. Methodology

2.1. Insect culture

The immature and adults of BPH were collected from the rice fields (31°43'25.5"N 74°16'17.4"E) of Kallar area using an aspirator each year from 2015 to 2019. The collected insects were reared in a growth chamber. The collected insects were reared on Basmati 515 seedlings in rearing cages (40 × 50 × 80 cm) under controlled conditions of 28 ± 2°C, 70-80% relative humidity, and a 16:8 (L: D) h photoperiod. The 3rd instars nymphs of F1 generations of the collected population were used for susceptibility assay.

2.2. Insecticides

Following insecticides were purchased from the local market; imidacloprid 20%SC, nitenpyram 25%SP, pymetrozine 50%WG (neonicotinoids) fipronil 80%WG (phenylpyrazole), buprofezin 25%WP (IGR), and chlorantranilipyrol 0.4%GR (anthranilic diamides) and tested against BPH. Five serial dilutions of each insecticide were prepared by following the methodology of Atta et al. (2015, 2020).

2.3. Bioassay

The dose-response assay was carried out using rice-stem dipping methodology (Wang, Gao, Zhu, et al., 2008; Ali et al., 2017) under laboratory conditions. Rice plants (55-70 days old) were pulled out of the soil, washed carefully, cut into 12 cm pieces, and air-dried for half an hour. Five stems were congregated together and immersed in the solution for half minute, and air-dried for 30 minutes. The rice stems were wrapped from the top and bottom with moistened cotton and put into a plastic jar (3L). Thirty 3rd-instar nymphs were collected using aspirator and transferred into plastic jars containing treated rice stems. There were five replications for each dose of a single insecticide. In control treatment, water was used. Mortality data were recorded at 72 and 96 h of insecticide application. The insects were observed with camel hair brush, and assumed dead if they were unable to move.

2.4. Data analysis

Probit analyses were carried out to calculate the LC_{50} values for each insecticide against BPH for the year 2015-19 using POLO-Plus 2.0 software (Liao et al., 2021). Pearson correlation coefficients between LC_{50} values were calculated for all pair-wise comparisons of six insecticides using Minitab 17.0 software (Arshad et al., 2019).

3. Results

3.1. Variations in susceptibility ratios to six insecticides

An increasing trend of LC_{50} values was recorded each year for each insecticide against BPH. There was a considerable increase (64.22 to 125.81 mg/L) in LC_{50} value for imidacloprid over five years. The susceptibility to imidacloprid decreased greatly from 2015 to 2019 (LC_{50}=64.2-125.8 mg/L). The susceptibility to buprofezin reduced drastically during the fourth and fifth years. The LC_{50} value increased from 185.0 to 315.0 mg/L showing a significant reduction in susceptibility to buprofezin. Susceptibility to fipronil decreased significantly from 2015 to 2019. The toxicity of fipronil to BPH reduced over five years as LC_{50} increased from 18.2 to 35.1 mg/L. After three years, LC_{50} value was dramatically increased (LC_{50}=38.58 mg/L) in the case of fipronil and then the value was reduced (LC_{50}=35.11 mg/L) for last year. The susceptibility to chlorantraniliprole varied each year. The susceptibility decreased each year from 1st to 3rd year (LC_{50}=199.2-275.8 mg/L), then increased in 4th year (LC50=225.8 mg/L), and again the value was decreased in last year (LC_{50}=263.3 mg/L). The susceptibility to pymetrozine was reduced each year. The susceptibility of the BPH field population to nitenpyram insecticide decreased during the 3rd year and then it remained almost constant for the next two years (Table 1).

Table 1. Trend of LC_{50} values of brown planthopper for six insecticides over the past five years 2015-19

Year	LC_{50} mg/L (slope)					
	Imidacloprid	Buprofezin	Fipronil	Chlorantraniliprole	Pymetrozine	Nitenpyram
2015	64.2±8.22 (0.67)	185.0±31.1 (0.96)	18.2±3.18 (1.45)	199.2±16.2 (1.41)	248.2±56.2 (0.96)	21.0±0.78 (0.85)
2016	85.5±7.84 (1.12)	201.1±35.9 (1.12)	22.6±4.17 (1.53)	222.3±25.1 (1.28)	262.0±61.5 (1.10)	25.1±2.49 (0.83)
2017	83.4±18.2 (0.92)	197.5±46.2 (0.89)	23.6±3.24 (1.38)	275.8±51.4 (2.01)	286.1±50.9 (0.86)	36.2±5.52 (1.00)
2018	108.6±17.3 (1.89)	255.6±62.5 (1.12)	38.5±4.81 (2.53)	225.8±20.4 (1.98)	271.4±44.0 (2.56)	32.4±3.84 (1.10)
2019	125.8±19.6 (3.48)	315.0±49.7 (2.27)	35.1±6.30 (1.29)	263.3±24.3 (1.78)	315.5±48.3 (3.36)	34.3±4.32 (1.13)

LC_{50} = Lethal concentrations

3.2. Cross-resistance development to insecticides in BPH

The cross-resistance pattern of six insecticides was investigated by correlation based on LC_{50} values. Significant ($P < 0.05$) relationship was found between fipronil and imidacloprid (r = 0.911), imidacloprid and buprofezin (r = 0.962). Chlorantraniliprole, nitenpyram, and pymetrozine showed no significant relation ($P > 0.05$) to other insecticides (Table2).

Table 2. Correlation matrix evaluating cross-resistance in brown planthopper population collected from Kallar tract, Pakistan during 2015-19

Insecticide	Fipronil	Imidacloprid	Buprofezin	Chlorantraniliprole	Nitenpyram
Imidacloprid	0.911 (0.031) *b*				
Buprofezin	0.850 (0.067)	0.962 (0.008)			
Chlorantraniliprole	0.315 (0.605)	0.501 (0.390)	0.411 (0.491)		
Nitenpyram	0.631 (0.253)	0.670 (0.215)	0.551 (0.334)	0.906 (0.337)	
Pymetrozine	0.595 (0.289)	0.822 (0.087)	0.816 (0.091)	0.843 (0.723)	0.812 (0.094)

b P < 0.05 shows the significance

4. Discussion

The use of insecticides for the control of BPH has increased since 2013 in the Kallar tract of Pakistan with the increased outbreak frequency of this notorious pest (Sabir et al., 2019). The extensive and frequent use of insecticides against BPH has evolved resistance to major classes of insecticides throughout Asia (Hemingway et al., 1999, Nagata et al., 2002, Punyawattoe et al., 2013, Yang et al., 2014) until the neonicotinoids provided the main means of control (Hemingway et al., 1999, Nagata, 2002). Imidacloprid has been widely used against rice planthoppers in Asia during the 1990s. However, up to 300-fold resistance in BPH to imidacloprid in China has already been reported previously (Wu et al., 2018). BPH resistance to imidacloprid and thiamethoxam has been reported in many Asian countries (Gorman et al., 2008, Matsumura et al., 2008, Wang, Gao, Xu, et al., 2008, Matsumura et al., 2013, Zhang et al., 2014, Garrood et al., 2016, Zhang et al., 2016) but no cross-resistance to fipronil and buprofezin was reported (Khoa et al., 2018). In our study, BPH has developed resistance to imidacloprid, as LC_{50} values were much higher in later years of study as compared to former years of study. Moreover, it has developed cross-resistance to fipronil and buprofezin. Hence, the development of resistance in the field population of BPH to imidacloprid is widely and faster.

In South Asia and South-East Asia, organophosphates and carbamates have been commonly used in the past. Further, IGRs such as buprofezin were considered useful insecticide for BPH management (Uchida et al., 1985, Kanno, 1987). Our findings showed that BPH has developed high resistance to buprofezin also. Hence, it may be no more useful for BPH management in the Kallar tract.

Our results showed that resistance in BPH to fipronil increased every year. A high level of resistance in the BPH population to fipronil has been reported in other countries such as Thailand, China, Philippines, and Vietnamese (Matsumura et al., 2008; Yang et al., 2014; Garrood et al., 2016; Punyawattoe et al., 2013). A high level of resistance against fipronil elucidates that efficacy would be lost in the coming years.

Chlorantraniliprole is also an effective synthetic chemical for BPH management. No cross-resistance against this insecticide was found with other chemicals. Pymetrozine had also been widely used for effective management of sucking insect pests (Nicholson et al., 1996; Polston, 2003; Chang and Synder, 2008). It is a new chemistry insecticide as compared to fipronil, imidacloprid, and buprofezin and is still effective for BPH management, as LC_{50} value did not increase too much over five years in our study. The LC_{50} values describe that the BPH population is moderately susceptible to nitenpyram. The LC_{50} value was not increased in the case of nitenpyram during the course of study. Hence, it is still effective when compared with other chemicals used in this study. Moreover, no cross-resistance of nitenpyram was observed with other chemicals.

The resistance to imidacloprid, nitenpyram, and buprofezin has dramatically increased in recent years (Wu et al., 2018) as compared to previous reports (Peng et al., 2013, Zhang et al., 2016). BPH has developed resistance against traditionally used insecticides such as fipronil, buprofezin, and imidacloprid. Sublethal concentrations may suppress the insect pest to some extent or it may enhance the fecundity of females depending upon the sublethal impact caused by the insecticide under consideration (Ali et al., 2017). So the use of fipronil, imidacloprid, and buprofezin may exacerbate the pest situation instead of its management. As per our knowledge, there is no study available on resistance of BPH to insecticides in the rice fields in Pakistan. Thus, the study is very helpful for farmers and extension workers of agriculture department in recommending synthetic insecticide for BPH management. Chemicals to which BPH has developed resistance will not only increase the cost of production but may increase its population tremendously resulting in greater damage to the rice crop.

The manipulation of resistant genetic sources is very important for BPH long-term management. Chemicals used in this study belong to different classes i.e., neonicotinoids (imidacloprid, pymetrozine, nitenpyram), phenylpyrazole (fipronil), IGRs (buprofezin), and anthranilic diamides (chlorantraniliprole). Thus, resistant development in BPH is not specific to any class of insecticides.

5. Conclusions and recomendations

Our findings showed a dramatic increase of resistance development in the BPH population to tested insecticides from 2015 to 2019. The cross-resistance development depicted that insecticides must be used carefully to prevent resistance development to other insecticides. There is a need to develop new chemistries and a strategy to minimize the resistance and cross-resistance development in BPH against insecticides. Moreover, there is a need to evaluate the field efficacy of all recommended/registered insecticides for BPH management.

References

Ali, E., Liao, X., Yang, P., Mao, K., Zhang, X., Shakeel, M., Salim, M. A., Wan, H., & Li, L. (2017). Sublethal effects of buprofezin on development and reproduction in the white-backed planthopper, *Sogatella furcifera* (Hemiptera: Delphacidae). *Scientific Reports*, 7, artículo 16913. https://doi.org/10.1038/s41598-017-17190-8

Arshad, M., Ullah, M. I., Afzal, M., Khalid, S., Raza, A. B. M., & Iftikhar, Y. (2019). Evaluation of plant extracts for the management of citrus leafminer, *Phyllocnistis citrella* (Lepidoptera: Gracillariidae). *Kuwait Journal of Science*, *46*(1), 58–67. https://journalskuwait.org/kjs/index.php/KJS/article/view/5880/314

Atta, B., Gogi, M. D., Arif, M. J., Mustafa, F., Raza, M. F., Hussain, M. J., Farooq, M. A., Nisar, M. J., & Iqbal, M. (2015). Toxicity of some insect growth regulators (IGRs) against different life stages of dusky cotton bugs *Oxycarens hyalinipennis* (Hemiptera: Lygaeidae: Oxycareninae). *Bulgarian Journal of Agricultural Science*, *21*(2), 367–371. https://www.agrojournal.org/21/02-25-1.pdf

Atta, B., Rizwan, M., Sabir, A. M., Gogi, M. D., Farooq, M. A., & Batta, Y. A. (2019). Efficacy of entomopathogenic fungi against brown planthopper *Nilaparvata Lugens* (Stål) (Homoptera: Delphacidae) under controlled conditions. *Gesunde Pflanzen*, *72*, 101–112. https://doi.org/10.1007/s10343-019-00490-6

Atta, B., Rizwan, M., Sabir, A. M., Gogi, M. D., Farooq, M. A., & Jamal, A. (2020). Lethal and sublethal effects of clothianidin, imidacloprid and sulfoxaflor on the wheat aphid, *Schizaphis graminum* (Hemiptera: Aphididae) and its coccinellid predator, *Coccinella septempunctata*. *International Journal of Tropical Insect Science*, *41*, 345–358. https://doi.org/10.1007/s42690-020-00212-w

Chang G. C., & Snyder W. E. (2008). Pymetrozine causes a nontarget pest, the Colorado potato beetle (Coleoptera: Chrysomelidae), to leave potato plants. *Journal of Economic Entomology*, *101*, 74–80.

Garrood, W. T., Zimmer, C. T., Gorman, K. J., Nauen, R., Bass, C., & Davies, T. G. E. (2016). Field-evolved resistance to imidacloprid and ethiprole in populations of brown planthopper *Nilaparvata lugens* collected from across South and East Asia. *Pest Management Science*, *72*(1), 140–149. https://doi.org/10.1002/ps.3980

Gorman, K., Liu, Z., Denholm, I., Brüggen, K., & Nauen, R. (2008). Neonicotinoid resistance in rice brown planthopper, *Nilaparvata lugens. Pest Management Science*, *64*(11), 1122–1125. https://doi.org/10.1002/ps.1635

Harris, C., & Trisyono, Y. A. (2019, December 16–19). Classifying, detecting, and predicting infestation patterns of the brown planthopper in rice paddies. 18th IEEE International Conference on Machine Learning and Applications (ICMLA). pp. 246–251, http://doi:10.1109/ICMLA.2019.00046

Hemingway, J., Karunaratn, S. H. P. P., & Claridge, M. F. (1999). Insecticide resistance spectrum and underlying resistance mechanisms in tropical populations of the brow planthopper (*Nilaparvata lugens*) collected from rice and the wild grass Leersia hexandra. *International Journal of Pest Management*, *45*, 215–223. https://doi.org/10.1080/096708799227824

Heong, K. L., & Hardy, B. (2009*). Planthoppers: New threats to the sustainability of intensive rice production systems in Asia*. Rice viruses transmitted by the brown planthopper *Nilaparvata lugens* Stål. International Rice Research Institute. 357–368.

Heong, K. L., Wong, L., & Delos Reyes, J. H. (2015). Addressing planthopper threats to Asian rice farming and food security: Fixing insecticide misuse. In K. L. Heong, J. Cheng & M. M. Escalada (Eds.), *Rice Planthoppers* (pp. 65–76). Springer.

Horgan, F. (2009). Mechanisms of resistance: A major gap in understanding planthopper-rice interactions. In K. L. Heong, & B. Hardy (Eds.), *Planthoppers: New threats to the sustainability of intensive rice production systems in Asia* (pp. 281–302). International Rice Research Institute.

Kanno, H. (1987). An approach to a novel insect growth regulator buprofezin (Applaud). *Pure and Applied Chemistry, 59*(8), 1027–1032. https://doi.org/10.1351/pac198759081027

Khan, S., Shah, S. A., Ali, S., Ali, A., Almas, L. K., & Shaheen, S. (2022). Technical efficiency and economic analysis of rice crop in Khyber Pakhtunkhwa: A stochastic frontier approach. *Agriculture*, *12*(4), 503. https://doi.org/10.3390/agriculture12040503

Khoa, D. B., Thang, B. X., Liem, N. V., Holst, N., & Kristensen, M. (2018). Variation in susceptibility of eight insecticides in the brown planthopper *Nilaparvata lugens* in three regions of Vietnam 2015-2017. *PLOS ONE*, *13*(10), artículo e0204962, 115–126. https://doi.org/10.1371/journal.pone.0204962

Liao, X., Xu, P. F., Gong, P. P., Wan, H., & Li, J. H. (2021). Current susceptibilities of brown planthopper *Nilaparvata lugens* to triflumezopyrim and other frequently used insecticides in China. *Insect Science*, *28*(1), 115–126. https://onlinelibrary.wiley.com/doi/epdf/10.1111/1744-7917.12764

Liu, J. L., Yu, J. F., Wu, J. C., Yin, J. L., & Gu, H. N. (2008). Physiological responses to *Nilaparvata lugens* in susceptible and resistant rice varieties: Allocation of assimilates between shoots and roots. *Journal of Economic Entomology*, *101*(2), 384–390. https://doi.org/10.1093/jee/101.2.384.

Liu, Z. W., Wu, J. C., Zhang, Y. X., Liu, F., Xu, J. X., & Bao, H. B. (2015). Mechanism of rice planthopper resistance to insecticides. In K. L., Heong, J. A., Cheng, & M. M., Escalada (Eds.), *Rice planthopper: Ecology, management, socio economics and policy* (pp. 117–141). Zhejiang University Press; Hangzhou; Springer Science Publisher.

Matsumura, M., Takeuchi, M., Satoh, M., Sanada-Morimura, S., Otuka, A., Watanabe, T., & Thanh, D. V. (2008). Species specific insecticide resistance to imidacloprid and fipronil in the rice planthoppers *Nilaparvata lugens* and *Sogatella furcifera* in East and South-east Asia. *Pest Management Science*, *64*(11), 1115–1121. https://doi.org/10.1002/ps.1641

Matsumura, M., Sanada-Morimura, S., Otuka, A., Ohtsu, R., Sakumoto, S., Takeuchi, H., & Satoh, M. (2013). Insecticide susceptibilities in populations of two rice planthoppers, *Nilaparvata lugens* and *Sogatella furcifera*, immigrating into Japan in the period 2005-2012. *Pest Management Science*, *70*(4), 615–622. https://doi.org/10.1002/ps.3590

Matsumura, M., Sanada-Morimura, S., Otuka, A., Sonoda, S., Van, T. D., Van, C. H., Van, T. P., Loc, P. M., Liu, Z. W., Zhu, Z. R., Li, J. H., Wu, G., & Huang, S. H. (2017). Insecticide susceptibilities of the two rice planthoppers *Nilaparvata lugens* and *Sogatella furcifera* in East Asia, the red River Delta, and the Mekong Delta. *Pest Management Science*, *74*(2), 456–464. https://doi.org/10.1002/ps.4729

Mota-Sanchez, D. & Wise J.C. (2022). The Arthropod Pesticide Resistance Database. Michigan State University. http://www.pesticideresistance.org

Miao, Y. X., Stewart, B. A., & Zhang, F. S. (2011). Long-term experiments for sustainable nutrient management in China:A review. Agronomy for Sustrainable Development, 31, 397–414. https://doi.org /10.1051/agro/2010034

Nagata, T. (2002). Monitoring on insecticide resistance of the brown planthopper and the white backed planthopper in Asia. *Journal of Asia Pacific Entomology*, *5*(1), 103–111.

Nagata, T., Kamimuro, T., Wang, Y. C., Han, S. G., & Noor, N. M. (2002). Recent status of insecticide resistance of long distance migrating rice planthoppers monitored in Japan, China and Malaysia. *Journal of Asia-Pacific Entomology*, *5*(1), 113–116. https://doi.org/10.1016/S1226-8615(08)60139-9

Nicholson, W., Senn, R., Fluckiger, C. R., & Fuog, D. (1996). Pymetrozine – A novel compound for control of whiteflies. In D. Gerling, & R., Mayer. (Eds.), *Bemisia 1995: Taxonomy, biology, damage, control and management* (pp. 635–639). Intercept.

Normile, D. (2008). Reinventing rice to feed the world. *Science*, *321*(5887), 330–333. https://doi.org/10.1126/science.321.5887.330

Pakistan Economic Survey (2020-21). Finance Division, Government of Pakistan, pp. 1-566. https://www.pc.gov.pk/uploads/cpec/PES_2020_21.pdf

Peng, W., ZuoPing, N., Shuai, Z., Tiantian, J., Lirong, T., Song, D., & CongFen, G. (2013). Resistance monitoring to conventional insecticides in brown planthopper, *Nilaparvata lugens* (hemiptera: delphacidae) in main rice growing regions in China. Chinese Journal of Rice Science, 27, 191–197.

Polston, J. E., & Sherwood, T. (2003). Pymetrozine interferes with transmission of tomato yellow leaf curl virus by the whitefly *Bemisia tabaci*. *Phytoparasitica, 31*, 490–498. https://doi.org/10.1007/BF02979742

Punyawattoe, P., Han, Z. H., Sriratanasak, W., Arunmit, S., Chaiwong, J., & Bullangpoti, V. (2013). Ethiprole resistance in *Nilaparvata lugens* (Hemiptera: Delphacidae): Possible mechanisms and cross-resistance. *Applied Entomology and Zoology*, *48*, 205–221. https://doi.org/10.1007/s13355-013-0174-6

Rizwan, M., Atta, B., Sabir, A. M., & Sabir, M. (2019, December 19–20). *Rice planthoppers: Issue and solution in Pakistan*. 2nd International Conference on Applied Zoology, Government College University, Faisalabad, Pakistan. https://gcuf.edu.pk/news-single?news=2084

Sabir, A. M., Shah, Z. U., Sabar, M., Rizwan, M., Atta, B., Qadir, A., & Asghar, M. (2019, March 4–6). *Rice planthoppers: Potential threat to the sustainable rice production in the Punjab, Pakistan*. 39th Pakistan Congress of Zoology, Department of Zoology, Islamia College University, Peshawar, Pakistan, pp 225–226, https://www.zsp.com.pk/PRO2019.pdf.

Uchida, M., Asai, T., & Sugimoto, T. (1985). Inhibition of cuticle deposition and chitin biosynthesis by a new insect growth regulator, Buprofezin, in *Nilaparvata lugens* Stål. *Agricultural and Biological Chemistry,* 49, 1233–1234. https://doi.org/10.1080/00021369.1985.10866885

Vanitha, K., Suresh, S., & Gunathilagaraj, K. (2011) Influence of brown planthopper *Nilaparvata lugens* (Stal.) feeding on nutritional biochemistry of rice plant. *Oryza, 48*(2), 142–146. https://bit.ly/3OKSDsO

Wang, Y. H., Gao, C. F., Zhu, Y. C., Chen, J., Li, W. H., Zhuang, Y. L., Dai, D. J., Zhou, W. J., Yong, C., & Shen, J. L. (2008). Imidacloprid susceptibility survey and selection risk assessment in field populations of *Nilaparvata lugens* (Homoptera: Delphacidae). *Journal of Economic Entomology*, *101*(2), 515–522. https://doi.org/10.1093/jee/101.2.515

Wang, Y., Gao, C., Xu, Z., Zhu, Y.C., Zhang, J., Li, W., Dai, D., Lin, Y., Zhou, W., & Shen, J. (2008). Buprofezin susceptibility survey, resistance selection and preliminary determination of the resistance mechanism in *Nilaparvata lugens* (Homoptera: delphacidae). *Pest Management Science*, *64*(10), 1050–1056. https://doi.org/10.1002/ps.1606

Wen, Y., Liu, Z., Bao, H., & Han, Z. (2009). Imidacloprid resistance and its mechanisms in field populations of brown planthopper, *Nilaparvata lugens* Stål in China. *Pesticide Biochemistry and Physiology*, *94*(1), 36–42. https://doi.org/10.1016/j.pestbp.2009.02.009

Wu, S. F., Zeng, B., Zheng, C., Mu, X. C., Zhang, Y., Hu, J., Zhang, S., Gao, C. F., & Shen, J. L. (2018). The evolution of insecticide resistance in the brown planthopper (*Nilaparvata lugens* Stål) of China in the period 2012–2016. *Scientific Reports*, 8, artículo 4586. https://doi.org/10.1038/s41598-018-22906-5

Yang, Y., Dong, B., Xu, H., Zheng, X., Tian, J., Heong, K. L., & Lu, Z. (2014). Decrease of insecticide resistance over generations without exposure to insecticides in *Nilaparvata lugens* (Hemiptera: Delphacidae). *Journal of Economic Entomology, 107*(4), 1618–1625. https://doi.org/10.1603/EC13550

Zhang, X. L., Liu, X. Y., Zhu, F. X., Li, J. H., You, J., & Lu, P. (2014). Field evolution of insecticide resistance in the brown planthopper (*Nilaparvata lugens* Stål) in China. *Crop Protection*, *58*, 61–66. https://doi.org/10.1016/j.cropro.2013.12.026

Zhang, X., Liao, X., Mao, K., Zhang, K., Wan, K., & Li, J. (2016). Insecticide resistance monitoring and correlation analysis of insecticides in field populations of the brown planthopper *Nilaparvata lugens* (Stål) in China 2012-2014. *Pesticide Biochemistry and Physiology*, *132*, 13–20. https://doi.org/10.1016/j.pestbp.2015.10.003