

Eco-Friendly Management of Brown Planthopper (*Nilaparvata lugens*) Via Flavonoids as Biopesticides in Rice (*Oryza sativa* L.)

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Abstract

Rice (*Oryza sativa* L.) is a significant source of nutrition for the human diet and is an economically important food crop worldwide. The brown planthopper (*Nilaparvata lugens*) severely limits its production by direct phloem feeding and indirect virus transmission. Chemical insecticides have given rise to resistance to brown planthopper (BPH), environmental pollution, and a negative impact on non-target organisms and human health due to their excessive use. In efforts to manage these concerns, environmentally acceptable and sustainable substitutes have intensified. The flavonoids play a crucial role in plant growth and protection by fostering tolerance to specific biotic stressors and environmental abiotic challenges. It is crucial to use these adaptable low molecular weight flavonoids for sustainable and environmentally friendly agriculture when finding a natural way. These are potential biopesticides due to their extensive biological activity against the BPH. The review highlights the existing evidence on the potential of flavonoids in sustainable management of BPH, with a particular focus on their various modes of action. Furthermore, the relative efficacies of flavonoids and synthetic insecticides are compared in terms of selectivity, environmental safety, and resistance development. Bio-pesticides can be used in integrated pest management (IPM) methods to limit the use of chemical insecticides and eco-friendly, sustainable management of BPH in the rice crop.

Keywords: Rice, *Nilaparvata lugens*, Flavonoids as biopesticides, Eco-friendly pest management

Introduction

Rice (*Oryza sativa* L.), on which half of the world's population depends, is a prominent staple crop in Asia and globally (Hori and Sun 2022; Kemparaju 2023; Ali et al. 2024; Ge 2026). Its production must be sustainable due to the expanding population growth and to ensure food security (Abduh et al. 2026). Biotic (pests and diseases) and abiotic (environmental) stressors make its production highly challenging and contribute to the decline in rice (Shi et al. 2023; Krishnan et al. 2026). Addressing these issues and reducing risks are essential in rice production to improve food security and sustenance for the billion people worldwide (Asma et al. 2023; Afzal et al. 2025).

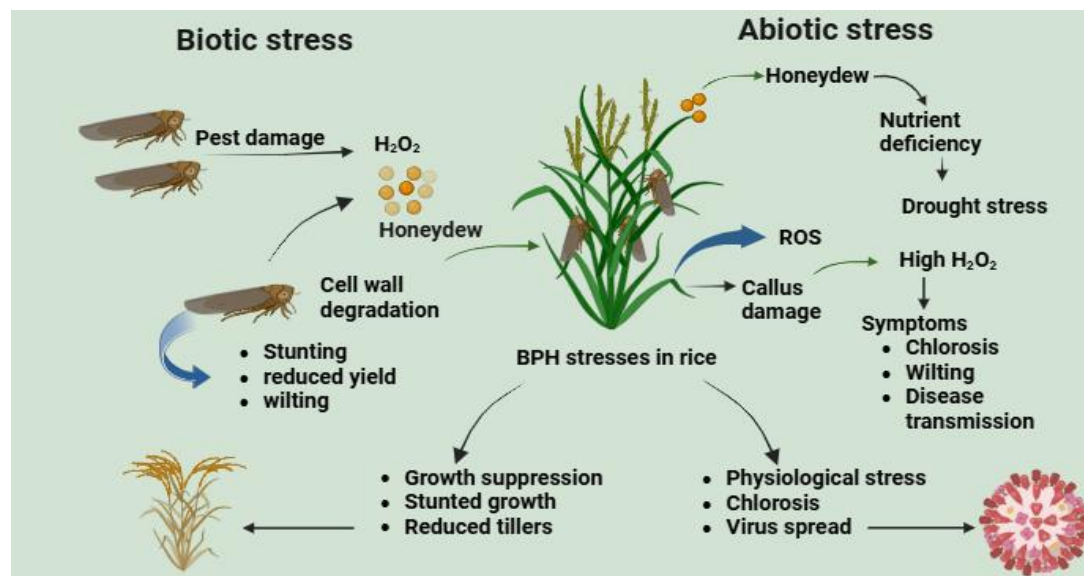
Globally, economic losses and crop yield in agriculture are affected by these stressors (Singh et al. 2024). The significant challenge in rice production is that pests cohabit with rice growth (Iftikhar et al. 2023). Brown plant hopper is a crucial economic pest of more than 100 species that severely damages rice plants (Iamba and Dono 2021). It can damage the rice crop directly through sap sucking and indirectly through vectors, from the vegetative to the reproductive stage, in all rice-producing regions of the world (Ganamala and Kumar 2024). Rising CO₂ levels contribute to climate change and may cause pest and disease outbreaks (Nawaz et al. 2025). Both the nymphal and adult stages of BPH extract sap from rice tillers and form the feeding tube sheath (Venugopal et al. 2025). When the persistent female laid their eggs in plant tissues, the plant dries up, resulting in "hopper burn" signs, which end in drying and lodging of the plant. The photosynthetic rate is affected by the diminution in leaf area, which causes significant yield reduction (Liu et al. 2025). The direct (feeding) damage and indirect transmission of viral diseases, including ragged stunt virus and grassy stunt virus, adversely affect plant health and cause severe yield losses (Iqbal et al. 2022). Chemical pesticides that are frequently used to control the BPH population are hazardous to human health and the environment (Jeevanandham et al. 2023). Flavonoids are secondary metabolites found in a wide variety of natural sources, such as plant species, known to enhance plant growth and survival in many ways (Abd El-Hack et al. 2025). The flavonols, flavones, Anthocyanidins, isoflavones, flavanones, and chalcones are the subclasses into which flavonoids are typically divided. The resistance to biotic and abiotic stressors, plant development, and flower colors to attract pollinators are greatly influenced by flavonoids (Shen et al. 2022). Rice byproducts from various varieties are rich sources of antioxidant compounds, including luteolin, apigenin, myricetin, quercetin, and catechin (Bagchi et al. 2021; Andriani et al. 2022; Zubair et al. 2023). These flavonoid compounds protect rice plants by inhibiting feeding, oviposition, and reproduction of Brown plant hopper (BPH) (Liu et al. 2023). These botanical insecticides are well known to prevent feeding, disrupt their growth stages, inhibit oviposition, and even kill the pest permanently (Acheuk et al. 2022). They provide an eco-friendly, sustainable substitute for chemical pesticides by reducing the hazards to the environment and human health (Muhyuddin et al. 2025). Flavonoids, when integrated with integrated pest management (IMP) techniques is a sustainable solution due to their compatibility with biological control agents for pests (Ramaroson et al. 2022). There is an urgent need for biopesticides like chrysoeriol7 (C7) for the development and dissemination that are utilized to manage plant diseases and pests like the brown planthopper in rice and keep the environment safe (Kim et al. 2022). The climatic variations, instability, limited life span, and knowledge gaps of environmental effectiveness on these biopesticides are some limitations (Kocamaz and Merhan 2026). This review article will synthesize the stressors in rice and the eco-friendly, sustainable management of brown planthopper via the use of biopesticides (flavonoids) rather than synthetic pesticides.

BPH Stressors in Rice

The rice brown planthopper (BPH) (*Nilaparvata lugens*) is a sap-sucking and pathogen-infecting pest. The BPH has a direct and indirect impact on the rice plant. Rice might experience significant biological stress due to BPH. Additionally, the BPH can indirectly propagate the rice grassy stunt virus (RGSV) and rice ragged stunt virus (RRSV). In extreme situations, the rice plant exhibits hopper burn appearance, a reduction in grain yield, and the plant dies (Li et al. 2024). They take enormous amounts of nutrients from the plant by inserting needle-like mouthparts results in stunted growth and ultimately the death of the plant. The adult female BPHs during the oviposition pierce rice plant tissues with their probosces, inflicting more extensive harm to the host plant. This injury encourages the spread of viruses, which contribute to actual insect-caused losses (Wang et al. 2024). It has the greatest contribution to productivity loss via inducing colonization of the rice plant, damaging tissues, and lowering plant nutrients. Chlorophyll content and plant height give

the best information regarding analyzing resistance and population following BPH infection (Kim et al. 2022).

Figure 1: Biotic and abiotic stress responses in rice induced by brown planthopper (*N.lugens*) infestation



Action of Flavonoids Against the Brown Planthopper:

Flavonoids play distinct roles at different stages of plant growth, such as altering plant color and regulating root growth (Wu et al. 2023). It contains Antifeedant qualities that shield plants from oviposition-inducing herbivores, attract parasitic and predatory insects, and protect against reactive oxygen species (ROS) and pathogen infection (Al-Khayri et al. 2023).

Antifeedant Activity

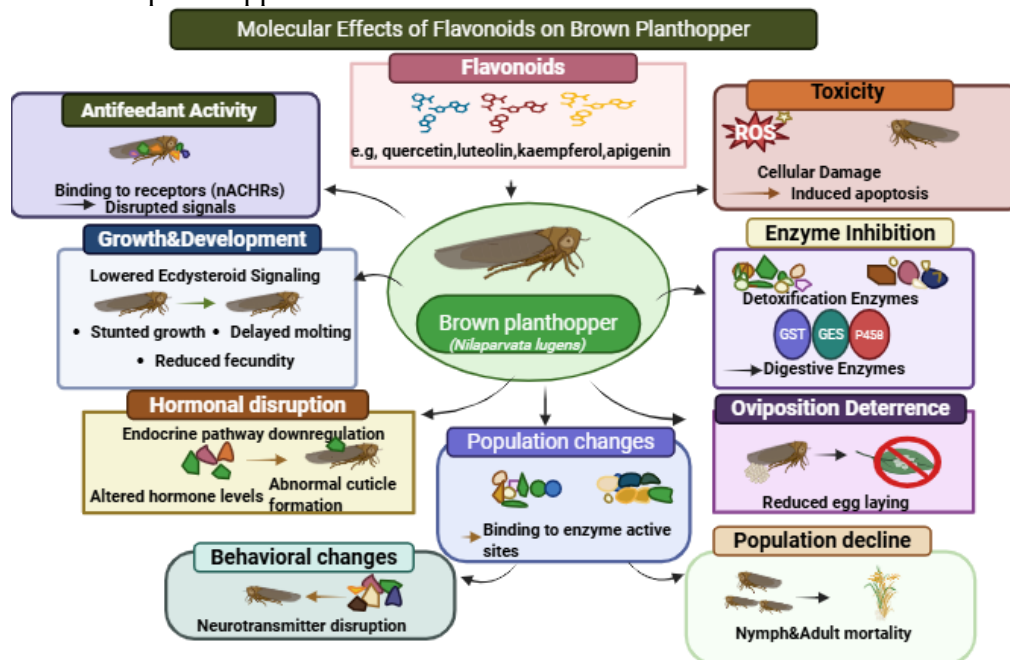
Many agricultural pests rely on chemical communication to detect the host plant via olfactory signals (Anton and Cortesero 2022). Schaftoside and isovitexin are two natural flavonoid compounds present in resistant varieties of rice, acting as antifeedants that alter the feeding behavior of the brown planthopper (Zhang et al. 2022). When BPH consumes these plants, its feeding activity is reduced due to the flavonoids makes the plant sap unappealing and unsuitable for feeding. These flavonoids shield the plant by preventing effective feeding instead of outright killing the plant-hopper that causes the nutritional stress and lowers the chances of survival of the plant-hopper (Hao et al. 2018). The researcher's analysis revealed that when the brown planthopper is exposed to these compounds, it takes less phloem sap because these substances disrupt normal stylet penetration and phloem ingestion (Duan et al. 2025). Flavonoids provide long-term environment friendly pest management by strong antifeedant efficacy and with minimal negative effects on non-target organisms (Riddick 2024).

Insecticidal Effects of Flavonoids

The review study found that, when BPH infestation occurred on the rice plant, the sakuranetin concentration in the plant phloem was detected ten times higher than that of other flavonoids. Artificial diet and plant-based essays showed that Sakuranetin-exposed BPH nymphs had lower survival rates, and deficient rice mutants promote rapid BPH development (Kundu et al. 2023). These findings show that sakuranetin, induced by BPH infestation crucial for rice defense by lowering BPH performance (Liu et al. 2023). The nymphal stage of agricultural sap-feeding pests is more sensitive to chemical pesticides than adults because they ingest more disruptive pesticides,

have low mobility, and a thin cuticle (Du et al. 2025). A chrysoeriol7 (C7), a secondary metabolite naturally produced by plants, confers resistance to BPH (Kim et al. 2022).

Figure 2: This figure shows the molecular mechanisms underlying flavonoid-mediated effects on the brown planthopper



Detoxification and resistance

The insects contain digestive enzymes such as amylases, lipases, proteases, sucrases, and trehalases to break complex plant compounds and get essential nutrients for growth and development. The plant secondary metabolites can be manipulated and used for preventing and suppressing particular digestive enzymes in pest insects to create pest-resistant crops. It is essential to develop more effective enzyme inhibitors and enzyme-based control methods in agricultural systems to reduce off-target effects (Chamani et al. 2025). These enzymes protect the insect from adverse effects by converting toxic substances into non-toxic substances. The secondary metabolite's toxicity inhibits detoxification enzymes (e.g., glutathione S-transferases and esterases) and suppresses the digestive enzymes of insects. The insect's energy is redirected from feeding to eliminate the toxins from the body, and the insect becomes weak, ultimately leading to death. This oxidative stress and nutritional imbalance increase the insect's fatality rate (Pereira et al. 2024).

Oviposition Deterrence

The triclin (5,7,4'-trihydroxy-3',5'-dimethoxyflavone) present in rice leaves protects the rice plant by preventing the feeding and oviposition of BPH infestation. BPH infestation changes the concentration of triclin depending on the density of the population attack (Zhang et al. 2017). Sakuranetin indirectly inhibits reproduction and oviposition by disrupting endosymbionts (Liu et al. 2023).

Table 1: Flavonoids' modes of action of flavonoids against the brown planthopper supporting sustainable pest management

Flavonoid Compound	Chemical class	Source (Plant/Extract)	Extraction Technique	Target Organism in Rice	Mode of Action	Effect/Outcome	References
Quercetin	Flavanols	Rice leaves, spinach, Onion skin, sumac, and <i>Pistacia eurycarpa</i> rootstock of the ginger	Microwave-assisted extraction (MAE), ultrasonic-assisted extraction (UAE), green solvent extraction	<i>N. lugens</i>	Acts as an antioxidant, with toxic effects on insects, and inhibitory effects on the symbionts	Reduce oxidative stress, modulate plant defense mechanisms, and suppress BPH and bacterial blight.	(Jan et al. 2021; Colombo et al. 2023; Deng et al. 2023; Patil et al. 2024; Baqer et al. 2024)
Tricin	Flavone	Rice plant, gramineous plants, rice straw, wheat straw, medicinal herbs	MAE, UAE	<i>N. lugens</i>	Antifeeding, Anti-oviposition, Anti-lethal effects on insects	Defend the rice plant against the Brown plant hopper	(Zheng et al. 2021; Gong et al. 2022; Rencoret et al. 2022; Deng et al. 2023; Duan et al. 2025; Hasibuan and Manurung 2025)
Kaempferol	Flavanols	Rice leaves, leaves, and stems of the Moringa oleifera	MAE, UAE	<i>N. lugens</i>	Acts as an antioxidant, inhibiting the symbionts and growth in adult female BPH	Symbionts contribute to the development of resistance in the BPH, mitigating the pathogenic stress	(Jan et al. 2021; Rencoret et al. 2022; Colombo et al. 2023; Deng et al. 2023)
Apigenin	Flavone	Rice plant, soy vegetables, branches, and soy pods	Hansen Solubility Parameters (HSP) and the Conductor-like Screening Model for Real Solvents (COSMO-RS)	<i>N. lugens</i>	inhibitory effects on the symbionts, inhibition effects on the growth of newly emerged female adults of BPH	Resist the invasion of BPH, resistance against BPH in rice	(Rencoret et al. 2022; Deng et al. 2023; Bragagnolo et al. 2024)
Luteolin	Flavone	Rice bran and medicinal plants	UAE, solvent extraction, immersion extraction, and supercritical fluid extraction	<i>N. lugens</i>	Antioxidant and antimicrobial Reduces feeding behavior and inhibitory effects on the symbionts	Resist the invasion of BPH, defend the rice plant against BPH	(Muruganathan et al. 2022; Liang et al. 2023; Deng et al. 2024; Ren et al. 2024; Gul et al. 2025)
Naringenin	Flavanone	Rice, citrus	Conventional extraction, UAE, solvent extraction, MAE, and pressurized liquid extraction	Rhizobium species and <i>N. lugens</i>	negatively regulates rice resistance to <i>N. lugens</i> and rice blast by the JA pathway and the flavonoid pathway.	Resistance in rice against <i>N. lugens</i> , Nitrogen fixation, and boost soil fertility	(Shilpa et al. 2023; Singh et al. 2023; Patil et al. 2024; Chen et al. 2025)
Anthocyanin	Anthocyanidins	Vegetables and fruits	UAE, MAE, Enzyme-assisted extraction (EAE), PEF	<i>N. lugens</i> and <i>Pyricularia grisea</i>	A defense mechanism against BPH	Resistance in rice against BPH inhibits the growth and spore germination of rice blast fungus	(Deng et al. 2023; Tena and Asuero 2022)
Sakuranetin	Flavanone	Rice, cherry	EAE, UAE	<i>N. lugens</i>	Inhibiting the growth of the YLS within the BPH, the compound acts as anti-parasitic, anti-viral, and anti-microbial	improve the rice plant's resistance to infections, and defend rice against the BPH	(Bernardo and Braga 2022; Patil et al. 2024; Deng et al. 2023)
Genistein	Isoflavone	Legumes, chickpeas, soya, broad beans	Hansen Solubility Parameters (HSP) and the Conductor-like Screening Model for Real Solvents (COSMO-RS)	Sucking pests such as BPH in rice	Applied in different concentrations on feeding behavior, these concentrations of flavonoids alter the stylet and ingestion activity result in hindered feeding behavior of the pest.	Protect the plant against sucking pests.	(Sarao et al. 2022; Bragagnolo et al., 2024; Goławska et al. 2024; Kciuk et al. 2025)
chrysoeriol7	Flavones	wheat (<i>Triticum aestivum</i>), rice, barley (<i>Hordeum vulgare</i>), millet (<i>Sorghum bicolor</i>), and corn (<i>Zea mays</i>)	Conventional Solvent Extraction, UAE, green solvent extraction, and MAE	<i>N. lugens</i>	C7, which contains an aromatic compound emitting a volatile and unique aroma, could also confer resistance to BPH in rice by spreading its aroma, which repels BPH	Induce resistance in rice plants against BPH, a repellent for BPH, and an eco-friendly and safe compound	(Kim et al. 2022; Goyal and Verma 2023; Patil et al. 2024)

Environmental and Ecotoxicological Aspects

Flavonoids are included in plant-derived biopesticides; they are biodegradable and readily broken down, exhibit low persistence in the ecosystem, and offer an eco-friendly alternative to chemical pesticides. Their mode of action is selectively toxic towards target pests and is less harmful to humans and animals. These secondary metabolites not only control pests but also improve plant development, boost beneficial insect populations, improve disease resistance, and diminish health

risks (Hejran et al. 2024). They act as defensive molecules and are vital instruments for advancing sustainability in agriculture by shielding crops from pests and diseases and reducing the need for chemical pesticides (Tirunagaru et al. 2025). Pesticides such as carbamate, organochlorine, organophosphate, and pyrethroid are categorized on the basis of their chemical structures. The physicochemical properties of these pesticides led to their contamination of the lithosphere, hydrosphere, and biosphere through overuse in paddy fields. This could result in the pest population becoming resistant to them, environmental pollution, hazardous to human health, and non-target organisms (Mohd Nizam et al. 2023). The botanicals are a growing trend in organic farming, and customers are prepared to pay more for organic produce due to its safety profile (Ngegba et al. 2022). Biopesticides can replace chemical pesticides with commensurate agricultural production (Fenibo et al. 2022). According to reviews, they can serve as a sustainable pest control technique, integrated with biological control agents (BCAs), to promote ecological balance and reduce pesticide use. Their compatibility with BCAs is crucial for pest suppression (Ramaroson et al. 2022; Iftikhar et al. 2023).

Table 2: This table evaluates the comparative effectiveness of synthetic insecticides and flavonoids against brown planthopper in rice, with emphasis on resistance development, environmental impact, and selectivity toward non-target organisms.

Compound / Group	Type	Target Organism	Effect on BPH Feeding	Effect on Survival	Resistance Development Risk	Impact on Natural Enemies	Environmental Persistence	Residue Risk in Rice	References
Imidacloprid	Neonicotinoid	<i>N.lugens</i>	Inhibit feeding: Strong effect	High Mortality	High	High doses are not safe for natural enemies	High environmental persistence	High	(Kang et al. 2022; Bhende and Dafale 2023; Netra et al. 2024; Choi et al. 2025; Hu et al. 2025)
Buprofezin	IGR	<i>N.lugens</i>	Inhibit feeding	High mortality	High	Decrease the diversity of natural enemies	Moderate	Moderate	(Zeng et al. 2023; Zeng et al. 2023; Satpathi 2024; Authority et al. 2025)
Deltamethrin	pyrethroid	<i>N.lugens</i>	Inhibit feeding: strong effect	High mortality	High	Kill natural Enemies	Adverse impact on the environment	High	(Meena et al. 2023; Jiang et al. 2024; Netra et al. 2024; Shi et al. 2024)
Fipronil	Phenylpyrazole	<i>N.lugens</i>	Indirect effect	Reduce the biomass density of BPH	Moderate	Toxic to natural enemies	High	High	(Gonçalves et al. 2022; Horgan and Peñalver-Cruz, 2022; Satpathi 2024; Fujii et al. 2024; Hidavat et al. 2025)
Chlorpyrifos	Organophosphate	<i>N.lugens</i>	Inhibit feeding strong effect	High mortality	High	high toxicities against natural enemies	Adverse impact	High	(Meena et al. 2023; Chaudhary et al. 2025; Purnama et al. 2025)
Quercetin	Flavonoid	<i>N.lugens</i>	Inhibit feeding	Strong reduction	Low	Minimal	Low	Negligible	(Deng et al. 2023; Li et al. 2023; Duan et al. 2025)
Kaempferol	Flavonoid	<i>N.lugens</i>	Alter feeding behavior	Reduction	Low	Attract natural enemies	Low	Negligible	(Kim et al. 2022; An et al. 2022; Deng et al. 2023; Li et al. 2023; Schnarr et al. 2024)
Rutin	Flavonoid	<i>N.lugens</i>	Moderate reduction	High reduction of BPH	Low	Minimal	Low toxic	Negligible	(Zhu et al. 2023; Zhang et al. 2025)
Sakuranetin	Flavonoid	<i>N.lugens</i>	Strongly inhibits the feeding effect	High reduction	Low	Attract natural enemies	low	Negligible	(Kundu 2023; Liu et al. 2023)

Challenges and Limitations

Farmers prefer to use chemical pesticides for rapid pest control (Ngegba et al. 2022). Factors including climatic variability, variations in standardized extraction and formulation techniques, instability in field settings, and high regulatory standards are all barriers to the broad adoption of these botanicals (Saikumar et al. 2025). Mostly, research focused on the target pest and did not describe the effectiveness of flavonoids on beneficial organisms. The use of biopesticides is limited because they are rapidly biodegradable and have lower efficacy in the environment as

compared to conventional insecticides (Pereira et al. 2024). There is a need to advance public acceptance, address regulatory obstacles, and increase market penetration (Afzal et al. 2025; Fenibo and Matambo 2025). The long-term effects of biopesticides on non-target organisms and the environmental data on biopesticides are still scarce. Inconsistent field performance, limited shelf life, and slow action in various climatic conditions make their practical implementation challenging (Fenibo et al. 2022; Kocamaz and Merhan 2026).

Future Perspectives

The ecological compatibility and formulation stability of flavonoid compounds can be strengthened by the use of green synthesis techniques, non-toxic solvents, and energy-efficient procedures. RNA interference, omics, and nano-based technologies can address the drawbacks, such as sluggish action and limited shelf life (Afzal et al. 2025). Nanoencapsulation and Biotechnological approaches can be used for metabolite synthesis and stability. Future research should focus on develop formulation with a clear mechanism of action and identifying new plants that have bio-pesticidal effects. Researchers should concentrate on the controlled release of these bio-pesticides over time and their administration to ensure a safe environment. Plant-based pesticides should become an essential part of integrated pest management (IPM) to mitigate the risk of resurgence of pests, resistance development, reduce reliance on chemical pesticides, and promote ecological safety (Fatima et al. 2026). The utilization of research, abilities, and biopesticides with IPM would promote sustainable agriculture by boosting agricultural output while minimizing the use of chemical pesticides.

Conclusion

The growing challenges of using chemical pesticides to control the brown plant hopper support the urgency of having an environmentally safe, sustainable solution. There is evidence that flavonoids have great potential as biopesticides against the brown planthopper. They interfere with feeding habits, survival, growth, reproduction, enzyme inhibition, hormonal control, and oviposition, and thus they have been shown to effectively make planthopper populations stagnate and minimize the chances of resistance development. Flavonoids have higher ecological superiority than synthetic insecticides, including lower toxicity to non-target organisms, biodegradability, and the ability to be utilized in integrated pest management programs. Flavonoids provide an easy-to-use, environmentally friendly alternative to managing brown planthoppers and can be used to even greater effect to make rice production methods even more sustainable. Irrespective of these edges, they have challenges in formulation, stability, and the absence of research on a field scale, which restricts their use in practice. In the future, evaluating ecological effects, nano-based technology, and emerging formulation technologies, with a clear mechanism of action, may fulfill these gaps and challenges

References

- Abd El-Hack ME, Aldhalmi AK, Kamal M, Khafaga AF, Moustafa M, Al-Shehri M, Attia YA (2025) Flavonoids as a phytobiotic agent: sources, classifications, biological benefits, and useful impacts on broilers and layers. *Phytochemistry Reviews*:1–27. <https://doi.org/10.1007/s11101-025-10129-2>
- Acheuk F, Basiouni S, Shehata AA, Dick K, Hajri H, Lasram S, Ntougias S (2022) Status and prospects of botanical biopesticides in Europe and Mediterranean countries. *Biomolecules* 12(2):311. <https://doi.org/10.3390/biom12020311>
- Afzal, M. A., Ashraf, S., Noor, N., Rasheed, S., Jilani, M., Afzal, H. B., ... & Arshad, B. (2025). Legal Frameworks for Nutrition and Food Security in Pakistan: An Analysis of Laws,

- Programs, and Parliamentary Records. *Journal of Media Horizons*, 6(5), 525-539. <https://doi.org/10.5281/zenodo.17336790>
- Afzal, M. A., Shahzadi, N., Ijaz, M., Ali, M. A., & Saadat, S. (2025). Sustainable transformation road map to improved global food and nutrition security: a narrative review. *Frontier in Medical and Health Research*, 3(6), 844-853. <https://doi.org/10.5281/zenodo.16885883>
- Afzal, M. A., Shahzadi, N., Saadat, S., Seemab, R., Tariq, I. S. N., Ashraf, S. R., ... & Kharl, H. A. A. (2025). CRISPR-Cas9 genome-editing technology: A transformative tool for curing human disorders. *Journal of Medical & Health Sciences Review*, 2(3). <https://doi.org/10.62019/YN6WEZ71>
- Ali L, Khan MB, Ahmed F, Nisar I, Fatima A, Khadim MU, Khan J (2024) Influence of abiotic stresses on the production and sustainability of rice crop. *Agrobiological Records* 16:99–101.
- Al-Khayri JM, Rashmi R, Toppo V, Chole PB, Banadka A, Sudheer WN, Rezk AAS (2023) Plant secondary metabolites: the weapons for biotic stress management. *Metabolites* 13(6):716. <https://doi.org/10.3390/metabo13060716>
- An J, Nguyen XC, Kim SH, Bahk S, Kang H, Le Anh Pham M, Chung WS (2022) Kaempferol promotes pathogen resistance via NPR1 activation. *Plant Biotechnology Reports* 16(6):655–663. <https://doi.org/10.1007/s11816-022-00806-5>
- Andriani R, Subroto T, Ishmayana S, Kurnia D (2022) Enhancement methods of antioxidant capacity in rice bran: a review. *Foods* 11(19):2994. <https://doi.org/10.3390/foods11192994>
- Anton S, Cortesero AM (2022) Plasticity in chemical host plant recognition in herbivorous insects and its implication for pest control. *Biology* 11(12):1842. <https://doi.org/10.3390/biology11121842>
- Asma J, Subrahmanyam D, Krishnaveni D (2023) The global lifeline: a staple crop sustaining two thirds of the world's population. *Agriculture Archives*. <https://doi.org/10.51470/AGRI>
- Authority EF, Álvarez F, Arena M, Auteri D, Leite SB, Binaglia M, Villamar-Bouza L (2025) Peer review of pesticide risk assessment of buprofezin. *EFSA Journal* 23(4):e9392. <https://doi.org/10.2903/j.efsa.2025.9392>
- Bagchi TB, Chattopadhyay K, Sivashankari M, Roy S, Kumar A, Biswas T, Pal S (2021) Effect of different processing technologies on phenolic acids, flavonoids and other antioxidants content in pigmented rice. *Journal of Cereal Science* 100:103263. <https://doi.org/10.1016/j.jcs.2021.103263>
- Baqer SH, Al-Younis ZK, Al-Shawi SG (2024) Extracting quercetin from different plant sources, purifying it using different extraction methods (chemical, physical, and enzymatic), and measuring its antioxidant activity. *Frontiers in Bioscience-Elite* 16(4):35. <https://doi.org/10.31083/j.fbe1604035>
- Bernardo LR, Braga ARC (2022) Sakuranetin state of the art: physical properties, biological effects, and biotechnological trends. *Industrial Biotechnology* 18(6):341–350. <https://doi.org/10.1089/ind.2022.0030>
- Bhende RS, Dafale NA (2023) Insights into the ubiquity, persistence and microbial intervention of imidacloprid. *Archives of Microbiology* 205(5):215. <https://doi.org/10.1007/s00203-023-03516-w>
- Bragagnolo FS, Wojeicchowski JP, Soukup-Carne D, González-Miquel M, Esteban J, Funari CS (2024) A green approach for genistein and apigenin extraction optimization from by-products of soybean crops. *Sustainable Chemistry and Pharmacy* 37:101343. <https://doi.org/10.1016/j.scp.2023.101343>
- Chamani M, Dadpour M, Dehghanian Z, Panahirad S, Chenari Bouket A, Oszako T, Kumar S (2025) From digestion to detoxification: exploring plant metabolite impacts on insect

- enzyme systems for enhanced pest control. *Insects* 16(4):392. <https://doi.org/10.3390/insects16040392>
- Chaudhary A, Maithani D, Singh R, Singh S, Yadav S, Kumar D, Malyan SK (2025) Chlorpyrifos pollutants and remediation approaches. *Environmental Claims Journal*:1–41. <https://doi.org/10.1080/10406026.2025.2550390>
- Chen S, Tao Z, Shen Y, Yang R, Yan S, Chen Z, Yang X (2025) Magnaporthe oryzae infection triggers rice resistance to brown planthopper through the influence of jasmonic acid on the flavonoid biosynthesis pathway. *Insect Science* 32(1):243–259. <https://doi.org/10.1111/1744-7917.13378>
- Choi M, Khan M, Han C, Jeong IH, Choi N, Kim J (2025) RNA-seq-based identification of imidacloprid resistance mechanisms in Nilaparvata lugens. *Pesticide Biochemistry and Physiology* 209:106351. <https://doi.org/10.1016/j.pestbp.2025.106351>
- Colombo R, Moretto G, Barberis M, Frosi I, Papetti A (2023) Rice byproduct compounds: from green extraction to antioxidant properties. *Antioxidants* 13(1):35. <https://doi.org/10.3390/antiox13010035>
- Deng Q, Zhang X, Chen H, Hao M, Li R, Lou Y, Lu J (2024) The jasmonate pathway and water loss in rice leaves induced by a stem-borer inhibit leaf-feeder growth. *Plant, Cell & Environment* 47(11):4416–4431. <https://doi.org/10.1111/pce.15024>
- Deng Z, Lai C, Zhang J, Sun F, Li D, Hao P, Yu X (2023) Effects of secondary metabolites of rice on brown planthopper and its symbionts. *International Journal of Molecular Sciences* 25(1):386. <https://doi.org/10.3390/ijms25010386>
- Du Y, Scheibener S, Zhu Y, Pierce C, Perera O, Portilla M (2025) Comparative toxicity and P450-mediated detoxification of flonicamid in Lygus lineolaris and Lygus hesperus. *Insects* 16. <https://doi.org/10.3390/insects16080757>
- Duan R, Xiao X, Song Z, Huang J, Zhang Y, Zhang L, Chen F (2025) Isovitexin and schaftoside from rice plants have antifeedant activity on brown planthoppers. *Pest Management Science* 81(12):8333–8343. <https://doi.org/10.1002/ps.70134>
- Duan R, Xiao X, Song Z, Huang J, Zhang Y, Zhang L, Chen F (2025) Isovitexin and schaftoside from rice plants have antifeedant activity on brown planthoppers. *Pest Management Science*. <https://doi.org/10.1002/ps.70134>
- Duan R, Xiao X, Song Z, Huang J, Zhang Y, Zhang L, Chen F (2025) Isovitexin and schaftoside show antifeedant activity against brown planthopper. *Pest Management Science* 81(12):8333–8343. <https://doi.org/10.1002/ps.70134>
- Fatima, T., Sajjad, I., Qamar, M., Afzal, M. A., Noor, N., Tariq, N., Yawar, A., Abbasi, A. J., Rahim, F., Farooq, M. U., Noor, M., & Zahid, I. (2026). The expanding role of artificial intelligence in health, life, and applied sciences: A multidisciplinary review. *Social Science Review Archives*, 4(2), 237–257. <https://doi.org/10.70670/sra.v4i2.2046>
- Fenibo EO, Ijoma GN, Matambo T (2022) Biopesticides in sustainable agriculture: current status and future prospects. In: *New and Future Development in Biopesticide Research: Biotechnological Exploration*. pp 1–5. https://doi.org/10.1007/978-981-16-3989-0_1
- Fenibo EO, Ijoma GN, Nurmahomed W, Matambo T (2022) Green chemistry attributes of biopesticides. *Sustainability* 14(21):14417. <https://doi.org/10.3390/su142114417>
- Fenibo EO, Matambo T (2025) Biopesticides for sustainable agriculture adoption. *Frontiers in Sustainable Food Systems* 9:1657000. <https://doi.org/10.3389/fsufs.2025.1657000>
- Fujii T, Matsukura K, Van Chien H, Cuong LQ, Loc PM, Estoy GF, Sanada-Morimura S (2024) Insecticide resistance reduces virulence to host defenses in brown planthopper. *Entomologia Experimentalis et Applicata* 172(4):301–311. <https://doi.org/10.1111/eea.13413>

- Ganamala R, Kumar V (2024) Distribution and infestation of brown plant hopper in rice. *Just Agriculture* 5(2):Article ID 14.
- Ge S (2026) Genomic insights into origin of African rice: implications for crop domestication. *Molecular Plant* 19(1):19–21. [10.1016/j.molp.2025.10.018](https://doi.org/10.1016/j.molp.2025.10.018)
- Abduh AM, Sari NN, Khairullah I, Fahmi A, Anwar K, Hairani A, Darsani YR (2026) Rice crop management to increase productivity and reduce methane emissions in Indonesia. *Chilean Journal of Agricultural Research* 86(1):140–153. <http://dx.doi.org/10.4067/s0718-58392026000100140>
- Goławska S, Łukasik I, Czerniewicz P (2024) Genistein and naringenin as defense molecules. *Molecules* 29(23):5505. <https://doi.org/10.3390/molecules29235505>
- Gonçalves S, Vasconcelos MW, Mota TFM, Lopes JMH, Guimaraes LJ, Miglioranza KSB, Ghisi NDC (2022) Global research trends on pesticide fipronil. *Environmental Science and Pollution Research* 29(52):79111–79125. <https://doi.org/10.1007/s11356-022-21135-8>
- Gong G, Yuan LY, Li YF, Xiao HX, Li YF, Zhang Y, Zhang ZF (2022) Salivary protein 7 of the brown planthopper functions as an effector for mediating triclin metabolism in rice plants. *Scientific Reports* 12(1):3205. <https://doi.org/10.1038/s41598-022-07106-6>
- Goyal J, Verma PK (2023) An overview of biosynthetic pathway and therapeutic potential of rutin. *Mini Reviews in Medicinal Chemistry* 23(14):1451–1460. <https://doi.org/10.2174/1389557523666230125104101>
- Gul MZ, Das PP, Babu KR, Juarez-Colunga S, Weber AM, Yoosuf B, Ghazi IA (2025) Rice bran: a comprehensive review of phytochemicals and bioactive components with therapeutic potential and health benefits. *Nutrition Reviews*:nuaf147. <https://doi.org/10.1093/nutrit/nuaf147>
- Hao PY, Feng YL, Zhou YS, Song XM, Li HL, Ma Y, et al (2018) Schaftoside interacts with NICDK1 protein: A mechanism of rice resistance to brown planthopper, Nilaparvata lugens. *Frontiers in Plant Science* 9:710. <https://doi.org/10.3389/fpls.2018.00710>
- Hasibuan N, Manurung B (2025) The effect of weed species on the survival and reproduction of green leafhopper Nephrotettix virescens (Distant). *Journal of Applied Entomologist* 5(1):27–32.
- Hejran AB, Azizi A, Saken K, Ardak K, Sawicka B, Niazi P (2024) Plant-derived bio-pesticides for eco-friendly control of the Prodenia litura (Fabricius) insect pest. *Journal of Entomology and Zoology Studies* 12(5):192–205. <https://doi.org/10.22271/j.ento.2024.v12.i5c.9397>
- Hidayat P, Wiyono S, Prabowo DP, Subagyo VNO (2025) Impact of straw incorporation and insecticides on brown planthopper. In: *IOP Conference Series: Earth and Environmental Science* 1528:012016. IOP Publishing. 10.1088/1755-1315/1528/1/012016
- Horgan FG, Peñalver-Cruz A (2022) Compatibility of insecticides with rice resistance to planthoppers. *Insects* 13(2):106. <https://doi.org/10.3390/insects13020106>
- Hori K, Sun J (2022) Rice grain size and quality. *Rice* 15(1):33. <https://doi.org/10.1186/s12284-022-00579-z>
- Hu Z, Hu S, Liu J, Gu S, Mo X, Xu Y, Zhang Q (2025) Dietary exposure risk of neonicotinoid from rice in China. *Exposure and Health* 17(2):599–610. <https://doi.org/10.1007/s12403-024-00680-2>
- Iamba K, Dono D (2021) A review on brown planthopper (Nilaparvata lugens Stål), a major pest of rice in Asia and Pacific. *Asian Journal of Research in Crop Science* 6:7–19. 10.9734/AJRCS/2021/v6i430122
- Iftikhar R, Hafeez S, Masood S, Shaheen A, Manzoor M (2023) Biological control of rice insect pest: a critical review. <https://doi.org/10.47278/journal.abr/2023.016>

- Iqbal Z, Sattar MN, Naqqash MN (2022) Diversity and management of plant viruses infecting rice. In: *Modern Techniques of Rice Crop Production*. Springer, Singapore, pp 423–470. <https://doi.org/10.1007/978-981-16-4955-4-23>
- Jan R, Aaqil Khan M, Asaf S, Lubna, Park JR, Lee IJ, Kim KM (2021) Flavonone 3-hydroxylase relieves bacterial leaf blight stress in rice via overaccumulation of antioxidant flavonoids and induction of defense genes and hormones. *International Journal of Molecular Sciences* 22(11):6152. <https://doi.org/10.3390/ijms22116152>
- 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>
- Jiang T, Deng F, Dong W, Zhang Q, Liu P (2024) Rice quality prediction and pesticide residue assessment during storage. *Scientific Reports* 14(1):9130. <https://doi.org/10.1038/s41598-024-59816-8>
- Kang Y, Koo HN, Kim HK, Kim GH (2022) Analysis of the feeding behavior and life table of Nilaparvata lugens and Sogatella furcifera under sublethal concentrations of imidacloprid and sulfoxaflo. *Insects* 13(12):1130. <https://doi.org/10.3390/insects13121130>
- Kciuk M, Kruczkowska W, Wanke K, Gałęzewska J, Kołat D, Mujwar S, Kontek R (2025) The role of genistein in type 2 diabetes and beyond: mechanisms and therapeutic potential. *Molecules* 30(5):1068. <https://doi.org/10.3390/molecules30051068>
- Kemparaju KB (2023) Diversity in rice germplasm. *Biodiversity, Ecosystem Services and Genetic Resources* 58.
- Kim EG, Yun S, Park JR, Jang YH, Farooq M, Yun BJ, Kim KM (2022) Bio-efficacy of chrysoeriol7, a natural chemical and repellent, against brown planthopper in rice. *International Journal of Molecular Sciences* 23(3):1540. <https://doi.org/10.3390/ijms23031540>
- Kim EG, Yun S, Park JR, Jang YH, Farooq M, Yun BJ, Kim KM (2022) Bio-efficacy of chrysoeriol7, a natural chemical and repellent, against brown planthopper in rice. *International Journal of Molecular Sciences* 23(3):1540. <https://doi.org/10.3390/ijms23031540>
- Kim TJ, Kim YJ, Seo WD, Park SU, Kim JK (2022) Improved quantification of catechin and epicatechin in red rice (*Oryza sativa* L.) using stable isotope dilution liquid chromatography-mass spectrometry. *Applied Biological Chemistry* 65(1):85. <https://doi.org/10.1186/s13765-022-00754-2>
- Kocamaz D, Merhan O (2026) Environmental perspectives on biopesticides: current knowledge and research gaps.
- Krishnan K, Sagarika M, Karunakaran M, Marimuthu A, Subbiah R, Muthusamy R, Sundararajan T (2026) Rice false smut: a re-emerging disease; biology, detection and its mitigation—a review. *Rice Production Strategies—Addressing Abiotic and Biotic Stresses and Socioeconomic Changes*. 10.5772/intechopen.1012514
- Kundu A (2023) Sakuranetin inhibits brown planthopper via targeting endosymbionts. *Physiologia Plantarum* 175(6):e14110. <https://doi.org/10.1111/ppl.14110>
- Li C, Zha W, Wang J, Wu Y, Shi S, Wang H, You A (2024) Transcriptome analysis of biotic and abiotic stress mediated by the suction of brown planthopper in two rice cultivars. *Plant Stress* 11:100380. <https://doi.org/10.1016/j.stress.2024.100380>
- Li S, Qi L, Tan X, Li S, Fang J, Ji R (2023) Small brown planthopper infestation regulates plant defenses. *International Journal of Molecular Sciences* 24(5):4764. <https://doi.org/10.3390/ijms24054764>

- Liang C, Guan Z, Wei K, Yu W, Wang L, Chen X, Wang Y (2023) Characteristics of antioxidant capacity and metabolomics analysis of flavonoids in the bran layer of green glutinous rice (*Oryza sativa* L. var. *Glutinosa* Matsum). *Scientific Reports* 13(1):16372. <https://doi.org/10.1038/s41598-023-43466-3>
- Liu M, Hong G, Li H, Bing X, Chen Y, Jing X, Gershenzon J, Lou Y, Baldwin I, Li R (2023) Sakuranetin protects rice from brown planthopper attack by depleting its beneficial endosymbionts. *Proceedings of the National Academy of Sciences of the United States of America* 120. <https://doi.org/10.1073/pnas.2305007120>
- Liu M, Hong G, Li H, Bing X, Chen Y, Jing X, Li R (2023) Sakuranetin protects rice from brown planthopper attack by depleting its beneficial endosymbionts. *Proceedings of the National Academy of Sciences* 120(23):e2305007120. <https://doi.org/10.1073/pnas.2305007120>
- Liu XD, Zhang B, Liu Y (2025) A new method to monitor the brown planthopper population size and its damage using canopy temperature of rice plants. *Precision Agriculture* 26(4):74. <https://doi.org/10.1007/s11119-025-10271-z>
- Meena DK, Madavi PN, Meena SK (2023) Pesticide induced resurgence of rice planthoppers. In: *Recent Advances in Agriculture*. pp 46–55.
- Mohd Nizam SN, Haji Baharudin NS, Ahmad H (2023) Application of pesticide in paddy fields: a Southeast Asia case study review. *Environmental Geochemistry and Health* 45(8):5557–5577. <https://doi.org/10.1007/s10653-023-01668-8>
- Muhyuddin S, Nomi ZA, Maryam B, Mobashar M, Yaseen A, Noor-e-Hira MAM, Ahmed W (2025) Biopesticides for use in agriculture and the health sector. *Agrobiological Records* 21:37–50.
- Muruganathan N, Dhanapal AR, Baskar V, Muthuramalingam P, Selvaraj D, Aara H, Sivanesan I (2022) Recent updates on source, biosynthesis, and therapeutic potential of natural flavonoid luteolin: a review. *Metabolites* 12(11):1145. <https://doi.org/10.3390/metabo12111145>
- Nawaz MS, Ali A, Iltaf B, Akram S, Khan S (2025) Advances in genomic approaches for developing climate-resilient vegetable crops. *Agrobiological Records* 20:131–145.
- Netra H, Hurali S, Barkeer S, Prabhuraj A, Badariprasad PR, Gowder SB (2024) Reduction of the natural enemy population by deltamethrin and imidacloprid leads to resurgence of brown planthopper in rice. *International Journal of Tropical Insect Science* 44(4):2161–2168. <https://doi.org/10.1007/s42690-024-01306-5>
- Ngegba P, Cui G, Khalid M, Zhong G (2022) Use of botanical pesticides in agriculture as an alternative to synthetic pesticides. *Agriculture* 12:600. <https://doi.org/10.3390/agriculture12050600>
- Patil JR, Mhatre KJ, Yadav K, Yadav LS, Srivastava S, Nikalje GC (2024) Flavonoids in plant-environment interactions and stress responses. *Discover Plants* 1(1):68. <https://doi.org/10.1007/s44372-024-00063-6>
- Patil JR, Mhatre KJ, Yadav K, Yadav LS, Srivastava S, Nikalje GC (2024) Flavonoids in plant-environment interactions and stress responses. *Discover Plants* 1(1):68. <https://doi.org/10.1007/s44372-024-00063-6>
- Pereira V, Figueira O, Castilho PC (2024) Flavonoids as insecticides in crop protection—a review of current research and future prospects. *Plants* 13(6):776. <https://doi.org/10.3390/plants13060776>
- Purnama I, Malhat F, Mutamima A, Nelvia N, Amalia A (2025) Multiple pesticide residues in rice and chlorpyrifos persistence. *Sustainable Chemistry One World*:100080. <https://doi.org/10.1016/j.scowo.2025.100080>

- Ramaroson M, Koutouan C, Helesbeux J, Clerc L, Hamama L, Geoffriau E, Briard M (2022) Role of phenylpropanoids and flavonoids in plant resistance to pests and diseases. *Molecules* 27. <https://doi.org/10.3390/molecules27238371>.
- Ren F, Li Y, Luo H, Gao S, Jiang S, Yang J, Peng C (2024) Extraction, detection, bioactivity, and product development of luteolin: a review. *Heliyon* 10(24). [10.1016/j.heliyon.2024.e41068](https://doi.org/10.1016/j.heliyon.2024.e41068)
- Rencoret J, Rosado MJ, Kim H, Timokhin VI, Gutiérrez A, Bausch F, Del Río JC (2022) Flavonoids naringenin chalcone, naringenin, dihydrotricin, and tricetin are lignin monomers in papyrus. *Plant Physiology* 188(1):208–219. <https://doi.org/10.1093/plphys/kiab469>
- Riddick EW (2024) Evaluating the effects of flavonoids on insects: implications for managing pests without harming beneficials. *Insects* 15(12):956. <https://doi.org/10.3390/insects15120956>
- Saikumar T, Manideep S, Paschapur AU, Thrilekha D (2025) Botanical pesticides in sustainable pest management. *Journal of Plant Diseases and Protection* 132(6):175. <https://doi.org/10.1007/s41348-025-01177-z>
- Sarao L, Kaur S, Malik T, Singh A (2022) Genistein and daidzein. In: *Nutraceuticals and Health Care*. Academic Press, pp 331–341. <https://doi.org/10.1016/B978-0-323-89779-2.00016-8>
- Satpathi CR (2024) Diversity of major predators under different insecticide regimes in rice. *Indian Journal of Entomology* 86(1).
- Schnarr L, Olsson O, Kümmerer K (2024) Biodegradation of flavonoids and structural influences. *Chemosphere* 359:142234. <https://doi.org/10.1016/j.chemosphere.2024.142234>
- Shen N, Wang T, Gan Q, Liu S, Wang L, Jin B (2022) Plant flavonoids: classification, distribution, biosynthesis, and antioxidant activity. *Food Chemistry* 383:132531. <https://doi.org/10.1016/j.foodchem.2022.132531>
- Shi J, An G, Weber AP, Zhang D (2023) Prospects for rice in 2050. *Plant, Cell & Environment* 46(4):1037–1045. <https://doi.org/10.1111/pce.14565>
- Shi T, Zhang Q, Chen X, Mao G, Feng W, Yang L, Chen Y (2024) Overview of deltamethrin residues and toxic effects. *Environmental Geochemistry and Health* 46(8):271. <https://doi.org/10.1007/s10653-024-02043-x>
- Shilpa VS, Shams R, Dash KK, Pandey VK, Dar AH, Ayaz Mukarram S, Kovács B (2023) Phytochemical properties, extraction, and pharmacological benefits of naringin: a review. *Molecules* 28(15):5623. <https://doi.org/10.3390/molecules28155623>
- Singh K, Gupta R, Shokat S, Iqbal N, Kocsy G, Pérez-Pérez JM, Riyazuddin R (2024) Ascorbate, plant hormones and their interactions during plant responses to biotic stress. *Physiologia Plantarum* 176(4):e14388. <https://doi.org/10.1111/ppl.14388>
- Singh S, Sharma A, Monga V, Bhatia R (2023) Compendium of naringenin: potential sources, analytical aspects, chemistry, nutraceutical potentials and pharmacological profile. *Critical Reviews in Food Science and Nutrition* 63(27):8868–8899. <https://doi.org/10.1080/10408398.2022.2056726>
- Tena N, Asuero AG (2022) Up-to-date analysis of the extraction methods for anthocyanins: principles of the techniques, optimization, technical progress, and industrial application. *Antioxidants* 11(2):286. <https://doi.org/10.3390/antiox11020286>
- Tirunagaru KC, Ansari ZG, Jadhav R, Kumar S (2025) Applications of plant secondary metabolites in sustainable agriculture. In: *Plant Secondary Metabolites*. CRC Press, pp 357–383.
- Venugopal S, Thornavalli B, Soundararajan RP, Baskaran V, Alagar M, Anandhi P, et al (2025) Plant defense versus pest defense—a case study with *Oryza sativa* L. and *Nilaparvata*

- lugens Stal. *International Journal of Tropical Insect Science* 45(5):2235–2248. <https://doi.org/10.1007/s42690-025-01593-6>
- Wang X, Wang Y, Yang H, Liu F, Cai Y, Xiao J, Wan P (2024) Integrative omics strategies for understanding and combating brown planthopper virulence in rice production: a review. *International Journal of Molecular Sciences* 25(20):10981. <https://doi.org/10.3390/ijms252010981>
- Zeng B, Chen FR, Liu YT, Guo D, Zhang YJ, Feng ZR, Gao CF (2023) Chitin synthase mutation confers resistance to buprofezin in brown planthopper. *Journal of Pest Science* 96(2):819–832. <https://doi.org/10.1007/s10340-022-01538-9>
- Zeng B, Liu YT, Feng ZR, Chen FR, Wu SF, Bass C, Gao CF (2023) Cytochrome P450 overexpression confers buprofezin resistance in brown planthopper. *Pest Management Science* 79(1):125–133. <https://doi.org/10.1002/ps.7181>
- Zhang Q, Li T, Gao M, Ye M, Lin M, Wu D, et al (2022) Transcriptome and metabolome profiling reveal the resistance mechanisms of rice against brown planthopper. *International Journal of Molecular Sciences* 23(8):4083. <https://doi.org/10.3390/ijms23084083>
- Zhang Y, Wang X, Bian Z, Se C, Yang G, Lu Y (2025) Flavonoid compounds suppress cotton aphid. *Frontiers in Plant Science* 16:1545499. <https://doi.org/10.3389/fpls.2025.1545499>
- Zhang Z, Cui B, Yan S, Li Y, Xiao H, Zhang Y (2017) Evaluation of tricin, a stylet probing stimulant of brown planthopper, in infested and non-infested rice plants. *Journal of Applied Entomology* 141. <https://doi.org/10.1111/jen.12353>
- Zheng T, Wong ECW, Yue GGL, Li XX, Wu KHY, Lau DTW, Lau CBS (2021) Identification and quantification of tricin present in medicinal herbs, plant foods and by-products using UPLC-QTOF-MS. *Chemical Papers* 75(9):4579–4588. <https://doi.org/10.1007/s11696-021-01651-6>
- Zhu X, Wei Q, Wan P, Wang W, Lai F, He J, Fu Q (2023) Paclobutrazol enhances efficacy of nitenpyram against brown planthopper. *International Journal of Molecular Sciences* 24(13):10490. <https://doi.org/10.3390/ijms241310490>
- Zubair M, Anwar F, Arshad I, Malik S, Zafar MN (2023) Rice nutraceuticals and bioactive compounds: extraction, characterization and antioxidant activity: a review. *Combinatorial Chemistry & High Throughput Screening* 26(15):2625–2643. <https://doi.org/10.2174/1386207326666230512144834>