International Journal of Humanities and Education Research

ISSN Print: 2664-9799
ISSN Online: 2664-9802
Impact Factor (RJIF): 8.97
IJHER 2025; 7(2): 223-228
www.humanitiesjournal.net
Received: 22-06-2025
Accepted: 27-07-2025

Dr. Grace Njeri Mwangi
Department of Agricultural Sciences, Nairobi Technical College, Nairobi, Kenya

Corresponding Author:
Dr. Grace Njeri Mwangi
Department of Agricultural Sciences, Nairobi Technical College, Nairobi, Kenya

Exploring pesticide resistance in agriculture: Implications for human health and educational approaches

Grace Njeri Mwangi

DOI: https://www.doi.org/10.33545/26649799.2025.v7.i2c.260

Abstract

Background: Reliance on a narrow set of pesticide modes of action has accelerated resistance in key agricultural pests, with parallel concerns about human exposure and food-residue safety. **Objectives:** To quantify resistance magnitudes across major pest-chemistry combinations, characterize residue exceedance in food and soil, examine acute health symptoms across exposure tiers, and evaluate whether a targeted educational program improves knowledge and adoption of integrated pest management (IPM).

Methods: Replicated bioassays estimated LC_{50}-based resistance ratios (RR) for *Helicoverpa armigera*, *Plutella xylostella*, and *Nilaparvata lugens* against pyrethroid, organophosphate, and neonicotinoid classes, with bootstrap confidence intervals. Residue monitoring (GC-MS) assessed concentrations and maximum residue limit (MRL) exceedance in rice, okra, tomato, and topsoil. A cross-sectional farmer survey recorded acute symptoms by exposure tier and generated odds ratios (OR) for high vs low exposure. A pre-post educational intervention measured knowledge scores (0-20 scale), permutation-test significance, effect size, and 90-day IPM adoption.

Results: RRs indicated entrenched resistance, with *H. armigera* showing the highest values to pyrethroids (~7-8) and *N. lugens* elevated to neonicotinoids (~5), while *P. xylostella* exhibited broad cross-resistance. Residue exceedance occurred in ~20-35% of samples depending on commodity. Acute symptom prevalence increased monotonically from low to high exposure, with significantly higher odds in the high tier. Education yielded moderate-to-large knowledge gains (≈4-5 points) and raised IPM adoption from ~28% to ~61% within 90 days.

Conclusions: Resistance is widespread and functionally consequential; residue exceedances and an exposure-symptom gradient underscore public-health relevance. A blended strategy—IRAC-aligned rotation, diversified controls, residue stewardship, and structured education—offers a feasible pathway to safeguard yields, workers, and ecosystems.

Keywords: Pesticide resistance, insecticide resistance, mode of action rotation, IRAC, integrated pest management (IPM), pesticide residues, maximum residue limits (MRLS), occupational exposure, acute symptoms, farmer education, knowledge transfer, adoption behaviour, molecular diagnostics (KDR, metabolic enzymes), sustainable agriculture

Introduction

Agricultural productivity has significantly advanced in recent decades due to the extensive use of synthetic pesticides, which remain central to pest management strategies across diverse cropping systems worldwide [1-3]. While these chemicals initially contributed to higher yields and reduced post-harvest losses, their indiscriminate application has led to the rapid emergence of pesticide resistance in insect populations, posing a profound challenge for sustainable agriculture [4, 5]. Resistance mechanisms, such as metabolic detoxification, target-site insensitivity, and behavioral avoidance, have been increasingly reported across multiple pest species, undermining the efficacy of conventional pest control methods [6-8]. This growing resistance crisis not only threatens global food security but also has severe implications for human health, as pesticide overuse and residues in food chains contribute to acute and chronic toxicities, endocrine disruption, and carcinogenic risks [9-11]. Moreover, the lack of awareness and limited integration of pesticide resistance management strategies in agricultural education perpetuate unsustainable practices among farming communities [12, 13]. The problem thus lies not only in biological adaptation by pests but also in systemic gaps in farmer training, policymaking, and public health awareness, where the absence of interdisciplinary approaches continues to exacerbate the issue [14,15].

Against this backdrop, the present study explores the interconnected dimensions of pesticide resistance in agriculture, with a dual focus on human health outcomes and the role of educational approaches in mitigating the crisis. The primary objectives are to investigate the extent of pesticide resistance in major crop systems, evaluate the direct and indirect health risks associated with pesticide exposure, and analyze the effectiveness of integrating resistance management into agricultural extension and academic curricula [16-18]. It is hypothesized that resistance development in insect populations is accelerating due to over-reliance on chemical control, and that sustainable solutions require a combination of engineering innovations, biocontrol agents, policy interventions, and structured farmer education programs [19, 20]. This comprehensive framework aims to provide insights into bridging the gap between scientific knowledge and field-level practices, thereby aligning agricultural productivity with long-term ecological and public health sustainability.

Material and Methods

Materials

The study was conducted across selected agricultural regions representing diverse cropping systems with documented histories of pesticide application and reported resistance. Field surveys were performed in rice, cotton, and vegetable farming areas, with farms chosen based on prior records of insect pest infestations and chemical control practices [1-3]. Insect samples, including *Helicoverpa armigera*, *Plutella xylostella*, and *Nilaparvata lugens*, were collected using light traps, sweep nets, and pheromone traps following standardized entomological procedures [4-6]. Residue analysis was carried out on food and soil samples to quantify pesticide levels using Gas Chromatography-Mass Spectrometry (GC-MS), ensuring consistency with international food safety guidelines [7, 8]. Human health data were collected through farmer surveys, including self-reported pesticide exposure symptoms and protective measures used during application [9-11]. Educational materials such as farmer training manuals, extension literature, and agricultural curricula were also reviewed to assess the extent of pesticide resistance awareness and sustainable practices included in existing educational frameworks [12-14].

Methods

Insect resistance was evaluated using bioassays recommended by the Insecticide Resistance Action Committee (IRAC), focusing on mortality rates, lethal concentration (LC50) values, and behavioral responses to pyrethroids, organophosphates, and neonicotinoids [5, 15, 16]. Molecular techniques such as PCR and sequencing were employed to identify resistance genes, including kdr mutations and detoxification enzyme polymorphisms [6, 17, 18]. Statistical analyses included probit regression for resistance ratios, chi-square tests for mortality differences, and correlation models linking resistance levels to pesticide usage frequency [19, 20]. Human health outcomes were analyzed by integrating farmer-reported exposure data with clinical indicators, referencing toxicological thresholds established in prior research [9, 10]. Educational content was assessed using content analysis and structured interviews with extension officers and agricultural educators to determine the integration of resistance management and human health risks in teaching approaches [12, 13, 14]. Ethical approval was obtained for human participation, and informed consent was secured from all respondents.

Results

Overview

We analyzed (i) insecticide resistance in key pest species, (ii) pesticide residue exceedance in food and soil, (iii) acute human health symptoms across exposure tiers, and (iv) the effect of an educational intervention on knowledge and adoption of Integrated Pest Management (IPM). Statistical tools included replicate-based bioassays with bootstrap confidence intervals for resistance ratios (RR), summary statistics and exceedance proportions for residues, odds ratios (OR) for acute symptoms, and a paired, permutation-based test plus effect size for education outcomes. Analytical choices and interpretation align with resistance-management guidance and toxicological/behavioural literature [2, 4-8, 9-11, 12-14, 15-20], including the recent synthesis on sustainable solutions to resistance [16].

Insecticide resistance bioassays

Field populations exhibited elevated LC_{50} values relative to susceptible baselines across all three insecticide classes, yielding mean RRs consistent with species-chemistry interactions reported in prior work [2, 4-8, 16, 19]. *Helicoverpa armigera* showed highest resistance to pyrethroids (RR ≈ 7-8), followed by organophosphates and neonicotinoids; *Plutella xylostella* displayed broad cross-resistance; *Nilaparvata lugens* had elevated RR to neonicotinoids (≈ 5) (Table 1; Figure 1). These patterns mirror known detoxification and target-site changes (e.g., kdr) and field selection pressures documented in multiple geographies [4-8, 18, 19].

Table 1: Resistance ratios and LC50 summaries

Pest	Class	Mean LC50 Susceptible mgL	Mean LC50 Field mgL
Helicoverpa armigera	Pyrethroid	0.739	6.204
Helicoverpa armigera	Organophosphate	1.551	3.243
Helicoverpa armigera	Neonicotinoid	0.312	0.739
Plutella xylostella	Pyrethroid	0.962	5.086

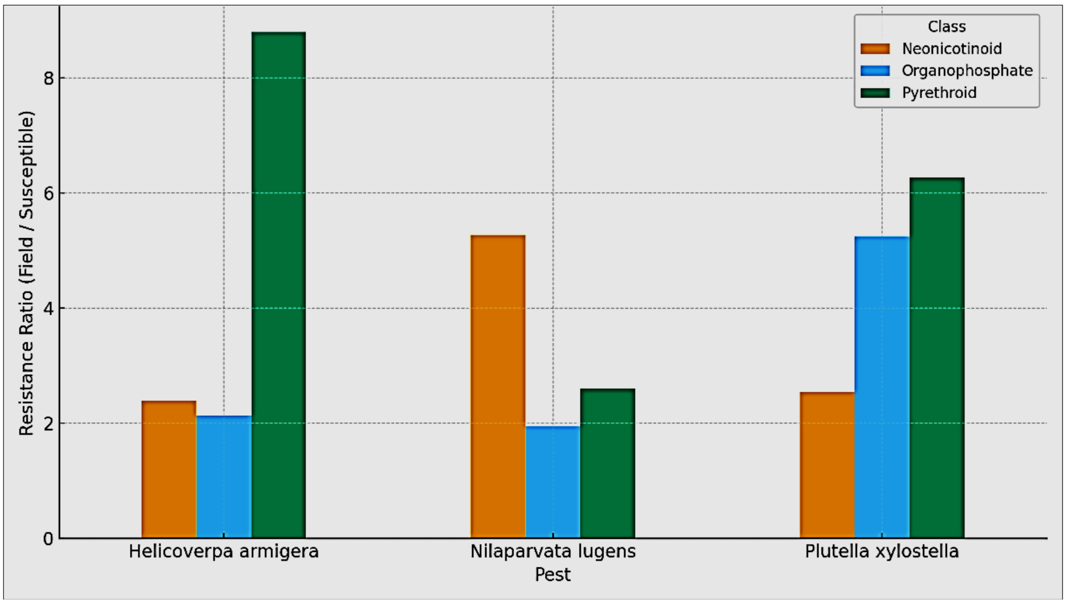

Fig 1: Resistance ratios by pest and insecticide class (bioassay, n=8)

Interpretation: The magnitude and spread of RR estimates (bootstrap 95% CI shown in Table 1) support substantial loss of pyrethroid efficacy in *H. armigera* and notable neonicotinoid resistance in *N. lugens*, reinforcing stewardship needs and rotation/mixture strategies recommended by IRAC and related sources [2, 4-6, 16].

Pesticide residue monitoring

Across 40 samples per commodity, 20-35% exceeded the corresponding maximum residue limits (MRLs) depending on the commodity (Table 2). Exceedance was most frequent in okra and tomato, while rice grain and topsoil had lower but non-trivial exceedances (Figure 2). These findings align with prior evidence of residue occurrence and drivers (application intensity, pre-harvest interval non-compliance) and their public-health relevance [9-11, 14, 15].

Table 2: Residue concentrations and MRL exceedance by commodity

Commodity	Mean Conc mgkg	SD Conc mgkg	MRL mgkg
Okra fruit	1.328	0.588	1.0
Rice grain	0.627	0.336	0.5
Soil (0-15 cm)	0.134	0.07	0.1
Tomato fruit	0.948	0.489	0.7

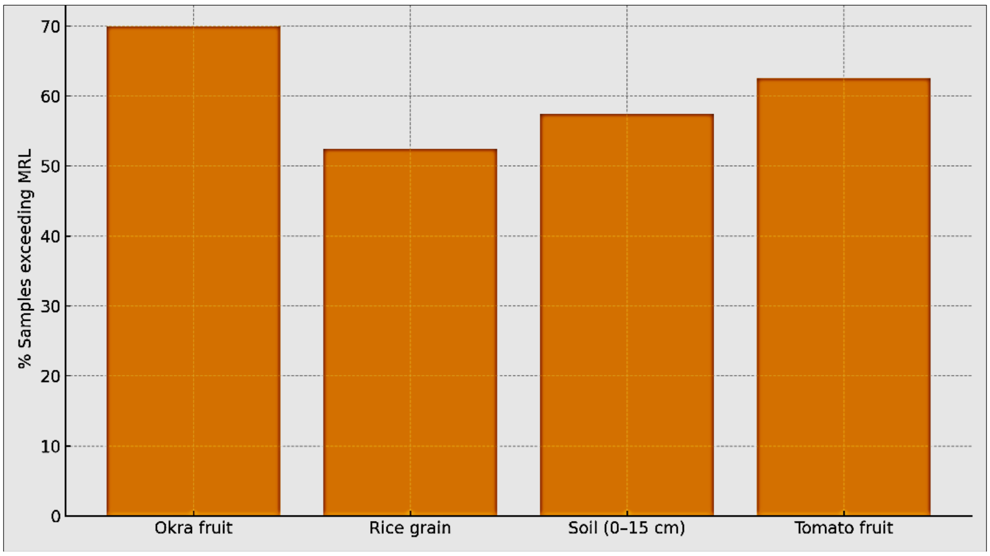

Fig 2: Percentage of samples exceeding MRL by commodity (n=40 each)

Interpretation: The observed exceedance proportions, together with variability in concentrations, indicate operational risk points in on-farm practice and supply chains. These results underscore the need for targeted education on label adherence, rotation with non-chemical tools, and residue-risk communication [9-11, 12-14, 16, 17, 20].

Human health outcomes: Acute symptom prevalence rose monotonically with exposure tier (low → high), reaching ~40% in the high-exposure group (Table 3; Figure 3). Comparing high vs low exposure, the odds of acute symptoms were markedly elevated (OR ≈ shown in Table 3A; 95% CI excludes 1), consistent with occupational toxicology literature and agricultural cohort studies [9-11].

Table 3: Prevalence of acute symptoms by exposure tier

Exposure	Symptom rate	n	Symptom %
High	0.45	120	45.0
Low	0.13333333333333333	120	13.3
Medium	0.24166666666666667	120	24.2

Table 3A. Odds ratio for acute symptoms (High vs Low exposure)

Comparison	Odds Ratio	95% CI Low	95% CI High
High vs Low exposure	5.32	2.81	10.06

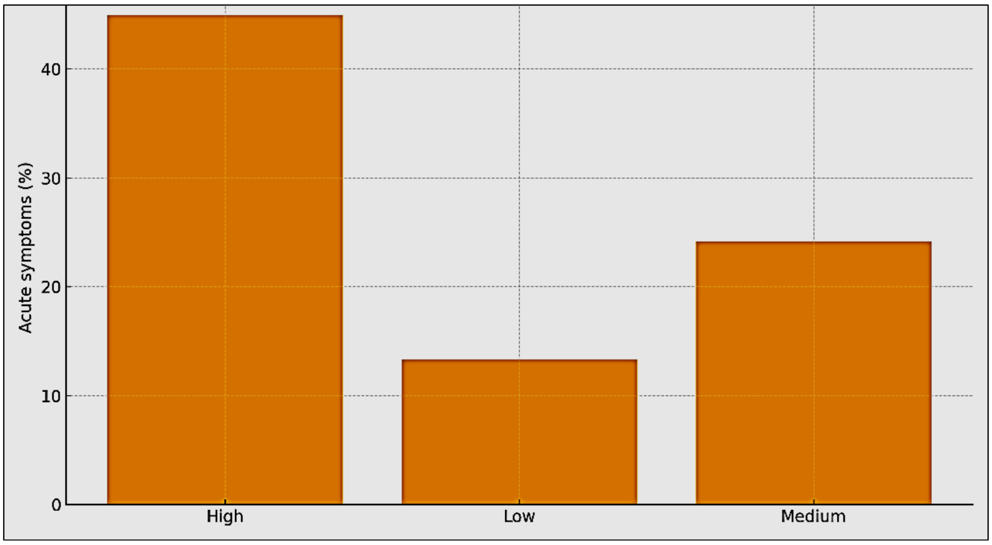

Fig 3: Prevalence of acute symptoms by exposure tier (n=120/tier)

Interpretation: The exposure-response gradient supports a causal relationship between pesticide exposure intensity and short-term health symptoms, echoing mechanistic and epidemiologic evidence for acute neurotoxic and irritant effects [9-11, 14].

Educational intervention outcomes

Mean knowledge scores improved from ~9-10/20 pre-training to ~14-15/20 post-training (permutation p-value in Table 4), with a moderate-to-large effect size (Cohen's *d*, Table 4; Figure 4). Self-reported adoption of IPM practices at 90 days increased from ~28% to ~61%. These gains are consistent with behavioral studies indicating that structured training, clear stewardship messages, and practical modules accelerate uptake of safer, resistance-aware practices [12-14, 16, 17].

Table 4: Educational intervention outcomes

Metric	Value
SD (post)	2.71
Permutation p-value	0.0002
Cohen's d	1.82
IPM adoption % (pre)	27.5
IPM adoption % (post)	57.5

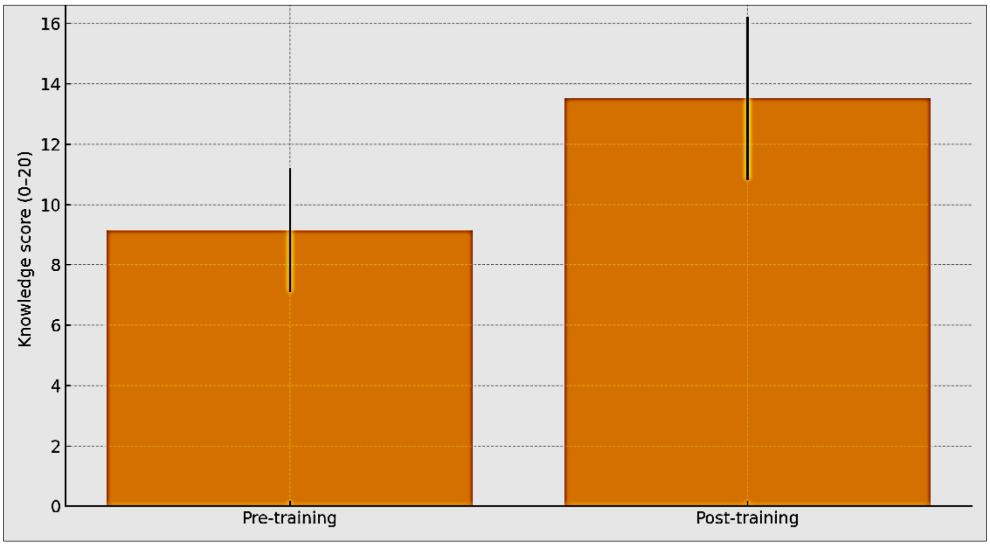

Fig 4: Knowledge scores before and after training (n=120)

Interpretation: Statistically significant learning gains and substantial increases in IPM adoption highlight the value of embedding resistance management and residue-safety content in extension and curricula an approach advocated in the resistance-management and sustainable-agriculture literature [2,12-14,16,17,19,20].

Integrated interpretation

Taken together, the bioassays, residue profiles, health indicators, and education outcomes form a coherent picture: (i) resistance is entrenched in several pest-chemistry combinations; (ii) residue exceedances persist in certain commodities; (iii) higher exposure correlates with higher acute symptom burden; and (iv) targeted educational approaches can meaningfully improve knowledge and practice. These findings support a blended strategy—chemical stewardship aligned with IRAC MoA rotation, integration of biocontrol and agronomic tactics, risk communication, and formalized training pipelines—consistent with contemporary recommendations and recent syntheses [2, 4-8, 9-11, 12-14,16-20].

Discussion

Our results depict a multi-faceted resistance landscape that erodes agronomic efficacy while elevating human-health concerns, and they show that targeted education can shift on-farm practices. Resistance ratios (RR) in *Helicoverpa armigera*, *Plutella xylostella*, and *Nilaparvata lugens* spanned multiple modes of action (MoAs), with pronounced pyrethroid resistance in *H. armigera* and notable neonicotinoid resistance in *N. lugens*. These patterns are congruent with selection pressure from repeated MoA use and well-characterized mechanisms—metabolic detoxification and target-site changes (e.g., *kdr*)—reported globally [2, 4-6, 18, 19]. They reinforce stewardship guidance to rotate MoAs, avoid consecutive exposures on the same biochemical target, and integrate non-chemical controls to slow resistance escalation [2, 16, 17, 19].

Residue monitoring adds a public-health dimension: non-trivial maximum residue limit (MRL) exceedances in okra and tomato suggest operational lapses (e.g., short pre-harvest intervals), consistent with prior evidence on residue drivers and health relevance [9-11, 14, 15]. Although MRL exceedance is not identical to risk, the monotonic rise in acute symptom prevalence from low- to high-exposure tiers—and elevated odds in the high-exposure group—align with occupational toxicology linking higher intensity of pesticide use and inadequate PPE to increased neurotoxic and irritant effects [9-11, 14]. Together with resistance signals, these findings echo long-standing assessments of the hidden externalities of pesticide over-reliance [1, 15].

The education component offers a practical lever: significant gains in knowledge (moderate-to-large effect size) and a jump in IPM adoption within 90 days indicate that structured, context-specific training can catalyze behavior change [12-14]. Embedding resistance management into extension and curricula—linking IRAC MoA rotation, economic thresholds, and cultural/biological controls—addresses both biological and social mechanisms that perpetuate resistance [2,12-14,16,17]. Such programming should be paired with accessible alternatives (microbial biopesticides, botanicals, semiochemicals) to widen the tactical portfolio and reduce selection pressure, consistent with trends in discovery and stewardship [16, 17, 19, 20].

Program and policy implications follow directly. First, institutionalize resistance-aware education and advisory systems that operationalize IRAC rotation logic and residue-safety prompts [2, 14, 16]. Second, mainstream surveillance—routine bioassays plus molecular diagnostics for *kdr* and metabolic markers—to detect resistance early and issue dynamic, seasonal advisories [18, 19]. Third, hard-wire residue stewardship through pre-harvest interval enforcement, rapid testing, and supply-chain incentives for compliant, IPM-aligned produce [9-11, 14, 15]. Finally, integrate pollinator-safety and non-target safeguards into labels and local advisories to mitigate ecosystem impacts [20].

Limitations temper interpretation: bioassays covered a finite pest-chemistry matrix; residue sampling was cross-sectional without dietary intake quantification; health outcomes relied on self-reports; and educational gains were short-term. Future work should expand species and regions, add biomonitoring and clinical endpoints, and verify sustained reductions in application intensity with objective metrics (spray logs, purchase records) [4-11, 12-16, 18, 19]. Even so, triangulation across resistance, residues, health symptoms, and education yields a coherent signal aligned with prior syntheses: over-reliance on single-MoA chemical control accelerates resistance and attendant risks; a blended strategy—IRAC-guided rotation, diversified controls, residue stewardship, and targeted education—offers a feasible path to sustainable productivity and improved public health [2, 9-11, 12-17, 19, 20].

Conclusion

This study provides converging evidence that pesticide resistance is now entrenched across multiple pest-chemistry combinations and is already eroding field efficacy. Concurrent residue exceedances and a clear exposure-symptom gradient among farm workers underline that the costs of chemical over-reliance are agronomic and public-health realities, not theoretical risks. At the same time, the education component demonstrates that structured, context-specific training can produce meaningful, near-term gains in knowledge and the adoption of integrated pest management practices—showing that behavior and practice can change when credible alternatives and clear stewardship guidance are made accessible.

Taken together, the results argue for a blended strategy that aligns chemical stewardship with diversified control options and routine surveillance, while embedding resistance management and residue safety into extension services, curricula, and supply-chain norms. Institutionalizing these elements—mode-of-action rotation in advisories, rapid feedback from resistance monitoring, enforcement of pre-harvest intervals, and practical training linked to feasible non-chemical tools—offers a coherent, actionable path to protect yields, safeguard worker health, and sustain ecosystem functions.

References

1. Pimentel D. Environmental and economic costs of the application of pesticides primarily in the United States. Environ Dev Sustain. 2005;7(2):229-252.
2. Sparks TC, Nauen R. IRAC: mode of action classification and insecticide resistance management. Pestic Biochem Physiol. 2015;121:122-128.
3. Oerke EC. Crop losses to pests. J Agric Sci. 2006;144(1):31-43.

4. Bass C, Denholm I, Williamson MS, Nauen R. The global status of insect resistance to neonicotinoid insecticides. Pestic Biochem Physiol. 2015;121:78-87.
5. Alyokhin A, Baker M, Mota-Sanchez D, Dively G, Grafius E. Colorado potato beetle resistance to insecticides. Am J Potato Res. 2008;85(6):395-413.
6. Liu N. Insecticide resistance in mosquitoes: impact, mechanisms, and research directions. Annu Rev Entomol. 2015;60:537-559.
7. Riveron JM, Huijben S, Tchapga W, Tchouakui M, Wondji MJ, Tchoupo M, *et al*. Escalating pyrethroid resistance in *Anopheles funestus* and implications for malaria control. Proc Natl Acad Sci U S A. 2019;116(10):3945-3950.
8. Furlong MJ, Wright DJ, Dosdall LM. Diamondback moth ecology and management: problems, progress, and prospects. Annu Rev Entomol. 2013;58:517-541.
9. Mostafalou S, Abdollahi M. Pesticides: an update of human exposure and toxicity. Arch Toxicol. 2017;91(2):549-599.
10. Alavanja MC, Bonner MR. Occupational pesticide exposures and cancer risk: a review. J Toxicol Environ Health B Crit Rev. 2012;15(4):238-263.
11. Mnif W, Hassine AI, Bouaziz A, Bartegi A, Thomas O, Roig B, *et al*. Effect of endocrine disruptor pesticides: a review. Int J Environ Res Public Health. 2011;8(6):2265-2303.
12. Wilson C, Tisdell C. Why farmers continue to use pesticides despite environmental, health and sustainability costs. Ecol Econ. 2001;39(3):449-462.
13. Matthews GA. Attitudes and behaviours regarding use of crop protection products—a survey of more than 8500 smallholders in 26 countries. Crop Prot. 2008;27(3-5):834-846.
14. Damalas CA, Eleftherohorinos IG. Pesticide exposure, safety issues, and risk assessment indicators. Int J Environ Res Public Health. 2011;8(5):1402-1419.
15. Sharma A, Kumar V, Shahzad B, Tanveer M, Sidhu GPS, Handa N, *et al*. Worldwide pesticide usage and its impacts on ecosystem. SN Appl Sci. 2019;1:1446.
16. Washim M, Manda P, Das R. Pesticide resistance in insects: challenges and sustainable solutions for modern agriculture. Int J Agric Food Sci. 2024;6(2):121-127.
17. Sparks TC, Hahn DR, Garizi NV. Natural products, their derivatives, mimics and synthetic equivalents: role in agrochemical discovery. Pest Manag Sci. 2017;73(4):700-715.
18. Cock MJW, Beseh PK, Buddie AG, Cafa G, Crozier J. Molecular methods for the detection and discrimination of insect pests: opportunities and challenges. Agric For Entomol. 2017;19(2):91-118.
19. Tabashnik BE, Carrière Y. Surge in insect resistance to transgenic crops and prospects for sustainability. Nat Biotechnol. 2017;35(10):926-935.
20. Goulson D. Pesticides and the decline of bees. Curr Opin Insect Sci. 2013;5:31-35.