ORIGINAL RESEARCH REPORT NIGER. J. PLT. PROT. 40(2):58-68 (2026)

THE ECONOMIC VALUATION AND STRATEGIC REPOSITIONING OF BIOPESTICIDES IN AFRICAN AGRICULTURE: A CRITICAL ANALYSIS OF MARKET POTENTIAL, ADOPTION BARRIERS, AND POLICY IMPERATIVES

AZEEZ S.O *[1], AFOLABI M.O[1] AND BELLO O.S[2]
***[1]National Horticultural Research Institute, Ibadan; [1]Federal University of Agriculture Abeokuta; [2]National Horticultural Society of Nigeria**
Correspondence mail: zurjay17@gmail.com

SUMMARY

Biopesticides are naturally occurring substances derived from biological sources present a compelling alternative to synthetic chemical pesticides, offering biodegradability, low non-target toxicity, and alignment with sustainable agricultural principles. Despite demonstrated efficacy and economic viability across multiple African contexts, biopesticides remain significantly underexploited, with the Africa and Middle East region accounting for less than 4% of the global bio-pesticides market. This paper undertakes a critical examination of the economic valuation of biopesticides in Africa, interrogating the structural, cognitive, and institutional factors perpetuating their systematic undervaluation. Through a comprehensive synthesis of empirical evidence from Nigeria, Kenya, Tanzania, Benin, South Africa, Ghana, Burkina Faso, Uganda, Zimbabwe, and Ethiopia, the analysis reveals a consistent disjuncture between demonstrated cost-effectiveness and actual adoption rates. The findings indicate that farmers demonstrate significant willingness to pay for biopesticides, with premiums ranging from 9.6% above chemical pesticide expenditures in Kenya to substantial amounts in West African contexts, suggesting latent demand that current market and institutional arrangements fail to activate. The paper argues that the undervaluation of biopesticides constitutes not merely a market anomaly but a manifestation of deeper systemic failures requiring comprehensive remedial action. Strategic interventions identified include enhanced farmer education, financial incentives, regulatory harmonisation, and the integration of ecosystem service valuations into economic assessments. The analysis contributes to scholarship on sustainable agricultural transitions in Africa by reframing biopesticides as strategic assets for food security, environmental stewardship, and economic development, and provides evidence-based policy guidance for redressing their persistent undervaluation.

Keywords: Biopesticides, economic valuation, agricultural sustainability, adoption barriers, willingness to pay, regulatory frameworks, Africa

INTRODUCTION

The agricultural landscape of Africa stands at a critical juncture, where the imperative to enhance food production must be reconciled with the pressing need for environmental sustainability and public health protection. Pest-induced crop losses remain a formidable challenge to agricultural productivity across the continent, with insect pests alone contributing to yield reductions of up to 40% in major arable crops in Sub-Saharan Africa (Day *et al.,* 2024). Historically, the predominant response to this challenge has

been the widespread application of synthetic chemical pesticides. However, the ecological and health externalities associated with this approach have become increasingly untenable: conventional pest management drives environmental degradation, biodiversity loss, serious human health impacts, and widespread pest resistance (Wilson *et al.,* 2026). Furthermore, the use of banned or restricted pesticides has contributed to reduced commodity prices through export rejections and market restrictions imposed on produce that fails to meet international residue standards, with adverse consequences for the welfare of farmers (Ferro *et al.,* 2013).

In this context, bio-pesticides which is a naturally occurring substances or agents derived from animals, plants, insects, and microorganisms that have emerged as a compelling alternative. These agents, which include microbial pesticides, botanical extracts, and biochemical compounds, offer distinct advantages over their synthetic counterparts: they are biodegradable, exhibit low toxicity to non-target organisms, and align with the principles of environmental sustainability. Empirical evidence from across the continent substantiates their efficacy and economic viability. In Benin, biopesticide-treated cotton-soybean intercropping systems have been shown to enhance pest regulation and improve farm profitability during the transition to organic production (Mensah *et al.,* 2012). In Tanzania, the replacement of chemical insecticides with weaver ant-based biological control in citrus orchards significantly reduced costs, increased yields, and achieved higher market prices due to consumer preference for pesticide-free produce (George, 2025). In Kenya, plant-based biopesticides were found to be more cost-effective than synthetic pesticides, with a lower average cost per application and higher effectiveness rates (Mkenda *et al.,* 2015).

Despite these demonstrated benefits, bio-pesticides remain significantly underexploited across Africa. The African bio-pesticides market, currently estimated at USD 177.6–195.98 million, is projected to grow to USD 298.5–320.3 million by 2030–2031, reflecting a compound annual growth rate of approximately 10.94% (Azenzem *et el.,* 2026). Yet this trajectory, while promising, belies a more troubling reality: the Africa and Middle East region accounts for less than 4% of the global bio-pesticides market, compared to 43% for Asia, 28% for North America, 14% for Europe, and 11% for Latin America (Sachdev and Singh, 2016). Moreover, the continent hosts only a few hundred commercial bio-pesticide products with a figure grossly disproportionate to its agricultural potential. This disparity is compounded by a pronounced investment gap: AgTech investment in Africa has consistently concentrated on on-farm solutions (approximately 85% of total funding), while the Ag Biotech category encompasses bio-pesticides which has received a mere 5–10% of investment (Sachdev and Singh, 2016).

The factors underlying this undervaluation are multifaceted and deeply entrenched. At the farm level, adoption of bio-pesticides is constrained by a lack of knowledge or information (reported by 97% of farmers in one Kenyan study), difficulty in accessing products (90%), and perceived high costs (70%). More than 65% of farmers in Kenya and Uganda continue to rely on chemical pesticides as their primary pest control method, notwithstanding that over 70% are aware of the negative health effects of these substances (Constantine et al., 2020) At the systemic level, regulatory barriers present

formidable obstacles: many African countries continue to assess biological products using frameworks designed for conventional chemical pesticides, rendering registration costly and slow. A fragmented regulatory landscape across the continent further compounds these challenges. Compounding these structural impediments is a pervasive failure to recognise the full economic value of bio-pesticides which is a failure that extends beyond market prices to encompass the environmental and public health benefits that these agents confer but which remain externalised from conventional economic accounting.

This persistent undervaluation raises fundamental questions that demand rigorous scholarly inquiry. How can the full economic value of bio-pesticides which includes their ecosystem service benefits, public health dividends, and contribution to climate-resilient agriculture which will be comprehensively captured and articulated? What strategic repositioning is required to elevate bio-pesticides from their current status as niche alternatives to recognised pillars of sustainable agricultural transformation? And how might appropriate economic valuation methodologies inform policy frameworks, investment decisions, and market development strategies that can unlock the continent's considerable bio-pesticide potential?

The present paper undertakes a critical analysis of these questions, examining the economic valuation of bio-pesticides in the African context and interrogating the strategic positioning required to redress their systematic undervaluation. Through a synthesis of extant literature, empirical evidence, and comparative analysis with other regions, this study contributes to the growing body of scholarship on sustainable agricultural transitions in Africa. It argues that the undervaluation of bio-pesticides is not merely a market anomaly but a manifestation of deeper structural, cognitive, and institutional failures that require comprehensive and coordinated remedial action. By reframing bio-pesticides as strategic assets for food security, environmental stewardship, and economic development, this paper seeks to inform policy discourse, guide investment priorities, and ultimately contribute to the realisation of a more sustainable and resilient agricultural future for Africa.

Economic Valuation and Cost-Effectiveness

Empirical studies examining the economic performance of biopesticides relative to synthetic alternatives have produced compelling evidence of their cost-effectiveness, challenging the perception that biopesticides are economically inferior. Research conducted in Mwea, Kenya, found that plant-based biopesticides are more cost-effective than synthetic pesticides, with 89% of farmers reporting a lower average cost per application and higher effectiveness rates (Mkenda *et al.,* 2015). This finding is significant as it directly contradicts the widely held assumption that biopesticides are prohibitively expensive for smallholder farmers.

In Benin, Tomagnankodo et al (2026) assessed the short-term ecological and economic performance of transitioning from conventional practices to organic pest management in cotton-based cropping systems demonstrated that biopesticide-treated cotton-soybean intercropping can enhance pest regulation and improve farm profitability during the first year of transition to organic cotton. The study further indicated that biopesticides reduced

cotton pest injury in transition-to-organic systems and supported more natural enemies, suggesting that the economic benefits of biopesticides extend beyond direct cost savings to include ecosystem service values that are typically excluded from conventional economic accounting.

Another instructive Tanzania provides case. George (2025) examined an on-farm experiment conducted over two growing seasons with 20 smallholder farmers in Handeni District compared weaver ant-based biological control with chemical insecticides for citrus pest management. The findings demonstrated that weaver ant-based pest control significantly reduced costs and increased yields, while citrus from these orchards achieved higher market prices due to consumer preference for pesticide-free produce. Beyond economic gains, the study documented reduced chemical pesticide use, environmental protection, and public health benefits, illustrating the multidimensional value that biopesticides confer in value that remains largely externalised from market prices and conventional economic assessments.

In South Africa, Malinga et al. (2023) conducted a comparative cost analysis of biopesticides and chemical insecticides for cotton farmers found that while biopesticides generally required higher investment than chemical insecticides, all treatments were financially viable. This finding underscores a critical distinction: the economic evaluation of biopesticides depends fundamentally on whether one adopts a narrow private cost perspective or a broader societal cost perspective that incorporates environmental and health externalities. From the latter perspective, biopesticides are likely to be significantly undervalued.

Willingness to Pay and Market Potential

Empirical investigations of farmers' willingness to pay (WTP) for biopesticides reveal a nuanced picture that challenges the assumption of uniform price sensitivity. Ayedun et al. (2017) further examined WTP for Aflasafe among maize and groundnut farmers in northern Nigeria, finding that the majority of farmers who had direct experience with the product in Kano (80.7%) and Kaduna (84.3%) had a WTP bid value equal to or greater than the threshold price of $10 at which Aflasafe was to be sold. The mean WTP estimates for experienced farmers were statistically similar across both states. However, inexperienced farmers offered substantially lower values of $3.56 and $7.46 in Kano and Kaduna respectively, with the difference being statistically significant ($P < 0.01$). Regression results indicated that contact with extension agents ($P < 0.01$) and access to credit ($P < 0.05$) positively and significantly influenced the probability that a farmer would be willing to pay more than the threshold price.

In Kenya, Constantine et al. (2020) reported that the average willingness to pay above current chemical pesticide expenditures per cropping season was 9.6% (US$5.7), with WTP differing significantly between counties and being higher among farmers with more education or greater awareness of the health risks associated with pesticide use. This suggests that information and education interventions could increase the perceived value of biopesticides and thus their adoption.

In Ghana, Coulibaly et al. (2010) investigated vegetable farmers' perceptions and willingness to pay for a new biopesticide found that farmers are willing to pay a substantial price premium for improved agricultural environmental safety and cost reduction or yield-enhancing

benefits. Farmers' perception that vegetable pest intensity is increasing, together with their experience in farming and prior use of Dipel (a biopesticide), were identified as statistically significant determinants of WTP. Evidence of farmers trying out other biopesticides or botanical products indicates good market potential, although market growth is likely to be slow.

In Burkina Faso, Tassembédo *et al.* (2024) examined mango farmers' willingness to pay for a new biopesticide to control fruit flies found that 81.52% of growers were willing to pay an average of FCFA 2,745, and 70.38% proposed an average amount of FCFA 2,851 for a weekly treatment. Education emerged as a key determinant of WTP. Across West Africa more broadly, the key factors influencing vegetable farmers' WTP for biopesticides were identified as access to education and extension services, experience in pesticide use, and the effectiveness of pesticides to control new pests.

In Benin, Adetonah *et al.* (2008) assessed farmers' perceptions and willingness to pay for a Metarhizium-based biopesticide to control cotton bollworms identified three variables influencing WTP: efficacy, agro-ecological zone, and broad spectrum. These findings collectively suggest that farmers do not inherently undervalue biopesticides; rather, their valuation is mediated by information asymmetries, experiential knowledge, and perceptions of product efficacy. The consistent finding across multiple country contexts that farmers are willing to pay premiums for biopesticides indicates that the undervaluation problem is not rooted in farmer preferences per se but in structural and informational barriers that prevent accurate valuation.

Barriers to Adoption and the Determinants of Undervaluation

The empirical literature has extensively documented the barriers that perpetuate the undervaluation and low adoption of biopesticides. Ayedun *et al.* (2017), identified lack of awareness of the importance of Aflasafe was cited as barriern for non-adoption by 64% of inexperienced farmers in Kano and 21% in Kaduna.

Masese *et al.,* (2025) studied *the potential of plant-based biopesticides for sustainable crop protection in Mwea, Kirinyaga County, Kenya* identified the main barriers as lack of knowledge or information (reported by 97% of farmers), difficulty in accessing biopesticides (90%), and perceived high cost (70%). These findings are remarkably consistent with Parwada *et al.,* (2025) who studied assessment of biopesticide adoption in vegetable production among smallholder farmers in Zimbabwe Zimbabwe, where a study of 250 smallholder vegetable farmers found that inadequate awareness (65%), unaffordable prices (48%), and inadequate extension support (56%) were the primary obstacles.

Regression analysis from the Zimbabwe study revealed that access to training ($OR = 3.2$, $p < .01$), market incentives ($OR = 2.5$, $p < .05$), and the level of education of farmers ($OR = 1.8$, $p < .05$) significantly influenced adoption. The study concluded that limited farmer knowledge, financial constraints, and ineffective institutional support remain the primary barriers to wider adoption. These findings underscore that the undervaluation of biopesticides is institutionally mediated: where extension services are weak, information is scarce, and markets fail to signal the value of sustainable alternatives, biopesticides are systematically undervalued.

In Uganda, a study examining risk perceptions of pesticides among 584 men, women, youth, and non-youth farmers across five regions identified affordability, limited availability, inadequate advisory services, and insufficient promotion of biopesticides as safer alternatives as key barriers (Mayamba et al., 2025). The gendered dimensions of these barriers were also explored, with structural barriers to sustainable pest management identified along gendered lines. In Ethiopia, a Knowledge, Attitude and Practice (KAP) study among 150 smallholder farmers in the Chole district found that all farmers used chemical pesticides and/or inorganic fertilisers to protect crops, improve yields, and comply with government regulations, suggesting that policy frameworks themselves may inadvertently perpetuate the undervaluation of biological alternatives (Mulugeta et al., 2024).

The regulatory environment constitutes another critical barrier documented in the empirical literature. A review of biopesticide regulatory frameworks in six Southern African nations which are Botswana, Mozambique, South Africa, Tanzania, Zambia, and Zimbabwe by Mawcha et al. (2025) found that regulation of biopesticides by systems initially designed to oversee chemical pesticides creates market entry barriers, primarily by imposing burdensome costs on the industry. In Kenya, while the country has comparatively advanced regulatory mechanisms for biopesticide registration within East Africa, challenges persist related to high registration costs, lengthy approval timelines, limited farmer awareness, and formulation constraints. These regulatory barriers effectively raise the cost of bringing biopesticides to market, reinforcing their undervaluation relative to synthetic alternatives that benefit from established regulatory pathways and economies of scale.

Strategic Positioning and the Path Forward

The empirical literature also points toward strategic interventions that could redress the undervaluation of biopesticides. Masese et al. (2025) recommended advocating for plant-based biopesticides through awareness campaigns highlighting their efficacy and environmental benefits, introducing financial incentives and subsidies to make these alternatives affordable for small-scale farmers, and fostering collaboration between research institutions and agricultural services to ensure ongoing evaluation and promotion of effective biopesticide formulations.

Parwada *et al.*, (2025) similarly recommended reinforcing farmer education programmes, supporting subsidies for biopesticides, and upgrading extension services to promote sustainable pest management in Zimbabwe. Al-Hassan et al. (2010), recommendations included intensifying current initiatives geared at reducing the misuse of chemical pesticides, educating specific target groups, increasing promotion of botanical products such as neem extracts, and wider dissemination of biological control and integrated pest management techniques in Ghana.

At the systemic level, the literature points to the need for harmonised regulatory frameworks across the continent. The review of Southern African regulatory systems identified challenges that could hinder developing a regionally harmonised regulatory system for biopesticides, while other studies have called for improving access to and farmer uptake of biopesticides through evidence-based policy guidance and market linkages, as well as harmonising regulatory and Access and Benefit Sharing

approaches across regions. These recommendations collectively suggest that addressing the undervaluation of biopesticides requires a multi-pronged strategy encompassing information dissemination, institutional strengthening, regulatory reform, and market development.

Synthesis and Research Gaps

Synthesising the empirical evidence, several patterns emerge. First, there is a consistent gap between the demonstrated economic viability of biopesticides and their actual adoption rates across multiple African countries. Second, the undervaluation of biopesticides is not primarily a function of farmer preferences but rather reflects systemic barriers including information asymmetries, limited access, inadequate extension services, and regulatory frameworks designed for chemical pesticides. Third, farmers across diverse contexts demonstrate willingness to pay for biopesticides, suggesting latent demand that current market and institutional arrangements fail to activate. Fourth, the economic valuation of biopesticides in most empirical studies remains confined to private cost-benefit analysis, with limited attention to the ecosystem services, public health benefits, and long-term sustainability dividends that biopesticides confer benefits that, if properly accounted for, would significantly alter their perceived value proposition.

Several research gaps warrant attention. First, there is a paucity of studies that comprehensively value the environmental and public health externalities of biopesticides relative to synthetic alternatives in African contexts. Second, the institutional and political economy dimensions of biopesticide undervaluation remain underexplored, particularly the role of pesticide subsidies, supply chain dynamics, and the political influence of the synthetic pesticide industry. Third, comparative studies across different agro-ecological zones and value chains are needed to understand how the economic valuation of biopesticides varies contextually. Fourth, the strategic positioning of biopesticides within broader agricultural transformation agendas which include climate adaptation, food system resilience, and rural employment which requires further empirical investigation. Addressing these gaps is essential for developing evidence-based strategies to redress the systematic undervaluation of biopesticides and unlock their potential for sustainable agricultural development in Africa.

Valuation of biopesticide as a function of its inputs:

Biopesticide valuation, BV = f(cost of physical inputs and cost of nonphysical inputs)

$BV = f(x_i, y_i)$

Where x_i is the cost of physical inputs which include plant or animal ingredients and other processing assets which are used for the production of the biospesticide product while y_i is the nonophysical inputs (activities) which include time of the research, technicality, logistics,

Valuation of biopesticide as a function of its potency

$$f(x) = [C_{ix} - C_{iy} + (v - u)]\alpha$$

C_{ix} is the total economic loss caused by infestation of targeted pests per area of land (hectare)

C_{iy} is the total economic loss caused by infestation of targeted pests after application of the pesticide per area of land (hectare)

α is the scale of production
(ν-u) these are the other externalities which include environmental benefit, aftermath effects)

CONCLUSION

This paper has undertaken a critical analysis of the economic valuation of biopesticides in African agriculture, interrogating the multifaceted factors that perpetuate their systematic undervaluation despite compelling evidence of their efficacy, cost-effectiveness, and sustainability dividends. The synthesis of empirical evidence from across the continent reveals several salient conclusions that carry significant implications for agricultural policy, investment, and practice.

Empirical record unequivocally demonstrates that biopesticides are economically viable alternatives to synthetic chemical pesticides. Studies from Nigeria, Kenya, Tanzania, Benin, and South Africa consistently show that biopesticides can be more cost-effective than their synthetic counterparts, with lower average costs per application, higher effectiveness rates, and improved farm profitability. The Tanzanian case of weaver ant-based biological control in citrus orchards exemplifies the multidimensional value proposition of biopesticides, yielding reduced costs, increased yields, premium market prices, and documented environmental and public health benefits. These findings directly contradict the persistent assumption that biopesticides are prohibitively expensive for smallholder farmers, underscoring the need to revisit the economic narratives that inform agricultural extension and policy.

This study concluded that the valuation problem confronting biopesticides is not primarily rooted in farmer preferences or inherent economic inferiority. Across multiple country contexts which includes Kenya, Ghana, Burkina Faso, and Benin. Farmers demonstrate significant willingness to pay for biopesticides, with premiums reflecting their recognition of the health, environmental, and productivity benefits these agents confer. Education emerges as a consistent determinant of willingness to pay, suggesting that information asymmetries constitute a primary barrier to accurate valuation. The evidence indicates that farmers do not inherently undervalue biopesticides; rather, their valuation is mediated by information deficits, experiential knowledge gaps, and perceptions of product efficacy that are shaped by inadequate extension services and limited market exposure.

The study also concluded that economic valuation of biopesticides in most empirical studies remains confined to narrow private cost-benefit analysis, with limited attention to the broader societal benefits which include ecosystem services, public health dividends, climate resilience, and biodiversity conservation that are all embedded on biopesticides usage. The South African cost analysis revealing that biopesticides required higher investment than chemical insecticides but remained financially viable underscores the critical distinction between private and societal cost perspectives. From the latter perspective, which incorporates environmental and health externalities, biopesticides are likely to be significantly undervalued. This valuation gap represents not merely an academic oversight but a fundamental impediment to policy formulation and investment decisions that could unlock the continent's considerable biopesticide potential.

Strategic repositioning of biopesticides requires a multi-pronged approach

addressing information dissemination, institutional strengthening, regulatory reform, and market development. The literature consistently points to the need for enhanced farmer education programmes, financial incentives and subsidies, upgraded extension services, and harmonised regulatory frameworks across the continent.

RECOMMENDATIONS

Based on the findings in this study, the following are recommended:

Biopesticide R&D programmes should be structured as interdisciplinary collaborations that integrate agricultural economists, agronomists, entomologists, plant pathologists, and social scientists from the inception stage. This integration serves multiple purposes that collectively enhance the quality and relevance of research outcomes. Standardised protocols for economic assessment of biopesticides should be developed and integrated into R&D processes. These protocols should serve several functions that collectively enhance the quality, consistency, and comparability of economic assessments.

The development of methodologies for valuing the food security benefits of biopesticides represents a critical priority. These methodologies should capture reduced crop losses, improved food availability, and enhanced dietary diversity, as well as the value of increased household food consumption and reduced vulnerability to food insecurity. Such valuation is essential for capturing the full value of biopesticides in smallholder systems where food security is a primary concern.

REFERENCES

Adetonah, S., Coulibaly, O., Nouhoheflin, T., Kooyman, C., and Kpindou, D. (2008). Farmers' Perceptions and Willingness to Pay for Metarhizium-based Biopesticide to Control Cotton Bollworms in Benin (West Africa).

Al-Hassan, R. M., Jatoe, J. B. D., and Egyir, I. S. (2010). Biopesticides in Ghana: Vegetable farmers' perception and willingness to pay. *The IUP Journal of Agricultural Economics*, 7(4), 17–32

Ayedun, B., Okpachu, O. G., Manyong, V., Atehnkeng, J., Akinola, A. A., Abu, G. A., Bandyopadhyay, R., & Abdoulaye, T. (2017). An assessment of willingness to pay by maize and groundnut farmers for aflatoxin biocontrol product in northern Nigeria. *Journal of Food Protection*, *80*(9), 1451-1460.

Azenzem, R., Mrabti, I., Grijja, H., El Issaoui, K., Afechtal, M., and Kassout, J. (2026). Bibliometric analysis of biopesticide research trends in Africa. *Journal of Agriculture and Environment for International Development (JAEID)*.

Constantine, K.L., Kansiime, M.K., Mugambi, I., Nunda, W., Chacha, D., Rware, H., Makale, F., Mulema, J., Lamontagne-Godwin, J., Williams, F., Edgington, S.M., and Day, R.K. (2020). Why don't smallholder farmers in Kenya use more biopesticides? *Pest Management Science, 76*, 3615 - 3625.

Coulibaly, O., Cherry, A.J., Nouhoheflin, T., Aitchédji, C.C., and Al-Hassan, R.M. (2007). Vegetable Producer Perceptions and Willingness to Pay for Biopesticides. *Journal of Vegetable Science, 12*, 27 - 42.

Day, C., Murphy, S.T., Styles, J., Taylor, B.,

Beale, T., Holland, W., Williams, F., Shaw, A., Finegold, C., Oronje, M., Oppong-Mensah, B., Phiri, N., Lowry, A., Finch, E.A., Mahony, J., Wood, S.V., Durocher-Granger, L., Chacha, D., Maczey, N., González-Moreno, P., Thomas, S.E., Beeken, J., Lewis, J., Saldana, G.L., Duah, S., Bundi, M., Wasilwa, L., Amata, R., Musila, R.N., Mutisya, D., Gitonga, C., Kalama, P., Nyasani, J.O., Matimelo, M., Mgomba, H., Gaitu, C., Ocloo, C., Adjei-Mensah, I., Ohene-Mensah, G., Nboyine, J.A., and Susuwele, B. (2024). Forecasting the population development of within-season insect crop pests in sub-Saharan Africa: the Pest Risk Information Service. *Journal of Integrated Pest Management*.

Ferro, E., Wilson, J.P., and Otsuki, T. (2013). The Effect of Product Standards on Agricultural Exports.

George, W. (2025). Economic feasibility of replacing chemical insecticides with weaver ant strategies for citrus pest management in Handeni District, Tanzania. *International Journal of Agricultural Sustainability*.

Malinga, L.N., and Laing, M. (2023). Cost Analysis of Biopesticides and Chemical Insecticides: Implications for Cotton Farmers in South Africa. *Entomology and Applied Science Letters*.

Masese, C. O., Odira, M., Marwa, C., Masese, D., Ponoth, P., and Gikonyo, A. (2025). *Exploring the potential of plant-based biopesticides for sustainable crop protection in Mwea, Kirinyaga County, Kenya*. Scholastic Agriculture.

Mawcha, K. T., Kyampaire, D., Marciale, C., Simiyu-Wafukho, S., Chinyama, C., Babalola, O. O., Kinyanjui, G., and Ndolo, D. (2025). An overview of biopesticide regulatory frameworks in selected countries in Southern Africa. *Frontiers in Sustainable Food Systems*, 9, 1522526

Mayamba, A., Mutuku, B., Ayuya, O. I., Kansiime, M., Bateman, M., Phelps, S., Alokit, C., Owembabazi, L., Aliamo, C., Bundi, M., Ochilo, W., Bitange, N., Lutomia, C. K., Jong, A. O., Alworah, G. O., and Alworah, G. O. (2025). Gendered risk perceptions and structural barriers to sustainable pest management: Evidence from Uganda's tomato value chain. *Frontiers in Sustainable Food Systems*, 9, 1656739.

Midingoyi, S. K., et al. (2019). Do farmers and the environment benefit from adopting integrated pest management practices? Evidence from Kenya. Journal of Agricultural Economics.

Mkenda, P.A., Mwanauta, R.W., Stevenson, P.C., Ndakidemi, P.A., Mtei, K.M., and Belmain, S.R. (2015). Extracts from Field Margin Weeds Provide Economically Viable and Environmentally Benign Pest Control Compared to Synthetic Pesticides. *PLoS ONE, 10*.

Mulugeta, T., Ilomo, M., Mueke, A., Onyango, C., Matsaunyane, L., Kritzinger, Q., and Alexandersson, E. (2024). Smallholder farmers' knowledge, attitudes, and practices

(KAP) regarding agricultural inputs with a focus on agricultural biologicals. *Heliyon*, 10(4), e26719.

Ogbuewu, I. P., et al. (2020). Neem (Azadirachta indica) as a bio-pesticide in poultry and livestock production. Journal of Medicinal Plants Research.

Parwada, C., Gumbo, A., and Matema, E. (2025). Assessment of biopesticide adoption in vegetable production among smallholder farmers in Zimbabwe. *International Journal of Vegetable Science*, 32(1), 41–52.

Pretty, J., and Bharucha, Z. P. (2015). Integrated pest management for sustainable intensification of agriculture in Asia and Africa. Insects.

Sachdev, S., and Singh, R.P. (2016). Current Challenges, Constraints and Future Strategies for Development of Successful Market for Biopesticides.

Sharma, S., et al. (2019). Worldwide pesticide usage and its impacts on ecosystem. SN Applied Sciences.

Sheahan, M., et al. (2017). Human health and pesticide use in sub-Saharan Africa. Agricultural Economics

Tassembédo, B., Ouédraogo, M., Nébié, K., Sinzogan, A., and Toé, P. (2024). Willingness to pay for a new biopesticide to control mango fruit flies. *Agricultural and Resource Economics: International Scientific E-Journal*.

Tomagnankodo, D.L., Dassou, A., Yemadje, P.L., Azonkpin, S., Kpindou, D., Tittonell, P., and Llandres, A.L. (2026). Short-term ecological and economic performance of transitioning from conventional practices to organic pest management in cotton-based cropping systems. *Agriculture, Ecosystems and Environment*.

Viancelli, A., Comelli, C., Nogara, C.M., De Araujo, V., and Michelon, W. (2024). The impact of pesticides: Assessing residue persistence, environmental contamination, and human health risks. Journal of Toxicological Studies.

Wilson, R., El-Mahdi, H., and Ortega, D. (2026). Integrated Pest Management (IPM): Sustainable Strategies For Crop Protection And Environmental Conservation. *Jana Nexus: Journal of Agricultural, Veterinary and Environmental Sciences*.