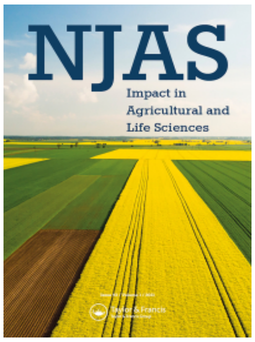


Taylor & Francis
Taylor & Francis Group

NJAS: Impact in Agricultural and Life Sciences

ISSN: 2768-5241 (Online) Journal homepage: www.tandfonline.com/journals/tjls21

Economic and behavioural effects of farmers' adoption of integrated pest management practices in low- and middle-income countries: A systematic review and meta-analysis

Ebenezer Kondo, Freda Elikplim Asem, Yaw Osei-Asare, Akwasi Mensah-Bonsu, Edward Ebo Onumah, Selorm Ofori, Dinah Marri, Francis Dompae & Michael Osae

To cite this article: Ebenezer Kondo, Freda Elikplim Asem, Yaw Osei-Asare, Akwasi Mensah-Bonsu, Edward Ebo Onumah, Selorm Ofori, Dinah Marri, Francis Dompae & Michael Osae (2025) Economic and behavioural effects of farmers' adoption of integrated pest management practices in low- and middle-income countries: A systematic review and meta-analysis, NJAS: Impact in Agricultural and Life Sciences, 97:1, 2534478, DOI: 10.1080/27685241.2025.2534478

To link to this article: https://doi.org/10.1080/27685241.2025.2534478

Published online: 18 Jul 2025.

NJAS: IMPACT IN AGRICULTURAL AND LIFE SCIENCES
2025, VOL. 97, NO. 1, 2534478
https://doi.org/10.1080/27685241.2025.2534478

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

Economic and behavioural effects of farmers' adoption of integrated pest management practices in low- and middle-income countries: A systematic review and meta-analysis

Ebenezer Kondo [a,b], Freda Elikplim Asem [b], Yaw Osei-Asare [b], Akwasi Mensah-Bonsu [b], Edward Ebo Onumah [b], Selorm Ofori [a], Dinah Marri[a], Francis Dompae[c] and Michael Osae [a]

[a]Ghana Atomic Energy Commission (GAEC)-Biotechnology and Nuclear Agriculture Research Institute (BNARI), Accra, Ghana; [b]Department of Agricultural Economics and Agribusiness, University of Ghana. Legon, Accra, Ghana; [c]Institute of Statistical, Social and Economic Research (ISSER), University of Ghana, Accra, Ghana

ABSTRACT

The adoption of integrated pest management practices has been widely promoted in low- and middle-income countries to enhance farmers' economic outcomes. The main challenge is the lack of quantitative synthesis of scholarly works to ascertain whether, for farmers in these countries, those who adopt a single component or a full bundle of integrated pest management practices achieve higher yields, farm income, food security and reduced pesticide use compared to non-adopters. The review followed the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) methodology. A total of 24 studies were used for the review based on strict inclusion and exclusion criteria. Meta-analysis was employed to combine the individual and overall effect sizes across these studies. The results indicate that there is evidence that adopting integrated pest management practices has the potential to lead to a large improvement in crop yield for farmers. The findings also reveal that such adoption causes a small effect in food security level, and a moderate to large effect in farm income for farmers. The evidence further suggests that adopting these practices does not directly lead to behavioural change among farmers in reducing synthetic pesticide use. Overall, the findings demonstrate that adopting integrated pest management practices is a promising strategy for improving farmers' economic outcomes in low- and middle-income countries. Policymakers and development partners should not only focus on IPM programmes for economic improvements for farmers, but also address behavioural barriers to ensure effective and consistent adoption for the desired environmental benefits.

ARTICLE HISTORY
Received 5 March 2025
Revised 27 June 2025
Accepted 10 July 2025

KEYWORD
Integrated pest management practices; farm income; yield; food security; pesticide use

1. Introduction

Agricultural production systems globally and especially low- and middle-income countries (L&MICs) in South Asia, North Africa, Europe, South America and sub-Saharan Africa continue to face unprecedented challenges (FAO, 2017; Giller, 2020). A significant proportion of the rural population in these low- and middle-income countries depends on agriculture as their primary source of income, food and employment. However, pest-related challenges continue to derail their efforts and threaten their already fragile food systems and livelihoods. Improving the effectiveness of IPM adoption can play a crucial role in ensuring food security, rural incomes and resilience in these countries.

Globally, over 2.5 billion people rely on food systems for their livelihoods, and global food demand is projected to increase by 50% in 2025, with sustainable agricultural intensification becoming imperative (FAO, 2023). However, for several decades, farmers in these low- and middle-income countries have heavily resorted to and continue to resort to the use of synthetic pesticides in managing crop pests (Peshin & Dhawan, 2009; Pimentel & Peshin, 2013). The downside is that many of these farmers have limited knowledge on safe usage and inadequate training, leading to the misapplication of these pesticides with little recourse for actual pest infestation levels and in stronger dosages to achieve control effectiveness (Möhring et al., 2020; Wangithi et al., 2021). Chemical pesticide overuse and its consequent harmful effects on human

CONTACT Ebenezer Kondo kondoebenezer@gmail.com

health and the environment have been a recurring concern in agriculture in L&MICs over the past 50 years (Resosudarmo, 2014; Waddington, Aloe, et al., 2014).

The promotion and adoption of integrated pest management (IPM) practices have become an important consideration in the quest to ensure the sustainable production of crops for human consumption (Misango et al., 2022; Nyang'au et al., 2020; Peshin & Dhawan, 2009). Integrated pest management practices developed in many countries consist of a mixture of cultural, biological, mechanical, and/or chemical techniques to control pest populations (Eckstein et al., 2021; Sekabira et al., 2022). The argument has been that IPM is the most economically viable form of crop protection (Cuynoat et al., 2001; Kibira et al., 2010; Morse & Buhler, 1997; Peshin et al., 2007; Pimentel & Peshin, 2013; Singh et al., 2008). The practice promotes sustainable farming through the minimal usage of pesticides, thereby protecting the environment, improving the health of communities as well as conferring resilience on agriculture and food systems (Pimentel & Peshin, 2013).

Integrated pest management practices also minimise the environmental impact of pest control measures, providing environmental and human health benefits (Huang & Li, 2024; Li & Fantke, 2022). It also maximises the prospects for farmers to improve economic return on their crops. Through the farmer-field schools' concept, IPM programmes have been introduced to farmers in the developed and developing world, with farmers being trained on the use of various control technologies (Waddington, Snilstveit, et al., 2014). These IPM components include soil treatment, selection of suitable plant varieties (Priya et al., 2022); crop rotation (Khan et al., 2021); inter-planting or strip cropping (Hassan et al., 2016), choice of planting dates (Rahman et al., 2021), weed control and use of trap plants (pull and push systems). Others include the male annihilation technique (MAT) using pheromone traps or mass trapping, bait application technique, sterile insect technique, burying of fallen fruits, burning of fallen fruits and crop residues, fruit bagging technology, minimally prescribed pesticide application, early harvesting and biological control using parasitoids, predators or insect pathogens (Kibira et al., 2010; Korir et al., 2015; Nyang'au et al., 2020; Rajashekhar et al., 2024).

Most of the studies analysing the effects of adoption of IPM technologies by farmers in L&MICs have applied quasi-experimental approaches using observational data. For instance, Propensity Score Matching (PSM) by Githiomi et al. (2019); regression discontinuity designs by Salazar et al. (2020) and differences-in-differences (Gichungi et al., 2021; Kibira et al., 2015; Nyang'au et al., 2020). Others include the instrumental variable analysis by Fernandez-Cornejo (1996), ex-post facto design using with and without comparison after IPM programme implementation (Sharma et al., 2015), multinomial endogenous switching regression/treatment effects (Ma & Abdulai, 2019; Midingoyi et al., 2019). Other studies have also adopted the discrete and multinomial choice models (Abdollahzadeh et al., 2017; Bonabana-Wabbi et al., 2012; Kabir et al., 2023; Owusu & Abdulai, 2019; Rahman et al., 2021) as well as count data and machine learning approaches (B. Muriithi et al., 2018; Singh et al., 2008; Mulungu et al., 2024; Zakaria et al., 2020). A limited dependent variable approach and mixed methods analysis of the concept have also been done (Bonabana-Wabbi & Taylor, 2008; Borkhani et al., 2013; Norton et al., 2008).

The evidence and synthesis conundrum lies in the fact that despite the extensive promotion and adoption of IPM practices among farmers in L&MICs, the evidence on their effectiveness remains scattered and context-dependent. There is a need to quantitatively synthesise existing studies to ascertain whether among crop farmers in low- and middle-income countries (L&MICs), adopters of integrated pest management practices have higher yield, farm income, food security and reduced pesticide use compared to non-adopters. The objective of this systematic review and meta-analysis is to contribute to the literature by filling the quantitative synthesis gap by examining the effects of adoption of IPM practices on economic and behavioural outcomes of farmers in L&MICs to inform evidence-based decision-making, and to present an almost complete picture of the best available evidence. Additionally, the review addresses a critical gap in the literature on the effectiveness of adoption of IPM practices in low- and middle-income countries.

Following the PICOS (Population, Intervention, Comparison or Control, Outcome and Study) framework for systematic reviews, White et al. (2020), the population considered for the review comprises farmers who cultivate any food crop, tree crop or cash crop in an L&MIC setting. The key intervention involves farmers' adoption of Integrated Pest Management (IPM) practices or technologies for pest management (including insects, diseases) with a clearly defined comparison or control group. To reflect the various definitions of IPM in the literature, the review operationalises IPM adopters as farmers who adopt at least one component or full bundle of an IPM intervention method or tool (treatment) developed to manage crop pests or diseases, or farmers who use synthetic pesticides together with IPM adoption. These definitions are adopted to capture the different components of IPM interventions analysed in the retrieved papers for the review. The economic outcomes of interest include yield, farm income, food security, and a behavioural aspect pertaining to the quantity of pesticide use. These economic outcomes necessitate specific investigation, as they represent the productive, financial, and welfare dimensions of farm households' livelihoods Midingoyi et al., 2019; Pretty & Bharucha, 2015). IPM practices or IPM technologies, though slightly different, have been used interchangeably in studies, for example, Midingoyi et al. (2019), Nyang'au et al. (2020) and B. W. Muriithi et al. (2016), and the approach is adopted throughout the paper. The studies retrieved for the review are studies that employed the quasi-experimental design methodology or the non-randomised controlled trials approach.

Our findings demonstrate that adoption of a component or a full bundle of integrated pest management practices appears to be a promising approach to improving the economic outcomes of farmers in L&MICs. First, the review establishes evidence that adoption of a component or a full bundle of IPM practices has the potential to lead to a large improvement in the yield of farmers in L&MICs. Second, adoption of IPM practices causes a small effect in food security, and a moderate to large effect in the farm income for farmers who adopt such practices in L&MICs. Third, there is evidence that adoption of IPM practices does not directly reduce the quantity of the use of synthetic pesticides by farmers, leading to a sub-optimal desired environmental effect. This finding could be attributed to the easy accessibility of all forms of synthetic pesticides, the initial costs associated with IPM packages and a lack of understanding or awareness of IPM principles, despite its perceived benefits. Additionally, in countries where the prevalence of pest infestations is high, farmers trained in IPM may still use pesticides as a risk mitigation strategy, especially when market or weather-related uncertainties are high.

The rest of the paper is organised as follows: we outline the review protocol and methodology in Section 2, which details the data sources, search strategy, study selection and data extraction process, while Section 3 presents the statistical synthesis approach. In Section 4, we present the results and discussion, while the conclusion and implications for future research are presented in Section 5

2. Materials and methods

2.1. Review protocol and methodology

In the absence of randomised control trials (RCTs), non-randomised control trials or quasi-experimental designs that define treatment and control (comparison) groups based on observational data can be used for systematic reviews and meta-analysis (Harris et al., 2005; Petticrew & Roberts, 2006; Rockers et al., 2015). Results from these studies may represent the best available evidence and should be employed in review analysis where there are no RCTs (Oya et al., 2017). Studying evidence generated from credible quasi-experimental designs can give an estimate of the nature, direction, and size of effects on which future RCTs could be based on while also representing the best evidence in some fields (Barker et al., 2024; Petticrew & Roberts, 2006).

However, the drawback of using quasi-experimental designs or observational studies for meta-analysis is premised on the low certainty of evidence assumption since such designs usually do not confer strong causality as against the high certainty of evidence assumption employed in experimental design studies or RCTs (Rockers et al., 2015). This study, therefore, followed the low certainty of bias assumption since only quasi-experimental studies were used for the review. The low certainty evidence assumption implies a high likelihood that confidence in the estimate of the effect size reported in such studies might be significantly different from the actual effect size.

The review employed the Preferred Reporting Items for Systematic and Meta-Analysis (PRISMA) methodology (Moher et al., 2009; Oya et al., 2017; Page et al., 2021; Pahlevan Sharif et al., 2019; Sekabira et al., 2022). The PRISMA checklist for systematic reviews and meta-analysis includes a checklist of items that must be strictly followed in undertaking the review. Items considered for the review comprised plausible published articles related to the study. The features of interest in these articles include the title of the article, abstract, introduction, methods used, discussion and the reported results. The objective of the PRISMA method of systematic review and meta-analysis is to assist in a complete review of all possible original studies that quantitatively analysed the subject matter, and in particular, reference to low- and middle-income countries.

2.2. Data sources, search strategy and study selection

The gathering of evidence for the study was undertaken through the search of the Scopus database as well as a general internet search. The initial command using the Scopus search engine resulted in 7,173 documents, while other internet sources yielded 78 documents. Screening of the documents was done to only include relevant papers for the study while following strict inclusion and exclusion criteria. The inclusion and exclusion criteria were applied by limiting the document type to only papers found in journals that have reached the final publication stage. This implies that papers that are not journal articles and at the pre-print stage of publication, and articles in the press were all excluded from the study. Only papers within the domain of social science and in the economics subject area, and agriculture, and on integrated pest management conducted in Africa, Asia and South America, which constitute the largest block of countries that fall under the L&MICs bracket were included.

We included only peer-reviewed journal articles, implying that conference papers, working papers, etc. were all excluded from the review. Only papers published in the English Language that addressed adoption of IPM practices or technologies, were accessed for the study. The drawback here is that relevant articles published in languages other than English, which were excluded, could bias the results. The review did not include papers that did not consider the key economic outcomes of interest. Though the review was limited to IPMs, studies dealing with other variants of IPM, such as Integrated Production and Pest Management (IPPM) were included. Additionally, the primary articles for the final review included only quantitative studies that employed quasi-experimental designs using observational data and were published in the last 20 years for which information for comparison groups was available.

The Boolean operators ANDs and ORs were constructed to search for published papers on the subject from the Scopus database. Other papers were also searched using the general internet Google search. The Mendeley Reference Manager was the Bibliographic reference tool to save all downloaded primary articles. The Boolean indicators and command or syntax used for the Scopus search are: *((“adoption AND impacts AND integrated AND pest AND management OR practices OR technologies (LIMIT-TO (SRCTYPE,‘j’)) AND (LIMIT-TO (PUBSTAGE,final’)) AND (LIMIT-TO (SUBJAREA , ‘SOCI’) OR LIMIT-TO (SUBJAREA , ‘ECON’)) AND (LIMIT-TO (DOCTYPE , ‘ar’)) AND (LIMIT-TO (LANGUAGE , ‘English’)) AND (LIMIT-TO (EXACTKEYWORD , ‘Integrated Pest Management’) OR LIMIT-TO (EXACTKEYWORD , ‘Agriculture’) OR LIMIT-TO (EXACTKEYWORD , ‘IPM’) OR LIMIT-TO (EXACTKEYWORD , ‘Africa’) OR LIMIT-TO (EXACTKEYWORD , ‘Asia’ OR LIMIT-TO (EXACTKEYWORD , “South America”))*.

The PRISMA flow diagram displays the databases from which articles were searched for the review and shows the identification and selection criteria employed (Figure 1).

In the study identification stage, 6,050 articles were removed before screening following a rigorous, robust and systematic review of the articles as outlined above. Duplicates found from both the Scopus database and the internet search resulted in 100 studies were duly removed from the study. One Thousand One Hundred and One articles representing 15% of all articles identified were screened based on their titles and abstracts. The authors, titles, abstracts and other features of the Scopus-accessed articles were saved in Excel, and manual screening was done to check their suitability for subsequent selection for inclusion or exclusion. Screened articles were later retrieved and saved in the Mendeley Bibliographic Reference Manager. Two hundred and thirty-two articles, representing 3% of the identified papers, were successfully retrieved and assessed for eligibility for the review. A further 208 articles representing approximately 3% of the papers identified were finally removed from the study based on the inclusion and exclusion criteria stated and their lack of suitability for the review as stated in the PRISMA flow chart. In all, 24 studies representing about 10% of the articles accessed for eligibility were included in the final review (with data extracted from these studies for the review).

The retrieved and analysed articles in the L&MICs that met the strict inclusion and exclusion criteria outlined in the methodology include studies from Kenya (6 studies), India (2 studies), China (1 study), Peru (1 study), Thailand (1 study), Bangladesh (5 studies), Pakistan (1 study), Philippines (1 study), Serbia (1 study), Iran (2 studies), Ghana (1 study) and Uganda (2 studies) constituting 24 studies in all.

LIST OF FIGURES

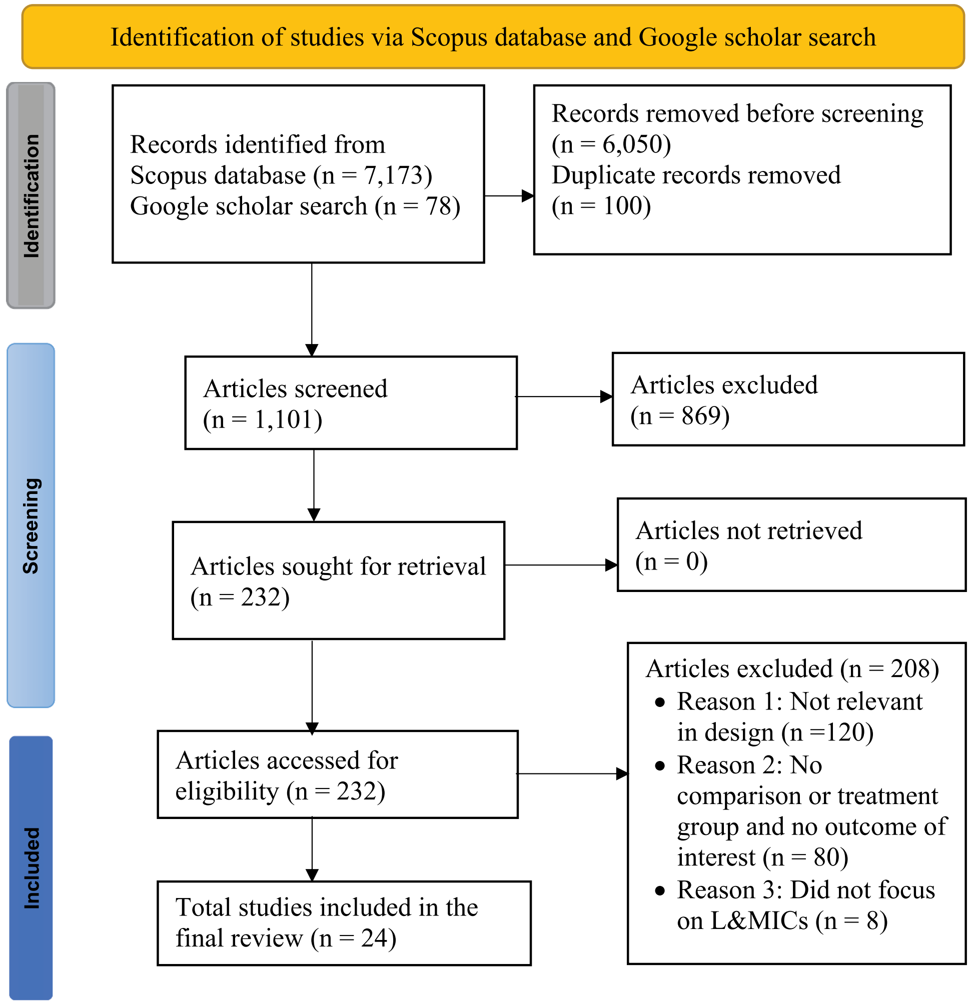


Figure 1. Identification and selection of articles based on PRISMA methodology.

2.3. Data extraction process

Systematic reviews aim to identify all studies that are relevant to the research question and to synthesise data about the design and risk of bias of studies (Litte et al., 2008; Stanley & Doucouliagos, 2012). Results (data) extracted from the included studies were therefore synthesised and critically appraised. Data retrieved from these studies followed the guidelines of the Centre for Reviews and Dissemination (CRD) (2009) and included data on general information of the papers including the name of the author(s), year of publication, country of intervention; and study characteristics including data on study or evaluation design, and unit of allocation. Outcome data/results detailing standard deviation, sample size, treated sample size, control sample size, mean difference, significance level, and p-values (or t-statistic) were also retrieved (see Table 1). Data extracted to determine effect size also included the regression coefficients and regression standard errors. For a thorough and meaningful meta-analysis, only evidence generated from studies that analysed the same outcome at the time points indicated was used for the synthesis (Stanley & Doucouliagos, 2012).

3. Statistical synthesis

The statistical synthesis of the results was carried out using meta-analysis. Meta-analysis is a statistical technique for combining results of independent, but similar, studies to obtain an overall estimate of

Table 1. Description of studies in order of outcome variables analysed.

Publication information	Metadata			
Author(s)/Year	Country of intervention	Evaluation method/study design	Outcome variable	Analysis method
[1] Nyang'au et al. (2020)	Kenya	Difference-in-Differences	Household dietary diversity index (HDDI)	Differences in mean outcomes between participants and non-participants
[2] Midingoyi et al. (2019)	Kenya	Multinomial endogenous switching treatment regression	Mango income	Differences in mean outcomes between adopters and non-adopters
[3] Kibira et al. (2015)	Kenya	Difference-in-Differences (With and without; before and after comparison)	Mango income	Differences in mean outcomes between participants and non-participants
[4] Isoto et al., (2014)	Uganda	Treatment and endogenous selection model	Income from Arabica coffee production	Mean differences between adopters and non-adopters
[5] Githiomi et al. (2019)	Kenya	Propensity score matching	Gross margin (farm income) from avocado, citrus, pawpaw and banana production	Differences in mean outcomes between adopters and non-adopters
[6] Owusu and Abdulai (2019)	Ghana	Two-step Multinomial logit model	Income from vegetable production	Mean differences between adopters and non-adopters
[7] Chepchirchir et al. (2017)	Uganda	Generalised propensity score matching	Income from maize production	Differences in mean outcome between adopters and non-adopters
[8] Gichungi et al. (2021)	Kenya	Difference-in-Differences (With and without; before and after comparison)	Pesticide use in mango production	Differences in mean outcomes between participants and non-participants
[9] Abdollahzadeh et al. (2017)	Iran	Multinomial logistic regression model	Pesticide use in rice production	Mean difference between adopters and non-adopters
[10] Allahyari et al. (2016)	Iran	Multinomial endogenous switching regression	Pesticide use in olive production	Mean differences between adopters and non-adopters
[11]Josue-Canacan (2022)	Philippines	Multinomial endogenous switching regression	Pesticide use in rice and corn production	Mean differences between adopters and non-adopters
[12] Khan and Damalas (2015)	Pakistan	Multinomial endogenous switching regression	Pesticide use in cotton production	Mean differences between adopters and non-adopters
Publication information	**Metadata**			
Author(s)/Year	**Country of intervention**	**Evaluation method/study design**	**Outcome variable**	**Analysis method**
[13] Despotović et al. (2019)	Serbia	Mixed methods-structural equation models	Pesticide use in wheat-maize-sugar beet-sunflower-soya productions	Mean differences between adopters and non-adopters
[14] Kabir et al. (2022)	Bangladesh	Multinomial endogenous switching regression	Pesticide use in vegetable production	Differences in mean between adopters and non-adopters
[15] Kabir et al. (2023)	Bangladesh	Multinomial logistic regression	Pesticide use in vegetable production	Mean differences between adopters and non-adopters
[16] Rahman et al. (2018)	Bangladesh	Propensity score matching	Pesticide use in vegetable production	Mean differences between treated and control groups
[17] Sharma et al. (2015)	India	Ex-post factor design. (Using a pre-existing condition as treatment)	Pesticide use in vegetable production	Differences in mean outcomes between treated and control groups
[18] Salazar et al. (2020)	Peru	Regression discontinuity design	Mango yield (total output)	Differences in mean outcomes between treated and control groups
[19] Ma and Abdulai (2019)	China	Endogenous switching probit model regression	Apple yield	Differences in mean outcomes between adopters and non-adopters

(*Continued*)

Table 1. (Continued).

Publication information	Metadata			
Author(s)/Year	Country of intervention	Evaluation method/study design	Outcome variable	Analysis method
[20] Peshin et al. (2009)	India	With treatment and without treatment analysis. (One-group before and after comparison design)	Cotton yield	Differences in mean outcomes between participants and non-participants
[21] Timprasert et al. (2014)	Thailand	Heckman sample selection model	Vegetable yield	Mean differences between adopters and non-adopters
[22] Midingoyi et al. (2024)	Kenya	Control function (Dose-response function)	Maize yield	Mean differences between adopters and non-adopters
[23] Rahman and Norton (2019)	Bangladesh	Inverse probability weighted regression adjustment	Bitter-gourd yield	Differences in mean outcomes between adopters and non-adopters
[24] Fuad et al. (2019)	Bangladesh	Propensity score matching	Vegetable yield	Mean differences between adopters and non-adopters

Source: Authors' compilation.

treatment effect (Dettori et al., 2021; Glass, 1976; Margaliot & Chung, 2007; Nyaga & Arbyn, 2022; Palmer & Sterne, 2016). The main components of meta-analysis include effect sizes, forest plots, funnel plots, heterogeneity and publication bias. In meta-analysis of binary outcomes, odds ratios and risk ratios are the commonly reported effect size measures, but for continuous outcomes, Hedges's adjusted *g* and Cohen's *d* are the commonly reported effect size measures (Çoğaltay & Karadağ, 2015; Hedges, 1982; Litte et al., 2008; Stanley & Doucouliagos, 2012). In this study, Hedges's *g* is the reported effect size measure due to the continuous nature of the outcome variables. The three common models for meta-analysis are the common-effect, fixed-effects and random-effects models. This current synthesis employs a random-effect model, which assumes that the true effect of treatment estimate for each study varies (Hunter & Schmidt, 2004; Moore et al., 2020; Vaessen et al., 2013).

For a general model

$$\hat{\theta}_j = \theta_j + \varepsilon_j j = 1, 2, \ldots, K \tag{1}$$

Where $\varepsilon_j's$ are sampling errors and $\varepsilon_j \sim N\left(0, \sigma_j^2\right)$, although the $\sigma_j^2 s$ are unknown, meta-analysis does not estimate them. It treats the estimated values, $\sigma_j^2 s$ of these variances as unknown and uses them during the estimation. A random effects model assumes that the study effect sizes in Equation (1) are different, that is, $\theta_j \neq \theta_j{}'$ for$j \neq j'$, but that they are random. The population parameter on which the sample studies were used can therefore be expressed as

$$\hat{\theta}_{pop} = \frac{\sum_{j=1}^{K} w_j \hat{\theta}_j}{\sum_{j=1}^{K} w_j} \tag{2}$$

The random effects model assumes that the study effect sizes are different and that the collected studies represent a random sample from the larger population of studies and can thus be described as follows (DerSimonian & Laird, 1986; Hedges, 1982).

$$\hat{\theta}_j = \theta_j + \varepsilon_j = \theta + u_j + \varepsilon_j \tag{3}$$

Where $u_j(0, \tau^2)$, and as indicated before $\varepsilon_j \sim N\left(0, \sigma_j^2\right)$.The parameter τ^2 represents the between-study variability and is often referred to as the heterogeneity parameter. It estimates the variability among the studies beyond the sampling variability. When $\tau^2 = 0$, the random effects model reduces to the common-effect model. Where there is excess variability (heterogeneity) between study results, random-effects models typically produce more conservative estimates of the significance of the treatment effect than fixed-effects models. The random-effects models also give higher weights to smaller studies and lower weights to larger studies than fixed-effects analysis. We employ the maximum likelihood estimation method for the analysis.

4. Results and discussion

This section reports the results of the review. The outcome variables identified in the studies include yield, farm income (net farm returns), pesticide use, health, environment, food security (per capita calorie consumption, household dietary diversity index), farmer knowledge and attitudes. However, the analysis was limited to yield, farm income, food security and pesticide use outcomes. Table 1 shows the description of studies from which the data for the study were generated.

As earlier indicated, the studies retrieved for the analysis include Kenya (6 studies), India (2 studies), China (1 study), Peru (1 study), Thailand (1 study), Bangladesh (5 studies), Pakistan (1 study), Philippines (1 study), Serbia (1 study), Iran (2 studies), Ghana (1 study) and Uganda (2 studies) constituting 24 studies in all. Most of the studies from Kenya that addressed the objective were heavily focused on the adoption of IPM practices or technologies in mango production. The studies from India evaluated the impact of adoption of IPM among vegetable and cotton farmers, while the study from China evaluated the impact of the adoption of IPM among apple farmers. The study from Peru evaluated the impact of a fruit-fly eradication programme among agricultural fruit producers. The study from Serbia assessed the adoption of IPM practices among wheat farmers; Bangladesh on bitter gourd and vegetable growers; Pakistan, Thailand, and Iran on cotton, vegetable, and rice growers, respectively. The Ghana study examined the impact of adoption of IPM technologies among vegetable farmers.

4.1. Descriptive statistics of variables

Prior to the statistical analysis, the dataset was set or declared in a meta-analysis format in STATA. The descriptive statistics of the results are presented in Table 2. The total number of observations is 24. The minimum (oldest) year of an included paper based on the inclusion criteria is 2009, and the maximum (newest) year of an identified paper is 2024. The descriptive statistics for the other variables, including the system and moderating variables, are displayed.

4.2. Effects of adoption of IPM practices on farmers' economic outcomes

The effect size measured individual study outcomes between the intervention (treatment/adoption) group and the control (comparison/non-adoption) group. The meta-analysis summary also includes

Table 2. Descriptive statistics of variables, including system variables and moderators.

Variable	Observation	Mean	Std. Dev.	Min	Max
Year of publication	24	2018.17	3.41	2009.00	2024.00
Treated mean	24	218.38	239.36	33.50	990.42
Treated standard deviation	24	96.69	83.50	11.61	365.63
Treated sample	24	197.21	111.38	64.00	455.00
Control mean	24	169.37	188.19	5.63	644.11
Control standard deviation	24	132.54	195.27	2.09	871.29
Control sample	24	166.88	93.40	50.00	403.00
Author	24	12.50	7.07	1.00	24.00
Country	24	5.54	3.50	1.00	12.00
Outcome	24	3.08	0.88	1.00	4.00
Yield	24	0.38	0.49	0.00	1.00
Income	24	0.25	0.44	0.00	1.00
Pesticide use	24	0.38	0.49	0.00	1.00
Food security	24	0.04	0.20	0.00	1.00
Crops	24	7.46	3.27	1.00	12.00
Study design	24	1.13	0.45	1.00	3.00
Intervention	24	11.88	6.66	1.00	23.00
Meta identifier	24	12.50	7.07	1.00	24.00
Meta effect size	24	1.17	2.37	−2.93	7.77
Meta standard error	24	0.15	0.07	0.08	0.41
Meta confidence interval (lower)	24	0.88	2.29	−3.24	6.97
Meta confidence interval (upper)	24	1.46	2.46	−2.62	8.57
Meta study size	24	364.08	161.23	132.00	655.00
Meta weight	24	0.18	0.00	0.18	0.18

Source: Authors' computation.

Table 3. Intervention outcome by subgroup meta-analysis.

Study	Hedges's g	[95% conf. interval]		% weight
Group: Food security				4.18
Nyang'au et al. (2020)	0.118	−0.109	0.344	
theta	0.118	−0.109	0.344	
Group: Farm income				
Midingoyi et al. (2019)	1.324	1.108	1.541	4.18
Kibira et al. (2015)	−0.786	−1.074	−0.497	4.17
Isoto et al (,2014)	2.236	1.899	2.574	4.16
Githiomi et al. (2019)	−2.932	−3.241	−2.623	4.17
Owusu and Abdulai (2019)	1.284	0.911	1.657	4.16
Chepchirchir et al. (2017)	2.710	2.468	2.952	4.17
theta	0.640	−0.910	2.190	
Group: Pesticide use				
Gichungi et al. (2021)	2.504	2.197	2.811	4.17
Abdollahzadeh et al. (2017)	−1.659	−1.918	−1.400	4.17
Allahyari et al. (2016)	1.100	0.821	1.378	4.17
Josue-Canacan (2022)	−0.602	−0.850	−0.355	4.17
Khan and Damalas (2015)	0.603	0.389	0.817	4.18
Despotović et al. (2019)	0.081	−0.085	0.247	4.18
Kabir et al. (2022)	−1.023	−1.303	−0.744	4.17
Kabir et al. (2023)	−0.192	−0.366	−0.017	4.18
Rahman et al. (2018)	6.510	6.119	6.901	4.16
Sharma et al. (2015)	−0.102	−0.435	0.231	4.16
theta	0.719	−0.652	2.090	
Group: Yield				
Salazar et al. (2020)	0.659	0.486	0.832	4.18
Ma and Abdulai (2019)	3.872	3.548	4.196	4.17
Peshin et al. (2009)	7.766	6.966	8.567	4.06
Timprasert et al. (2014)	0.302	0.066	0.537	4.18
Midingoyi et al. (2024)	0.673	0.508	0.837	4.18
Rahman and Norton (2019)	2.153	1.800	2.506	4.16
Fuad et al. (2019)	1.420	1.178	1.662	4.17
theta	2.386	0.587	4.185	
Overall				
theta	1.159	0.237	2.080	

Heterogeneity summary

Group	*df*	*Q*	*P > Q*	*tau*^{2}	*%I*^{2}	*H*^{2}
Food security	0	0.00		0.000		
Farm income	5	1013.43	0.000	3.728	99.44	179.03
Pesticide use	9	1602.48	0.000	4.876	99.68	315.74
Crop yield	6	682.90	0.000	5.861	99.73	370.80
Overall	**23**	**3550.25**	**0.000**	**5.281**	**99.70**	**329.82**

Test of group differences: Q_b = $\chi^2(3) = 7.00$ Prob > Q_b = 0.072.
Source: Authors' computation.

heterogeneity analysis, individual and overall effect sizes (Table 3). The overall effect size indicated by θ is 1.159 with a 95% CI of [0.237–2.080]. The corresponding test of significance of $H_0 : \theta = 0$; $(p < 0.1)$, which is statistically significantly different from zero. The homogeneity test that indicates the presence of between-study heterogeneity further shows a Q-test statistic of 3550.25 with a $(p < 0.1)$, indicating a significant heterogeneity among the individual studies (see Appendix 1 for further confirmation). The intervention outcome by subgroup analysis also reveals interesting findings.

The results indicate that all four outcomes respond positively to farmers' adoption of a component or a full bundle of IPM practices. In other words, the outcome variables increase with farmers' adoption of IPM practices. Specifically, the results from the subgroup meta-analysis indicate that the individual effect sizes for three outcomes: food security, farm income and pesticide use, are 0.118, 0.640 and 0.719, respectively. Following Cohen's (1988) effect size benchmarks, these findings indicate only small to medium positive effects generated in these outcomes through the adoption of IPM practices among farmers. Small effect in the food security outcome and a moderate to large effect in the farm income and pesticide use outcomes. These findings imply there is room to ramp up the promotion and adoption of specific and relevant IPM practices among farmers in L&MICs to generate a large effect on these outcome variables (especially for food security and farm income). This may also call for the development of tailor-made IPM packages that suit the conditions of L&MICs to make adoption more impactful.

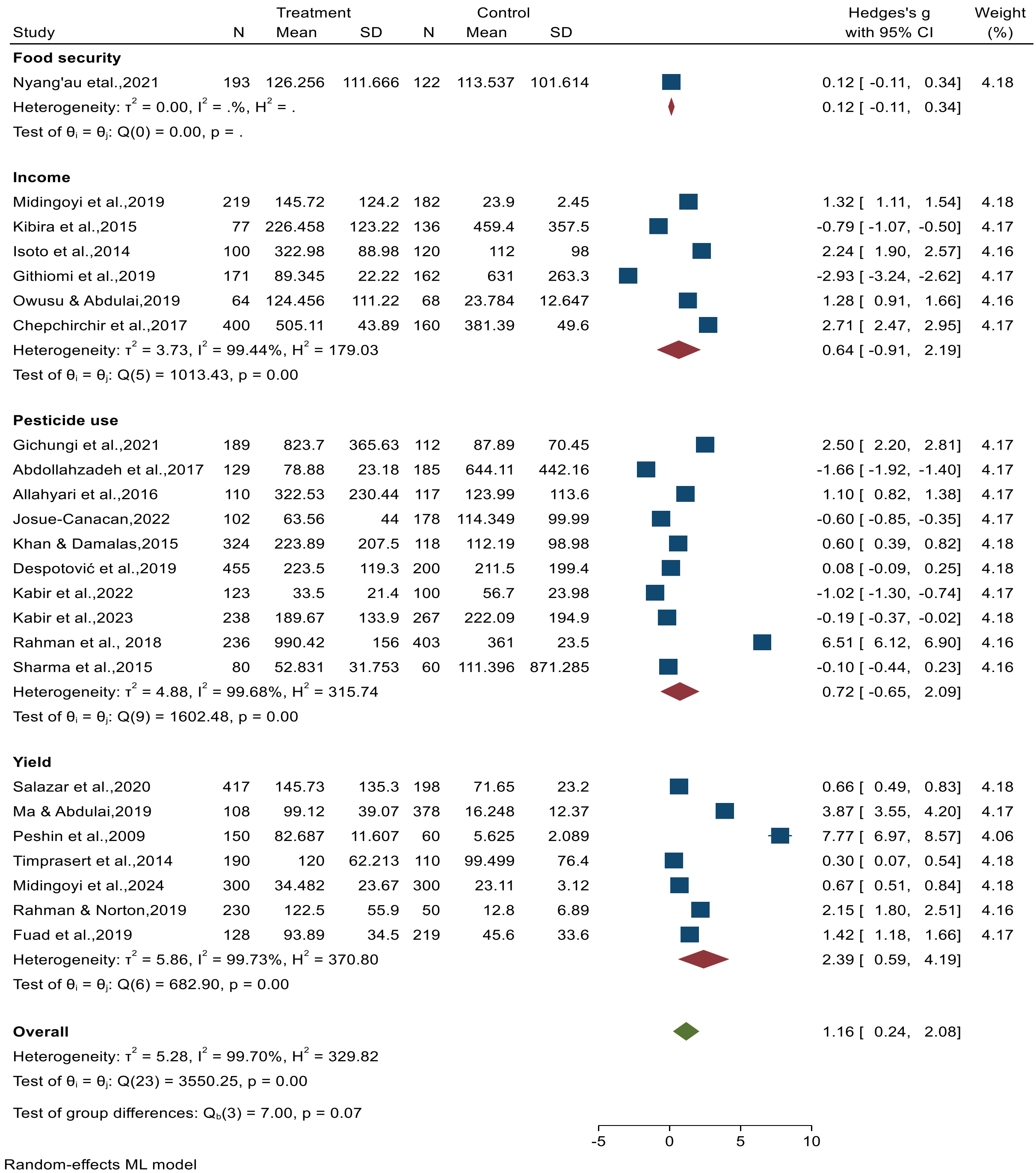


Figure 2. Forest plot with bars showing the effect sizes in outcomes between treated (adopters) and control (non-adopters).

The findings also imply that farmers may not be deriving the optimal benefit from the adoption of existing IPM practices, thereby requiring IPM policy interventions that focus on training farmers in these practices. Furthermore, the findings suggest that there is a high level of ineffectiveness in adopting existing IPM practices in L&MICs, particularly in terms of improving food security and farm income. However, with respect to yield, the finding shows an individual effect size of 2.386, indicating a large effect in this outcome. This finding suggests that there is a significant improvement in agricultural yield when farmers in L&MICs adopt IPM practices. To further visually explore the study-specific effect sizes and to demonstrate how close they are to the overall effect size, a forest plot is presented as shown in Figure 2. The individual study effect sizes, as well as the pooled effect size, measure the average number of standard deviation changes in the respective economic outcomes of treated groups over control groups. The 95% confidence interval indicates the likely range of effect sizes across different studies and also represents the chance that the true effect in the population will lie within the range estimated (Dettori et al., 2021; Stewart et al., 2016).

The red diamond below the studies represents the individual effect, while the green diamond represents the overall pooled effect for the included studies with the width of the diamond showing the confidence interval for the individual or overall effect. As earlier indicated, the presence of between-study heterogeneity is evident in the different outcomes analysed. The implication, therefore, is that in L&MICs, there is a high level of variability (heterogeneity) in studies assessing the effect of adoption of IPM practices on producer outcomes when different outcomes are considered. To account for the likely cause(s) of these between-study heterogeneities, a meta-regression using the maximum likelihood approach was estimated using moderators (see Appendix 2).

Three moderators (sample size, crop type, and country of study), which could be potential sources of between-study variance, were controlled for. The analysis reveals that 7% of the between-study variance is explained by the three covariates used as moderators. The I^2_{ml} statistic from the meta-regression output indicates that approximately 99% of the residual variation in the studies is due to heterogeneity, which may be explained by other covariates, with the null hypothesis of no residual heterogeneity rejected (see Appendix 2). An alternative presentation of the forest plot using the Standardised Mean Difference (SMD) as the measure of effect size is presented in Appendix 3.

4.3. Effect of adoption of IPM practices on food security

Only one study investigated the effects of participation in IPM programmes on the food security of farming households in L&MIC. Nyang'au et al. (2020) in their study in Kenya reported that the adoption of IPM technology had no significant effect on household dietary diversity index (HDDI) in comparison to non-adoption. The meta-analysis revealed a similar finding. The effect size indicated that the intervention results in a small effect on the food security outcome. Hence, evidence of the finding indicates that IPM intervention causes a small increase in the household dietary diversity index. In a related study, in improving food security using four pathways of production, value chains, market reforms and land tenure, Bodnár et al. (2011), established clear evidence between agricultural production and food availability which in turn ensures households' dietary diversity.

4.4. Effect of adoption of IPM practices on farm income

The review examined six studies that analysed the effect of adopting IPM practices on farm income, which for all the reviewed studies was measured in the currencies of the study countries. The results reveal that adoption of a component or a full bundle of IPM practices was found to have a positive and significant effect on household farm income. The joint pooled effect from the meta-analysis also reveals a medium effect of the intervention on the outcome for adopters as compared to non-adopters. This evidence suggests that adoption of IPM practices causes a slight or moderate increase in farm income. The moderate positive effect on farm income compared to the large positive effect on yield could be due to the high levels of postharvest loss and lack of market access to farmers since postharvest loss is very high in L&MICs (Jarman et al., 2023; Karoney et al., 2024; Kumar & Kalita, 2017). The lack of market access due to poor roads and trade restrictions, linked to the blanket application of policies on harmful organisms and pesticide residues, could be contributing to the small positive effects on farm income.

4.5. Effect of adoption of IPM practices on pesticide use

Ten studies investigated the effects of adopting IPM technologies on pesticide use and pest treatment decision-making (e.g. Githiomi et al., 2019; Sharma et al., 2015). The meta-analysis of the evidence from the included studies produced a moderate to large effect of adopting IPM interventions on the quantity of pesticide use. This finding implies that the adoption of IPM technologies does not directly translate into reduced pesticide use among farmers in L&MICs, as they continue to use pesticides in pest management. Typically, since IPM interventions are designed to reduce synthetic pesticide use among farmers, the increase in pesticide application use may be due to enhanced precision or better targeting under IPM practices.

Furthermore, this finding may be attributed to the ready availability of synthetic pesticides, the initial costs associated with IPM packages, and a lack of understanding or awareness of IPM principles, despite the perceived benefits of IPM. Additionally, in countries where pest infestations are prevalent, farmers trained in IPM may continue to use pesticides as a risk mitigation strategy, particularly when faced with market or weather-related uncertainties.

4.6. Effect of adoption of IPM practices on yield

The review investigated seven studies that analysed the effects of adoption of IPM practices on agricultural crop yield. Yield was either measured in kilograms per acre or fruits per tree (Gichungi et al., 2021; Ma & Abdulai, 2019; Peshin et al., 2009; Salazar et al., 2020). The findings from the reviewed studies all indicate that adopting IPM practices results in an increased level in yield for adopters compared to non-adopters. With the low certainty of evidence assumption underpinning quasi-experimental evaluation studies, the meta-analysis findings show that with respect to the yield outcome, adoption of IPM practices leads to a large effect. Based on the estimated joint pooled effect estimates, the evidence suggests that the IPM intervention results in a large increase in crop yield. However, we generalise this evidence with caution due to the low certainty of evidence assumption as indicated.

5. Conclusions, policy recommendations and limitations of the review

The objective of this systematic review and meta-analysis was to examine the economic and behavioural effects of adopting integrated pest management practices in low- and middle-income countries. Considering quasi-experimental studies and employing quantitative synthesis to 24 articles retrieved based on strict inclusion and exclusion criteria under the PRISMA methodology, it explored the hypothesis that IPM adopters have significantly higher yield, farm income, food security and reduced pesticide use compared to non-adopters. In particular, this systematic review establishes that there is evidence that adoption of integrated pest management practices has the potential to lead to a large improvement in the yield of farmers in L&MICs. This finding calls for the prioritisation and targeted scaling and promotion of IPM practices under local biotic and abiotic stress conditions.

The findings highlighted that adoption of integrated pest management practices causes a small increase in the food security outcome and a moderate to large effect in farm income for farmers. Policy-wise, low- and middle-income countries could leverage these findings to ensure unhindered market access for IPM-cultivated crops, which may command premium prices to boost farmers' income and ensure food security. Furthermore, IPM could be incorporated into nutrition-sensitive agricultural policies and climate-resilient agriculture to promote steady food crop production and safer environments. We also recommend the deliberate promotion of IPM in areas with high food insecurity and frequent pest-related crop losses within these countries.

With the findings showing no evidence of the desired behavioural change of reduction in pesticide use among adopters of integrated pest management practices, policymakers and development partners in low – and middle-income countries should not only target IPM programmes to improve farmers' economic outcomes, but that such programmes must also crucially address behavioural barriers to effective and consistent adoption to achieve the optimally desired environmental outcomes.

Interpreting the positive meta-analysis results for certain outcomes as definitive evidence regarding the effects of adopting IPM practices on farmers' economic outcomes in low- and middle-income countries should be approached with caution. The reliance on purely quasi-experimental studies, which do not establish strong causality, the limited number of studies included in the primary articles for the review, and the significant level of heterogeneity in the outcomes should be taken into account in this context. Lastly, the study's exclusive focus on low- and middle-income countries, without comparison to high-income countries, represents a limitation that should be addressed in any future review.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Ebenezer Kondo http://orcid.org/0000-0001-5525-6984
Freda Elikplim Asem http://orcid.org/0000-0003-0331-2256
Yaw Osei-Asare http://orcid.org/0009-0000-3635-8061
Akwasi Mensah-Bonsu http://orcid.org/0000-0002-7109-2868
Edward Ebo Onumah http://orcid.org/0000-0001-7307-1270
Selorm Ofori http://orcid.org/0000-0001-5986-7977
Michael Osae http://orcid.org/0000-0002-6465-5036

Data availability statement

The datasets used for the study can be made available upon reasonable request from the first author.

Use of AI language tools

The authors used Grammarly Pro to improve grammar and phrasing. All AI-assisted edits were reviewed and verified before inclusion in the manuscript. Aside from these language improvements, no AI-generated content was used.

References

Abdollahzadeh, G., Damalas, C. A., & Sharifzadeh, M. S. (2017). Understanding adoption, non-adoption, and discontinuance of biological control in rice fields of northern Iran. *Crop Protection*, *93*, 60–68. https://doi.org/10.1016/j.cropro.2016.11.014

Allahyari, M. S., Damalas, C. A., & Ebadattalab, M. (2016). Determinants of integrated pest management adoption for olive fruit fly (bactrocera oleae) in Roudbar, Iran. *Crop Protection*, *84*, 113–120. https://doi.org/10.1016/j.cropro.2016.03.002

Barker, T. H., Habibi, N., Aromataris, E., Stone, J. C., Leonardi-Bee, J., Sears, K., Hasanoff, S., Klugar, M., Tufanaru, C., Moola, S., & Munn, Z. (2024). The revised JBI critical appraisal tool for the assessment of risk of bias for quasi-experimental studies. *JBI Evidence Synthesis*, *22*(3), 378–388. https://doi.org/10.11124/JBIES-23-00268

Bodnár, F., de Steenhuijsen Piters, B., & Kranen, J. (2011). Improving food security: A systematic review of the impact of interventions in agricultural production, value chains, market regulation and land security (pp. 1–188). Ministry of Foreign Affairs.

Bonabana-Wabbi, J., & Taylor, D. B. (2008). Health and environmental benefits of reduced pesticide use in Uganda. *Research Papers in Economics*, *0401*, 0–33. https://ageconsearch.umn.edu/record/6441

Bonabana-Wabbi, J., Taylor, D. B., & Kasenge, V. (2012). A limited dependent variable analysis of integrated pest management adoption in Uganda. *Journal of Agricultural Science and Technology A*, *2*(June), 1162–1174.

Borkhani, F. R., Rezvanfar, A., Fami, H. S., & Pouratashi, M. (2013). Social factors influencing adoption of integrated pest management (IPM) technologies by Paddy Farmers. *International Journal of Agricultural Management and Development*, *3*(3), 211–218.

Chepchirchir, R. T., Macharia, I., Murage, A. W., Midega, C. A. O., & Khan, Z. R. (2017). Impact assessment of push-pull pest management on incomes, productivity and poverty among smallholder households in Eastern Uganda. *Food Security*, *9*(6), 1359–1372. https://doi.org/10.1007/s12571-017-0730-y

Çoğaltay, N., & Karadağ, E. (2015). Introduction to meta-analysis. https://doi.org/10.1007/978-3-319-14908-0_2

Cohen, J. (1988). *Statistical Power analysis for the behavioural sciences* (2nd ed.). Lawrence Erlbaum Associates, United States of America.

CRD. (2009). *Systematic reviews: CRD's guidance for undertaking reviews in health care*. CRD, University of York. www.yps-publishing.co.uk

Cuynoat, L. C. M., George, W. N., & Rolac, A. (2001). Economic analysis of environmental benefits of integrated pest management: A Philippine case study. *Agricultural Economics*, *25*, 227–233.

DerSimonian, R., & Laird, N. (1986). Meta-analysis in clinical trials. *Controlled Clinical Trials*, *7*(3), 177–188. https://doi.org/10.1016/0197-2456(86)90046-2

Despotović, J., Rodić, V., & Caracciolo, F. (2019). Factors affecting farmers' adoption of integrated pest management in Serbia: An application of the theory of planned behavior. *Journal of Cleaner Production*, *228*, 1196–1205. https://doi.org/10.1016/j.jclepro.2019.04.149

Dettori, J. R., Norvell, D. C., & Chapman, J. R. (2021). Seeing the forest by looking at the trees: How to interpret a meta-analysis forest plot. *Global Spine Journal*, *11*(4), 614–616. https://doi.org/10.1177/21925682211003889

Eckstein, Z., Ansah, I. G. K., Oduro, H., Osae, A. L., Huang, C. J., Huang, T. H., Liu, N. H., LaFrance, J., Pope, R., Tack, J., Ng'ombe, J. N., Function, P., Functions, H., Progress, T., Us, L., Up, S., Asante, B. O., Villano, R. A., Battese, G. E., & Ma, X.

(2021). Agricultural Policy Analysis. *Enhancing Smallholder Farmers' Access to Seed of Improved Legume Varieties Through multi-Stakeholder Platforms*, *6*(3), 1080–1087. https://doi.org/10.1016/j.landusepol.2021.105488

FAO. (2017). *The state of food and agriculture 2021. Leveraging food systems for inclusive rural transformation*. The State of Agriculture Food.

FAO. (2023). *The state of food security and nutrition in the world: Urbanisation, agrifood systems transformation and healthy diets across the rural-urban continuum*. https://doi.org/10.1016/S2213-8587(22)00220-0

Fernandez-Cornejo, J. (1996). The microeconomic impact of IPM adoption: Theory and application. *Agricultural and Resource Economics Review*, *25*(2), 149–160. https://doi.org/10.1017/s1068280500007814

Fuad, M. A. F., Nurhasan, M., & Kayess, M. O. (2019). Impact of integrated Pest management (IPM) practices on tomato cultivation in Gazipur District of Bangladesh. *Advances in Entomology*, *07*(02), 33–46. https://doi.org/10.4236/ae.2019.72004

Gichungi, H., Muriithi, B., Irungu, P., Diiro, G., & Busienei, J. (2021). Effect of technological innovation on gender roles: The case of fruit fly IPM adoption on Women's decision-making in mango production and marketing in Kenya. *The European Journal of Development Research*, *33*(3), 407–426. https://doi.org/10.1057/s41287-020-00282-z

Giller, K. E. (2020). The food security conundrum of sub-saharan Africa. *Global Food Security*, *26*(August), 100431. https://doi.org/10.1016/j.gfs.2020.100431

Githiomi, C., Muriithi, B., Irungu, P., Mwungu, C. M., Diiro, G., Affognon, H., Mburu, J., & Ekesi, S. (2019). Economic analysis of spillover effects of an integrated pest management (IPM) strategy for suppression of mango fruit fly in Kenya. *Food Policy*, *84*, 121–132. https://doi.org/10.1016/j.foodpol.2019.03.006

Glass, G. V. (1976). Primary, secondary, and meta-analysis of research. *Educational Researcher*, *5*(10), 3. https://doi.org/10.3102/0013189X005010003

Harris, A. D., Lautenbach, E., Perencevich, E., & Perencevich, E. (2005). A systematic review of quasi-experimental study designs in the fields of infection control and antibiotic resistance. *Clinical Infectious Diseases*, *41*(1), 77–82. https://doi.org/10.1086/430713

Hassan, M. B., Baiyegunhi, L. J. S., Ortmann, G. F., & Abdoulaye, T. (2016). Adoption of striga (striga hermonthica) management technologies in Northern Nigeria. *Agricultural Economics Research, Policy and Practice in Southern Africa*, *55*(1–2), 168–188. https://doi.org/10.1080/03031853.2016.1159587

Hedges, L. V. (1982). Estimation of effect size from a series of independent experiments. *Psychological Bulletin*, *92*(2), 490–499. https://doi.org/10.1037/0033-2909.92.2.490

Huang, Y., & Li, Z. (2024). Assessing pesticides in the atmosphere: A global study on pollution, human health effects, monitoring network and regulatory performance. *Environment International*, *187*(January), 108653. https://doi.org/10.1016/j.envint.2024.108653

Hunter, J. E., & Schmidt, F. L. (2004). *Methods of meta-analysis: Correcting error and bias in research findings* (2nd ed.). SAGE Publications Ltd.

Isoto, R. E., Kraybill, D. S., & Erbaugh, M. J. (2014). Impact of integrated pest management technologies on farm revenues of rural households: The case of smallholder arabica coffee farmers. *African Journal of Agricultural and Resource Economics*, *9*(2), 119–131.

Jarman, A., Thompson, J., McGuire, E., Reid, M., Rubsam, S., Becker, K., & Mitcham, E. (2023). Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. *Postharvest Biology and Technology*, *206* (November 2022), 112491. https://doi.org/10.1016/j.postharvbio.2023.112491

Josue-Canacan, D. R. (2022). Adoption of integrated pest management (IPM) technologies in Southern Philippines: constraints and motivations. *International Journal of Agricultural Technology*, *18*(1), 179–192.

Kabir, M. H., Biswas, S., Rahman, M., Islam, M. S., & Tan, M. L. (2022). Determinants of vegetable growers' knowledge and willingness to adopt botanical pesticides. *International Journal of Pest Management*, 1–10. https://doi.org/10.1080/09670874.2022.2066733

Kabir, M. H., Nur-E-Alam, S. M., Datta, A., Tan, M. L., Rahman, M. S., & Bashir, M. K. (2023). Understanding vegetable farmers' adoption, dis-adoption, and non-adoption decisions of pest management by pheromone trapping. *PLOS ONE*, *18* (9 September), 1–13. https://doi.org/10.1371/journal.pone.0292254

Karoney, E. M., Molelekoa, T., Bill, M., Siyoum, N., & Korsten, L. (2024). Global research network analysis of fresh produce postharvest technology: Innovative trends for loss reduction. *Postharvest Biology and Technology*, *208*(October 2023), 112642. https://doi.org/10.1016/j.postharvbio.2023.112642

Khan, F. Z. A., Manzoor, S. A., Gul, H. T., Ali, M., Bashir, M. A., Akmal, M., Haseeb, M., Imran, M. U., Taqi, M., Manzoor, S. A., Lukac, M., & Joseph, S. V. (2021). Drivers of farmers' intention to adopt integrated pest management: A case study of vegetable farmers in Pakistan. *Ecosphere*, *12*(10). https://doi.org/10.1002/ecs2.3812

Khan, M., & Damalas, C. A. (2015). Factors preventing the adoption of alternatives to chemical pest control among Pakistani cotton farmers. *International Journal of Pest Management*, *61*(1), 9–16. https://doi.org/10.1080/09670874.2014.984257

Kibira, M., Affognon, H., Njehia, B., Muriithi, B., Mohamed, S., & Ekesi, S. (2010). Economic evaluation of integrated management of fruit fly in mango production in Embu County, Kenya. *African Journal of Agricultural and Resource Economics*, *10*(4), 343–353.

Kibira, M., Affognon, H., Njehia, B., Muriithi, B., Mohamed, S., & Ekesi, S. (2015). Economic evaluation of integrated management of fruit fly in mango production in Embu County, Kenya. *African Journal of Agricultural and Resource Economics*, *10*(4), 343–353.

Korir, J. K., Affognon, H. D., Ritho, C. N., Kingori, W. S., Irungu, P., Mohamed, S. A., & Ekesi, S. (2015). Grower adoption of an integrated pest management package for management of mango-infesting fruit flies (Diptera: Tephritidae) in Embu, Kenya. *International Journal of Tropical Insect Science*, *35*(2), 80–89. https://doi.org/10.1017/S1742758415000077

Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods*, *6*(1), 1–22. https://doi.org/10.3390/foods6010008

Li, Z., & Fantke, P. (2022). Toward harmonizing global pesticide regulations for surface freshwaters in support of protecting human health. *Journal of Environmental Management*, *301*(June 2021), 113909. https://doi.org/10.1016/j.jenvman.2021.113909

Litte, J. H., Corcoran, J., & Pillai, V. (2008). *Systematic review and meta- analysis: Pocket guides to social work research methods*. http://ifile.it/mt9o1d/ebooksclub.org__Systematic_Reviews_and_Meta_Analysis__Pocket_Guides_to_Social_Work_Research_Methods_.pdf%5Cnpapers2://publication/uuid/4955D114-0F18-48B4-BFB2-026C69DDB7C0

Ma, W., & Abdulai, A. (2019). IPM adoption, cooperative membership and farm economic performance: Insight from apple farmers in China. *China Agricultural Economic Review*, *11*(2), 218–236. https://doi.org/10.1108/CAER-12-2017-0251

Margaliot, Z., & Chung, K. C. (2007). Systematic reviews: A primer for plastic surgery research. *Plastic and Reconstructive Surgery*, *120*(7), 1834–1841. https://doi.org/10.1097/01.prs.0000295984.24890.2f

Midingoyi, S. K. G., Kassie, M., Muriithi, B., Diiro, G., & Ekesi, S. (2019). Do farmers and the environment benefit from adopting integrated pest management practices? Evidence from Kenya. *Journal of Agricultural Economics*, *70*(2), 452–470. https://doi.org/10.1111/1477-9552.12306

Midingoyi, S., Kifouly, G., Kassie, M. B., Affognon, H. D., Macharia, I., & , B. (2024). Estimating the impact of biological control of maize stemborers on productivity and poverty in Kenya: A continuous treatment approach. *Environment, Development, and Sustainability*, *26*(2), 5067–5088. https://doi.org/10.1007/s10668-023-02924-8

Misango, V. G., Nzuma, J. M., Irungu, P., & Kassie, M. (2022). Intensity of adoption of integrated pest management practices in Rwanda: A fractional logit approach. *Heliyon*, *8*(1), e08735. https://doi.org/10.1016/j.heliyon.2022.e08735

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J. A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J. J., Devereaux, P. J., Dickersin, K., Egger, M., Ernst, E., Gøtzsche, P. C., & Tugwell, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLOS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Möhring, N., Bozzola, M., Hirsch, S., & Finger, R. (2020). Are pesticides risk decreasing? The relevance of pesticide indicator choice in empirical analysis. *Agricultural Economics (United Kingdom)*, *51*(3), 429–444. https://doi.org/10.1111/agec.12563

Moore, N., Glandon, D., Tripney, J., Kozakiewicz, T., Shishler, S., Eyres, J., Zalfou, R., Anda Leon, M. D., Kurkjian, V., Snilstveit, B., & Perdana, A. (2020). Effects of access to electricity interventions on socioeconomic outcomes in low- and middle-income countries. International Initiative for Impact Evaluation. https://doi.org/10.23846/SR00045

Morse, S., & Buhler, W. (1997). IPM in developing countries: The danger of an ideal. *Integrated Pest Management Reviews*, *2*(4), 175–185. https://doi.org/10.1023/A:1018457219228

Mulungu, K., Abro, Z. A., Muriithi, W. B., Kassie, M., Kidoido, M., Sevgan, S., Mohamed, S., Tanga, C., & Khamis, F. (2024). One size does not fit all: Heterogeneous economic impact of integrated pest management practices for mango fruit flies in Kenya—a machine learning approach. *Journal of Agricultural Economics*, *75*(1), 261–279. https://doi.org/10.1111/1477-9552.12550

Muriithi, B., Diiro, G., Berresaw, M. K., & Muricho, G. (2018). Does gender matter in the adoption of sustainable agricultural technologies? A case of push-pull technology in Kenya. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3159275

Muriithi, B. W., Affognon, H. D., Diiro, G. M., Kingori, S. W., Tanga, C. M., Nderitu, P. W., Mohamed, S. A., & Ekesi, S. (2016). Impact assessment of integrated pest management (IPM) strategy for suppression of mango-infesting fruit flies in Kenya. *Crop Protection*, *81*(March), 20–29. https://doi.org/10.1016/j.cropro.2015.11.014

Norton, G. W., Heinrichs, E. A., Luther, G. C., & Irwin, M. E. (2008). Globalizing integrated pest management: A participatory research process. *Globalizing Integrated Pest Management: A Participatory Research Process*. https://doi.org/10.1002/9780470290163

Nyaga, V. N., & Arbyn, M. (2022). Metadta: a Stata command for meta-analysis and meta-regression of diagnostic test accuracy data - a tutorial. *Archives of Public Health*, *80*(1), 1–15. https://doi.org/10.1186/s13690-021-00747-5

Nyang'au, P. N., Muriithi, B. W., Nzuma, J. M., Irungu, P., Gichungi, H. M., & Diiro, G. (2020). Impact of integrated fruit fly management strategy on food security among smallholder mango farmers in Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, *20*(2), 15431–15454. https://doi.org/10.18697/AJFAND.90.18455

Owusu, V., & Abdulai, A. (2019). Examining the economic impacts of integrated pest management among vegetable farmers in Southern Ghana. *Journal of Environmental Planning and Management*, *62*(11), 1886–1907. https://doi.org/10.1080/09640568.2018.1517085

Oya, C., Schaefer, F., Skalidou, D., McCosker, C., & Langer, L. (2017). Effects of certification schemes for agricultural production on socio-economic outcomes in low- and middle-income countries: A systematic review. *Campbell Systematic Reviews*, *13*(1), 1–346. https://doi.org/10.4073/csr.2017.3

Page, M. J., McKenzie, J. E., Bossuyt, P., Mayo-Wilson, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., McDonald, E., Brennan, S. E., Li, R., Lalu, J., Grimshaw, J. M., Hróbjartsson, A., Glanville, M. M., Chou, T., Loder, E. W., Boutron, E. . . . Shamseer, L. (2021). The prisma 2020 statement: An updated guideline for reporting systematic reviews. *Medicina Fluminensis*, *57*(4), 444–465. https://doi.org/10.21860/medflum2021_264903

Pahlevan Sharif, S., Mura, P., & Wijesinghe, S. N. R. (2019). A systematic review of systematic reviews in tourism. *Journal of Hospitality & Tourism Management*, *39*(November 2018), 158–165. https://doi.org/10.1016/j.jhtm.2019.04.001

Palmer, T. M., & Sterne, J. A. C. Palmer, T.M. & Sterne, J.A.C. (Eds.). (2016). *Meta-analysis in Stata : An updated collection from the Stata journal* (2nd ed.). Stata Press., United States of America.

Peshin, R., & Dhawan, A. K. (2009). *Integrated Pest Management: Innovation-Development Process*. R. Peshin, & A. K. Dhawan (Eds.). Springer Netherlands. https://doi.org/10.07/978-1-4020-8992-3

Peshin, R., Dhawan, A. K., Kranthi, K. R., & Singh, K. (2009). Evaluation of the benefits of an insecticide resistance management programme in Punjab in India. *International Journal of Pest Management*, *55*(3), 207–220. https://doi.org/10.1080/09670870902738786

Peshin, R., Kalra, R., Dhawan, A. K., & Kumar, T. (2007). Evaluation of insecticide resistance management based integrated pest management programme. *AI and Society*, *21*(3), 357–381. https://doi.org/10.1007/s00146-006-0078-x

Petticrew, M., & Roberts, H. (2006). *Systematic reviews in the social sciences: A Practical Guide*. Blackwell Publishing Ltd. https://doi.org/10.1002/9780470754887

Pimentel, D., & Peshin, R. (2013). Integrated pest management. *Integrated Pest Management*, *3*. https://doi.org/10.1007/978-94-007-7796-5

Pretty, J., & Bharucha, Z. P. (2015). Integrated pest management for sustainable intensification of agriculture in Asia and Africa. *Insects*, *6*(1), 152–182. https://doi.org/10.3390/insects6010152

Priya P., & Singh, S. P. (2022). Factors influencing the adoption of sustainable agricultural practices: A systematic literature review and lesson learned for India. *Forum for Social Economics*, *53*(1), 1–17. https://doi.org/10.1080/07360932.2022.2057566

Rahman, M., Kamal, M., Islam, M., Ahammed, B., & Das, S. (2021). Integrated pest management practices adopted by mango growers at Meherpur region in Bangladesh. *SAARC Journal of Agriculture*, *19*(1), 125–138. https://doi.org/10.3329/sja.v19i1.54784

Rahman, M. S., & Norton, G. W. (2019). Adoption and impacts of integrated pest management in Bangladesh: Evidence from smallholder bitter gourd growers. *Horticulturae*, *5*(2). https://doi.org/10.3390/horticulturae5020032

Rahman, M. S., Norton, G. W., & Rashid, M. H. A. (2018). Economic impacts of integrated pest management on vegetables production in Bangladesh. *Crop Protection*, *113*(January), 6–14. https://doi.org/10.1016/j.cropro.2018.07.004

Rajashekhar, M., Rajashekar, B., Reddy, T. P., Manikyanahalli Chandrashekara, K., Vanisree, K., Ramakrishna, K., Sunitha, V., Shaila, O., Sathyanarayana, E., Shahanaz, S., Kumar, A., Shankar, A., Jahan, P. V., Reddy, M. J. M., & Reddy, M. J. M. (2024). Evaluation of farmers friendly IPM modules for the management of fall armyworm, Spodoptera frugiperda (JE Smith) in maize in the hot semiarid region of India. *Scientific Reports*, *14*(1), 1–13. https://doi.org/10.1038/s41598-024-57860-y

Resosudarmo, B. P. (2014). The political economy of the Indonesian integrated pest management program during the 1989-1999 period. In R. Peshin, & D. Pimentel (Eds.), *Integrated Pest Management: Experiences with Implementation, Global Overview, Vol. 4* (pp. 255–267). Springer Netherlands. https://doi.org/10.1007/978-94-007-7802-3_10

Rockers, P. C., Røttingen, J. A., Shemilt, I., Tugwell, P., & Bärnighausen, T. (2015). Inclusion of quasi-experimental studies in systematic reviews of health systems research. *Health Policy*, *119*(4), 511–521. https://doi.org/10.1016/j.healthpol.2014.10.006

Salazar, L., Aramburu, J., Agurto, M., Maffioli, A., & Fahsbender, J. (2020). Sweeping the flies away: Evidence from a fruit fly eradication program. *European Review of Agricultural Economics*, *47*(5), 1920–1962. https://doi.org/10.1093/erae/jbaa015

Sekabira, H., Tepa-Yotto, G. T., Djouaka, R., Clottey, V., Gaitu, C., Tamò, M., Kaweesa, Y., & Ddungu, S. P. (2022). Determinants for deployment of climate-Smart integrated pest management practices: A meta-analysis approach. *Agriculture (Switzerland)*, *12*(7), 1–19. https://doi.org/10.3390/agriculture12071052

Sharma, R., Peshin, R., Shankar, U., Kaul, V., & Sharma, S. (2015). Impact evaluation indicators of an integrated pest management program in vegetable crops in the subtropical region of Jammu and Kashmir, India. *Crop Protection*, *67*, 191–199. https://doi.org/10.1016/j.cropro.2014.10.014

Singh, A., Vasisht, A. K., Kumar, R., & Das, D. K. (2008). Adoption of integrated pest management practices in paddy and Cotton: A case study in Haryana and Punjab. *Agricultural Economics Research Review*, *21*(2), 221–226. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=34973346&site=ehost-live

Stanley, T. D., & Doucouliagos, H. (2012). Meta-regression analysis in economics and business. https://doi.org/10.4324/9780203111710

Stewart, R., Langer, L., Da Silva, N. R., & Muchuri, E. (2016). Effects of training, innovation and new technology on African smallholder farmers ' economic outcomes and food security. International Initiative for Impact Evaluation.

Timprasert, S., Datta, A., & Ranamukhaarachchi, S. L. (2014). Factors determining adoption of integrated pest management by vegetable growers in Nakhon Ratchasima Province, Thailand. *Crop Protection*, *62*, 32–39. https://doi.org/10.1016/j.cropro.2014.04.008

Vaessen, J., Rivas, A., Duvendack, M., Leeuw, F., Von Gils, G., Lukach, R., Holvoet, N., Bastiaensen, J., Hobrados, J. G, & Waddington, H. (2013). The effects of microcredit on women's control over household spending: A systematic review. International Initiative for Impact Evaluation.

Waddington, H., Aloe, A., Becker, B., Djimeu, E., & Reeves, B. (2014). Risk of bias assessment in credible quasi-experimental studies 1 Hugh Waddington, Ariel Aloe, Betsy Becker, Eric Djimeu, Barney Reeves and Peter Tugwell.

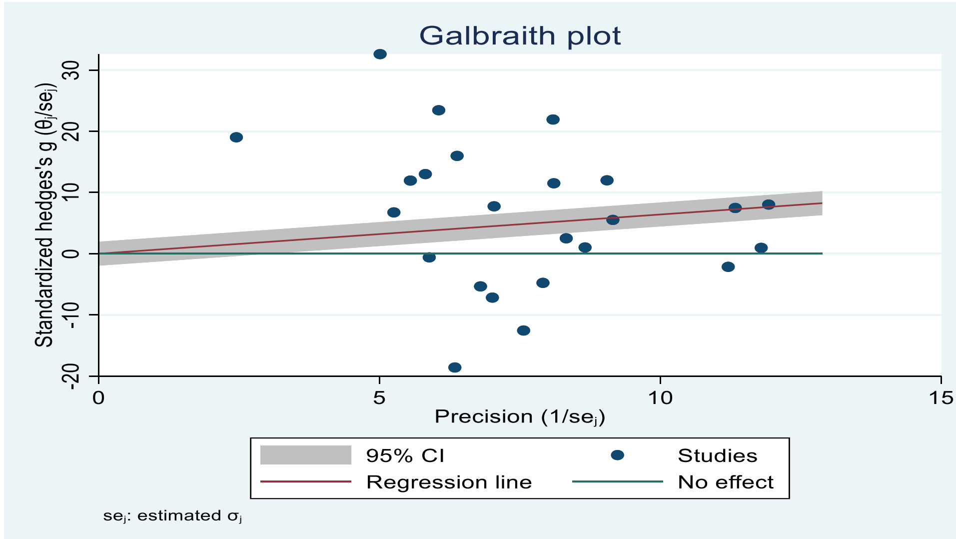
Waddington, H., Snilstveit, B., Hombrados, J., Vojtkova, M., Phillips, D., Davies, P., & White, H. (2014). Farmer Field Schools for improving farming practices and farmer outcomes: A systematic review. *Campbell Systematic Reviews*, *10*(1). https://doi.org/10.4073/csr.2014.6

Wangithi, C. M., Muriithi, B. W., & Belmin, R. (2021). Adoption and dis-adoption of sustainable agriculture: A case of farmers' innovations and integrated fruit fly management in Kenya. *Agriculture (Switzerland)*, *11*(4), 338. https://doi.org/10.3390/agriculture11040338

White, H., Albers, B., Gaarder, M., Kornør, H., Littell, J., Marshall, Z., Matthew, C., Pigott, T., Snilstveit, B., Waddington, H., & Welch, V. (2020). Guidance for producing a Campbell evidence and gap map. *Campbell Systematic Reviews*, *16*(4). https://doi.org/10.1002/cl2.1125

Zakaria, A., Alhassan, S. I., Kuwornu, J. K. M., Azumah, S. B., & Derkyi, M. A. A. (2020). Factors influencing the adoption of climate-smart agricultural technologies among rice farmers in Northern Ghana. *Earth Systems and Environment*, *4*(1), 257–271. https://doi.org/10.1007/s41748-020-00146-w

Appendix 1. The Galbraith plot showing heterogeneity in the studies and potential outliers



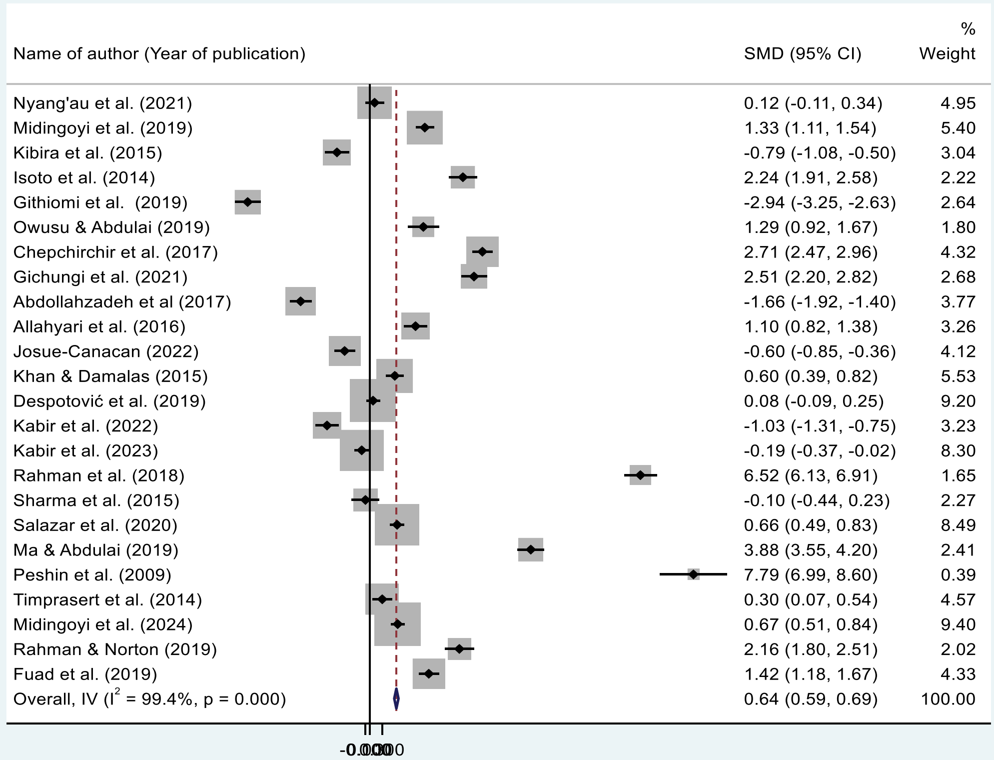
Source: Authors' computation.

Appendix 2. Meta-regression results

Effect size	Coefficient
Constant	1.326 (1.835)
Sample size	0.003 (0.003)
Crop type	−0.045 (0.145)
Country	−0.145 (0.136)

Number of observations = 24.
Residual heterogeneity.
Tau2 = 4.902.
I2 (%) = 99.7.
H2 = 291.56.
R-squared (%) = 7.17.
Wald chi2 (3) = 1.79.
Probability > X^2 = 0.62.
Test of residual homogeneity: Q_res = X^2 (20) = 3118.70 Prob > Q_res = 0.0000.
Source: Authors' computation.

Appendix 3. Presentation of forest plot using the Standardised Mean Difference (SMD)



Source: Authors' computation.