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Bridging The Knowledge-Behaviour-Injury Divide: A Comparative Systematic Literature Review of Agricultural Occupational Safety Training in Developed and Developing Contexts

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Abstract

Agricultural safety training is widely used to reduce occupational injuries and pesticide-related morbidity. However, whether knowledge gains lead to sustained behavioral change and measurable injury reduction remains uncertain, particularly across different regulatory and structural contexts. This research aimed to synthesize evidence on the effectiveness of agricultural occupational safety training in developed and developing settings and to examine outcomes along the knowledge–behavior–injury pathway. This review followed the PRISMA 2020 guidelines. Searches were conducted in PubMed, ScienceDirect, and Google Scholar using terms such as agricultural safety, occupational safety training, knowledge–behavior translation, injury prevention, and safety behavior. Studies underwent title/abstract and full-text screening using predefined criteria. Exclusions included gray literature, conference abstracts, editorials, non-English studies, non-agricultural contexts, publications below Q2 ranking, and articles without verifiable DOI or PMID identifiers. The review was registered on the Open Science Framework. Educational interventions consistently improved safety knowledge across contexts. Behavioral outcomes were moderate and context-dependent, with stronger effects observed in participatory or structurally supported interventions. Evidence linking training alone to sustained injury reduction was limited. A clear attenuation pattern was observed from knowledge acquisition to behavioral change and injury outcomes. Psychosocial factors were key moderators in developed settings, while structural constraints were more influential in developing contexts. Agricultural safety training improved knowledge but showed reduced impact on behavior and injury outcomes when implemented alone. A systems-oriented approach is needed, integrating education with regulatory, structural, and behavioral reinforcement to achieve sustainable injury prevention.

INTRODUCTION

Agriculture is one of the most hazardous occupational sectors worldwide, characterized by high rates of traumatic injuries, machinery-related accidents, pesticide poisoning, and illnesses associated with chronic exposure (ILO, 2023; Merisalu et al., 2019; Rautiainen et al., 2008). Agricultural workers are routinely exposed to mechanical, chemical, environmental, and ergonomic hazards, often without consistent regulatory oversight (Food and Agriculture Organization [FAO], 2025). Although safety training is widely promoted as a primary strategy for injury prevention, significant data gaps persist regarding its effectiveness in reducing injuries.

Educational interventions are frequently implemented as cost-effective and scalable strategies to improve occupational safety behaviors. However, the assumption that enhanced safety knowledge will automatically result in behavioral change and injury reduction has been increasingly challenged. Empirical evidence in agricultural settings reveals a consistent pattern: training reliably improves knowledge, but behavioral adoption varies, and reductions in injury directly attributable to education are not always measurable.

Even at an early stage, systematic evidence undermined the effectiveness of education-only approaches in reducing agricultural injuries. A review of farm safety intervention studies presented at a landmark conference reported limited and inconsistent evidence that education programs could lead to measurable injury reduction (DeRoo & Rautiainen, 2000). Although this synthesis did not examine how educational gains diminish over time within outcome domains, it was foundational in the field. More than 20 years after the emergence of behavioral science and intervention delivery, uncertainty persists regarding how knowledge can be effectively applied to achieve long-term behavioral change and injury prevention in agricultural systems.

This highlights a broader issue in occupational safety research: the gap between cognitive acquisition and effective risk mitigation. The Theory of Planned Behavior and the Capability–Opportunity–Motivation Behavior (COM-B) framework, both integral to behavioral science, suggest that knowledge alone does not determine safety behavior. Factors influencing the application of knowledge include structural constraints, regulatory enforcement, the availability of personal protective equipment (PPE), social norms, risk perception, and economic pressures.

Notably, the moderating conditions of agricultural systems in both developed and developing countries vary significantly (Sapbamrer et al., 2024). Behavioral barriers in higher-income settings can be motivational or perceptual, particularly among experienced workers accustomed to established routines (Caffaro et al., 2022; Surendran et al., 2024). In low- and middle-income countries, several structural barriers may impede the translation of behavioral intentions into practice, even when sufficient knowledge has been acquired. These barriers include the affordability of personal protective equipment, limited enforcement capacity, low literacy levels, and restricted extension services (Desye et al., 2024; Jørs et al., 2014; Sapbamrer et al., 2024). Therefore, it is difficult to accurately measure the effectiveness of safety training programs without considering the broader systemic context.

Earlier reviews provide important background information but contain critical conceptual gaps. Meta-analyses of occupational health and safety training conducted across various sectors have reported strong effects on knowledge and attitudes, small effects on behavior, and limited evidence regarding impacts on health (Ricci et al., 2016). However, this synthesis was cross-sectoral and did not specifically focus on agricultural systems or consider the moderating influence of contextual factors. Subsequently, a systematic review focused on the agricultural sector emphasized the value of integrating training, access to personal protective equipment, regulation, and health services (Nugraheni & Susilo, 2025). Although this was an important contribution, it primarily cataloged practices without critically examining the systematic translation of training effects into outcome domains (Frank et al., 2021).

Although previous reviews provide evidence of differences in the effects of knowledge, behavior, and health outcomes, few have synthesized these results directly along a causal

translation pathway or examined how this pathway is influenced by varying regulatory and economic contexts. The process by which educational gains can either mitigate or fail to mitigate the risk of injury in agriculture has not yet been adequately theorized.

This review addresses this gap by evaluating the effectiveness of occupational safety training along a hypothesized knowledge–behavior–injury attenuation gradient. Drawing on evidence from systematic reviews, meta-analyses, randomized trials, quasi-experimental studies, and longitudinal field research, it synthesizes findings from both developed and developing agricultural contexts. Rather than treating knowledge, behavior, and injury as discrete endpoints, this framework enables a systematic examination of where and why intervention effects diminish as outcomes progress from proximal cognitive gains to distal health impacts.

This review aims to determine how effectively occupational safety training enhances agricultural workers' knowledge of safety measures, assess the extent to which acquired knowledge is reflected in behavioral change, examine evidence on the relationship between training and injury- or exposure-related outcomes, and compare the contextual moderation of these relationships in developed and developing agricultural systems. By situating educational interventions within the broader context of occupational safety systems, this review offers a comparative and mechanistic understanding of training effectiveness, enabling a more precise understanding of how education can contribute to the prevention of agricultural injuries and how structural conditions are most likely to translate knowledge into meaningful risk reduction.

METHOD

This review followed PRISMA 2020 guidelines and was prospectively registered on the Open Science Framework (DOI: 10.17605/OSF.IO/VQ29S) to enhance transparency and research integrity (Liberati et al., 2009; Moher, Liberati, et al., 2009). Searches were conducted in PubMed, Scopus, and Google Scholar to identify studies published between 2015 and 2025. Keywords related to agricultural safety, occupational safety training, knowledge–behavior translation, injury prevention, and safety behavior were used in structured search strings combining three conceptual domains: population (farm* OR agri* OR smallholder OR "rural worker" OR "pesticide applicator"), intervention ("safety training" OR "educational intervention" OR "occupational health training" OR "farmer field school" OR "behavior change"), and outcomes ("injury prevention" OR "pesticide safety" OR "occupational injury" OR "knowledge attitude practice"), structured as Population AND Intervention AND Outcome. Searches were limited to English-language publications.

Study selection was conducted in two stages: title and abstract screening followed by full-text assessment against predefined eligibility criteria. Inclusion criteria consisted of studies published in Q1 or Q2 journals, employing designs such as systematic reviews, randomized controlled trials, cluster randomized trials, quasi-experimental studies, or controlled pre–post designs, involving agricultural workers and safety training interventions with measurable outcomes including safety knowledge, behaviors, pesticide handling practices, PPE use, injury rates, or health symptoms. Studies were excluded if they were grey literature, conference abstracts, editorials, commentaries, non-English publications, studies outside the agricultural sector, or publications below Q2 ranking.

Quality assessment of the twenty included studies was conducted, and risk of bias was evaluated using design-appropriate tools (Ma et al., 2020; Moher, Cook, et al., 1999; Shea et al., 2007). Systematic reviews were assessed using AMSTAR 2, randomized controlled trials using RoB 2, and non-randomized intervention studies using ROBINS-I and ROBINS-E. Quasi-experimental studies were assessed using the JBI Quasi-Experimental Checklist, while qualitative studies were evaluated using the CASP Qualitative Checklist. These tools assessed key domains such as study design integrity, selection bias, confounding, outcome measurement, and reporting transparency. Domain-level judgments and justifications were documented in the supplementary materials to ensure transparency and reproducibility.

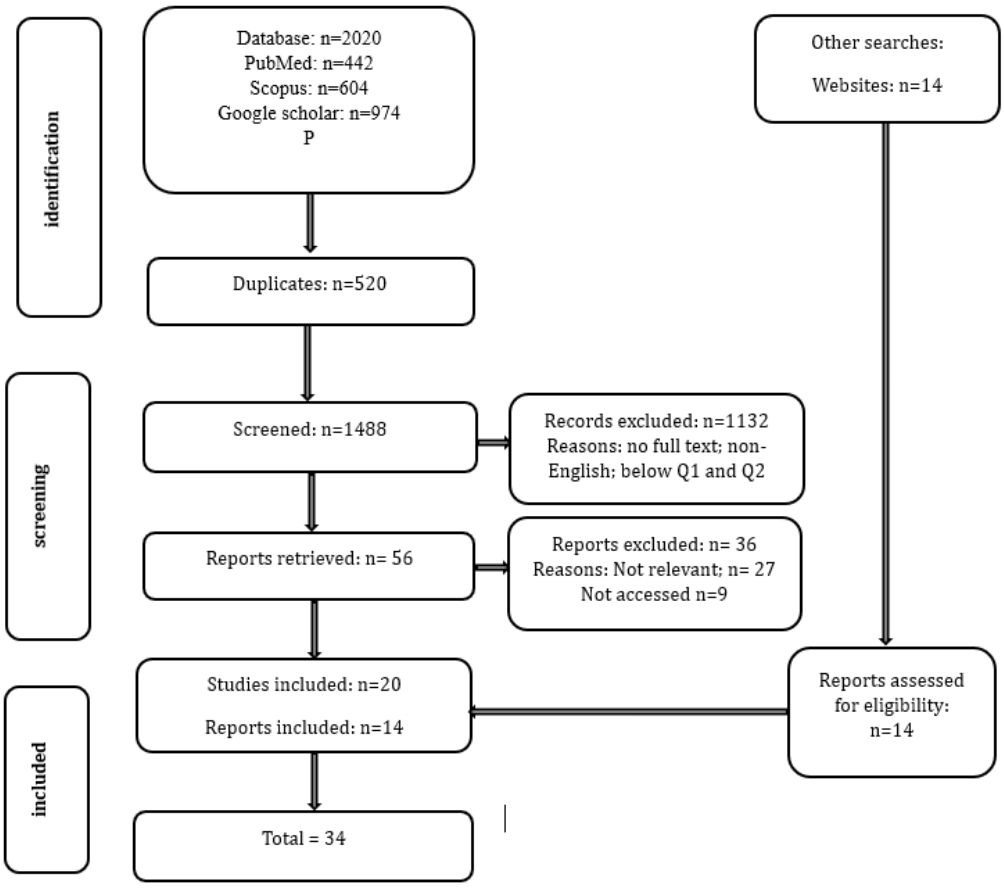

Figure 1. Prisma Flow Diagram
Source: Adapted from Page et al. (2021)

Table 1: Studies selected and extracted data

Author (Year)	Country / Context	Study Design	Population / Intervention	Outcomes Measured	Key Findings
Systematic Reviews & Meta-Analyses					
Afshari et al. (2021)	Multi-region (Global)	Systematic review	Pesticide safety training interventions	Knowledge, attitudes, behaviour	Educational and behavioural strategies effectively enhance knowledge and attitudes; multifaceted interventions more effective than single-component programs
Ayaz et al. (2022)	Multi-region (Global)	Meta-analysis	Pesticide safety training	Knowledge, behaviour	Knowledge: pooled effect size g = 0.890 (p = 0.001) ; Behaviour: pooled effect size g = -0.707 (p = 0.001)
Coman et al. (2020)	Multi-region (Global)	Systematic review	Agricultural health and safety interventions	Safety literacy, knowledge	Consistent improvements across modalities; methodological heterogeneity precluded meta-analysis
Desye et al. (2024)	Developing countries (Global)	Systematic review & meta-analysis	Pesticide safety practices	Knowledge, practices, health symptoms	Good knowledge associated with safe practices (OR = 3.83; 95% CI: 2.36–5.29); pooled safe practice prevalence: 43.1%; acute symptom prevalence: 3%
Kangavari et al. (2024)	Multi-region (Global)	Systematic review	PPE use interventions	PPE use, behavioural determinant	Knowledge, attitudes, perceived control, and physical access to PPE work synergistically; structural access prerequisite for behavioural enactment
Nugraheni & Susilo (2025)	Multi-region (Global)	Systematic review	Agricultural safety interventions	Multi-component programs	Integration of training, PPE access, regulation, and health services valuable; catalogued practices without critical translation analysis
Rautiainen et al. (2008)	High-income (Cochrane review)	Systematic review	Agricultural injury prevention	Injury rates	No evidence education alone reduces injury; legislative/financial incentives more promising
Sapbamrer et al. (2024)	Multi-region (Global)	Systematic review	Pesticide safety interventions	PPE use, practices	Training and knowledge strongest predictors of PPE use; barriers: PPE cost, discomfort, climatic unsuitability
Randomized Controlled Trials					
Akkouch et al. (2025)	Lebanon (Developing)	RCT (digital vs. face-to-face)	Farmers; WhatsApp video vs. in-person training	Knowledge (label comprehension, safe handling)	Digital non-inferior to face-to-face; scalable for cognitive outcomes
Ssekkadde et al. (2025)	Uganda (Developing)	RCT (3-arm)	Farmers; education-only vs. education	Knowledge, practices, poisoning symptoms	Knowledge: +4.4% (education), +6.1 % (education +SMS); Behaviour: no significant change; Milder symptoms in SMS group

			+SMS vs. control		
Non-Randomized Intervention Studies (with comparison groups)					
Arcury et al. (2009)	USA (Developed)	Quasi-experimental	Latino migrant farmworkers; promotora-delivered education	Knowledge, behaviours	No significant behavioural changes; insufficient intervention intensity
Arcury et al. (2010)	USA (Developed)	Quasi-experimental	Latino farmworkers; 6-lesson community curriculum	Knowledge, risk perception, behaviours	Three domains improved significantly; behavioural gains partially mediated by knowledge and risk perception
Bradman et al. (2009)	USA (Developed)	Quasi-experimental	Farmworkers; glove use intervention	Urinary malathion metabolites (biomarker)	Significant reduction in urinary metabolites ($p < .05$); only study with objective biomarker
Clausen et al. (2017)	Uganda (Developing)	Quasi-experimental	Farmers; Farmer Field Schools (FFS)	Pesticide use, diffusion effects	Significant decrease in pesticide use ($p = 0.021$); diffusion to neighbouring farmers
Jørs et al. (2014)	Bolivia (Developing)	Quasi-experimental (longitudinal)	Farmers; FFS training (7-year follow-up)	Knowledge, attitudes, practices, poisoning	Knowledge retained at 7 years; hierarchical gradient: trained > neighbours > controls; decreased self-reported poisoning
Suratman et al. (2016)	Indonesia & Australia (Cross-context)	Quasi-experimental (cross-context)	Farmers; group-based delivery	Knowledge, perception	Multiple domain improvements in Indonesia; cross-contextual differences not fully controlled
Quantitative Observational Studies					
Caffaro et al. (2022)	Italy (Developed)	Cross-sectional (Theory of Planned Behaviour)	Farmers; safety training exposure	Safety behaviour, TPB constructs	Training effect indirect, mediated through perceived behavioural control and attitudes
Single-Group Pre-Post Study					
Maddah et al. (2020)	Lebanon (Developing)	Single-group pre-post	Farmers; community-based pesticide	Knowledge, practices	Knowledge/practices improvement: effect size range 0.663–1.466 ($p < .05$)

			safety training		
Qualitative Study					
Surendran et al. (2024)	Ireland (Developed)	Qualitative (focus groups)	Older farmers (n=19); safety perception	Risk perception, barriers, habits	Low risk perception and ingrained habitual practices most significant obstacles; motivational limitations > knowledge deficits

Source: Compiled from literature review (2024)

Table 2: Quality assessment of studies included in the review

Study Type	Tool	Low Risk	Some Concerns / Moderate	Serious Risk	Total
Systematic Reviews	AMSTAR-2	5	3	0	8
RCTs	RoB 2	1	1	0	2
Non-randomised intervention (with comparison)	ROBINS-I	0	5	1	6
Quantitative observational	ROBINS-E	0	2	0	2
Single-group pre-post	JBI	0	1	0	1
Qualitative	CASP	1	0	0	1
Total		7	12	1	20

Source: Compiled from literature review (2024)

RESULTS AND DISCUSSION

Study Characteristics

Due to methodological heterogeneity, quantitative meta-analysis was not feasible; instead, a structured narrative synthesis with comparative analysis was conducted, organizing findings by outcome domain (knowledge, behaviour, injury) and context (developed vs. developing countries) along a knowledge-behaviour-injury attenuation gradient. Twenty studies met the inclusion criteria: The evidence base spans both high-income countries and low- and middle-income countries, as well as global multi-region syntheses. Interventions varied in modality and intensity, including classroom-based education, community-based curricula, Farmer Field Schools (FFS), digital delivery (e.g., WhatsApp videos), participatory approaches, and theory-based behavioural designs. Outcome measurement spanned three domains: (i) knowledge acquisition (e.g., pesticide safety comprehension, label understanding); (ii) behavioural change (e.g., PPE use, handling practices); and (iii) injury or exposure-related outcomes (e.g., self-reported poisoning, biomarker-verified exposure).

Knowledge Outcomes: Strong and Replicable Effects

Educational interventions have consistently demonstrated strong positive effects on safety knowledge across various contexts, as supported by robust meta-analytic evidence. Knowledge improvement showed a large, pooled effect size (Hedges' $g = 0.890$; $p = 0.001$), indicating that participants made significant cognitive gains following pesticide safety training (Ayaz et al., 2022). Similarly, educational and behavioural strategies effectively enhance pesticide safety knowledge and attitudes (Afshari et al., 2021). Consistent clear improvements

in safety and health literacy across all types of intervention modalities were found; however, methodological heterogeneity prevented quantitative synthesis (Coman et al., 2020).

Quasi-experimental and cluster-randomized trials have confirmed these findings in developing country settings. For example, a significant improvement in knowledge among Lebanese farmers was reported, with gains ranging from 0.663 to 1.466 ($p < 0.05$) (Maddah et al., 2020). Knowledge increases of 4.4% (education-only) and 6.1% (education plus SMS) were observed compared to the control group (Ssekkadde et al., 2025). In another study it was demonstrated that Bolivian farmers retained knowledge seven years after training (Jørs et al., 2014). Indonesian farmers demonstrated multiple domain knowledge and perceptions improvements following group-based delivery (Suratman et al., 2016).

Online methods were not inferior to traditional methods. WhatsApp video-based instruction for pesticide label comprehension and safe handling was equally effective as face-to-face training (Akkouch et al., 2025). Additionally, this approach can be scaled to enhance cognitive training outcomes.

These findings are supported by system-level syntheses. In developing countries, good pesticide knowledge is strongly associated with safe practices (OR = 3.83, 95% confidence interval = 2.36–5.29) (Desye et al., 2024). Globally, training and knowledge have been identified as the strongest predictors of personal protective equipment (PPE) use (Sapbamrer et al., 2024).

Behavioural Results: Moderate and Context-Dependent Effects

In contrast to the strong knowledge effects, behavioural outcomes are more heterogeneous and sensitive to context. A pooled behavioural effect size of $g = -0.707$ ($p = 0.001$) was reported, which is significantly smaller than the corresponding effect on knowledge (Afshari et al., 2021; Ayaz et al., 2022). It is concluded that evidence for sustained behavioural change remains limited and that multifaceted interventions are more effective than single-component educational programs.

Primary studies illustrated this variability. A significant improvement was reported in pesticide handling practices ($M = 0.663–1.466$; $p = .05$) (Maddah et al., 2020). There was also a statistically significant decrease in pesticide use among members of the Ugandan Family Farming System ($P' = 0.021$), accompanied by measurable diffusion effects among neighbouring farmers (Clausen et al., 2017). A hierarchical gradient was identified in Bolivia, where trained farmers outperformed neighbouring farmers, who, in turn, performed better than control groups in terms of knowledge, attitudes, and practices (Jørs et al., 2014).

However, not every intervention translated cognitive change into behavioural change. Despite statistically significant improvements in knowledge, no significant change in practice scores was found (Ssekkadde et al., 2025). Similarly, no significant behavioural changes among Latino migrant farmworkers were found after receiving education from promotoras, attributing this outcome to insufficient intervention intensity (Arcury, Marín, et al., 2009).

On the other hand, a higher intervention dosage appears to be significant. Three pesticide domains of safety behaviour improved significantly after six lessons of a community-based curriculum, with mediation analysis indicating that the behavioural gains were partially attributable to changes in knowledge and risk perception (Arcury, Estrada, et al., 2010).

In developed countries, psychosocial determinants play a significant role. The Theory of Planned Behaviour framework demonstrates that the effect of training on safety behaviour is

indirect, mediated through perceived behavioural control and attitudes (Caffaro et al., 2022). Low risk perception and deeply ingrained habitual practices were found to be the most significant obstacles among older Irish farmers, suggesting that motivational limitations may have a greater impact than a lack of knowledge in this population (Surendran et al., 2024).

The importance of structural moderators is well-supported by systematic reviews worldwide. These structural barriers persist due to factors such as the cost of personal protective equipment (PPE), discomfort, and climatic unsuitability (Sapbamrer et al., 2024). It was concluded that knowledge, attitudes, perceived behavioural control, and physical access to PPE work synergistically, with structural access serving as a prerequisite for behavioural enactment (Kangavari et al., 2024).

Injury and Exposure Outcomes: Direct Evidence of Education Is Limited.

The direct link between educational interventions and injury reduction is relatively weak. The Cochrane review found no evidence that educational interventions significantly reduce agricultural injuries; however, legislative and financial incentive mechanisms appeared more promising (Rautiainen et al., 2008). This conclusion has remained largely unchanged in subsequent studies.

However, a few studies have reported improvements in exposure-related measures. One study used biomarker confirmation rather than self-report and demonstrated objective decreases in biological pesticide exposure among glove users, with a significant reduction in urinary malathion metabolites ($p < 0.05$) (Bradman et al., 2009). This finding is particularly noteworthy because it provides objective evidence of change rather than relying on participant recall.

Milder symptoms of pesticide poisoning were reported in the education plus SMS intervention group, although there were no significant changes in practice scores (Ssekkadde et al., 2025). A long-term decrease in self-reported cases of pesticide poisoning among participants in the Bolivian Farmer Field Schools was reported (Jørs et al., 2014).

In developing countries, the pooled prevalence of safe pesticide use was 43.1% (95% confidence interval not provided), and the prevalence of acute health symptoms was 3% (Desye et al., 2024).

Comparative Pattern Across Contexts

When synthesized across developed and developing regions, a systematic attenuation pattern emerges: In both developed and developing regions, there is a systematic reduction in attenuation.

1. Knowledge effects are consistently strong across all contexts.
2. Behavioural effects are moderate and context-dependent.
3. Injury reduction directly attributable to education alone is minimal and inconsistent.

The pathways of attenuation differ by context. In developed countries, motivation and psychosocial factors (risk perception, perceived behavioural control, and social norms) are the most significant influences on behaviour. In contrast, in low- and middle-income countries, structural barriers (including PPE access, cost, enforcement gaps, and literacy limitations) play a more substantial role.

When interventions are intensive and reinforced culturally, structurally, and socially, behavioural improvements are more likely, and in some cases, these improvements are accompanied by changes in exposure-related outcomes.

Risk of Bias Assessment

All 20 included studies were evaluated using design-appropriate, internationally validated tools: AMSTAR 2 for systematic reviews (n = 8); Cochrane RoB 2 for randomized controlled trials (n = 2); ROBINS-I for non-randomized intervention studies with comparison groups (n = 6); ROBINS-E for quantitative observational studies (n = 2); the JBI Quasi-Experimental Checklist to assess a single-group pre-post study (Higgins et al., 2024; Maddah et al., 2020). Detailed domain-level analysis is provided in the Supplementary Material (Tables S1–S6).

Systematic reviews and meta-analyses (n = 8): AMSTAR 2 assessment identified four studies with high confidence (Ayaz et al., 2022; Afshari et al., 2021; Desye et al., 2024; Rautiainen et al., 2008). Two studies were rated as moderate confidence due to non-critical weaknesses (Coman et al., 2020; Sapbamrer et al., 2024). One review received a low confidence rating due to a single flaw: the exclusion list of studies was not justified (Kangavari et al., 2024). No studies were rated as critically low.

Randomized controlled trials (n = 2): Using the RoB 2 tool, one trial was rated as low risk of bias (Ssekkadde et al., 2025). The other was classified as having some concerns due to the inherent impossibility of blinding participants in a digital versus in-person training comparison (Akkouch et al., 2025).

Non-randomized intervention studies with comparison groups (n = 6): ROBINS-I appraisal classified five studies as moderate risk of bias (Arcury, Marín, et al., 2009; Bradman et al., 2009; Clausen et al., 2017; Jørs et al., 2014; Suratman et al., 2016). One study received a serious risk rating due to inadequate control for confounding from cross-contextual differences between Indonesian and Australian subsamples. The study by Bradman et al. (2009) is noteworthy for its use of objective urinary biomarker measurement, reducing bias (Suratman et al., 2016).

Quantitative observational studies (n = 2): Both studies were considered to have a moderate bias due to factors arising from training exposure and the use of sampling (Caffaro et al., 2022; Clausen et al., 2017).

Single-group pre-post study (n = 1): The JBI Quasi-Experimental Checklist rated the risk of bias as moderate (Maddah et al., 2020). Although the study does not allow for causal inference, it was not excluded due to its contextual significance, as it represents the first community-based pesticide safety intervention in Lebanon.

A qualitative focus group study (n = 1): CASP 1): The checklist assigned a low concern rating (Surendran et al., 2024). The sample size (n=19) met qualitative methodological requirements, and rigorous independent coding by two researchers enhanced methodological strength.

Cross-cutting themes: Fifteen of the eighteen primary studies relied on self-reported behavioural outcomes, exposing them to potential social desirability and recall biases. One study utilizing an objective biological measure (Bradman et al., 2009). The single study rated as having serious risk of bias (Suratman et al., 2016) was included due to its unique cross-context comparative design.

Understanding the Knowledge-Behaviour-Injury Gradient.

This review synthesized data from twenty studies conducted in both developed and developing settings to evaluate the effectiveness of occupational safety training in agriculture. Gains in knowledge were consistently significant and reproducible (Afshari et al., 2021; Ayaz et al., 2022). Changes in behaviour, however, were moderate in intensity and dependent on the context (Maddah et al., 2020; Ssekkadde et al., 2025). The impact of educational interventions on reducing injuries remained limited (Desye et al., 2024; Rautiainen et al., 2008).

This attenuation gradient offers a more nuanced understanding than simplistic binary assessments of training effectiveness. Meta-analyses indicate a strong cognitive impact, evidenced by large pooled effect sizes on knowledge. Primary studies conducted in Lebanon, Uganda, Bolivia, and Indonesia corroborate these findings (Jørs et al., 2014; Maddah et al., 2020; Merisalu et al., 2019). However, the translation of knowledge into sustained behavioural change is neither automatic nor uniform. Even when knowledge improvements are statistically significant, behavioural change often remains incomplete, inconsistent, or constrained by contextual factors (Arcury, Marín, et al., 2009; Clausen et al., 2017; Rautiainen et al., 2008; Ssekkadde et al., 2025).

The outcome, injury reduction or decreased biological exposure, is the most variable. High-quality syntheses indicate that education does not necessarily reduce the rates of agricultural injury (Rautiainen et al., 2008). In cases involving exposure reduction or alleviation of poisoning symptoms, such outcomes are more likely to be observed in multifaceted or structurally supported intervention settings than in didactic training (Bradman et al., 2009; Jørs et al., 2014; Ssekkadde et al., 2025).

Collectively, these findings establish that knowledge acquisition is the most consistent and reproducible outcome of agricultural safety training, regardless of economic conditions, delivery methods, or regulatory environments.

Theoretical attenuation gradient interpretation

The attenuation gradient identified in this review represents an expanding causal gap between the proximal targets of interventions (knowledge and attitudes) and distal health outcomes (injuries). Educational interventions directly affect cognitive determinants such as knowledge, awareness, and attitudes, which can be changed instantly (Ajzen, 1991). Behaviour is mediated by motivational, normative, and opportunity conditions (Michie et al., 2011). The most distal endpoint (injury reduction) requires alignment across individual capacity, behavioural opportunity, and regulatory reinforcement (Davis et al., 2015).

Therefore, this gap should not be interpreted as intervention failure but rather as a manifestation of the causal architecture of occupational safety systems. When viewed through this lens, training can be understood as a proximal lever within a broader risk governance framework, rather than a standalone intervention.

Why knowledge does not automatically translate into Behaviour.

The gap between learning and behaviour aligns with established behavioural science models. Rather than functioning as a direct causal chain, educational effects are mediated by motivational, normative, and opportunity-related factors. Studies grounded in the Theory of Planned Behaviour and the COM-B model demonstrate that knowledge indirectly influences behaviour through perceived behavioural control, attitudes, social norms, and motivational readiness (Ajzen, 1991; Michie et al., 2011).

In developed countries, motivational and habitual factors are particularly significant. In Ireland, risk perception and unsafe routines are deeply ingrained among older farmers, even when they are aware of potential hazards (Surendran et al., 2024). Similarly, psychosocial determinants especially perceived behavioural control, mediated the effects of training among Italian farmers (Caffaro et al., 2022). These findings suggest that behavioural inertia may pose a greater barrier under high-experience, controlled conditions than a lack of information.

In contrast, structural constraints play a dominant role in developing-country contexts. Systematic reviews have found that barriers to behavioural translation persist in the form of personal protective equipment (PPE) costs, climatic discomfort, lack of access, and inadequate enforcement (Kangavari et al., 2024; Sapbamrer et al., 2024). Recent qualitative data from Guyana highlight this trend, identifying seven themes such as barriers to PPE use, difficulties in training, adoption of risky behaviours by farmers, and absence of monitoring. These findings indicate that despite possessing adequate knowledge, systemic gaps hinder behavioural enactment (Parasram & Choudhury, 2025). Meta-regression data confirm these factors as strong predictors of safe practices, although these associations are constrained by structural limitations (Desye et al., 2024).

This contrast underscores that behavioural change cannot be reduced to individual cognition alone; it is deeply embedded within material, regulatory, and social contexts. In general, behaviour change depends on the intensity of interventions, cultural adaptation, structural feasibility, and the regulatory environment. When opportunities and motivational factors are limited, knowledge alone is insufficient.

Contextual Moderation: Developed and Developing Systems.

The comparative synthesis indicates that training effectiveness is shaped by the systemic context rather than by national income status alone. Psychosocial constructs and prior accident experiences appear to mediate behavioural translation in higher-income regulatory systems. For example, it was found that training indirectly influenced safety behaviour through perceived behavioural control, rather than through deeply ingrained unsafe routines (Caffaro et al., 2022). This finding is particularly relevant for older Irish farmers and suggests that motivational factors may be more significant than knowledge deficits in this demographic. Therefore, in such cases, training primarily serves as a cognitive reinforcement process within already established safety frameworks.

In low- and middle-income smallholder systems, structural opportunity conditions play a more decisive role. Interventions through Farmer Field Schools indicate that community-based participatory models promote knowledge retention and behavioural diffusion (Clausen et al., 2017; Jørs et al., 2014). Recent FAO initiatives in Zambia and Zimbabwe affirm that this strategy, when supported by structural aids, can enhance the adoption of safety measures (FAO, 2025). However, in contexts with limited structural support such as inadequate availability of personal protective equipment (PPE), extension services, and regulation, behavioural improvements may fail to follow from cognitive gains.

Notably, recent digital delivery models, including WhatsApp-based education, demonstrate that effective knowledge transmission is scalable even in resource-limited settings (Akkouch et al., 2025). However, digital scalability does not eliminate the structural barriers that impede behavioural performance. These comparative findings suggest that agricultural

safety training should be conceptualized as an engagement with regulatory, infrastructural, and cultural subsystems, rather than being an independent intervention.

Injury Prevention and the Limits of Education Alone

The limited evidence for injury reduction from education-only interventions aligns with previous Cochrane review findings, which concluded that legislative and economic mechanisms yield better results in injury prevention than education alone (Rautiainen et al., 2008).

The authors do not imply that education is insignificant; rather, they suggest that educational interventions are most effective when reinforcing structures are in place, such as supervision, financial incentives, PPE provision, and community norm support. Data obtained through biological follow-ups support the idea that behaviourally enhanced protective strategies can reduce pesticide exposure (Bradman et al., 2009; Nugraheni & Susilo, 2025; Rautiainen et al., 2008). Achieving these results requires conditions that extend beyond mere knowledge acquisition.

This understanding repositions agricultural safety training as a crucial yet incomplete component of broader injury prevention systems. Taken together, these findings suggest that injury and exposure reduction are most likely when education is integrated into broader structural or behavioural reinforcement frameworks. Isolated educational interventions consistently improve knowledge, produce inconsistent behavioural effects, and only occasionally reduce injury outcomes.

Theory and New Information

A major contribution of this review is the presentation of a cross-contextual gradient linking knowledge, behaviour, and injury reduction, based on comparative evidence from twenty studies. Unlike other reviews that have examined either knowledge or behavioural outcomes alone, few have synthesized these elements across a causal translation pathway spanning different regulatory environments (DeRoo & Rautiainen, 2000; Nugraheni & Susilo, 2025; Ricci et al., 2016). By combining meta-analytic findings, longitudinal studies of field training in low- and middle-income countries (LMICs), psychosocial modelling, and biomarker-validated exposure data, this review advances a systems-based conceptualization of training effectiveness.

The findings demonstrate that cognitive acquisition is highly responsive to educational interventions (Ayaz et al., 2022; Afshari et al., 2021). However, behavioural enactment is not solely determined by knowledge but is instead contingent upon a range of motivational and structural moderators (Parasram & Choudhury, 2025; Sapbamrer et al., 2024; Surendran et al., 2024). Consequently, meaningful injury prevention cannot rely on education alone; rather, it requires a comprehensive approach that integrates educational, regulatory, and material support (Bradman et al., 2009; Rautiainen et al., 2008), ensuring that workers are both informed and enabled to adopt safer practices within their occupational environments.

Such a stratified interpretation extends beyond descriptive reviews of training effects and situates the educational approach to agricultural safety within the broader context of occupational safety systems (Davis et al., 2015). This cross-context synthesis indicates that agricultural safety training is most effective when implemented as part of a comprehensive safety system rather than as a standalone intervention. The attenuation gradient should

therefore be understood not as a mere empirical observation but as a structurally patterned phenomenon requiring theoretical explanation.

Implications for Policies and Systems

Relying solely on training as the primary tool for injury prevention is insufficient to achieve sustained reductions in occupational injuries (Rautiainen et al., 2008). Empirical evidence instead supports a multi-component approach that integrates participatory and culturally sensitive training methods (Clausen et al., 2017; Jørs et al., 2014), structural support mechanisms (Kangavari et al., 2024; Sapbamrer et al., 2024), regulatory enforcement (Nugraheni & Susilo, 2025; Rautiainen et al., 2008), community-based normative reinforcement (Arcury, Estrada, et al., 2010; Jørs et al., 2014), and scalable digital delivery platforms (Akkouch et al., 2025).

In low- and middle-income countries, strengthening extension systems and reducing material barriers can enhance behavioural change (FAO, 2025; Parasram & Choudhury, 2025). Interventions based on motivational constructs and risk recalibration are likely to be more effective in developed settings (Caffaro et al., 2022; Surendran et al., 2024).

Thus, this review recommends a paradigm shift: viewing safety training not as an isolated solution but as an integral component of agricultural safety governance.

Summary

Across agricultural systems, a consistent pattern emerges whereby knowledge acquisition occurs relatively easily, behavioural changes are often selective and inconsistent, and meaningful injury prevention ultimately depends on the presence of adequate structural support. Future research should therefore prioritise longitudinal study designs that link behavioural changes to objective measures of exposure or injury, enabling a clearer understanding of causal pathways over time. In addition, there is a need for structural intervention trials that integrate educational components with material provision or regulatory support to address practical constraints faced by workers. Emphasis should also be placed on theory-driven analyses of behavioural processes that are carefully adapted to context-specific barriers and facilitators. While agricultural safety training remains a cornerstone of occupational health strategies, its effectiveness is determined less by the informational content delivered and more by the broader systemic environment in which it is implemented.

Limitations

Several limitations should be considered when interpreting the findings of this review. Methodological heterogeneity in intervention design, outcome measures, and follow-up periods precluded comprehensive meta-analytic pooling; consequently, a systematic narrative synthesis was adopted. In addition, self-reported behavioural outcomes were prevalent, appearing in 16 of the 20 included studies, rendering the findings susceptible to recall and social desirability biases. Injury outcome measurement was also inconsistent across studies, limiting the strength of causal inferences regarding sustained injury reduction, particularly as longitudinal assessments were rarely conducted. Furthermore, while the classification of countries as developed or developing is analytically useful, this binary distinction oversimplifies substantial intra-country variation in regulatory frameworks and socioeconomic conditions.

Additionally, restricting inclusion to Q1 and Q2 peer-reviewed journals may have excluded relevant findings published in lower-tier or non-English journals, potentially

introducing publication bias. This criterion may have unintentionally omitted pertinent intervention studies, particularly those from low- and middle-income countries where research dissemination patterns differ. Finally, publication bias cannot be ruled out, as studies reporting null intervention effects may be under-represented in the published literature.

Despite these limitations, this review offers a comparative and theoretically grounded synthesis of contemporary evidence on the effectiveness of occupational safety training in agriculture.

CONCLUSION

This comparative systematic review evaluated the effectiveness of occupational safety and health (OSH) training interventions in agricultural settings across both developed and developing contexts. The synthesis confirms a systematic decline in intervention effectiveness as outcomes progress from cognitive acquisition to behavioral adoption and, ultimately, to injury prevention. Educational interventions reliably generate significant knowledge gains and produce moderate but heterogeneous behavioral effects; however, they yield limited and inconsistent evidence of sustained injury reduction when implemented alone. Although training effectively influences proximal cognitive determinants of safety, its impact diminishes for more distal outcomes. The transfer of knowledge to long-term behavioral compliance and, ultimately, to measurable injury reduction appears to depend on situational mediators operating at both psychosocial and structural levels.

These findings align with behavioral science frameworks, which conceptualize knowledge as a necessary but insufficient determinant of long-term behavioral and health outcomes. Importantly, the review identifies a context-dependent "bottleneck shift" in the knowledge–behavior–injury pathway. In developed agricultural systems, where structural supports are generally adequate, the primary bottleneck occurs between behavior and injury reduction; sustained behavioral adherence is impeded by psychosocial factors such as risk perception, habitual routines, and motivational inertia. In contrast, in developing agricultural systems, the bottleneck shifts upstream to the knowledge–behavior interface: cognitive gains are achieved, but structural constraints, including limited PPE access, enforcement gaps, and resource limitations, prevent their translation into safe practices. These contextual factors account for a substantial portion of the variability observed across intervention studies. The primary value of this review lies in its articulation and comparative validation of the knowledge–behavior–injury gradient, which integrates previously scattered research findings across regions and study designs. The bottleneck shift model extends this contribution by identifying where and why attenuation occurs in different contexts, thereby offering a targeted framework for intervention design. By situating training within broader occupational safety systems, this review demonstrates that education is a crucial but incomplete component of injury prevention frameworks. Sustainable injury reduction requires the alignment of cognitive capacity, behavioral reinforcement mechanisms, regulatory structures, economic support, and community-level norms.

The implications for policy and practice are clear. Agricultural safety training should continue to receive investment because of its enduring cognitive benefits. However, the effectiveness of such training must be evaluated within the broader context of multilevel approaches, including regulatory enforcement, resource access, community participation, and

culturally specific behavioral reinforcement. The bottleneck shift model suggests that interventions must be contextually targeted: in developed settings, strategies should focus on behavioral reinforcement and psychosocial engagement; in developing settings, structural enablement must accompany educational efforts. Future research should prioritize longitudinal studies that link sustained behavior change with verified injury outcomes and should explore system-level configurations that optimize the translation of knowledge into injury reduction. Agricultural occupational safety and health training remains a vital cornerstone of injury prevention. However, bridging the gap between knowledge, behavior, and injury requires systemic integration rather than simply increased educational efforts. Recognizing where the bottleneck occurs and targeting interventions accordingly represent the most promising approach to achieving sustained reductions in occupational harm across diverse agricultural contexts.

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