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# Climate change-driven changes in pest dynamics and their impact on pesticide residues in animal-derived foods: A systematic review

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**ABSTRACT**

This systematic review examined evidence linking climate-related changes in pest dynamics with pesticide use, livestock exposure pathways, and pesticide residues in animal-derived foods. Scopus, Web of Science Core Collection, PubMed/MEDLINE, and ScienceDirect were searched for studies published from 2000 to 2025. Of 2,230 records identified, 92 studies met the eligibility criteria. Owing to substantial heterogeneity, evidence was synthesized narratively with descriptive study-reporting frequencies. Increased pesticide application was reported in 63 studies (68.5%), and feed contamination was the most frequently reported livestock exposure pathway (73 studies; 79.3%). Residues were reported in studies of milk, meat, and eggs, but matrix-specific detection percentages were not calculated because reliable denominators were unavailable. Overall, the evidence supports an association-based climate-pest-pesticide-livestock-food framework rather than a complete causal sequence. The principal evidence gap is the scarcity of studies evaluating the full pathway within a single empirical design.

**Keywords:** climate change, pest dynamics, pesticide residues, livestock systems, food safety

## INTRODUCTION

Climate change is altering the environmental conditions under which agricultural production takes place, with implications for productivity, food security, and public health (Food and Agriculture Organization [FAO], 2022; Intergovernmental Panel on Climate Change [IPCC], 2023). Temperature, humidity, and precipitation are important determinants of pest development, survival, reproduction, and geographical distribution. Warmer conditions have been associated with faster development, altered overwintering success, and range shifts in several pest groups (Bebber et al., 2013; Deutsch et al., 2018; Ortiz-Bobea et al., 2021). Changes in rainfall and climatic variability may likewise modify ecological interactions and the timing or predictability of pest outbreaks (Skendžić et al., 2021). These responses are not uniform across species or regions, but they create practical challenges for pest-management strategies developed under historically more stable climatic conditions.

Several studies have reported increased pesticide use under conditions of greater or changing pest pressure associated with climatic variability.

Pesticides remain important tools for limiting agricultural losses, but inappropriate or excessive use is associated with environmental and health concerns, including soil and water contamination, biodiversity loss, ecological imbalance, and selection for pesticide-resistant pest populations (Sharma et al., 2019; Nicolopoulou-Stamati et al., 2016; Yasir et al., 2025). From a sustainable-development perspective, these concerns are relevant because they may affect ecosystem resilience and the long-term sustainability of agricultural production.

Pesticide use is also relevant to livestock systems and animal-derived foods because residues may enter livestock production systems through contaminated feed, drinking water, pasture, soil, and atmospheric deposition (Kan & Meijer, 2007; Rezaei et al., 2023). Following exposure, pesticide compounds may be retained in animal tissues or transferred to milk, meat, and eggs depending on their persistence, lipophilicity, and physicochemical properties (Jia

et al., 2024; Qian et al., 2023; LeDoux, 2011). Persistent organic pollutants and lipophilic pesticides are of particular concern because of their bioaccumulation and biomagnification potential within food chains, which may increase the potential for long-term dietary exposure in humans.

The occurrence of pesticide residues in foods of animal origin is an important food-safety concern. Chronic pesticide exposure has been associated with endocrine disruption, neurotoxicity, reproductive effects, immunotoxicity, and increased risk of chronic disease (Mostafalou & Abdollahi, 2013; Mnif et al., 2011; Lazarević-Pašti et al., 2025). In addition, simultaneous exposure to multiple pesticide compounds raises concerns about cumulative or synergistic toxicological effects that remain insufficiently addressed in existing regulatory and risk-assessment frameworks. Vulnerable populations, including children, pregnant women, and immunocompromised individuals, may be particularly susceptible to these adverse health outcomes.

Climate-related changes may also complicate pesticide management by altering the timing, duration, and geographical distribution of pest pressure. Longer pest-active periods, warmer conditions, and the emergence of resistant populations have been associated with changes in pesticide application patterns and the use of multiple chemical classes (Delcour et al., 2015; Motafeghia et al., 2026). These changes may, in turn, alter environmental exposure pathways relevant to livestock systems. However, relatively few studies have examined several links in this sequence within the same empirical framework, and most of the literature remains compartmentalized by discipline or outcome.

From a One Health and sustainable-agriculture perspective, understanding the relationships among climate change, pest dynamics, pesticide use, livestock exposure, and food safety is important for the design of resilient production systems. The present review therefore addresses a focused PECO-based question: How do climate change-related alterations in pest dynamics relate to pesticide use, and what evidence exists regarding pesticide exposure pathways and pesticide residues in livestock systems and animal-derived foods?

Although each component of this question has a substantial literature, the evidence is not equally developed across the full pathway. Climate effects on pests, pesticide-use patterns, environmental contamination, livestock exposure, and residues in animal-derived foods have generally been studied in separate bodies of work (IPCC, 2023; FAO, 2022; Delcour et al., 2015; Godde et al., 2021). The resulting gap is specific: few studies follow the complete climate-pest-pesticide-livestock-food sequence within a single empirical design, making it difficult to determine how strongly the individual links operate together under real production conditions.

This review was undertaken to map the available evidence across those links, distinguish recurring study-level patterns from direct causal evidence, and identify where the pathway remains empirically unsupported.

Its contribution is therefore more specific than the integration of several disciplines under a One Health perspective. By comparing evidence across climate factors, pest responses, pesticide-use patterns, livestock exposure routes, food matrices, study designs, and analytical approaches, the review identifies both the better represented links in the pathway and the points at which evidence becomes sparse or methodologically difficult to compare.

The One Health perspective is used here as an interpretive framework for the environmental, animal, and food-safety implications of the findings, rather than as the sole basis for claiming novelty.

Previous investigations have reported associations between climatic conditions and changes in pest abundance, geographical distribution, seasonal activity, and reproductive performance, with important implications for agricultural productivity and pest management (IPCC, 2023; FAO, 2022). Separate literatures have also documented pesticide residues in livestock products and their implications for food safety (Jia et al., 2024; Rafiei, 2025). Taken together, these bodies of evidence are compatible with an indirect relationship between climate-related ecological change and pesticide contamination in animal-derived foods, but most studies have examined individual components rather than the interconnected pathway within a single empirical framework.

Existing reviews have generally addressed individual components of this system, including climate impacts on agriculture, pesticide residues, food safety, livestock production, or environmental contamination (Qian et al., 2023; Godde et al., 2021). The present review instead asks whether the links reported across these literatures form a sufficiently supported empirical continuum and examines the methodological and contextual heterogeneity that limits such an inference.

The primary objective was to synthesize evidence on climate-related changes in pest dynamics and their reported relationships with pesticide use, livestock exposure pathways, and pesticide residues in animal-derived foods. Secondary objectives were to characterize heterogeneity, appraise methodological limitations qualitatively, and identify the evidence needed to test the complete pathway more directly.

Accordingly, the review focuses on evidence relevant to the predefined climate-pest-pesticide-livestock-food question, with One Health and sustainability discussed as implications of the synthesis rather than as independent review outcomes.

## MATERIALS AND METHODS

### Study Design and Review Framework

This systematic review examined reported relationships among climate-related environmental changes, pest dynamics, pesticide-use patterns, livestock exposure pathways, and pesticide residues in animal-derived foods. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 reporting guideline to promote methodological transparency and reporting consistency (Page et al., 2021).

Evidence from environmental science, agricultural production, food safety, toxicology, and livestock research was

**Table 1.** Information sources and records identified during the literature search

| Information source | Search route / scope | Records identified, n |
|---|---|---|
| Scopus | Multidisciplinary peer-reviewed scientific literature | 864 |
| Web of Science Core Collection | Citation-indexed multidisciplinary scientific literature | 642 |
| PubMed/MEDLINE | Biomedical, veterinary, and health-related literature | 358 |
| ScienceDirect | Environmental, agricultural, and food-science literature | 270 |
| **Subtotal: electronic databases** | | **2,134** |
| Additional sources | Backward/forward citation tracking and manual reference-list screening | 96 |
| **Total records identified** | | **2,230** |

Note. The literature search covered studies published from January 2000 to December 2025, and the final search was completed in February 2026. Reconstructed database-specific strategies are supplied in **Appendix A**, and the corresponding search concepts, keywords, controlled vocabulary where available, and Boolean logic are summarized in **Appendix B**.

synthesized within a single framework aligned with the predefined review question.

The climate-pest-pesticide-livestock-food sequence was treated as a conceptual pathway rather than as an assumed causal chain. Because many eligible studies evaluated only individual components of the sequence, the synthesis was designed to compare associations and reporting patterns across domains.

Although the review spans several disciplines, the eligibility criteria, study-selection procedures, data extraction, and evidence synthesis were developed around one predefined research question. The review should therefore be interpreted as a focused systematic review rather than a broad narrative overview of climate change and food systems.

The review was not prospectively registered in PROSPERO or another systematic-review registry. The research question, eligibility criteria, search framework, and data-extraction procedures were established before study selection and were reported in accordance with PRISMA 2020. The absence of prospective registration and complete archived search histories is acknowledged as a limitation.

### *Research question (PECO framework)*

The review question was developed using the Population-Exposure-Comparator-Outcome (PECO) framework to improve methodological transparency and ensure a clearly defined review scope.

Population (P): Agricultural and livestock production systems, including food-producing animals and animal-derived food products (milk, meat, and eggs).

Exposure (E): Climate change–related environmental changes, including increasing temperature, altered precipitation patterns, and extreme climatic events affecting pest dynamics.

Comparator (C): Agricultural systems experiencing lower climatic pressure, historical climatic conditions, or alternative climatic scenarios, where reported by the included studies. Because many eligible studies were observational, a formal comparator was not available in every study.

Outcome (O): Primary outcomes included:

- Changes in pest distribution, abundance, survival, and reproduction;
- Changes in pesticide application patterns;
- Pesticide exposure pathways in livestock systems;
- Detection of pesticide residues in animal-derived foods.

### Literature Search Strategy

A comprehensive and systematic literature search was performed in Scopus, Web of Science Core Collection, PubMed/MEDLINE, and ScienceDirect. The search included studies published between January 2000 and December 2025, and the final search was conducted in February 2026. The four electronic databases yielded 2,134 records, while an additional 96 records were identified through citation tracking and manual searching, resulting in a total of 2,230 records before duplicate removal (**Table 1**).

Most previous reviews have primarily focused on one component of this pathway, including climate change impacts on agriculture, pesticide occurrence, livestock production, or food safety, without comprehensively integrating these interconnected processes (López et al., 2017; Qian et al., 2023). Such compartmentalized perspectives make it difficult to evaluate whether climate-related ecological changes, pesticide-management responses, livestock exposure, and residue occurrence are empirically connected across the full pathway. An integrated synthesis is therefore needed to compare evidence across these links while preserving the distinction between association and causation.

Database-specific search strategies reconstructed from the retained review documentation are provided in **Appendix A**. The original database search-history exports were not retained; therefore, the supplementary strategies should be read as transparent reconstructions based on the documented search concepts, the representative Scopus syntax, date limits, and database-specific record counts, rather than as verbatim archived search logs. **Appendix B** summarizes the search concepts, free-text terms, controlled vocabulary where reconstructable, and Boolean logic.

Search terms were developed using the combinations of controlled vocabulary and free-text keywords related to climate change, pest dynamics, pesticide residues, livestock systems, and animal-derived foods. Boolean operators (“AND”, “OR”) were applied to optimize search sensitivity and specificity.

Representative Scopus search syntax: TITLE-ABS-KEY (("climate change" OR "global warming") AND ("pest dynamics" OR "insect distribution" OR "agricultural pests") AND ("pesticide residues" OR "agrochemical contamination") AND ("livestock" OR "animal-derived food" OR milk OR meat OR eggs).

**Table 2.** Eligibility criteria used for study selection

| Eligibility domain | Inclusion criteria | Exclusion criteria |
|---|---|---|
| Publication period | Studies published between January 2000 and December 2025. | Studies published outside the predefined review period. |
| Publication type | Peer-reviewed original research articles. | Review articles, editorials, conference abstracts, and other non-original publications. |
| Language | English-language publications. | Non-English publications. |
| Topical relevance | Studies reporting on at least two components of the review pathway: climate change/climatic conditions, pest status or dynamics, pesticide use or residues, and livestock systems or animal-derived foods. | Studies not addressing at least two components of the predefined review pathway. |
| Agricultural context | Climate-related studies conducted in agricultural, livestock-production, or animal-food contexts. | Non-agricultural studies. |
| Pesticide relevance | Studies reporting pesticide-related outcomes, including pesticide use/application, pesticide exposure, or pesticide residues. | Studies without a pesticide-related outcome relevant to the review question. |
| Livestock / food relevance | Studies involving livestock systems and/or animal-derived foods such as milk, meat, eggs, or multiple animal-food matrices. | Studies without a relevant livestock system or animal-derived food component. |
| Methodological adequacy | Studies providing sufficient methodological and analytical information to permit evidence extraction and interpretation. | Studies with insufficient methodological or analytical information. |
| Laboratory toxicology | Laboratory studies only when directly linked to the predefined climate-pest-pesticide-livestock/food review pathway. | Pure laboratory toxicology studies without direct relevance to the review pathway. |

**Note.** The criteria were applied during title/abstract screening and full-text eligibility assessment. No numerical full-text exclusion reasons are presented in this table; study-selection counts are reported separately in the PRISMA 2020 flow diagram.

## Eligibility Criteria

The included studies were published in English as peer-reviewed original research articles and reported on at least two aspects of the following: climate change, pest status and levels, pesticides or residues, and livestock systems or animal products. Studies lacking sufficient methodological or analytical information, review articles, editorials, and conference abstracts were excluded.

Eligibility criteria were established according to the predefined PECO framework. Studies were included if they investigated livestock production systems or animal-derived foods exposed to climate change-related environmental conditions influencing pest dynamics and reported outcomes related to pesticide use or pesticide residues. Reviews, editorials, conference abstracts, non-English publications, and studies not addressing the predefined outcomes were excluded (**Table 2**). The eligibility criteria applied during study selection are summarized in **Table 2**.

## Study Selection Process

All identified records were imported into EndNote X20 for reference management and duplicate removal. Reviewers screened the records at the title and abstract stage according to the predefined eligibility criteria. Full-text articles considered potentially eligible were subsequently assessed independently by both reviewers. Any disagreements regarding study eligibility were resolved through discussion and consensus.

Among the 2,230 records identified, 452 duplicate records were removed, leaving 1,778 unique records for title and abstract screening. Of these, 1,392 records were excluded according to the predefined eligibility criteria, leaving 386 reports sought for retrieval. All 386 reports were retrieved and assessed for full-text eligibility (reports not retrieved, n = 0). Following full-text assessment, 294 reports were excluded because they did not meet the predefined eligibility criteria. Ultimately, 92 studies were included in the systematic review. The complete study-selection process is presented in the PRISMA 2020 flow diagram (**Figure 1**).

## Minimization of Bias

Several methodological procedures were implemented to minimize potential sources of bias throughout the review process. Eligibility criteria were predefined before the literature search and consistently applied during study selection. Duplicate records were removed prior to screening using reference-management software. Titles, abstracts, and full-text articles were evaluated according to predefined inclusion and exclusion criteria. Data extraction followed a standardized extraction form to ensure consistency across studies. Any uncertainties encountered during study selection or data extraction were resolved through discussion among the review team to achieve consensus. These procedures were undertaken to reduce selection bias, extraction bias, and reviewer subjectivity.

## Data Extraction

Data were extracted using a standardized Microsoft Excel template. Extracted variables included study location, climatic factors, pest-related characteristics, pesticide class, exposure pathway, livestock type, food matrix, and residue-related outcomes (See **Table 3**).

## Qualitative Methodological Appraisal

The methodological limitations of the included studies were considered during interpretation of the evidence. The appraisal focused on study design and representativeness, characterization of climate-related and livestock exposures, assessment of pesticide-related outcomes, analytical methodology, control of potential confounding, and completeness of reporting.

The retained review documentation did not contain sufficiently detailed item-level judgments to reproduce a formal Newcastle-Ottawa Scale (NOS) assessment across the heterogeneous field, observational, and experimental designs. For that reason, the revised review does not claim a formal

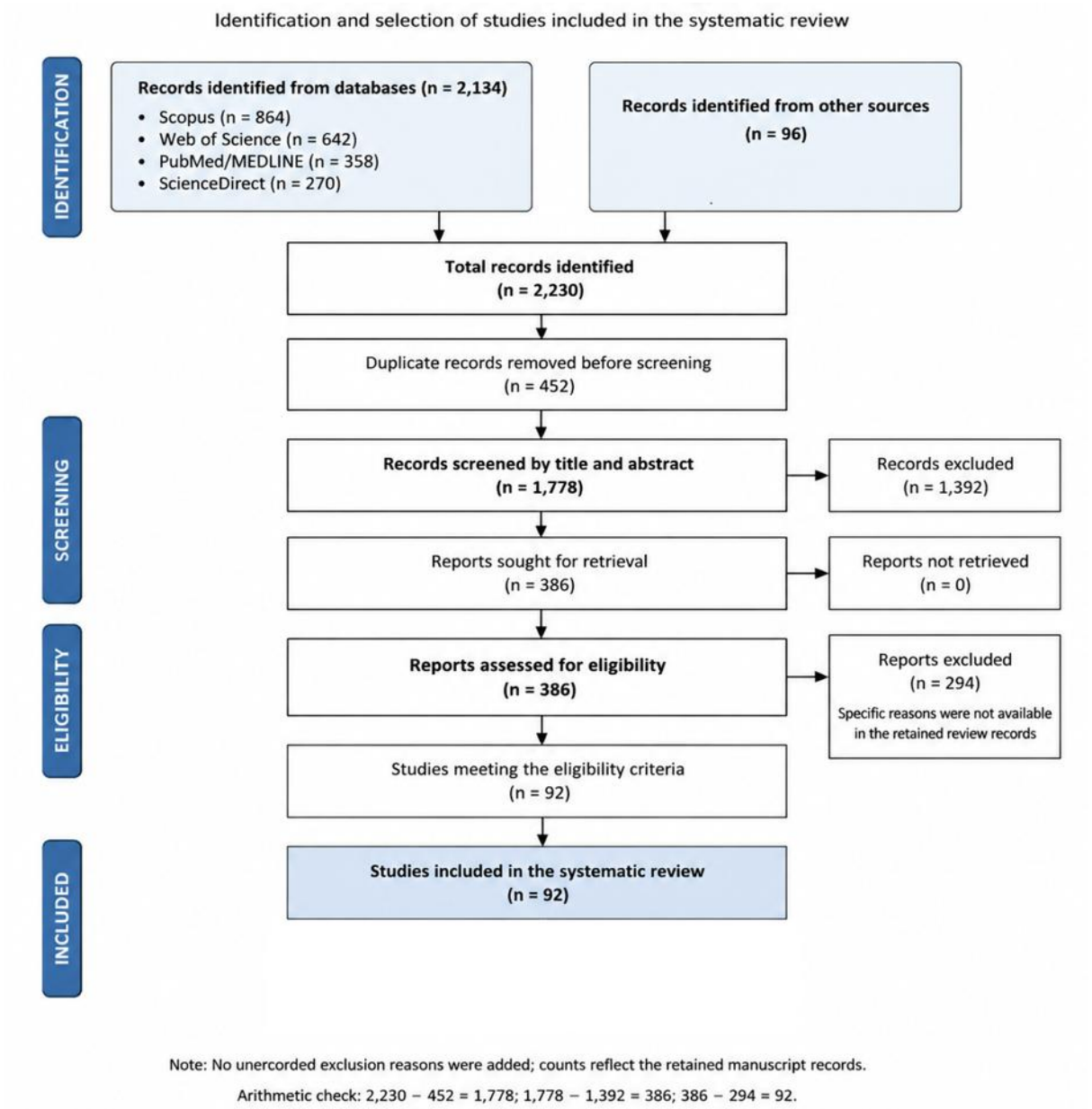


**Figure 1.** PRISMA 2020 flow diagram illustrating study identification, screening, eligibility assessment, and inclusion for the review of climate change-related pest dynamics, pesticide use, and pesticide residues in livestock systems and animal-derived foods (Page et al., 2021)

**Table 3.** Main variables extracted from the included studies (N = 92)

| Category | Extracted variables |
|---|---|
| Study characteristics | Author, publication year, and country of study |
| Climate variables | Temperature, precipitation, and extreme climatic events |
| Pest dynamics | Pest distribution, survival, and reproduction |
| Pesticide information | Pesticide class and reported changes in pesticide application |
| Livestock exposure | Feed, water, and environmental exposure pathways |
| Food products | Milk, meat, eggs, and multiple animal-derived food matrices |
| Outcomes | Pesticide residue occurrence and key study findings |

**Note.** Data were extracted using a standardized Microsoft Excel template. The table summarizes the principal variables documented for the 92 studies included in the systematic review.

NOS-based risk-of-bias assessment and does not assign retrospective numerical scores or low, moderate, or high risk categories.

Instead, methodological limitations were appraised qualitatively using the information available in the retained extraction and study records and were considered when judging the consistency and generalizability of the findings. No study was statistically weighted or excluded on the basis of methodological quality. Reviewer-specific item-level judgments and inter-reviewer agreement for a formal risk-of-

**Table 4.** General characteristics of included studies

| Variable | Category | Number of studies (n) | Percentage (%) |
|---|---|---|---|
| Region | Europe | 29 | 31.5 |
| | Asia | 26 | 28.3 |
| | North America | 17 | 18.5 |
| | Other regions[1] | 20 | 21.7 |
| | **Total** | **92** | **100.0** |
| Study design | Field studies | 48 | 52.2 |
| | Observational studies | 31 | 33.7 |
| | Experimental studies | 13 | 14.1 |
| | **Total** | **92** | **100.0** |
| Animal-derived products | Milk | 38 | 41.3 |
| | Meat | 29 | 31.5 |
| | Eggs | 15 | 16.3 |
| | Multiple products | 10 | 10.9 |
| | **Total** | **92** | **100.0** |

**Note.** Percentages represent the proportion of the 92 included studies reporting the specified characteristic or finding. These percentages describe study representation by food matrix and do not represent residue detection rates.

bias instrument cannot be reconstructed from the retained records and are therefore not reported.

### Evidence Synthesis

Given the substantial heterogeneity in study design, climatic exposure, pest species, pesticide class, livestock system, food matrix, analytical method, and outcome reporting, statistical pooling was not considered appropriate. The evidence was synthesized narratively, supplemented by descriptive study-reporting frequencies. Unless otherwise specified, each frequency was calculated as the number of included studies reporting a particular characteristic or finding divided by the full set of 92 included studies. No statistical weighting, pooled effect-size estimation, or formal meta-analysis was performed.

These percentages describe how often a characteristic or finding was reported in the included literature. They should not be interpreted as prevalence estimates, contamination rates, exposure proportions, source-attribution fractions, or pooled effect measures.

### Rationale for Narrative Synthesis and Study-Reporting Frequencies

A meta-analysis was not undertaken because the included studies differed markedly in geographical setting, climatic conditions, livestock production system, target pest, pesticide class, analytical method, exposure pathway, outcome definition, and study design. These differences limited direct quantitative comparability and precluded the calculation of defensible pooled effect estimates.

The synthesis therefore used narrative comparison together with descriptive study-reporting frequencies to identify recurring patterns while preserving the methodological diversity of the evidence base.

No separate quantitative subset or pooled analysis was undertaken. Numerical summaries in **Tables 4-8** refer to study-level reporting frequencies across the 92 included studies; where categories were not mutually exclusive, percentages were not expected to sum to 100%.

## RESULTS

### Study Selection

The study selection process is summarized in **Figure 1**. A total of 2,230 records were identified through electronic databases and additional sources. Following the removal of 452 duplicate records, 1,778 unique records remained for title and abstract screening. Of these, 1,392 records were excluded according to the predefined eligibility criteria. A total of 386 reports were subsequently assessed for full-text eligibility. Following full-text assessment, 294 reports were excluded because they did not meet the predefined eligibility criteria. Ultimately, 92 studies were included in the systematic review and contributed to the narrative synthesis and descriptive study-frequency summaries, as applicable to the outcomes reported by each study

### Characteristics of Included Studies

Among the 92 included studies, Europe represented the largest geographical group, with 29 studies (31.5%), followed by Asia with 26 studies (28.3%), North America with 17 studies (18.5%), and other regions, including Africa and South America, with 20 studies (21.7%).

Field-based investigations constituted 48 studies (52.2%), observational studies 31 (33.7%), and experimental studies 13 (14.1%). Regarding animal-derived food products, milk was investigated in 38 studies (41.3%), meat in 29 studies (31.5%), eggs in 15 studies (16.3%), and multiple product categories in 10 studies (10.9%) (**Table 4**).

### Climate Change Factors Influencing Pest Dynamics

Among the 92 included studies, temperature increase was the most frequently reported climate-related factor associated with changes in pest dynamics, being reported in 66 studies (71.7%). Altered precipitation patterns were reported in 50 studies (54.3%), while extreme climatic events were reported in 28 studies (30.4%). Because individual studies could report more than one climate-related factor, these categories were not mutually exclusive (**Table 5**).

**Table 5.** Climate-related factors reported in relation to pest dynamics

| Climate-related factor | Reported pest-related observation | Number of studies (n) | Frequency (%) |
|---|---|---|---|
| Temperature increase | Changes in reproduction and geographic distribution | 66 | 71.7 |
| Altered precipitation patterns | Changes in survival and life-cycle dynamics | 50 | 54.3 |
| Extreme climatic events | Population instability and outbreak fluctuations | 28 | 30.4 |

**Note.** Percentages represent the proportion of the 92 included studies reporting the specified characteristic or finding.

**Table 6.** Climate-related changes in pesticide application patterns

| Parameter | Reported observation | Number of studies (n)† | Percentage (%) |
|---|---|---|---|
| Increased pesticide application | Increase reported | 63 | 68.5 |
| Shift in pesticide class/type | Shift/change reported | 38 | 41.3 |
| Evidence of pesticide resistance | Resistance reported | 34 | 37.0 |

**Note.** Percentages represent the proportion of the 92 included studies reporting the specified characteristic or finding.

**Table 7.** Major pathways of pesticide exposure in livestock systems

| Exposure pathway | Reported role in livestock exposure | Number of studies (n)* | Percentage (%) |
|---|---|---|---|
| Feed contamination | Most frequently reported pathway | 73 | 79.3 |
| Water contamination | Additional reported exposure route | 33 | 35.9 |
| Environmental exposure (soil/air) | Additional environmental exposure route | 26 | 28.3 |

**Note.** Percentages represent the proportion of the 92 included studies reporting the specified characteristic or finding.

**Table 8.** Major pesticide classes identified in included studies

| Pesticide class | Number of studies (n) | Frequency (%) |
|---|---|---|
| Organochlorines | 41 | 44.6 |
| Organophosphates | 36 | 39.1 |
| Pyrethroids | 30 | 32.6 |

**Note.** Percentages represent the proportion of the 92 included studies reporting the specified characteristic or finding.

### Patterns of Pesticide Use Under Climate Change Conditions

Increased pesticide application was reported in 63 of the 92 included studies (68.5% study-reporting frequency). This value describes the proportion of studies reporting increased application and does not estimate the magnitude or prevalence of pesticide-use change. Shifts in pesticide class or type were reported in 38 studies (41.3%), and pesticide resistance in 34 studies (37.0%) (**Table 6**).

### Pathways of Pesticide Exposure in Livestock

Feed contamination was the most frequently reported livestock exposure pathway, identified in 73 of 92 included studies (79.3% of studies). This percentage represents reporting frequency across studies and does not quantify the proportion of livestock exposure attributable to feed.

Contaminated water was reported in 33 studies (35.9%), while environmental exposure through soil and/or air was reported in 26 studies (28.3%) (**Table 7**). Because individual studies could report more than one exposure pathway, these categories were not mutually exclusive.

### Occurrence of Pesticide Residues in Animal-Derived Foods

Pesticide residues were reported in studies involving all major animal-derived food matrices, including milk, meat, and eggs. Because matrix-specific detection denominators were not consistently available in the retained synthesis records, no pooled or prevalence-like detection percentages are reported for these matrices.

### Types of Pesticides Detected

Among the 92 included studies, organochlorines were reported in 41 studies (44.6%), organophosphates in 36 studies (39.1%), and pyrethroids in 30 studies (32.6%) (**Table 8**). Because individual studies could report more than one pesticide class, these categories were not mutually exclusive.

### Methodological Limitations of the Included Evidence

Methodological limitations varied across the evidence base. Studies differed in design, sampling strategy, exposure characterization, residue-detection methods, analytical sensitivity, control of confounding, and completeness of reporting. These differences were considered qualitatively when interpreting consistency and generalizability. Because the retained records do not support a reproducible formal risk-of-bias scoring procedure, no numerical risk scores or study-level risk categories are presented.

### Structured Assessment of Heterogeneity

Heterogeneity was examined descriptively across geographical region, study design, livestock and food context, pesticide class, and methodological characteristics. These comparisons are intended to show the composition and limitations of the evidence base; no statistical subgroup tests were performed (**Table 9**).

Geographical representation was uneven: 29 studies (31.5%) were conducted in Europe, 26 (28.3%) in Asia, 17 (18.5%) in North America, and 20 (21.7%) in other regions, including Africa and South America. These counts describe the distribution of studies and do not demonstrate regional differences in effect.

**Table 9.** Structured descriptive comparison of major sources of heterogeneity

| Dimension | Composition of the evidence base | Interpretive implication |
|---|---|---|
| Geographical region | Europe: 29 (31.5%); Asia: 26 (28.3%); North America: 17 (18.5%); other regions: 20 (21.7%). | Regional representation was uneven. No statistical test of regional differences was performed. |
| Study design | Field-based: 48 (52.2%); observational: 31 (33.7%); experimental: 13 (14.1%). | Differences in exposure definition, sampling, confounding control, and analytical methods limit direct comparison. |
| Livestock / food context | Milk: 38 (41.3%); meat: 29 (31.5%); eggs: 15 (16.3%); multiple products: 10 (10.9%). | These values describe study representation by matrix, not residue-detection prevalence. |
| Pesticide class | Organochlorines: 41 (44.6%); organophosphates: 36 (39.1%); pyrethroids: 30 (32.6%). | Classes were non-mutually exclusive; frequencies do not indicate comparative contamination rates. |
| Methodological characteristics | Substantial variation in climatic indicators, sampling strategy, pesticide-detection method, analytical sensitivity, outcome definition, and reporting completeness. | Methodological limitations were appraised qualitatively; no reproducible formal risk score or statistical subgroup analysis is reported. |

Note. Values are descriptive study-reporting frequencies based on the 92 included studies unless otherwise stated. No formal subgroup analysis or statistical test of between-group differences was performed.

Study designs also varied. Field-based investigations accounted for 48 studies (52.2%), observational studies for 31 (33.7%), and experimental studies for 13 (14.1%). Differences in exposure definition, sampling, confounding control, and analytical methods reduce direct comparability across these design groups.

The food and livestock context was similarly uneven: milk was investigated in 38 studies (41.3%), meat in 29 (31.5%), eggs in 15 (16.3%), and multiple products in 10 (10.9%). These figures indicate study representation by matrix, not residue-detection prevalence. Exposure-pathway categories were also non-mutually exclusive.

For pesticide class, organochlorines were reported in 41 studies (44.6%), organophosphates in 36 (39.1%), and pyrethroids in 30 (32.6%). Because a study could report more than one class, these values are reporting frequencies and cannot be used to infer comparative contamination rates.

Methodological heterogeneity included variation in climatic indicators, sampling strategies, pesticide-detection methods, analytical sensitivity, outcome definitions, and reporting completeness.

Taken together, these dimensions show that the evidence base is heterogeneous in both context and method.

No formal subgroup analysis or statistical test of between-group differences was conducted.

Accordingly, apparent differences across categories are treated as descriptive patterns only.

This heterogeneity is a major reason that pooled effect estimates were not calculated and should be considered when interpreting the study-reporting frequencies.

The qualitative methodological appraisal was used to temper interpretation where study design, exposure assessment, analytical method, or reporting completeness differed substantially.

More standardized designs and reporting would be required for robust cross-region or cross-system comparisons in future updates.

# DISCUSSION

The structured assessment of heterogeneity shows that the evidence does not support a single uniform response across agricultural systems. Interpretation should account for differences in geographical setting, study design, food and livestock context, pesticide class, and analytical method. Because no statistical subgroup tests were performed, the comparisons in Section 3.9 are descriptive and should not be read as evidence of statistically significant between-group differences.

Across the included studies, climate-related environmental changes, pest responses, pesticide-use patterns, livestock exposure pathways, and residue occurrence were reported with varying frequency. The strength and generalizability of these patterns are limited by heterogeneity and by the fact that most studies evaluated individual links rather than the complete pathway.

For this reason, consistency in study-reporting frequencies should not be equated with a pooled effect estimate or with uniform methodological certainty.

## Integrated Synthesis of the Main Findings

The reviewed literature supports a biologically plausible sequence of associations linking climate-related environmental change, pest dynamics, pesticide use, livestock exposure, and pesticide residues in animal-derived foods. It does not, however, demonstrate that sequence as a complete causal chain. Temperature, precipitation, and climatic extremes were commonly examined in relation to pest distribution or activity; changes in pesticide use were reported in many studies; and feed, water, and environmental pathways were described in livestock contexts. These observations arise from different studies and study designs and therefore provide converging, rather than direct, evidence across the pathway.

The most important scientific insight from the synthesis is the fragmentation of that evidence. Individual links are reasonably represented in the literature, whereas studies that follow climate conditions, pest response, pesticide-use change, livestock exposure, and food-residue outcomes together are uncommon.

That gap has direct consequences for interpretation: study-reporting frequencies can identify recurring

observations and under-studied areas, but they cannot establish effect size, mediation, or causal contribution across the complete sequence.

One Health remains useful for interpreting the implications for environmental, animal, and human health, but it is an interpretive framework rather than a substitute for direct empirical evidence.

### Climate-Related Changes in Pest Dynamics

Temperature, precipitation, and climatic extremes were frequently reported in studies examining pest ecology. Temperature increase was the most frequently reported climate-related factor (66/92 studies; 71.7% study-reporting frequency). Previous work has described temperature-sensitive changes in insect development, overwintering, and geographical distribution (Bebber et al., 2013; Deutsch et al., 2018; Ma et al., 2025). The direction and magnitude of these responses nevertheless vary by species, region, and study design.

Altered precipitation and climatic variability were also reported in relation to pest survival, population dynamics, and outbreak patterns. These relationships are context dependent and should not be generalized as uniform effects across agricultural systems (IPCC, 2021).

From a management perspective, such ecological changes may alter the timing, location, or intensity of pest pressure. The present review does not provide a pooled estimate of these effects, and attribution to climate change therefore remains cautious.

### Reported Pesticide-Use Patterns Under Climate-Related Pest Pressure

Increased pesticide application was reported in 63 of 92 studies (68.5% study-reporting frequency). This indicates that increased application was a common observation in the evidence base; it does not quantify the magnitude of change or establish that climate-related pest pressure caused the increase in every study.

Changes in pesticide-use patterns have relevant environmental and management implications. Greater reliance on chemical control can be associated with soil and water contamination, effects on non-target organisms, biodiversity loss, and selection for pesticide resistance (Nicolopoulou-Stamati et al., 2016; Riedo et al., 2025). These broader implications should be distinguished from the descriptive study-reporting frequencies presented here, which do not estimate pooled environmental effects.

### Livestock Exposure Pathways and Residue Transfer

Feed contamination was the most frequently reported livestock exposure pathway, identified in 73 of 92 studies (79.3% study-reporting frequency). This describes reporting frequency across the evidence base and does not establish the proportion of livestock exposure attributable to feed. Contaminated water and environmental exposure through soil or air were also reported, and individual studies could describe more than one pathway.

The transfer and persistence of pesticide compounds in livestock systems depend on compound-specific properties, such as persistence and lipophilicity, as well as on the exposure context. Previous literature has described transfer of persistent or lipophilic compounds to animal tissues and products (LeDoux, 2011; Riyaz et al., 2022). The present review did not estimate transfer coefficients or pooled bioaccumulation rates.

The frequency with which feed was reported highlights the need to study crop protection and livestock exposure together. Future studies should measure feed, water, environmental contamination, animal exposure, and food residues within the same design if the relative contribution of these pathways is to be established.

### Food Safety and Public Health Implications

Pesticide residues were reported in studies involving milk, meat, and eggs. Because the retained synthesis records do not contain reconstructable matrix-specific denominators for residue detection, pooled or prevalence-like detection percentages are not reported for these food matrices. Comparisons among milk, meat, and egg studies should therefore not be interpreted as comparative contamination rates (López et al., 2017; Muñoz-Bautista et al., 2025).

Chronic exposure to pesticide residues, including at relatively low concentrations, has been associated with toxicological outcomes such as endocrine disruption, neurotoxicity, reproductive effects, immunotoxicity, metabolic disorders, and carcinogenic effects (Mostafalou & Abdollahi, 2013). Endocrine-disrupting pesticides are of particular concern because they may interfere with hormonal signaling and developmental processes, especially in vulnerable populations such as infants, children, and pregnant women (Mnif et al., 2011).

Several studies reported more than one pesticide residue within the same food matrix, an issue that is relevant to cumulative-risk assessment. The available studies were too heterogeneous to support a pooled estimate of mixture exposure or toxicity. Standardized residue reporting and explicit mixture assessment would improve the usefulness of future evidence for food-safety evaluation.

### Implications for Livestock Health and Agricultural Sustainability

Several included studies reported associations between pesticide exposure and outcomes related to oxidative stress, endocrine function, immune function, reproduction, or growth in livestock species (García et al., 2012; Shekhar et al., 2024; Kioumarsi et al., 2026). Given variation in design and exposure assessment, these findings are best interpreted as reported associations rather than as pooled estimates of effect.

Potential effects on livestock health may have consequences for productivity and resource use, but those broader sustainability outcomes were not quantified in this review.

The most direct implication for livestock management is therefore the need for better integrated monitoring of pesticide exposure pathways and residues in animal-derived foods under climate-sensitive production conditions.

### Strengths and Limitations of the Review

This review has several strengths, including a focused PECO-informed question, PRISMA-based study selection, synthesis across 92 included studies, and explicit definition of study-reporting frequencies. It also brings together evidence that is usually considered in separate disciplinary literatures.

Several limitations are important. Most included studies evaluated only part of the climate-pest-pesticide-livestock-food pathway, so the synthesis identifies associations across domains rather than direct evidence of a complete causal sequence. The evidence base was also heterogeneous across region, study design, food and livestock context, pesticide class, analytical method, and reporting approach.

The original database search-history exports were not retained; **Appendix A** therefore presents reconstructed database-specific strategies rather than verbatim archived search logs. In addition, the retained documentation does not support a reproducible formal risk-of-bias scoring procedure, so methodological limitations were appraised qualitatively and no numerical NOS scores or study-level risk categories are reported.

Geographical representation was uneven, with a large share of studies from Europe and Asia and fewer data from several low-income and climate-vulnerable settings. Publication bias also cannot be excluded. Together with the absence of meta-analysis, these limitations mean that the study-reporting frequencies should not be interpreted as pooled effects, prevalence estimates, or statistically tested subgroup differences.

The review protocol was not prospectively registered. Future updates should prospectively archive the protocol, exact database search histories, extraction records, and design-appropriate item-level methodological appraisal judgments.

A future update should use a prospectively specified, design-appropriate appraisal tool and retain independent item-level judgments for each study so that study-level risk categories and, where appropriate, sensitivity analyses can be reported reproducibly.

### Research Priorities and Future Directions

The clearest research priority is for longitudinal or systems-based studies that evaluate several links in the climate-pest-pesticide-livestock-food pathway within the same empirical design. Further priorities include greater representation of climate-vulnerable regions, standardized residue-monitoring methods, and studies addressing pesticide mixtures, livestock-management practices, and environmental variability.

Priority areas for future investigation include:

- The development of integrated climate-pest-pesticide-livestock empirical and predictive models;
- The implementation of advanced residue-monitoring and biomonitoring technologies;
- The evaluation of sustainable alternatives such as biopesticides and integrated pest management (IPM);
- The assessment of contamination risks in climate-vulnerable regions, particularly low- and middle-income countries;
- The investigation of cumulative and mixture toxicity associated with multiple pesticide residues in animal-derived foods.

Addressing these gaps would make it easier to distinguish association from causation, compare findings across settings, and develop better supported food-safety and climate-adaptation strategies.

Future interdisciplinary work should prioritize harmonized climate and exposure assessment, pesticide-use reporting, livestock-pathway monitoring, and residue analysis so that multiple links in the pathway can be evaluated within the same study.

### Broader Policy and Sustainability Implications

The findings have policy relevance for pesticide stewardship, livestock exposure monitoring, and food-safety surveillance under changing climatic conditions. Policies that support integrated pest management, monitoring of feed and water contamination, standardized residue surveillance, and reduced unnecessary pesticide use may strengthen resilience while limiting environmental and food-safety risks. Because this review does not estimate causal effects or pooled contamination rates, these implications should be regarded as evidence-informed and precautionary rather than as direct estimates of policy effect.

A One Health perspective can help connect environmental contamination, animal exposure, and human food safety in policy and monitoring. Future policy-oriented work, however, should be grounded in integrated empirical studies and harmonized surveillance rather than in an assumption that the complete pathway has already been demonstrated.

Overall, the evidence supports an association-based conceptual framework linking climate-related environmental change, pest dynamics, pesticide-use patterns, livestock exposure pathways, and residue occurrence. The major unresolved gap is the scarcity of studies that evaluate these links together within one study design.

## CONCLUSION

This systematic review synthesized 92 studies addressing relationships among climate-related environmental change, pest dynamics, pesticide-use patterns, livestock exposure pathways, and pesticide residues in animal-derived foods. Because the evidence was heterogeneous, the findings were summarized narratively with descriptive study-reporting frequencies rather than pooled effect estimates.

Climate-related factors were frequently reported in studies describing changes in pest dynamics, and increased pesticide application was reported in 63 of 92 studies (68.5% study-reporting frequency). Feed contamination was the most frequently reported livestock exposure pathway (73/92 studies; 79.3% study-reporting frequency), while water and environmental pathways were also reported. These figures describe how often findings or pathways appeared in the

included literature; they do not represent prevalence, magnitude of exposure, or causal source attribution.

Residues were reported in studies involving milk, meat, and eggs, but matrix-specific detection percentages are not presented because the relevant denominators could not be reconstructed reliably. The review therefore does not estimate pooled contamination prevalence or comparative detection rates across food matrices.

The principal scientific conclusion is that evidence for the individual links in the climate-pest-pesticide-livestock-food pathway is more developed than evidence for the pathway as a whole. Few studies assess climate conditions, pest response, pesticide-use change, livestock exposure, and food residues together within the same empirical design. This fragmentation, combined with methodological heterogeneity, limits causal inference and direct quantitative comparison.

Future research should prioritize integrated longitudinal and systems-based studies, harmonized exposure and residue-monitoring methods, transparent archiving of search and appraisal records, and better representation of climate-vulnerable regions. These steps would provide a stronger empirical basis for pesticide stewardship, livestock management, food-safety surveillance, and climate-adaptation policy.

Within these limits, One Health remains a useful framework for interpreting the connections among environmental change, animal exposure, and human food safety. The conclusions of this review are therefore deliberately association-based rather than causal.

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# APPENDIX A

## Reconstructed Database-Specific Electronic Search Strategies

**Reporting note.** The original database search-history exports were not available at the revision stage. Accordingly, the strategies below were reconstructed from the documented review framework, the representative Scopus syntax reported in the manuscript, the stated search concepts, the publication period (January 2000-December 2025), the final search month (February 2026), and the database-specific record counts. They are provided for transparent reporting and should not be interpreted as verbatim archived search logs.

| Database | Platform / interface | Search field(s) | Coverage / limits | Search date | Records identified |
|---|---|---|---|---|---|
| Scopus | Elsevier | TITLE-ABS-KEY | Publication years 2000-2025 | February 2026 | 864 |
| Web of Science Core Collection | Clarivate | Topic (TS) | Publication years 2000-2025 | February 2026 | 642 |
| PubMed/MEDLINE | NCBI PubMed | MeSH where applicable + Title/Abstract | Publication dates 2000-2025 | February 2026 | 358 |
| ScienceDirect | Elsevier | Search interface; phrase/Boolean search | Publication years 2000-2025 | February 2026 | 270 |

**Table A1.** Scopus

| | |
|---|---|
| Reconstructed search strategy | TITLE-ABS-KEY(<br>("climate change" OR "global warming" OR "climate variability" OR "climatic change" OR "extreme weather" OR heatwave* OR drought* OR flood* OR temperature OR precipitation)<br>AND<br>("pest dynamics" OR "agricultural pest*" OR "insect distribution" OR pest* OR insect* OR arthropod* OR vector* OR parasite* OR infestation* OR "pest outbreak*" OR "pest population*")<br>AND<br>("pesticide residue*" OR "pesticide use" OR "pesticide application" OR pesticide* OR agrochemical* OR "agrochemical contamination" OR insecticide* OR acaricide* OR herbicide* OR fungicide*)<br>AND<br>(livestock OR cattle OR cow* OR dairy OR sheep OR goat* OR swine OR pig* OR poultry OR chicken* OR "animal-derived food*" OR "animal origin food*" OR milk OR meat OR egg* OR "dairy product*")<br>)<br>AND PUBYEAR > 1999 AND PUBYEAR < 2026 |
| Limits / reporting detail | Publication-year limit: 2000-2025. Final search month: February 2026. Reported records in manuscript: n = 864. No additional database-stage filter is asserted here unless documented in the archived review materials. |

**Table A2.** Web of Science core collection

| | |
|---|---|
| Reconstructed search strategy | TS=(<br>("climate change" OR "global warming" OR "climate variability" OR "climatic change" OR "extreme weather" OR heatwave* OR drought* OR flood* OR temperature OR precipitation)<br>AND<br>("pest dynamics" OR "agricultural pest*" OR "insect distribution" OR pest* OR insect* OR arthropod* OR vector* OR parasite* OR infestation* OR "pest outbreak*" OR "pest population*")<br>AND<br>("pesticide residue*" OR "pesticide use" OR "pesticide application" OR pesticide* OR agrochemical* OR "agrochemical contamination" OR insecticide* OR acaricide* OR herbicide* OR fungicide*)<br>AND<br>(livestock OR cattle OR cow* OR dairy OR sheep OR goat* OR swine OR pig* OR poultry OR chicken* OR "animal-derived food*" OR "animal origin food*" OR milk OR meat OR egg* OR "dairy product*")<br>) |
| Limits / reporting detail | Topic-field search with publication years restricted to 2000-2025. Final search month: February 2026. Reported records in manuscript: n = 642. The reconstructed string adapts the common concept structure to Web of Science syntax. |

**Table A3.** PubMed/MEDLINE

| | |
|---|---|
| Reconstructed search strategy | (<br>("Climate Change"[MeSH Terms] OR "climate change"[Title/Abstract] OR "global warming"[Title/Abstract] OR "climate variability"[Title/Abstract] OR "climatic change"[Title/Abstract] OR "extreme weather"[Title/Abstract] OR heatwave*[Title/Abstract] OR drought*[Title/Abstract] OR flood*[Title/Abstract] OR temperature[Title/Abstract] OR precipitation[Title/Abstract])<br>AND<br>("pest dynamics"[Title/Abstract] OR "agricultural pest"[Title/Abstract] OR "agricultural pests"[Title/Abstract] OR "insect distribution"[Title/Abstract] OR pest*[Title/Abstract] OR insect*[Title/Abstract] OR arthropod*[Title/Abstract] OR vector*[Title/Abstract] OR parasite*[Title/Abstract] OR infestation*[Title/Abstract])<br>AND<br>("Pesticides"[MeSH Terms] OR pesticide*[Title/Abstract] OR "pesticide residue"[Title/Abstract] OR "pesticide residues"[Title/Abstract] OR "pesticide use"[Title/Abstract] OR "pesticide application"[Title/Abstract] OR agrochemical*[Title/Abstract] OR insecticide*[Title/Abstract] OR acaricide*[Title/Abstract] OR herbicide*[Title/Abstract] OR fungicide*[Title/Abstract])<br>AND<br>(livestock[Title/Abstract] OR cattle[Title/Abstract] OR cow*[Title/Abstract] OR dairy[Title/Abstract] OR sheep[Title/Abstract] OR goat*[Title/Abstract] OR swine[Title/Abstract] OR pig*[Title/Abstract] OR poultry[Title/Abstract] OR chicken*[Title/Abstract] OR "animal-derived food"[Title/Abstract] OR "animal-derived foods"[Title/Abstract] OR milk[Title/Abstract] OR meat[Title/Abstract] OR egg*[Title/Abstract] OR "dairy product"[Title/Abstract] OR "dairy products"[Title/Abstract])<br>)<br>AND ("2000/01/01"[Date - Publication] : "2025/12/31"[Date - Publication]) |
| Limits / reporting detail | Publication-date range: 1 January 2000 to 31 December 2025. Final search month: February 2026. Reported records in manuscript: n = 358. MeSH terms are shown only where the reconstruction can be stated conservatively; free-text Title/Abstract terms preserve the documented concept domains. |

**Table A4.** ScienceDirect

| | |
|---|---|
| Reconstructed search strategy | ("climate change" OR "global warming" OR "climate variability" OR "climatic change" OR "extreme weather" OR drought OR flood OR temperature OR precipitation)<br>AND<br>("pest dynamics" OR "agricultural pests" OR "insect distribution" OR pest OR pests OR insect OR insects OR infestation)<br>AND<br>("pesticide residue" OR "pesticide residues" OR "pesticide use" OR "pesticide application" OR pesticide OR pesticides OR agrochemical OR agrochemicals OR "agrochemical contamination")<br>AND<br>(livestock OR cattle OR dairy OR sheep OR goats OR swine OR poultry OR "animal-derived food" OR "animal-derived foods" OR milk OR meat OR egg OR eggs) |
| Limits / reporting detail | Publication-year limit: 2000-2025. Final search month: February 2026. Reported records in manuscript: n = 270. Because ScienceDirect interface behavior differs from database field-tag syntax, the reconstructed strategy is presented as the Boolean/phrase expression used conceptually rather than as a verbatim archived query log. |

**Additional sources**

Backward/forward citation tracking and manual reference-list searching identified 96 additional records. These records are not part of the four electronic database search strings above. Electronic databases contributed 2,134 records and additional sources contributed 96 records, for 2,230 records identified before duplicate removal.

**Abbreviations:** MeSH, Medical Subject Headings; NCBI, National Center for Biotechnology Information; TS, Topic search; TITLE-ABS-KEY, title/abstract/keywords. An asterisk (*) denotes truncation where supported.

# APPENDIX B

## Search Concepts, Keywords, Controlled Vocabulary, and Boolean Logic

**Reporting note.** This table summarizes the conceptual search framework documented in the manuscript and used to reconstruct the database-specific strategies reported in **Appendix A**. Synonymous terms within each concept were combined with OR, while major concept blocks were combined with AND. Controlled vocabulary was used where applicable, particularly in PubMed/MEDLINE; however, the exact original archived subject-heading history was not available at revision.

| Concept / domain | Controlled vocabulary (where applicable) | Free-text terms used in the reconstructed framework | Within-domain logic | Primary field mapping | Role in review question |
|---|---|---|---|---|---|
| Climate change / climatic conditions | Climate Change [MeSH Terms] in the reconstructed PubMed strategy; other exact archived headings unavailable | "climate change"; "global warming"; "climate variability"; "climatic change"; "extreme weather"; heatwave*; drought*; flood*; temperature; precipitation | OR | Scopus: TITLE-ABS-KEY; Web of Science: TS; PubMed: Title/Abstract + MeSH; ScienceDirect: Boolean/phrase search | Defines the climate-related exposure context |
| Pest dynamics | Exact archived controlled-vocabulary headings unavailable | "pest dynamics"; "agricultural pest*"; "insect distribution"; pest*; insect*; arthropod*; vector*; parasite*; infestation*; "pest outbreak*"; "pest population*" | OR | Database-specific title/abstract/topic/key word fields | Captures changes in pest occurrence, distribution, survival, reproduction, and pressure |
| Pesticide use / residues | Pesticides [MeSH Terms] in the reconstructed PubMed strategy; other exact archived headings unavailable | "pesticide residue*"; "pesticide use"; "pesticide application"; pesticide*; agrochemical*; "agrochemical contamination"; insecticide*; acaricide*; herbicide*; fungicide* | OR | Database-specific title/abstract/topic/key word fields | Captures pesticide application, exposure, contamination, and residue outcomes |
| Livestock systems | Exact archived controlled-vocabulary headings unavailable | livestock; cattle; cow*; dairy; sheep; goat*; swine; pig*; poultry; chicken* | OR | Database-specific title/abstract/topic/key word fields | Restricts retrieval to relevant animal-production systems |
| Animal-derived foods | Exact archived controlled-vocabulary headings unavailable | "animal-derived food*"; "animal origin food*"; milk; meat; egg*; "dairy product*" | OR | Database-specific title/abstract/topic/key word fields | Captures animal-food matrices relevant to pesticide residue occurrence |

### Overall search construction

| Within each concept | Synonyms and related terms were combined using OR. |
|---|---|
| Between concept blocks | Climate change AND pest dynamics AND pesticide use/residues AND livestock systems/animal-derived foods. |
| Database adaptation | Syntax, field tags, truncation, phrase searching, and date limits were adapted to the functionality of each database; complete reconstructed strings are reported in **Appendix A**. |

**Note.** An asterisk (*) denotes truncation where supported by the database interface. Quotation marks indicate phrase searching. The concept domains reflect those explicitly reported in the manuscript: climate change, pest dynamics, pesticide residues, livestock systems, and animal-derived foods.