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# Mapping Global Research on Edible Insects in Food Science: Trends, Themes, and Geographic Gaps

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## ABSTRACT

*Entomophagy, the consumption of insects as a food source, has long been rooted in local traditions across many regions. As global food systems face increasing pressure from population growth and environmental degradation, entomophagy has attracted growing interest within the international research community. Nevertheless, the scientific knowledge landscape of entomophagy, particularly within the context of applied food science, has not yet been comprehensively mapped. This study aims to examine the structure, trends, and gaps in global edible-insect research using a quantitative bibliometric approach, based on 3,515 documents indexed in Scopus and Web of Science from 2003 to 2024 and retrieved through a systematic keyword-based search strategy. Analytical tools including VOSviewer, Bibliometrix, CiteSpace, and SciMAT were used to map research networks, identify key themes, and trace trends over time. The analysis indicates a marked increase in publications following the FAO's 2013 report, alongside a thematic shift from biological exploration toward applied food technology a shift accelerated by the European Union's Novel Food regulation (2021–2023). Research activity clusters around three dominant themes: insect biology; nutritional value and food applications; and food chemistry and methodology. The Netherlands, Italy, and the United States lead in citation impact, while countries of the Global South, despite their long-standing traditions of insect consumption, remain underrepresented in the literature. The study concludes that three pressing gaps inequality in geographic representation, limited use of industrial-scale Life Cycle Assessment, and weak integration of socio-cultural dimensions need to be prioritized on the global research agenda to support a more sustainable and inclusive transition in food systems.*

***Keywords**: applied food science, bibliometric analysis, edible insects, entomophagy, sustainable food systems*

## INTRODUCTION

The global food system is currently under increasing pressure. As the world's population continues to grow, food demand is projected to rise by approximately 35% to 56% between 2010 and 2050, depending on various socio-economic scenarios. At the same time, food insecurity remains a serious challenge; in 2023, about 28.9% of the global population equivalent to approximately 2.33 billion people experienced moderate to severe food insecurity, meaning they lacked stable and adequate access to food (Burki, 2022). In response to this situation, alternative food sources are being

increasingly explored, one of which is entomophagy, or the consumption of insects, which has recently regained scientific attention as a potentially sustainable and promising solution (Peshuk et al., 2023). Insects are recognized for their high nutritional value, containing protein, essential amino acids, and various micronutrients beneficial to human health, while also being produced with significantly lower environmental impacts compared to conventional livestock (Ordoñez-Araque et al., 2022; Rahmawati, Leksono, et al., 2025). Edible insects are expected to play a key role in future sustainability initiatives, both as a protein source in human food and in livestock feed.

The sustainability of food systems is not merely a matter of production efficiency, but concerns ecological balance, social justice, and overall economic resilience. Compared to cattle and pigs, insects have a faster growth rate, higher feed-to-meat conversion efficiency, and lower space and water requirements plus lower greenhouse gas and ammonia emissions (Jafir et al., 2024). The cultivation of edible insects produces fewer greenhouse gas emissions and has a smaller environmental footprint, aligning with global sustainability goals. In addition to these ecological advantages, insects can utilize organic waste as a feed substrate, thereby integrating circular economy practices into the food chain. Insects offer a viable pathway to address protein deficiencies in human and animal diets while supporting the transition toward more sustainable and resilient food and feed systems (Lisboa et al., 2024). However, although the environmental and nutritional benefits of insects are well-documented, consumer acceptance of edible-insect research products remains relatively low, particularly in Western countries, due to barriers such as food neophobia, disgust, and dietary restrictions (Kröger et al., 2022).

Scientific interest in entomophagy has grown substantially over the past two decades. The dataset (n = 3,515) mirrors a pattern already noted by Ogwu (2025), who analyzed 2,291 Scopus-indexed articles published between 2005 and 2024 and found a marked rise in publication output especially over the last decade with research activity peaking in 2023. This upward trend reached its peak in 2023, with 418 publications recorded in that year. This rapid growth spans a very broad spectrum of studies, ranging from the nutritional value and food safety of insects, processing technologies and insect protein encapsulation, allergenicity aspects, to cross-cultural consumer acceptance studies. Keyword analysis indicates that food security, food neophobia, functional properties, food processing, and sustainability are some of the primary areas reflecting the multidisciplinary nature of edible insect research. This unstructured growth has led to fragmented knowledge, making it difficult for researchers and policymakers to clearly understand the overall direction of research development (Ogwu, 2025). In this context, bibliometric studies in food science and food technology are useful, as they can reveal publication trends, patterns of international collaboration, and commonly used keyword clusters. Such information can help identify new insights as well as areas of research that remain underexplored.

Bibliometric analysis is a quantitative method used to examine and map the development of a scientific field based on publication data. It typically relies on databases such as Scopus and tools like VOSviewer to track keywords, explore relationships between topics, and identify how often certain topics appear together in the literature. Compared to conventional literature reviews, this approach is better suited to handling large volumes of data in a more structured way, resulting in a more comprehensive overview of the field (Gutiérrez-Salcedo et al., 2017). In research on edible insects, tools such as VOSviewer and Bibliometrix can be used to visualize connections among authors, keywords, and the most active countries, while also helping to clarify global research trends. In the broader field of food science, this method has been applied to trace the development of food security research over several decades, revealing shifts in scientific focus alongside major global issues such as the COVID-19 pandemic and climate change (Obrenovic et al., 2024). Therefore, applying bibliometric analysis to topics such as entomophagy and sustainable food systems can provide clearer insights and highlight potential areas for future research.

Although bibliometric studies on edible insects have begun to develop, several important gaps remain insufficiently addressed. Research in this field is still largely dominated by European countries such as Italy, Belgium, and the Netherlands, while contributions from Asia, Africa, and Latin America regions with long-standing traditions of insect consumption remain relatively limited (Mancini et al., 2022). This imbalance leads to a less representative global scientific picture, as perspectives from the

Global South are still underrepresented. In addition, information on the wide variety of insects traditionally consumed across different regions is still limited, particularly regarding processing methods and scientific evidence of their health benefits, which are important for increasing public acceptance. On the other hand, existing bibliometric studies have generally not linked applied food science aspects such as processing technologies, product innovation, and edible-insect research safety standards with a broader sustainable food systems framework (Wardiman et al., 2025). Regulations on edible insects are also still evolving and vary across regions; for example, in the European Union, only six insect species had been approved for commercialization by 2023, indicating that the regulatory framework is still developing. Considering these limitations, there is a clear need for a more comprehensive, up-to-date, and geographically inclusive scientific mapping to better understand the development of edible-insect research within the context of sustainable food systems. Using internationally reputable databases and state-of-the-art bibliometric analysis tools such as VOSviewer and Bibliometrix, this study maps publication trends over time, identifies the most influential authors, institutions, and countries, and uncovers key research themes through keyword cluster analysis. The results of this study are expected to benefit not only researchers seeking to position their work within a broader scientific landscape but also policymakers in need of a scientific foundation to design strategies for transitioning toward a more sustainable, equitable, and resilient food system.

## RESEARCH METHODS

### Study Design

This study employs a quantitative bibliometric approach to analyze trends in scientific publications on edible insects and their contribution to the sustainability of food systems. Bibliometric analysis is a statistical method used to analyze publication patterns in the scientific literature, including temporal publication trends, researcher collaboration networks, the geographical distribution of research, and the evolution of research topics (L. et al., 2023). This approach enables researchers to identify emerging trends, research gaps, and the evolution of knowledge within a specific field of study. This study focuses on documents within the broad scope of Applied Sciences, specifically at the intersection of Food Science, Data Science (bibliometric tools), Materials Science (insect biomass processing), and AI/Robotics-assisted food production technologies. This multidisciplinary scope reflects the increasing complexity of food system research.

This research employs a quantitative bibliometric approach to map and analyze the development of scientific publications on entomophagy and their contributions to the sustainability of food systems. In simple terms, bibliometrics can be understood as a way to trace the development of a scientific field through publication data in a measurable manner by identifying who is actively publishing, where the work appears, with whom collaborations are formed, and which topics are most frequently studied. This approach makes it possible to examine relationships among researchers, citation patterns, and links between topics, providing a clearer picture of how a field evolves and how its scientific networks are structured (Klarin, 2024). Science mapping within bibliometrics also helps reveal how authors, references, and keywords are interconnected, allowing the structure and dynamics of a field to be understood more comprehensively (Pessin et al., 2022). This study sits at the intersection of several disciplines, including food science, applied entomology, sustainable food systems, and data-driven analysis. Such a multidisciplinary approach is necessary because research on edible insects cannot be viewed from a single perspective; it involves aspects of food chemistry, ecology, consumer behavior, regulation, and processing technology.

### Data Sources

The data used in this study were obtained from two major international databases: Web of Science (WoS) and Scopus. WoS was selected for its well-curated journal coverage and structured classification system, while Scopus was included for its broader coverage, particularly of journals from developing countries and non-English publications relevant to entomophagy. Using both sources helps

ensure more comprehensive and complementary literature coverage (Kumpulainen & Seppänen, 2022).

## Search Strategy

The literature search combined keywords related to edible insects and sustainable food systems, developed through preliminary studies and expert input. Searches targeted titles, abstracts, and keyword fields for publications between 2003 and 2024, a window chosen to capture the field's development following the FAO's 2013 report on edible insects. Records exported from Scopus and Web of Science were converted into a common format using the *convert2df()* function in the Bibliometrix R package, which restructures each source's output into a standardized set of bibliographic fields.

The two datasets were then merged with *mergeDbSources()*, aligning shared fields authorship, keywords, affiliation, and citation counts into a single structure. To identify duplicates, we used the *duplicatedMatching()* function with DOI as the matching key: whenever a document appeared in both databases under the same DOI, only one record was kept, with the Scopus entry taking precedence because of its broader citation indexing. Variations in author names across the two sources were then resolved using Bibliometrix's built-in disambiguation routine, ensuring consistency before any author-level or collaboration analysis. Once merged and deduplicated, the dataset underwent a final manual screening to remove irrelevant records, following standard bibliometric data-cleaning practices.

## Inclusion and Exclusion Criteria

The included documents consist of original research articles, review papers, and conference proceedings that focus on edible insects for human consumption, published in English or with an English abstract. Articles focusing solely on insects as animal feed, as well as editorials, comments, and inaccessible full texts, were excluded.

## Analysis Methods

Data analysis was carried out using several bibliometric tools: VOSviewer for mapping networks of keywords, authors, and countries; Bibliometrix for statistical analysis and science mapping; CiteSpace for identifying emerging trends and rapidly growing topics; and SciMAT for tracking thematic development over time (Ji et al., 2023). Overall, the analysis focused on four main aspects: descriptive overview, relationships among key elements (such as authors and keywords), thematic mapping, and regional distribution.

## Metadata Completeness Assessment

The completeness of the metadata was assessed to ensure the quality of the dataset used in the analysis. Table 1 presents the completeness assessment of the datasets used in this study.

Table 1. Example of table title formatting metadata completeness assessment of the bibliometric dataset

| Metadata Field | Total | Missing | Missing % | Status |
|---|---|---|---|---|
| Authors (AU) | 3515 | 0 | 0.00% | Excellent |
| Document Type (DT) | 3515 | 0 | 0.00% | Excellent |
| Journal (SO) | 3515 | 0 | 0.00% | Excellent |
| Publication Year (PY) | 3515 | 0 | 0.00% | Excellent |
| Title (TI) | 3515 | 0 | 0.00% | Excellent |
| Total Citations (TC) | 3515 | 0 | 0.00% | Excellent |
| Keywords (DE) | 3515 | 210 | 5.97% | Good |
| Abstract (AB) | 3515 | 195 | 5.55% | Good |
| DOI (DI) | 3515 | 137 | 3.89% | Good |
| Affiliation (C1) | 3515 | 245 | 6.97% | Good |
| Corresponding Author (RP) | 3515 | 382 | 10.86% | Acceptable |
| Keywords Plus (ID) | 3515 | 1421 | 40.43% | Poor |
| Cited References (CR) | 3515 | 3515 | 100.00% | Not Available |
| Science Categories (WC) | 3515 | 3515 | 100.00% | Not Available |

## RESULTS AND DISCUSSION

### Trends in Annual Scientific Publication Output

Literature from Kavle et al. (2022) indicates that entomophagy publications between 1940 and 2005 were sparse and scattered, appearing well before the period our search set out to cover. This work focused on ethnographic accounts of insect consumption practices among local communities in Africa, Asia, and Latin America, with limited emphasis on developing a broader and coherent scientific framework for entomophagy research (Figure 1). During this period, insects were positioned solely as subjects of descriptive anthropology and entomology, not as a viable food solution on a global scale. The scarcity of publications during this period also reflected an academic stigma: the topic was considered “marginal” or lacking in prestige by mainstream research institutions.


Figure 1. Treemap of the most frequent keywords in global edible-insect research (2003–2024)

The most significant turning point occurred in 2013, when the FAO published the report Edible Insects: Future Prospects for Food and Feed Security, as well as Van Huis’s 2013 work. This report was not merely a standard policy document; it was a scientific manifesto that, for the first time, presented data-driven arguments regarding the potential of insects as a sustainable alternative protein source. With support from the FAO, the UN’s food agency, the report marked a turning point in the growing attention to research on edible insects. Following its release, research funding opportunities expanded across countries, scientific journals became more open to entomophagy-related studies, and researchers gained greater confidence to explore insects as a subject in applied food science. The impact was evident within a relatively short time; over the course of about a decade, the number of annual publications increased from a few dozen to hundreds.

An analysis of 2,291 Scopus-indexed articles from 2005 to 2024 shows that publications in this field have grown rapidly, reaching a peak of 418 articles in 2023. This figure exceeds earlier projections reported in previous studies. The slight decline observed in 2024 does not necessarily indicate a drop in interest but rather suggests the beginning of a stabilization phase. It may reflect a shift away from relatively straightforward topics toward more specific questions that require deeper and more complex approaches.

In terms of citation patterns, the average number of citations per year peaked between 2012 and 2016 and has since declined (Figure 2). However, this should not be interpreted as a decrease in research quality. In bibliometric studies, this pattern is known as citation lag, where more recent publications have had less time to accumulate citations (Jiang et al., 2023). For example, articles published in 2021 have had only about 3–4 years to gather citations, while those from 2013 have had more than a decade. Notably, recent research (2018–2024) has become increasingly advanced, covering topics such as Life Cycle Assessment (LCA) of industrial-scale insect farming, protein

encapsulation technologies, cross-species allergenicity analysis, and more sophisticated modeling of food regulatory policies than in earlier periods.

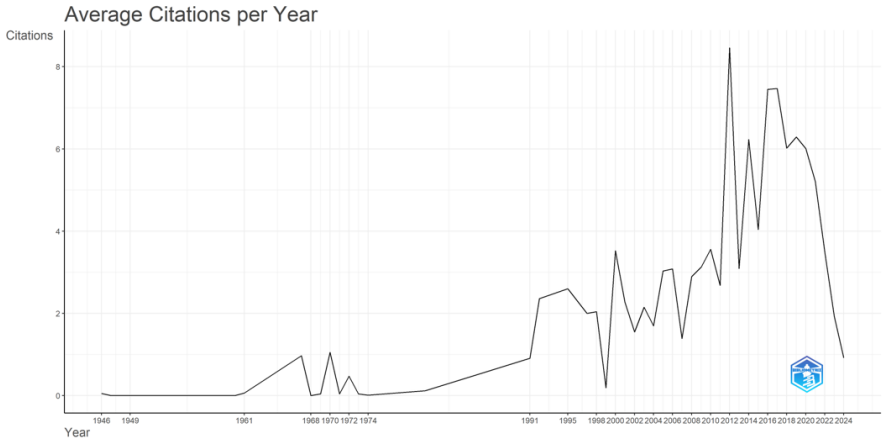


Figure 2. Average annual citations in global edible-insect research, 1940–2024

## Co-occurrence of Keywords and the Evolution of Research Paradigms

Keyword co-occurrence analysis is a bibliometric technique that calculates how often two keywords appear together in a set of articles. If two terms frequently appear together, it indicates that there is a topic or concept consistently linking them in the literature. This method allows researchers to visually "see" the conceptual architecture of a scientific field identifying which topics are central (heavily connected to other topics) and which remain isolated on the periphery. From this analysis, three main thematic clusters were identified, reflecting how the scientific community approaches edible insects from three distinct perspectives. The first cluster, Insect Biology & Ecology (animals: 511 occurrences; insects: 321; larvae: 289; *Tenebrio molitor*: 96), reflects the taxonomic and biological foundations that remain the basis for most experimental studies (Figure 3). *T. molitor*, or the mealworm, is the most widely studied species because it is relatively easy to rear in the laboratory, has a short life cycle, and has long been used as a model organism. Its extensive use over time has resulted in a much larger body of available data compared to other insect species, making it a common reference in research (Ribeiro et al., 2018).

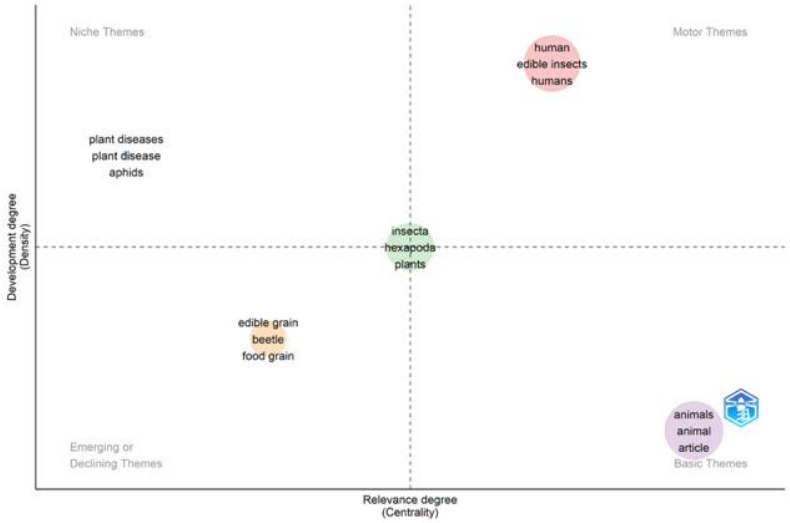


Figure 3. Strategic thematic map of global edible-insect research (1940–2024)

The second cluster, related to nutritional value and food applications (edible insects, humans, protein, nutritional value), shows a clear shift in research focus. While earlier studies mainly described insects, recent work has increasingly explored how they can be used to meet human needs. The frequent appearance of the keyword humans alongside edible insects reflects key questions in recent research, such as how the nutritional profiles of insects compare with conventional animal protein sources and how well the human body can utilize these nutrients. Meanwhile, the third cluster, associated with food methodology and chemistry (controlled studies, chemistry, metabolism), indicates that controlled experiments and detailed chemical analyses support research in this field.

Another notable point is the limited presence of sustainability-related terms such as circular economy, life cycle assessment, and carbon footprint among the most frequent keywords. This is striking, given that sustainability is often cited as a major reason for the growing interest in entomophagy. This suggests that studies directly measuring the environmental impacts of insect farming are still relatively scarce (Biteau et al., 2026; Rahmawati, Tesari, et al., 2025). As a result, claims about the sustainability of insects as a food source are often based more on assumptions than on systematic empirical evidence, highlighting a significant research gap.

Viewed over time, the field's development falls into three phases—not defined by fixed time intervals, but drawn qualitatively from shifts in the dominant keyword clusters seen in the Bibliometrix trending-topics output (Figure 4). The early phase (1960–1990) focused mainly on basic biological aspects of insects, such as immune responses and larval physiology, with little connection to food systems (Figure 4). The next phase (1990–2010) began to emphasize nutritional aspects, including amino acid composition, mineral content, and lipid profiles, reflecting growing recognition of insects as a potential alternative protein source. The most recent phase (2010–2023) shows a broader shift, with increasing attention to topics such as food security, sustainability, climate change, and alternative proteins (Nachtigall et al., 2025). This transition reflects not only a change in terminology but also a repositioning of entomophagy within a wider effort to develop more sustainable food systems. Consequently, research in this area has also begun to attract funding from sources that were previously less involved, such as climate-related and global food security programs.

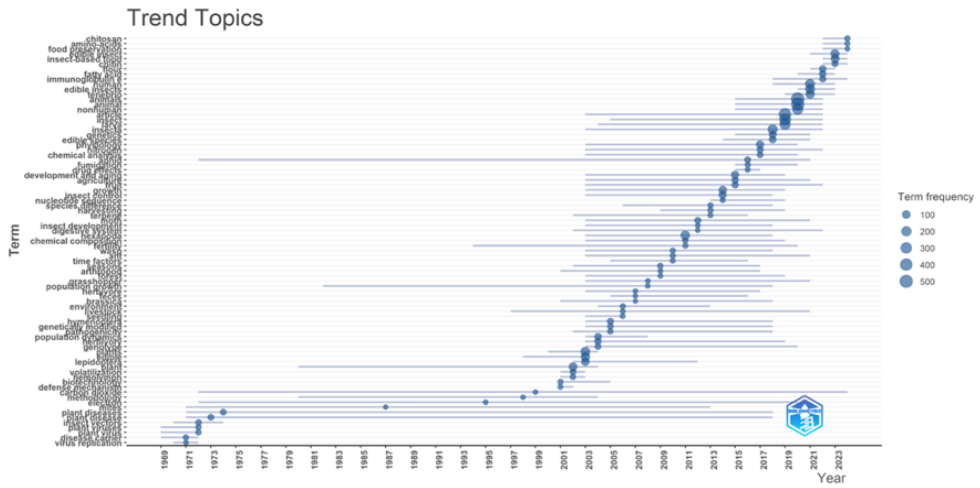


Figure 4. Trending topics from time to time (1960–2023): The temporal evolution of research themes from biological exploration to applied food systems science

## Strategic Thematic Mapping

Strategic thematic maps generated by tools such as Bibliometrix are analytical tools that go beyond simply counting the frequency of topics. They divide research themes into four quadrants based on two dimensions: centrality (how much a theme is connected to other themes in the network reflecting the theme's relevance or importance within the global discourse) and density (how deeply the theme is developed internally reflecting the maturity or level of research elaboration within that theme) (Figure

5). This four-quadrant analysis allows us to answer strategic questions: which topics are mature and dominant, which are emerging, and which may be on the decline?

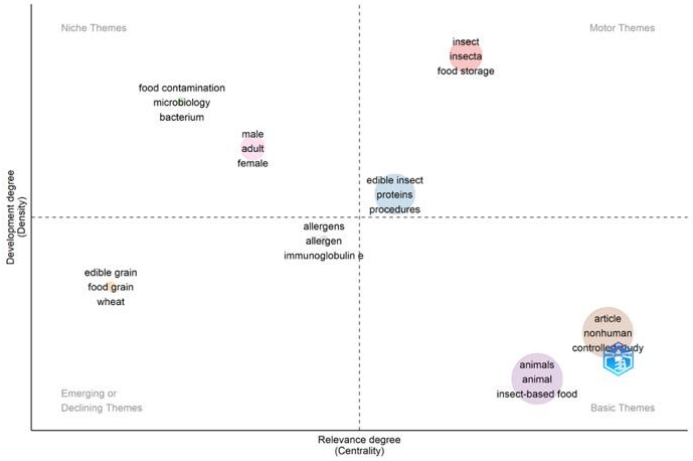


Figure 5. Strategic thematic map (first period): Distribution of the quadrants of the research theme motor, basic, specialized, and emerging/decreasing

Motor Themes (high centrality, high density) are the most central and rapidly evolving topics; they serve as the 'engine' driving the research field. In the first period (196-1990), this position was occupied by the 'edible insects' cluster, reflecting that the most fundamental question in entomophagy whether insects are safe and nutritious for humans remains the primary focus that has not yet been fully answered (Figure 6). The Foundational Theme (high centrality, low density) encompasses comparative biology and taxonomic studies that serve as a conceptual foundation: it is frequently cited by another research. However, it has not yet been deeply developed as a standalone topic. Niche Themes (low centrality, high density) include studies such as pest biology and insect ecology that overlap taxonomically with edible insect research but are not integrated into the main narrative of entomophagy, they exist on their own intellectual islands. Emerging or declining themes (low centrality, low density) are underdeveloped topics they may be in the early exploration phase (with the potential to become driving themes in the future), or they may be being abandoned by the research community.

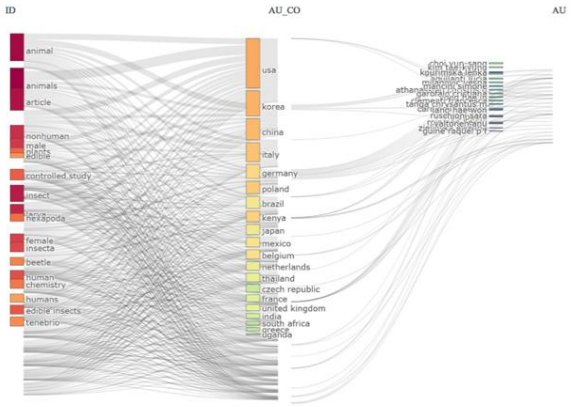


Figure 6. Sankey diagram illustrating the relationships among keywords, countries, and authors in global edible-insect research (1940-2024)

A comparison between the first (1960-1990) and second periods (1990-2010) reveals substantial thematic shifts. In the second period, 'edible-insect researchs,' food safety, and storage technologies moved toward driving positions indicating that research questions have evolved from 'what insects can we eat' to 'how do we scale insect protein into food systems' (Halloran et al., 2018). This shift did not

occur in a vacuum: it was accelerated by the escalation of international regulations. Between 2021 and 2023, the European Union officially authorized six insect species as novel foods including *Acheta domesticus* (crickets), *Alphitobius diaperinus* (small flour beetles), *Locusta migratoria* (migratory locusts), and *Tenebrio molitor* (yellow larvae) (de Carvalho et al., 2025). These authorizations directly spurred a surge in research across two nascent fields: allergenicity studies (as regulations mandate allergy risk labeling) and the standardization of processing technologies (as manufacturers must meet stringent food safety standards).

## Geographic Distribution and Global Scientific Contribution Disparities

Publication patterns reveal a clear contrast. Developed countries such as the United States, China, the Netherlands, Italy, and Germany account for most of the scientific output (Figure 7). At the same time, the richest and most diverse practices of insect consumption are found in Southeast Asia, sub-Saharan Africa, and Latin America (Ogwu, 2025). This difference is not only about numbers but also about who shapes knowledge production. Long-standing local knowledge from these regions is still underrepresented in the international scientific literature.

South Korea stands out for a high volume of publications produced largely through domestic research. This reflects strong national support and a clear research agenda, particularly in developing insects as an alternative protein source. In contrast, Italy and the United States are more involved in international collaborations, with many of their publications resulting from cross-country partnerships (Wardiman et al., 2025).

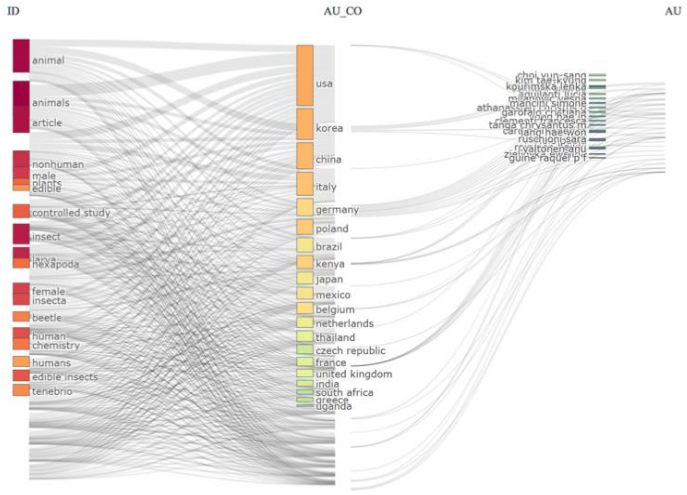


Figure 7. Global research production and citation impact by country: Developed countries (U.S., China, Netherlands, Italy, Germany) lead in output, with the Netherlands, Italy, and the U.S. also topping citation impact and South Korea and China rising as key Asian contributors

Developing countries such as Kenya, Brazil, and Thailand do participate in research, but their roles are often limited to providing field data rather than leading research design. However, local contexts in these countries are essential for a more comprehensive understanding of entomophagy. More broadly, the geographical distribution of publications influences how a topic is studied shaping the questions asked, the methods used, and the conclusions drawn.

Interestingly, countries that produce the most research on edible insects are not those where insect consumption is common. In contrast, in Southeast Asia, Sub-Saharan Africa, and Latin America, insects have long been part of local diets, involving hundreds of species and diverse preparation methods (van Huis, 2021). This suggests that rich local knowledge and experience are still not fully reflected in global scientific discussions.

These conditions point to the need for a more balanced research landscape. Local knowledge about edible insect species, traditional processing techniques, and the sociocultural context of insect consumption represents a valuable source of insight. Integrating this knowledge with modern scientific approaches would help enrich understanding and support the development of more sustainable food systems.

## Citation Impact, Collaboration Networks, and Key Institutions

Citation counts are often used to gauge the influence of research. When an article is widely cited, it usually means that its findings or ideas are considered important and are used by other researchers. At the country level, citation numbers also reflect which countries play a larger role in shaping global scientific thinking on a topic. The Netherlands ranks highest in citation impact, with 3,329 citations, even though its total number of publications is not the largest (Figure 8). This is largely driven by Wageningen University & Research (WUR), an institution that is not only productive but also consistent in producing work that becomes widely referenced.

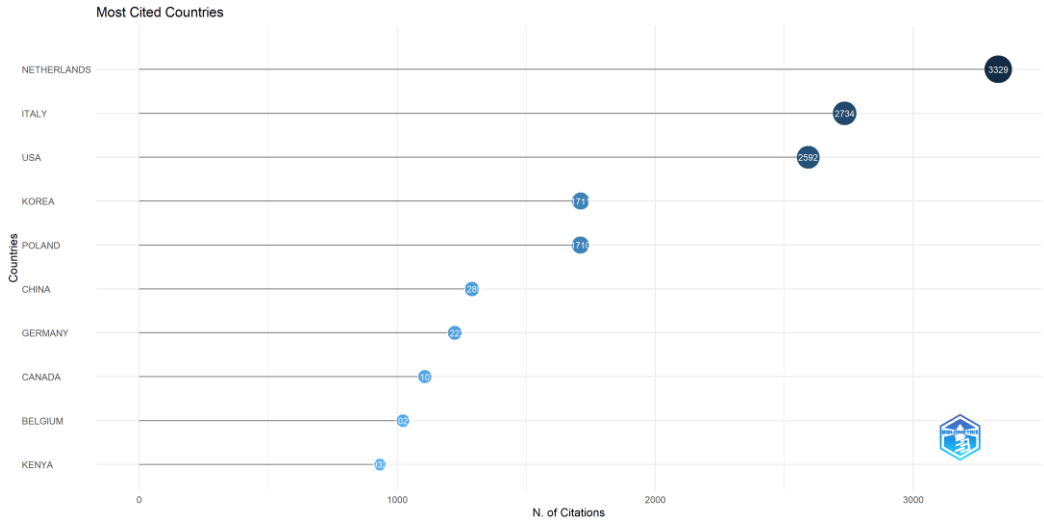


Figure 8. Most cited countries in global edible-insect research (1940–2024)

Since the late 1990s, WUR through researchers such as Arnold van Huis has contributed extensively to environmental sustainability in insect farming, nutritional composition, production technologies, and policy development. The influential 2013 FAO report on edible insects also involved significant input from the WUR team, demonstrating how a single institution with a clear, sustained research direction can have a major impact on a field. Italy and the United States follow the Netherlands in citation impact, while South Korea and China are emerging as increasingly important research centers in East Asia. Meanwhile, Kenya's presence among the top ten is a positive sign that developing countries are beginning to gain recognition in the global scientific landscape, though their contributions still do not fully reflect the richness of their local knowledge.

### *Bradford's Law and the Journal Core Zone*

Bradford's Law helps explain how publications are distributed across journals. In any given field, a small number of core journals typically publish most of the key articles, while the rest are spread across many others with lower frequency (Meller et al., 2025). In edible insect research, these core journals include the Journal of Insects as Food and Feed, which focuses specifically on entomophagy; Food Chemistry, well known for studies on food composition; Food Research International, which frequently publishes work on food technology innovation; and Foods, an open-access journal widely used for interdisciplinary food science research.

Of particular interest is the leadership of the Journal of Chemical Ecology, which holds the highest local H-index (H=36) in this field. The reason an ecology journal rather than a food journal achieves the

highest citation impact lies in the historical development of the field. Before insects were seriously studied as food, researchers interested in their chemical composition published findings in ecology and chemical entomology journals. These foundational articles subsequently became highly cited cross-references in newer food research, creating a historical citation pathway that elevated the journal's H-index within the bibliometric domain of entomophagy. This pattern serves as a reminder that citation influence is shaped not only by current relevance but also by the trajectory through which a field has developed over time.

### *Lotka's Law and Author Productivity Distribution*

Lotka's Law states that within a scientific field, the distribution of author productivity follows an inverse power law: the number of authors publishing n articles is a fixed proportion of the number of authors publishing one article (in theory, approximately $1/n^2$). In practice, this means that most contributors publish only one article, while very few authors publish multiple articles (Tarkang et al., 2017). Verifying this law within a field provides information about the structure of its intellectual output. The analysis of author productivity in this field places Choi Yun-Sang (25 articles) and Kim Tae-Kyung (22 articles) from South Korea as the most productive contributors. This concentration reflects a highly structured research ecosystem: both researchers are based at the Korea Food Research Institute, which has an institutional mandate and long-term funding to develop edible-insect research products, allowing them to publish consistently over many years. From Europe, the presence of Osimani Andrea (18 articles) from Italy reflects the intensity of European research in insect-based fermentation and food safety.

The application of Lotka's Law confirms that over 80% of contributors publish only one paper in this field, a pattern that requires careful interpretation. On one hand, it indicates a healthy multidisciplinary expansion, as many researchers from outside entomophagy including nutritionists, food technologists, sociologists, and economists contribute meaningfully because the topic overlaps with their primary areas of work. On the other hand, it also reveals that the intellectual sustainability of the field still rests on a very small, highly productive core. If this small group ceases to be active, research momentum could quickly lose steam (Mandviwalla & Flanagan, 2021).

## Strategis Implications for Applied Science and Sustainable Food Systems

### *Maturation of Edible-insect research Technology*

The shift in research focus from biology to applied food technology shows that the field is moving forward. Earlier studies were mostly limited to basic exploration, but research has now progressed to testing and practical application. The questions being asked to have also changed: instead of simply asking whether insects are nutritious, the focus is now on how insect proteins can be processed, stabilized, and used in real food products. Several approaches are being developed to address this, including encapsulation to protect proteins during processing, fermentation to improve digestibility and enhance flavor, extrusion to produce products such as nuggets or snacks from insect–cereal mixtures, and emulsion techniques to utilize insect oils. These developments are further shaped by regulatory frameworks such as the European Union's Novel Food policy, which has begun approving certain insect species for food use (Meijer et al., 2025).

However, these regulations also introduce new requirements that researchers must address. Insect-based products must meet strict food safety standards, including controls on contamination, pesticide residues, and allergen risks. As a result, research on insect allergenicity particularly potential cross-reactivity with crustacean allergens such as shrimp and crab has increased significantly in recent years. Taking together, these trends reflect a field that is not only expanding in scope but also becoming more rigorous in its engagement with real-world production and consumer safety concerns.

### *Consumer Acceptance as a Strategic Bottleneck*

Although processing technologies continue to advance and regulations are beginning to open the way, the main challenge in scaling up insects as food lies not in technical issues but in consumer acceptance, as even well-developed products will have little impact if they are not chosen and

consumed. Studies in Western societies consistently highlight two major barriers: reluctance to try unfamiliar foods (food neophobia) and feelings of disgust. These responses are not easily changed through information about nutritional or environmental benefits, as they are shaped by emotional, cultural, and experiential factors. Different approaches are therefore needed, such as gradual exposure, changes in product form, and efforts to make insect consumption more socially acceptable. One strategy that has proven effective is reducing the visibility of the ingredient for example, by processing insects into flour and incorporating them into familiar foods such as bread, pasta, or snacks (Reverberi, 2021). This allows consumers to focus on taste and texture rather than the source of the ingredient, though the approach still requires careful attention to transparency, as long-term consumer trust depends on clear and honest labelling.

In countries where insect consumption is already part of local traditions, the situation is markedly different and has received comparatively less attention in the literature. In places such as Indonesia, the challenge is not introducing insects as food, but rather integrating existing practices into modern food systems without losing cultural values, community autonomy, or economic accessibility (Anderson et al., 2019). This distinction reveals that consumer acceptance is not solely a matter of individual preference but is also deeply embedded in broader social and cultural contexts. A globally inclusive approach to edible-insect research must therefore account for this diversity, recognizing that strategies effective in one setting may be inappropriate or unnecessary in another.

### *Insect Chitin as a Circular Biomaterial*

One of the more promising but still underexplored areas in edible insect research is the use of chitin and chitosan derived from insect biomass. Chitin is a structural compound that forms the exoskeleton of insects and serves as a protective framework, much as bones do in vertebrates, and is also one of the most abundant natural materials, second only to cellulose. Traditionally sourced from shrimp and crab shell waste, this supply is limited and often associated with quality issues. Insects such as *Hermetia illucens* (black soldier fly) are now being considered as alternative sources because of their relatively high chitin content and year-round availability. Importantly, this material is a byproduct of insect farming systems already being developed for food and feed purposes (Xiong et al., 2023), meaning its extraction does not require additional production inputs. Chitin can be further processed into chitosan, which has a wide range of applications including food packaging, biomedical materials, and coatings to extend the shelf life of fresh products (Romanazzi & Moumni, 2022).

This approach offers a more efficient use of insect farming systems by enabling not only protein production but also the generation of additional valuable materials, effectively allowing nearly all parts of the insect to be utilized. The potential is considerable, yet research in this area remains limited. Further studies are needed, particularly to better understand material properties, optimize processing methods, and evaluate real-world applications across different sectors (Lucas et al., 2021). Developing this line of research more fully could strengthen the economic case for insect farming while also contributing to broader goals of reducing industrial waste and improving resource efficiency.

### *Three Most Urgent Research Gaps*

The three research gaps identified in this review emerged from different strands of the analyses presented above. The geographic gap follows directly from the country-level findings in Section 3.4, where the regions with the deepest entomophagy traditions turned out to be the least represented in indexed publications. The gap around industrial-scale environmental data comes from the keyword co-occurrence analysis: terms tied to life cycle assessment and circular economy appeared conspicuously rarely, even though sustainability is often framed as one of the field's central selling points. The third gap on socio-cultural integration stands on shakier ground. It came from reading the geographic and consumer-acceptance findings together rather than from any single quantitative marker, so we offer it here as a provisional observation rather than an established finding. A targeted keyword search for terms such as “consumer behavior” or “community participation” would be a natural next step to test it more rigorously.

The mapping results identify several important gaps that still require attention in global research, and Indonesia is well-positioned to contribute more actively. One key issue is representation. Countries

with long-standing traditions of insect consumption, including Indonesia, remain underrepresented in international scientific publications (Wardiman et al., 2025). In reality, these practices are highly diverse from sago caterpillars in Papua to winged termites in Java but they are rarely documented systematically in indexed research. As a result, the global picture does not fully reflect what is happening on the ground. In some cases, solutions developed elsewhere may not fit local conditions and could even be misaligned with them.

Another gap lies in environmental impact assessment on a larger scale. Much of the existing research on the sustainability of insect farming is still based on laboratory or small-scale studies that do not fully reflect real production conditions. Data on energy use, water consumption, emissions, and land use at an industrial scale are still limited (Smetana et al., 2021). Because of this, comparisons between insects and conventional livestock in terms of environmental impact remain uncertain and are not yet a strong basis for policy or investment decisions.

Social and cultural aspects are also often overlooked. Research has largely focused on laboratory results and quantitative data, while everyday realities have received less attention. For example, there is still limited discussion on how long-standing practices of eating insects can be integrated into modern food systems without losing their cultural meaning or the role of local communities. The shift from traditional practices to commercial systems is not only a technical matter; it also raises questions about who benefits and whether local communities are fairly included (Muñoz-Belloch et al., 2025). Addressing this issue requires more than food science or biology it calls for collaboration with social sciences and meaningful involvement of local communities as active partners rather than just research subjects.

## CONCLUSION

This study set out to map publication trends, identify the most influential countries and authors, and characterize the field's main research themes the same three aims laid out at the start. Across 3,515 entomophagy publications indexed in Scopus and Web of Science between 2003 and 2024, output grew from a handful of articles a year to a peak of 418 in 2023, with the climb becoming noticeable in the years after the FAO's 2013 report on edible insects. Keyword clustering pointed to three recurring themes: insect biology and ecology, nutritional value and food applications, and food methodology and chemistry. At the country level, the Netherlands led in citation impact with 3,329 citations, followed by Italy and the United States, while output itself was concentrated in the United States, China, the Netherlands, Italy, and Germany. Two researchers at the Korea Food Research Institute, Choi Yun-Sang and Kim Tae-Kyung, were the most prolific individual authors, with 25 and 22 articles respectively.

These are patterns in the indexed literature, not proof of cause and effect the rise after 2013 tracks alongside the FAO report but doesn't establish that the report caused it, and the concentration of output among a few countries and authors says more about what Scopus and Web of Science happen to index than about the true global reach of edible-insect research or practice. Scopus was chosen partly for its somewhat wider coverage of developing-country and non-English journals, but both databases still lean heavily toward internationally indexed, English-language publications so literature from the countries in the Global South is likely still underrepresented relative to how much edible-insect research and practice actually happens there.

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