Edible insects: A bibliometric analysis and current trends of published studies (1953–2021)

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Abstract

Edible insects have huge potential as an important alternative food and feed, and research in this area has developed considerably over the past few decades. In this study, a bibliometric analysis was conducted for the first time to provide a quantitative and visualization analysis of the trends in the edible insect research landscape. Documents on 'edible insects' OR 'insects as food' OR 'entomophagy' published from 1953 until 2021 were retrieved from the Scopus database and analyzed in terms of publication output, active journals and countries, leading authors, and institutes, and main keywords. The VOSviewer program was used to visualize trends in the bibliographic information. A total of 1376 documents were published in this time duration on the topic. Meyer-Rochow, Van Huis; Journal of Insect as Food and Feed; and Wageningen University and Research were respectively the top publishing authors, leading journals, and research institutes. Keywords analysis and categorization of studies highlighted 'food security', 'food neophobia', 'functional properties', 'food processing', and 'sustainability' as some of the main areas of interest and research trends, and that research on 'edible insects' is highly multidisciplinary. We have surmised potential 'hotspot' areas of developing research and key players and activities that can drive the research and development of edible insects for use as food. International collaborations to bridge knowledge and habit of entomophagy in many developing countries with the skills and facilities of developed countries could lead to accelerated utilization and commercialization of this food source.

Keywords Edible insects · Alternative food · Research trends · Bibliometric analysis · VOSviewer

Introduction

Bibliometric analysis is a cross-disciplinary science of quantitative analysis that uses mathematical and statistical tools to measure or identify the development and the relationship within several areas of a particular discipline (van Eck and Waltman 2010). Bibliometric analysis has several advantages. It allows the characterization of specific research areas by exploring word frequency, the timeline and development of the topic, and the geographical distribution, which helps draw useful conclusions about who is doing what. At present, this particular method is gaining interest as it contributes new insights into several fields such as economics (Homrich et al. 2018), library services (Coughlin and Jansen 2016; Welsh 2017), and information science (Merigó et al. 2018; Warriach and Ahmad 2016). Bibliometric analysis has also been applied in several fields in the life sciences (Gondivkar et al. 2018; Iftikhar et al. 2019; Shuaib et al. 2015). In this context, VOSviewer is one of the most widely used software for constructing, exploring, and visualizing bibliometric networks and maps (Merigó et al. 2019; van Eck and Waltman 2007; 2010).

In this study, bibliometric analysis is used to study the interesting topic of edible insects. Interestingly, there are no bibliometric studies on entomophagy/edible insects as food. Entomophagy, the consumption of insects, is an ancient indigenous practice that has played a significant role in human nutrition worldwide. It is reported that there are over 2100 species of insects consumed in 113 countries (Chantawannakul 2020; Yen 2009), mostly in Latin America, Asia, Europe, and Africa, where insects
contribute to cultural norms as food, medicine, and religious practices (Gahukar 2018; Raheem et al. 2019).

Globally, entomophagy has rich cultural and nutritional importance (Svanberg and Berggren 2021; Van Huis et al. 2015). However, societal norms and periods of food security have resulted in Western countries perceiving insect consumption only as a cultural novelty (Svanberg and Berggren 2021). However, that is all changing because sustainability concerns have prompted a recent shift to embrace entomophagy practices (Imathiu 2020), and the Food and Agriculture Organization has been actively recognizing edible insects since 2003 when they outlined goals to research and raise awareness of the importance of insects as a vital food and feed source (FAO 2013).

Moreover, this increasing global interest in entomophagy has developed to recognize the need to preserve the environment, provide alternatives to meat and meat-based products, and diversify food and feed sources (Di Mattia et al. 2019). In response to consumer interests, research and development in producing, processing, and utilizing edible insects continue to attract research attention globally. Effort aimed at assessing the evolution of the entomophagy research field is important as it helps identify the key contributions to the field, map the main research trends, highlight the impact of key publications, and generate knowledge of research gaps in the field. One of the most effective ways to study the research terrain of this topic is through a bibliometric analysis. Therefore, the objective of this study was to perform a bibliometric analysis of published studies on the topic of edible insects/insects as food/entomophagy, using information from the Scopus database. We aim to establish the first baseline bibliometric analysis of edible insect research data, align future research direction, and identify changes in trajectory in this growing field of entomophagy.

Methodology

The database used in the bibliometric analysis

Scopus was used in this study as it is one of the most frequently used in bibliometric analysis in the sciences (Airyalat et al. 2019; Herrera-Franco et al. 2020; Liao et al. 2018). This database hosts a wide range of interdisciplinary topics and several indexed scientific and authoritative publications. It is user-friendly and provides all the information needed for the bibliometric analysis, including citations, keywords, authors, reference information. The exported data were used to construct and visualize bibliometric network information using the VOSviewer program.

Search strategies and validation

After selecting a database, we built a valid search query that aimed to recover as many documents as possible with the lowest number of false positives (Naish et al. 2014). An initial manual check of publications retrieved using the search terms ‘edible insects’, ‘insects as food’, ‘entomophagy’, and the Boolean operator ‘OR’ between search phrases was used to capture published documents mentioning insects as a source of food. The search was performed on 20th October 2021. The language of publication was limited to English. The general methodological workflow used in this study is shown in Fig. 1.

Two strategies were used to validate the search queries. Firstly, 10 cited documents in ‘edible insects’ or ‘insects as food’ or ‘entomophagy’ were reviewed to check if they were indeed within the expected scope (i.e., whether they were studies on the consumption of insects as food). Secondly, for several randomly selected authors, the number of articles published by these authors was obtained from the authors’ Scopus ID, and the number of publications was compared to
those obtained using the search query above. These valida-
tion strategies have been used in other bibliometric studies
(Sweileh 2020a; 2020b).

Bibliometric analysis

Data retrieved from Scopus, containing published studies
and their citation information, bibliographic information,
abstract and keywords, and references, were exported as.csv
files for processing by Microsoft® Excel 2016. The data were
also imported into VOSviewer v.1.6.16 (Centre for Science
and Technology Studies (CWTS), Leiden University, Lei-
den, The Netherlands) program to create network visuali-
ization maps. VOSviewer was used to analyze and visual-
ize bibliometric indicators such as the publication output,
research themes, active countries, research collaborations,
institutions, journals, and authors.

The visualization of similarities (VOS) mapping was
used to estimate similarity/affinity according to association
strength. A higher strength indicated a greater similarity
between keywords of publications, and a co-occurrence indi-
cated that the keywords are mentioned together. The number
of clusters can vary depending on the similarity threshold
between the nodes. The resolution of the clusters was set
to a default of 1.00 in this study. This method was applied
to cluster keywords into different groups, with each cluster
being associated with a different color in diagrammatic rep-
resentation. Each word is represented by a circle whose size
indicates the number of publications that mention that term.
The distance between a pair of terms indicates the degree
to which those terms are associated. The threshold, i.e., the
minimum number of articles used in the VOSviewer set-
tings for each type of analysis is as follows: research themes
– 5, active countries – 5, active institute and journals – 5,
co-authorship – 5, and edible insect species studied – 1. In
addition, a full counting method was used, meaning each co-
authorship, co-occurrence, bibliographic coupling, or co-
citation link was assigned the same weight. A thesaurus (See
Online Resource Table S1) was created to categorize key-
words into groups. A VOSviewer thesaurus file was needed
to merge different variants of an item, such as a keyword, for
example, ‘protein’ and ‘proteins’.

Results and discussion

Edible insects—state of the art

Publication types and rate of output

The search query, ‘edible insects’ OR ‘insect as food’ OR
‘entomophagy’ of studies published in English, yielded 1,376
documents. The earliest study in our search results from the
Scopus database was in 1953. Therefore, the study date dura-
tion is indicated as 1953 – 2021. There were many research
articles (1063), accounting for 77.25% of total publications
on this topic. This was followed by review articles (13.01%),
and other documents including editorial materials (1.16%),
conference papers (0.8%), book chapters (5.09%), letters
(0.44%), books (0.51%), corrections (0.22%) and data paper
(0.15%) (see Table 1). The first study found in the Scopus
database concerned with ‘edible insects’ was published in
1953 (i.e., Bristowe 1953), and since then, the number of
studies in this area has grown substantially. Figure 2 illus-
trates the number of studies published and available on the
Scopus database per year. It can be observed that the annual
growth of publications in this area between 1953–1997
was quite low. However, the yearly number of publications
increased from 1997 to 2009, with at least 10 papers pub-
lished per year. By 2017, yearly publication rates surpassed
100 papers, and in 2020, 283 documents were published on
the topic. The number of papers in 2021 as of October 20th
was 263.

The data from Scopus indicate that this research area
is relatively new, judging from the very long ‘lag’ phase.
Most of the peer-reviewed studies on this topic have been
conducted in the past two decades, despite humans having
practiced entomophagy for a considerably longer time in
several geographic areas around the World (FAO 2009;
Bodenheimer 1951). Another interesting observation was
that in the 20th Century, most published studies involving
insects were from entomology and concerned agriculture
rather than food science. Moreover, although some insects
are largely considered pests in Western cultures, and their
use as food is considered primitive (Van Huis 2013), the
trend has been changing (Payne and Ryan 2019). This shift
in consideration of insects as food, interestingly coincided
with some major international events. For example, the topic
of entomophagy featured at the Pacific Science Congress,

| Type of document     | Number | Proportion (%) |
|----------------------|--------|----------------|
| Article              | 1064   | 77.25          |
| Review               | 179    | 13.01          |
| Book Chapter         | 70     | 5.09           |
| Note                 | 18     | 1.31           |
| Editorial            | 16     | 1.16           |
| Conference Paper     | 11     | 0.80           |
| Book                 | 7      | 0.51           |
| Letter               | 6      | 0.44           |
| Erratum              | 3      | 0.22           |
| Data Paper           | 2      | 0.15           |
| Total                | 1376   | 100            |

Table 1 Types of peer reviewed documents available in the literature on ‘edible insects’ OR ‘insects as food’ OR ‘entomophagy’
Seoul, August 1987, the International Conference on Minilivestock, Beijing, September 1995, and the topic of edible insects were discussed at the Insects in Oral Literature and Traditions (Les Insectes dans la tradition orale) conference, Paris, 2000 (Motte-Florac and Thomas 2000). In 2008, the FAO of the United Nations held a workshop in Chiang Mai, Thailand, entitled Forest Insects as Food: Humans Bite back. The focus was on the role of edible forest insects as food (Durst et al. 2010). In 2012, Wageningen University and FAO jointly organized a technical consultation meeting in Rome, where the potential of insects as food and feed in assuring food security was discussed (Van Huis et al. 2013). Some common themes evident in the proceedings and meeting reports of the aforementioned conferences were the renewed attention to entomophagy to improve nutritional status, increase food security, environmental conservation and sustainability, and growth in rural development initiatives. Such meetings may have generated global interest in the potential benefits of entomophagy, which may have accounted for the increased research interest on this topic.

Subject categorization of highly cited publications

In the analysis conducted in this study, ‘leading publications’ have been defined as those cited at least 100 times. This list of publications is shown in Online Resource Table S2. Together, these publications cover various aspects of the use of insects as food. For example, there are published studies (such as #30, 38, 49, in Online Resource Table S2) on entomology and the rearing of insects, the nutritional composition of insects (e.g., #2, 11, 12, 14, 24, 25, 35), consumer attitudes to entomophagy (#21, 22, 32, 39, 42), safety aspects of insects as food (e.g., #6, 8, 9, 16), and the sustainability and environmental impacts of the rearing and consumption of insects (#5, 19, 33, 40). Some of the studies were multidisciplinary (e.g., #1, 44, 52). Several of these studies fall into categories such as ‘food science & technology’, ‘entomology’, ‘agriculture multidisciplinary’, and ‘nutrition dietetics’. The rest of the studies fall into a range of categories, including ‘agriculture’, ‘green sustainable science’, ‘environmental sciences’, ‘engineering’, ‘economics, econometrics and finance’, and ‘sociology’, to name a few. These keywords show that the topic area of entomophagy is highly multidisciplinary, involving a broad range of disciplines, which is why this topic continues to receive the attention of researchers from diverse disciplines.

Countries active in research collaboration

Country co-authorship analysis is important as it can help detect the research-active countries and the extent of communication between them in the research field. Online Resource Figure S1 shows a bibliometric map of the citations of research-active countries on this topic. The bigger nodes represent the most research-active countries on this topic. The distance and thickness of the lines indicate the extent of co-operation among those countries. The United States of America was found to be the leading country with 163 documents, followed by Italy (146), South Korea (118), and the Netherlands (101) (see Table 2).

Insects are widely used as food in Asia, Africa, Oceania, and Central and South America (FAO 2012). In these geographical areas, likely, insects were not the subject of research curiosity because they are considered a common food component. However, in Western countries where insect consumption is not widely accepted, the idea of utilizing insects for food was seen as a research opportunity to study the potential value of a novel food source. It is worth noting that food preferences can be susceptible to change, being influenced by various factors, including the times, age, and trends within communities (Sogari et al. 2017). It is apparent from Table 2 that there are 11 Western
countries leading research in entomophagy (i.e., those having contributed at least 20 publications on the topic). This finding reflects an increased interest in Western countries towards using insect-based products to meet sustainable food demands. Such research activities have recently led the European Food Safety Authority (EFSA) to grant accreditation for dried yellow mealworms to be consumed as food by humans (EFSA et al. 2021). Such regional-level accreditation of a ‘novel’ food material provides reassurance about the consumption of insects in terms of safety and toxicity, thereby helping to promote the use of insects as food in the region. Moreover, topical issues such as climate change and the environmental impact of conventional agriculture have prompted many Western countries to consider ‘alternative’ and ‘novel’ food materials. Just as dietary lifestyles, such as veganism, vegetarianism (House 2016), and flexitarianism (Derbyshire 2017) have been on the rise, so is the practice of entomophagy, as insects are increasingly being considered as more sustainable and environmentally friendly than conventional food sources, such as meat (Sogari et al. 2017).

Although the United States has achieved the highest number of publications, the Netherlands leads in research citations (see Online Resource Figure S2 and Online Resource Table S2). This outcome may be due to collaboration between Wageningen University & Research (WUR, based in the Netherlands) and FAO in this research space. It could be deduced that studies originating from the WUR-FAO collaboration are given more credibility (Raheem et al. 2019), resulting in more citations. Consequently, the output from this research is seen as a foundation for subsequent research development.

Countries such as South Korea, Kenya, China, Mexico, Uganda, and India already have a long history of consuming insects as food, although only a few have contributed substantially to research in this area. Mapping research collaboration in the entomophagy literature, based on country, revealed the countries with substantial collaborations (see Table 2). Collaboration was strongest between the United States and Italy (link strength = 17,245), the United States and Netherlands (11,808), Italy and Germany (9,846), as well as between Italy and Denmark (9,450). A link strength exists between Uganda and Finland, between the United States and Australia, Kenya and Tanzania, and between Japan and Finland. It is worth noting that several African countries (mostly those in Eastern and Southern Africa) are actively engaged in collaborations in this research area. Some countries in Europe, such as the Netherlands, Italy, and Denmark, and some Asian countries, such as South Korea, India, and China, are actively engaged in collaborations. These findings indicate that collaboration in this research area is widespread and global and not confined to specific geographical regions. In other words, geographical location is not a determining factor for collaboration between various countries in this research area, and that is a good thing.

| Country           | Continent | Documents | Citations | Total link strength |
|-------------------|-----------|-----------|-----------|---------------------|
| United States     | North America | 163       | 3048      | 151,960             |
| Italy             | Europe    | 146       | 3610      | 159,373             |
| South Korea       | Asia      | 118       | 1064      | 66,189              |
| Netherlands       | Europe    | 101       | 4507      | 110,950             |
| Germany           | Europe    | 91        | 2450      | 90,074              |
| Kenya             | Africa    | 72        | 1019      | 75,760              |
| United Kingdom    | Europe    | 72        | 1631      | 73,776              |
| Belgium           | Europe    | 70        | 1866      | 74,571              |
| Denmark           | Europe    | 69        | 1646      | 77,196              |
| China             | Asia      | 66        | 1123      | 40,147              |
| Mexico            | South America | 60     | 1165      | 32,404              |
| India             | Asia      | 56        | 842       | 39,316              |
| South Africa      | Africa    | 55        | 682       | 50,146              |
| Finland           | Europe    | 47        | 852       | 47,273              |
| Japan             | Asia      | 46        | 1021      | 35,765              |
| Australia         | Australia | 45        | 843       | 40,551              |
| Canada            | North America | 41     | 669       | 39,608              |
| Thailand          | Asia      | 41        | 551       | 847,067             |
| Nigeria           | Africa    | 37        | 929       | 25,145              |
| Uganda            | Africa    | 35        | 358       | 29,258              |

*Thresholds used in VOSviewer: minimum number of documents of a country = 5, Total number of countries = 47
Document output from active institutions or organizations

The list of the top 20 active institutions/organizations is shown in Table 3. At the top of the list is Wageningen University & Research, with 86 publications. This is followed by Københavns Universitet (University of Copenhagen) (48 publications), then Jomo Kenyatta University of Agriculture and Technology, Kenya (35 publications). A large proportion of the top 20 institutions working on edible insects are based in Europe (13 institutions), and the others are based in Africa (4), the Americas (1), and Asia (2). The list contains only one non-academic institution/organization, the Rural Development Administration, in India, indicating that academic/research organizations are the main drivers of this area of research.

Active journals

Mapping active publishing journals for edible insects or insects as food or entomophagy yielded 4 main clusters (see Fig. 3). Cluster 1 (red) consisted of journals that mentioned 'insect', 'entomophagy', and 'ethno-' in the titles. Some of these journals include African Edible Insects As Alternative Source Of Food, African Entomology, Annals Of The Entomological Society Of America, Asian Myrmecology, Ecology Of Food And Nutrition, Ecology Of Food Nutrition, Entomological Research, Food Security, Indian Journal Of Traditional Knowledge, International Journal Of Tropical Insect Science, Journal Of Asia–Pacific Entomology, Journal Of Economic Entomology, Journal Of Ethnobiology, Journal Of Food Composition And Analysis, Journal Of Human Evolution, Journal Of Insect Science, Journal Of Insects As Food And Feed, Molecular Nutrition And Food Research, Nutrients, Plos One, and Scientific Reports. Among this list, the Journal Of Insects as Food and Feed was the leading journal in the red cluster with 150 documents.

Cluster 2 (green) is composed of standard food science journals and included Appetite, Berliner Und Munchener Tierarztliche Wochenschrift, British Food Journal, Edible Insects In Sustainable Food Systems, Food Quality And Preference, Food Research International, Food Science And Nutrition, Foods, Frontiers In Sustainable Food Systems, Insects, International Journal Of Environmental Research And Public Health, International Journal Of Food Science And Technology, International Journal Of Gastronomy And Food Science, Sustainability (Switzerland). The journal Food Research International was leading in this cluster with 34 documents.

Cluster 3 (blue) is made up of journals focusing on the nutritional aspects of foods. Examples include Animals, European Food Research and Technology, Food Chemistry, Food Science Of Animal Resources, Future Foods, Heliyon, International Journal Of Tropical Insect Science (2022) 42:3335–3355

Table 3 Top 15 institutes/organizations that have published on the topic of ‘edible insects’ OR ‘insects as food’ OR ‘entomophagy’ based on the Scopus database

| Institute                                                                 | Number of publications |
|--------------------------------------------------------------------------|------------------------|
| Wageningen University & Research, Netherlands                            | 86                     |
| Københavns Universitet (University of Copenhagen), Denmark               | 48                     |
| Jomo Kenyatta University of Agriculture and Technology, Kenya            | 35                     |
| Katholieke Universiteit Leuven (Catholic University of Leuven), Belgium   | 31                     |
| International Centre of Insect Physiology and Ecology, Nairobi, Kenya     | 31                     |
| Makerere University, Uganda                                              | 29                     |
| Sveriges lantbruksuniversitet (Swedish University of Agricultural Sciences), Sweden | 23                     |
| Università Politecnica delle Marche (Marche Polytechnic University), Italy | 22                     |
| Aarhus Universitet (Aarhus University), Denmark                          | 20                     |
| Universidad Nacional Autónoma de México (National Autonomous University of Mexico), Mexico | 20                     |
| University of Oulu, Oulu, Finland                                        | 19                     |
| Mendelova Univerzita v Brne (Mendel University in Brno), Czech Republic | 18                     |
| Univerzita Tomase Bati ve Zline (University of Tomase Bati of Zline), Czech Republic | 18                     |
| Czech University of Life Sciences, Prague, Czech Republic                | 18                     |
| Andong National University, South Korea                                  | 17                     |
| Università degli Studi di Napoli Federico II (University of Naples Federico II), Italy | 17                     |
| Leuven's Centrum voor Levensmiddelen en Voedingswetenschappen (Leuven Center for Food and Nutrition Sciences), Belgium | 17                     |
| Université de Liège (University of Liège), Belgium                      | 16                     |
| University of Pretoria, South Africa                                     | 16                     |
| Rural Development Administration, India                                   | 15                     |
**Fig. 3** Network visualization map of all the active journals. The map was created using VOSviewer.

Innovative Food Science and Emerging Technologies, LWT-Food Science and Technology, Molecules, Trends In Food Science And Technology. With 27 documents, Food Chemistry is the leading journal in the blue cluster.

Cluster 4 (yellow) consisted of multidisciplinary journals focusing on sustainability. Examples of journals in this cluster are Critical Reviews in Food Science and Nutrition, Food and Chemical Toxicology, Food Control, Food Microbiology, Frontiers in Microbiology, International Journal of Food Microbiology, Journal Of Food Science, Potravinarstvo Slovak Journal of Food Sciences. Food Control is the leading journal in this cluster and has 13 documents.

Put together, the Journal of Insects as Food and Feed, published by Wageningen Academic, is positioned at the center of the network visualization and has the highest total link strength, indicating that this journal plays a critical role in the research field. This journal is leading with 150 documents and has received nearly 54,431 citations. In addition, 8 out of the top 20 journals (i.e., those that have at least 5 articles on the topic) are published by Elsevier (Table 4), making Elsevier the leading publisher in this field.

**Active authors**

Table 5 shows the top twenty documents authors. Researchers from Europe, Africa, and Asia, dominate the list. The top active author is Meyer-Rochow, from Andong, South Korea, and most other authors are from Europe. Out of 3685 authors, 163 met the threshold of being associated with at least 5 documents, and the largest set contained 88 related names. A total of 75 authors were either single-authored or had their clusters. In Online Resource Figure S3, the number of citations does not reflect the number of papers published, as some authors received a higher number of citations due to their involvement in international collaborations. However, it must be recognized that citations are not necessarily the best index of the quality of a publication (Tahamtan et al. 2016).

**Trends in research of 'edible insects' OR 'insects as food' OR 'entomophagy'**

**Research themes**

Keywords can provide information about the core content of an article and can also be used to identify research trends in a particular domain (Lee et al. 2020). Co-occurrence of the keywords can effectively reflect the hotspots in the discipline fields and provide additional support for scientific research (Redding et al. 2016).

From the 1376 publications obtained from Scopus, VOSviewer retrieved 3120 keywords. A thesaurus file containing the 3120 keywords was made and used to remove overlaps and perform data cleaning. Using a threshold of 5 (i.e., to be selected, keywords must be mentioned at least once in at least 5 documents), 76 keywords were obtained and used to generate a visualization map of the most used keywords. In this analysis, author-reported keywords were used to identify the possible clusters of research topics. The author keyword co-occurrence network map and overlay timeline visualization map are shown in Figs. 5 and 6.
respectively. In these figures, the size of the nodes represents the strength of the keywords, the lines between keywords indicate that they appear together, and the presence of thicker lines means those words co-occur more often (Paull et al. 2017).

Table 4 Active journals, number of documents, and total citations for publications on the topic of ‘edible insects’ OR ‘insects as food’ OR ‘entomophagy’

| Source                                      | Publisher                      | Documents | Citations  | Total link strength |
|---------------------------------------------|--------------------------------|-----------|------------|---------------------|
| Journal of Insects as Food and Feed        | Wageningen Academic            | 150       | 1501       | 54,431              |
| Foods                                       | MDPI                           | 49        | 541        | 27,711              |
| Food Research International                 | Elsevier                       | 34        | 1022       | 20,973              |
| International Journal of Tropical Insect Science | Springer                     | 34        | 158        | 17,438              |
| Insects                                     | MDPI                           | 27        | 245        | 18,249              |
| Food Quality and Preference                 | Elsevier                       | 27        | 1748       | 23,990              |
| Food Chemistry                              | Elsevier                       | 27        | 714        | 8671                |
| Edible insects in sustainable Food Systems  | SpringerLink                   | 20        | 141        | 12,368              |
| Innovative Food Science and Emerging Technologies | Elsevier                      | 17        | 873        | 12,407              |
| Journal of Ethnobiology and Ethnomedicine   | BioMed Central Ltd             | 16        | 447        | 4227                |
| Journal of Asia-Pacific Entomology          | Elsevier                       | 16        | 412        | 7470                |
| Plos One                                    | PLOS                           | 16        | 951        | 5280                |
| Entomological Research                      | Wiley                          | 15        | 540        | 2776                |
| LWT- Food Science and Technology            | Elsevier                       | 15        | 142        | 5778                |
| European Food Research and Technology       | Springer                       | 14        | 224        | 7009                |
| British Food Journal                        | Emerald Publishing             | 13        | 235        | 14,321              |
| Food Control                                | Elsevier                       | 13        | 379        | 5737                |
| Journal of Food Composition and Analysis    | Elsevier                       | 12        | 460        | 6613                |
| Nutrients                                   | MDPI                           | 12        | 134        | 7050                |
| Scientific Reports                          | Nature                         | 11        | 107        | 3035                |

*Thresholds used in VOSviewer: minimum number of documents of a source = 5, Total number of sources = 498, with 55 journals meeting the threshold.

Table 5 Top 20 active authors and their affiliations from published literature on ‘edible insects’ OR ‘insects as food’ OR ‘entomophagy’ obtained from Scopus

| Author                        | Institute                                                                 | Frequency |
|-------------------------------|---------------------------------------------------------------------------|-----------|
| Meyer-Rochow, A               | Andong National University, Andong, South Korea                           | 22        |
| Van Huis, A                   | Wageningen University & Research, Wageningen, Netherlands                 | 22        |
| Kinyuru, J.N                  | Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya    | 21        |
| Ekesi, S                      | International Centre of Insect Physiology and Ecology Nairobi, Nairobi, Kenya | 20        |
| Osimani, A                    | Università Politecnica delle Marche, Ancona, Italy                        | 20        |
| Aquilanti, L                  | Università Politecnica delle Marche, Ancona, Italy                        | 19        |
| Clementi, F                   | Università Politecnica delle Marche, Ancona, Italy                        | 19        |
| Milanovic, V                  | Università Politecnica delle Marche, Ancona, Italy                        | 19        |
| Garofalo, C                   | Università Politecnica delle Marche, Ancona, Italy                        | 18        |
| Adamkova, A                   | Univerzita Tomase Bati ve Zline, Zlin, Czech Republic                     | 17        |
| Nakimbugwe, D                 | Makerere University, Kampala, Uganda                                     | 17        |
| Borkovcová, M                 | Univerzita Tomase Bati ve Zline, Zlin, Czech Republic                     | 15        |
| Cardinali, F                  | Università Politecnica delle Marche, Ancona, Italy                        | 15        |
| Choi, Y.S                     | Korea Food Research Institute, Seongnam, South Korea                      | 15        |
| van Campenhout, L             | Faculteit Bio-igenieurswetenschappen, Leuven, Belgium                     | 15        |
| Francis, F                    | Université de Liège, Liege, Belgium                                      | 15        |
| Halloran, A                   | Københavns Universitet, Copenhagen, Denmark                               | 14        |
| Mlik, J                       | Univerzita Tomase Bati ve Zline, Zlin, Czech Republic                    | 14        |
| Niassy, S                     | International Centre of Insect Physiology and Ecology Nairobi, Nairobi, Kenya | 14        |
| Roos, N                       | Københavns Universitet, Copenhagen, Denmark                               | 14        |
VOSviewer divided the author keywords into 10 clusters. The keywords 'edible insects' were located at the center of the map. The link strength between two nodes refers to the frequency of co-occurrence and can be used as a quantitative index to describe the relationship between two nodes. In this regard, the node 'edible insects' had the highest number of author keyword occurrence (i.e., 636), followed by 'entomophagy' (occurrence = 404), 'food consumption' (252), 'Tenebrio molitor' (106), 'alternative protein source' (90), 'consumer acceptance' (77), 'food security' (60), 'food safety' (57), 'food processing' (56), 'food neophobia' (51), and 'Gryllus bimaculatus' (51). These nodes are those whose link strength is greater than 50. Shown in Table 6 is the list of the top 20 co-occurring keywords obtained from the published studies. These keywords portray all the important themes, or areas researchers have studied on edible insect/entomophagy/insect as food.

**Research theme–cluster #1** The topics that have been grouped due to their high content interconnection are as follows: 'Africa', 'animal feed', 'Gryllus bimaculatus', 'entomophagy', 'entomotherapy', 'ethnoentomology', 'food', 'food products', 'functional properties', 'insect', 'marketing', 'protein source', 'Schistocerca americana', 'storage', 'texture', 'traditional knowledge'. These form Cluster #1. The practice of entomophagy in Africa is a theme that was picked up in this research cluster. Around 500 species of insects are used as food in several countries of Africa (Hlongwane

| (A) By Keywords | Rank | Keywords            | Occurrence | Total Link Strength |
|-----------------|------|---------------------|------------|---------------------|
|                 | 1    | Edible insects      | 636        | 965                 |
|                 | 2    | Entomophagy         | 404        | 737                 |
|                 | 3    | Food composition    | 252        | 524                 |
|                 | 4    | Tenebrio molitor    | 106        | 194                 |
|                 | 5    | Alternative protein sources | 90     | 221                 |
|                 | 6    | Consumer acceptance | 77         | 213                 |
|                 | 7    | Food security       | 60         | 152                 |
|                 | 8    | Food safety         | 57         | 143                 |
|                 | 9    | Food processing     | 56         | 133                 |
|                 | 10   | Food neophobia      | 51         | 135                 |
|                 | 11   | Gryllus bimaculatus | 51         | 101                 |
|                 | 12   | Sustainability      | 48         | 124                 |
|                 | 13   | Food               | 36         | 99                  |
|                 | 14   | Insect              | 33         | 71                  |
|                 | 15   | Insect farming      | 33         | 75                  |
|                 | 16   | Risk assessment     | 33         | 61                  |
|                 | 17   | Bioactivity         | 31         | 53                  |
|                 | 18   | Hermetia illucens   | 28         | 60                  |
|                 | 19   | Acheta domesticus   | 22         | 50                  |
|                 | 20   | Bombyx mori         | 22         | 44                  |

| (B) By insects studied | Rank | Scientific name (common name) | Occurrence | Total link strength |
|------------------------|------|-------------------------------|------------|---------------------|
|                        | 1    | Tenebrio molitor (Mealworm)   | 106        | 55                  |
|                        | 2    | Gryllus bimaculatus (Two-spotted cricket) | 51   | 42                  |
|                        | 3    | Hermetia illucens (Black soldier fly) | 28  | 13                  |
|                        | 4    | Acheta domesticus (House crickets) | 22  | 19                  |
|                        | 5    | Bombyx mori (Silkworm)        | 22        | 24                  |
|                        | 6    | Schistocerca gregaria (Desert locust) | 16    | 11                  |
|                        | 7    | Locusta migratoria (Migratory locust) | 8     | 7                   |
|                        | 8    | Rhynchophorus phoenicus (African palm weevil) | 5   | 10                  |
|                        | 9    | Apis mellifera (Western Honeybee) | 7    | 18                  |
|                        | 10   | Imbrasia oyemensis (Caterpillars) | 6    | 19                  |

*Thresholds used in VOSviewer: minimum number of occurrences of a term (keyword or insect species) = 5*
In some parts of Africa, certain species are considered of traditional importance, for example, jewel beetles, two-spotted cricket (*Gryllus bimaculatus*), grasshopper (*Schistocerca americana*), and stink bugs (Hlongwane et al. 2021). In South Africa, edible insects have been a part of the human diet since prehistoric times (Hlongwane et al. 2021). For instance, Ledger (1971) reported that South Africans had consumed *Trinervitermes trinervoides* (termite) and *Apis mellifera* (honey bee) as early as 100,000 BC.

Entomophagy plays a huge role in the food systems of indigenous people. Therefore, combining indigenous knowledge about entomophagy with scientific knowledge can help promote and preserve this practice (Hlongwane et al. 2021).

Enthomotomopthy is a branch of entomology that focuses on insect-human interactions in traditional society. The role of insects as food, or their use in medicine (i.e., entomotherapy), is an upcoming regional and global trend (Sidali et al. 2019). Edible insect products have become a major source of income in several countries. In South Africa, for example, edible insect products create approximately US$202,915 per trader when in season, creating revenue and employment, reducing poverty, and improving wellbeing (Makhado et al. 2014; Netshifhefe et al. 2018).

Insects have been consumed as food and used as feed. A study by Harikrishnan et al. (2012) showed that supplementation of farmed fish diet with chitin and chitosan from edible insects increased white/red blood cell levels and improved immune functions in the fish. Another study showed that supplementing chicken feed with black soldier fly lowered cholesterol and triglyceride levels and increased calcium levels in the blood of chickens (Schiavone et al. 2017). Anti-microbial peptides derived from the consumption of insect material were found to improve gut health by altering the gut microbiota, increasing immune functioning while promoting nutrient digestibility (Gasco et al. 2018). However, more in vivo studies need to be conducted to fully understand the mechanisms involved in these bioactive functions and any additional benefits of utilizing edible insects as human food and animal feed.

Research theme–cluster #2

A second cluster (shown in green in Fig. 4) consisting of 8 items, focused mainly on keywords such as 'agriculture', 'alternative protein', 'biodiversity', 'climate change', 'edible insects', 'food security', 'gastronomy', 'legislation', 'livelihoods', 'Mexico', 'policy', 'rural development', 'Thailand'.

This second cluster highlights topics that are relevant in today’s world. The term 'food security' is typically used to describe the situation where there is risk associated with food available for consumption, an uneven distribution of food, or food that is not affordable (Raheem et al. 2019). The demand for a more affordable and sustainable protein supply, especially in developing countries, is considerable and will increase in the future due to animal and plant protein becoming more expensive and less available in some regions (Raheem et al. 2019). Edible insects are an important protein source.

**Fig. 4** Network visualization map of all the author keywords in documents in the literature on edible insects.
source, and consumption of these insects plays an important role in ensuring food security and improving rural livelihood. Moreover, the prospect of the global population reaching 9 billion by the year 2050 suggests the possibility of food shortages if current food production practices are not augmented (Van Huis 2020). Conventional animal- and plant-based food sources might not meet the increased demands. In addition, meat consumption per capita is predicted to increase by 9% in high economy countries by 2030, and meat and crop prices are anticipated to increase by 18–21% (Van Huis 2017). Any further utilization of additional land at the current rate will likely lead to loss of natural ecology. In addition, climate change presents a growing threat to global food security due to currently intensively used farmland becoming unsuitable for farming (Hasegawa et al. 2018). In lower altitude areas, cereal farming is predicted to decrease, directly impacting underdeveloped regions and increasing poverty and malnutrition (Dickie et al. 2019).

Research theme–cluster #3 A third cluster contained keywords such as 'bioconversion', 'circular economy', 'environmental impact', 'food waste', 'health', 'insect farming', 'insects as food', 'invertebrates', 'mini-livestock', 'survey', 'sustainability', and 'welfare'. This cluster mainly focuses on the environmental, health, and welfare aspect of edible insects. Bioconversion is an economically viable method for converting large quantities of food waste into valuable materials like food and feed (Fowles and Nansen 2020). Insect-based bioconversion is a marketable option for reducing food waste in a way that is manageable, modest both in space and energy requirements, and environmentally friendly. Insects have higher feed conversion ratios than conventional livestock (Van Huis and Oonincx 2017). Insect rearing and 'mini livestock food production systems are considered sustainable and have a low ecological footprint (Van Huis 2020). Hence insect protein production through 'mini livestock farming is considered to have the potential for reducing global food insecurity (Dickie et al. 2019). Historically, the most common way to obtain insects has been wild harvest. However, wild catch of insects has declined in several areas due to increased urbanization, overexploitation of wild insect fauna, and forest and land conversion (Halloran et al. 2018). This concern has promoted the development of rearing/farming of edible insects, creating the possibility of improving the availability of this food source and limiting the environmental consequences of wild harvesting. Therefore, the rearing of insects provides possibilities for improved food security, better nutritional status through meeting dietary needs, and economic and societal benefits (such as contributing to gender equality (Belluco et al. 2013). Thus, the development of insect farming could contribute to addressing some of the UN Sustainable Development Goals (such as goals # 1, 2, 3, 5, 8, 13, 15, and 17) (Chia 2019). Human welfare concerns such as malnutrition and food shortage are major challenges in certain countries (Mmari et al. 2017). Consumption of insects can be good for wellbeing as the nutritional value can help promote human health and reduce vulnerability to malnutrition in pregnant women, children, and older persons (Belluco et al. 2013).

Research theme–cluster #4 The fourth cluster (Fig. 4) could be divided into two categories. Firstly, some research studies concentrated on a few of the most studied insects such as 'Acheta domesticus', 'Bombyx mori', 'Glykys bimaculatus', 'Hermetia illucens', 'Locusta migratoria', 'Tenebrio molitor', 'Zophobas morio', and 'Alphitobius diaperinus'. Secondly, this category included 'bioactivity', 'diet', 'digestion', 'microbiota'. This cluster contributes information related to the health benefits of edible insects. Most insects contain relatively high important nutrients such as minerals, lipids, and proteins (Raheem et al. 2019). Many edible insects are rich in protein and are estimated to contain 7–48% protein on a dry weight basis (Churchward-Venne et al. 2017; Kinyuru et al. 2015; Nowakowski et al. 2020). For instance, the house cricket (Acheta domesticus) contains 65% protein based on dry matter, which is substantially higher than that of conventional protein sources such as milk (30%), eggs (52%), beef (50%), and soybean (45%), based on dry matter (Churchward-Venne et al. 2017; Rumpold and Schlüter 2015). Grasshoppers, mealworms, and crickets have been reported to have a higher bioavailable copper, calcium, zinc, manganese, and magnesium content compared to the bioavailability levels of these minerals in sirloin beef (Latunde-Dada et al. 2016). In addition, it has been reported that the chitin found in insect exoskeletons is indigestible and provides a good source of dietary fiber (Kinyuru et al. 2015).

A recent trend in the health benefits of edible insects is in gastrointestinal health. According to Stull et al. (2018), supplementing the diet of healthy adults with 25 g of dried, roasted cricket powder per day for 14 days increases levels of the probiotic gut microbe Bifidobacterium animalis. An abundance of this gut microbe is reported to prevent respiratory infections, curtail the effects of antibiotics, and improve gastrointestinal health (Stull et al. 2018).

The keywords of this particular cluster are important in the current global situation, as consumers want to know where their food has come from and that it is safe to consume. While evaluating the microbiological aspect of any organism, it is necessary to presume that insects might harbor a complex microbial population composed of fungi, bacterial viruses, protozoa (Marshall et al. 2016). The varied diets of different insects play a vital role in their gut microbiota; for instance, grasshoppers are grass-feeders while Tenebrio molitor mainly feeds on cereal matrix (Garofalo et al. 2019). Intrinsic components such as pH and the redox potential of the gut compartment might have a major influence on...
the species-specific microbiota. In addition, environmental factors can also alter the microbiota present. Microbial contamination of insects can occur due to farming, handling, shipping, processing, and storage (De Sécurité Sanitaire 2011; Ng’ang’a et al. 2019; Schlüter et al. 2017). The European regulatory body has not specifically established any criteria for microbiological hygiene in insects or insect products sold for human consumption. However, the Netherlands food and consumer product safety authority (NVWA) has proposed a threshold of 6 log CFU/g for total mesophilic aerobes in lyophilized insect material (Food and Authority 2014). Several insects are being studied concerning their use as food, so microbiological studies are needed to profile the microorganisms in insect material (Garofalo et al. 2019). In addition, it is highly recommended to consume insects that are fed an appropriate diet to avoid the risk of consuming heavy metals. As seen in Fig. 4, there are limited studies on microbial legsibility aspects of insect-based food products. To improve the safety of insects as food, they should be reared in a controlled environment instead of harvesting from the wild. Implementation of a Hazard Analysis and Critical Control Point (HACCP) system and legislation for edible insects can also be a step towards ensuring the safety and quality of insect-based foods (Garofalo et al. 2019).

Another important trend concerning the health benefits of the consumption of edible insects is insect protein for producing bioactive peptides. The most common bioactive properties studied in insects are antioxidant, anti-inflammatory, and antimicrobial activities. Glycosaminoglycans produced from the two-spotted cricket Gryllus bimaculatus were found to exhibit anti-inflammatory bioactivity against chronic arthritis in rats (Ahn et al. 2016, 2019). Many insect-based proteins contain bioactive peptides with anti-microbial and antioxidant properties encrypted within the proteins. These peptides also exhibit other bioactive properties, such as anti-cancer and anti-diabetic properties, that need to be studied (Nowakowski et al. 2020). A study by Di Mattia et al. (2019) found that water-soluble extracts of grasshopper, crickets, and silkworms exhibit antioxidant properties in vitro, 5 times greater than that found in fresh orange juice. Insect protein powders and their peptide hydrolysates may prevent disease related to oxidative stress and chronic inflammation.

**Research theme–cluster #5** A fifth cluster (shown in yellow in Fig. 4) contains 5 items, ‘alternative protein source’, ‘consumer acceptance’, ‘food neophobia’, ‘familiarity’, ‘food choice’, ‘sensory analysis’, ‘willingness to eat’, and ‘Italy’. The European Commission recently focused on new and alternative sources due to increasing food demand due to the surge in the population (Palmieri et al. 2019). According to a study by Piha et al. (2018) suggested that in Europe, the Northern population is more inclined to consider insects as food than people in Central European countries. Fear or refusal of new food is called neophobia (Laureati et al. 2015). Neophobia could be reduced by encouraging people to taste and get acquainted with edible insects (Megido et al. 2016). Italy is a fairly special case among Western countries. Many studies on consumer acceptance, neophobia, food choice sensory analysis were found to have been published by institutions based in Italy. In many Italian regions, old traditional foods (especially cheese) have insect larvae as a part of the production process (Devin 2016). Palmieri et al. (2019) conducted a study and found that the Italian population has a positive attitude to new food and that taste, health, and environmental concerns motivate their food choices. The study also portrayed a positive aspect in increasing the acceptance of edible insects. Profiling consumers willing to eat insects/insect-based food is an essential step to understanding consumer reaction and their preferences, which should be conducted in all parts of the world to establish a potential international market for insect-based products (Palmieri et al. 2019).

**Research theme–Cluster #6** A sixth cluster also contained 4 items (shown in light blue in Fig. 4), comprising ‘allergenicity’, ‘food processing’, ‘cross-reactivity’, and ‘risk assessment’ as keywords. This cluster majorly illustrates the trend relating to the safe utilization of insects as food. Recently, many studies have been published on the processing and marketing of insect materials to decrease the perception of disgust and phobia associated with consuming insect-based food products. One study concluded that mayfly and termites have good potential for utilization in crackers and biscuits (Ayiieko et al. 2010). However, acquiring large quantities of quality insect material and safely processing these remain a challenge. Appropriate modern and sustainable farming, processing, storage, and preservation methods should be studied and applied to promote the utilization of insects (Nowadowski et al. 2020). Secondly, although risk assessment of edible insects is a major consideration in the food supply chain, it is observed in Fig. 4 that the topic ‘risk assessment’ is linked to only a few keywords. As opposed to large terrestrial animals, the consumption of insects is of interest because insect consumption is considered to have a lower ecological footprint. However, the safety of wild-caught reared or processed insect material needs to be assured, and this requires a risk assessment. EFSA (2015) published a scientific opinion of the risk profile related to the production and consumption of insects as either food or feed. The report reviewed the biological and chemical hazards associated with the production methods, harvest stage, and insect species. This report indicated that a case-by-case risk assessment should be conducted for all new insect-based products before being marketed. Risk assessment of insect-based products is one of the least studied aspects of
edible insect production and utilization, based on the node size of this keyword (see Fig. 4).

Research theme–clusters #7–10 A seventh cluster (shown in orange in Fig. 4) contains only 3 topics, 'food composition', 'Antheraea pernyi', and 'Rhyynchophorus phoenicis'. Food composition was the main node in this cluster, as seen in Fig. 4. Edible insects contain substantial amounts of digestible protein and chemical components such as carbohydrates (3.68–78.68% on a dry weight basis) (Singh et al. 2015). Variation in the nutritional profile can occur within species, developmental stages, habitats, and diets (Lawal et al. 2021). The amino acid profile, food efficiency ratio, and protein efficiency ratio (PER) determine the protein quality available in a food material. The predicted-PER of *Rhyynchophorus phoenicis* is 3.57, while the PER of soy and crayfish protein are 1.33 and 1.66, respectively (Halloran et al. 2018; Igwe 2015). Therefore, edible insects can be utilized as supplements to improve the nutritional value of other products.

An eighth cluster (Fig. 4) contains only 3 topics, 'culture', 'Ruspolia differens', and 'termites'.

Termites and *Ruspolia differens*, also known as 'senene' in Uganda or 'longhorn grasshopper', are two of the most culturally significant insects in South and East Africa, respectfully. *Ruspolia differens* and termites are highly nutritious as they contain essential amino acids and minerals (Mmari et al. 2017; Van Huis and Oonincx 2017). *Ruspolia differens* is one of the most eaten insects in Sub-Saharan Africa and has great economic potential (Agea et al. 2008). *Senene* has been widely harvested and consumed as a traditional snack in Zambia and around the Lake Victoria crescent, including the Democratic Republic of Congo, Kenya, and Uganda. According to Mmari et al. (2017), different societies’ traditions, cultures, and beliefs highly influence their dietary choices. There are over 2500 species of termites globally, and Africa, having more than 100 of these species, has the richest intercontinental diversity.

The ninth cluster is associated with *Antheraea pernyi*, *Rhyynchophorus phoenicis*, and food composition. The larvae or beetle *Rhyynchophorus phoenicis* (African palm weevil) are popularly known as edible worms and are a delicacy in many parts of Africa. Ethnic communities in Nigeria strongly believe the palm weevil to have high nutritive and pharmaceutical properties (Ekpo and Onigbinde 2005). In recent years, non-mulberry silkworms (*Antheraea pernyi*) have been put on the list of ‘novel food resources managed as common food’ by the Ministry of Health, PR China (Zhu 2004).

The tenth cluster only contained 'biological control', which we interpret as the use of pesticides to control insect pests. However, the increased use of pesticides and fertilizers is reported to negatively affect insect biodiversity (Rundlöf et al. 2015). Yet, there is a case to be made for the use of insects as food and feed. For example, there is a growing environmental pressure to diversify food sources due to diminishing land resources, increased demand for nutritious foods, and climate change. Insects have a high feed conversion rate, limiting the demand for land for food and feed production (Jansson and Berggren 2015). Moreover, insects emit fewer greenhouse gases compared to conventional livestock. Importantly, harvesting vegetation not suitable for human consumption for use as feed for farmed insects will be an important valorization strategy. Plant material could also be sustainably grown for use as insect feed, thus enhancing native biodiversity of both plants and insects (Jansson and Berggren 2015).

The timeline overlay visualization (Fig. 5) shows that keywords such as 'mini-livestock' and 'biodiversity' appeared in published studies around 2015, whereas words such as 'edible insects', 'entomophagy', and 'food composition' mainly started appearing in late 2016. It is as though the focus slowly shifted from an inquiry into the rearing and nutritional composition of edible insects to the social dimensions (involving the keywords ‘consumer acceptance’, ‘food neophobia’), health impacts (e.g., ‘functional properties’, ‘food safety’) and environmental perspectives (e.g., ‘climate change’, ‘sustainability’). Keywords like circular economy, survey, cross-reactivity were also found in this cluster. This shift is consistent with the recent trend in food science research where, beyond its nutritional quality, the impact of food on human health and the environment is also receiving attention (Sweileh 2020a).

Edible insect species reported in the literature

Analysis of author keywords in the edible insect literature indicates that *Tenebrio molitor* (106 occurrences), *Gryllus bimaculatus* (51 occurrences), *Hermetia illucens* (28 occurrences), *Acheta domesticus* (19 occurrences), *Bombbyx mori* (22 occurrences) have been the most frequently studied insects. The top 10 insects that have been studied are listed in Table 6(B), and a complete list of all insect species studied to date is shown in Online Resource Table S2.

Garino et al. (2019) reported that mealworms (*Alphitobius diaperinus*, *Tenebrio molitor* and *Zophobas morio*) are frequently used as animal feed as they are easy to rear, have high nutritional properties, and have low chitin levels, as they are usually harvested at the third larval stage before development of an exoskeleton. Mealworm belongs to the group Coleoptera and is potentially one of the most promising insect species for human and animal consumption. The larval stage occurs from 1 to 8 months; their main diet is cereal-related products such as flour, pasta, and bran. Mealworm is omnivorous (Rho and Lee 2014); therefore, there is an opportunity to use animal- and plant-derived food waste to feed them, providing a suitable avenue for utilizing
food waste. However, in Europe, only plant-based materials are used as feed for mealworms (Halloran et al. 2018). Mealworms are easy to breed and produce a consistent protein level with good flavor, digestibility, and functionality (Lee et al. 2019). For these reasons, *Tenebrio molitor* can be considered one of the most researched insect species in the world.

Crickets, especially the house cricket, *Acheta domesticus*, are also considered to have a huge potential as farmed insects due to their attractive nutritional characteristics. Crickets have a short growth cycle, numerous offspring, and average protein content of 60% dry weight. The World Health Organization (WHO) has recommended the consumption of crickets due to the high levels of amino acids and the essential fatty acid profile (Orinda 2018). Usually, crickets are consumed in their adult form, including the exoskeleton containing chitin, an indigestible component that can be modified. This insoluble fiber is reported to have potential prebiotic health benefits.

Edible insects not connected to the center cluster of Fig. 6 have very limited literature, meaning they can be the focus of future research studies. For instance, palm weevil consists of several species, and although the nutritional content is well established (Omotoso and Adedire 2007; Okoli et al. 2019), the functional properties of major constituents such as proteins are yet to be determined. The same goes for termites and stink bugs, where the characterization of proteins or other components is lacking. Several human communities traditionally eat several other insects, but whose composition is yet to be studied in detail. For instance, the beetle *Prionoplus reticularis* is found in New Zealand, of which the juvenile form, called the Huhu grub, is considered a local delicacy, particularly by indigenous peoples. However, the nutritional composition of this species has not been studied in detail. Similarly, many insects are found in other countries whose chemical/nutritional composition remains unknown.

The overlay visualization map (Fig. 7) shows the types of insects studied and the year the research was published. For example, around 2012 or before, most research was done on insect species such as two-lined velvet hawkmoth (*Clanis bilineata*), and witchetty grubs (*Endoxyla leucomochla*). However, studies on other insect species such as the Mopane worm (*Gonimbrasia belina*), wild silkworm (*Bombyx mori*), and white-spotted flower chafer beetle (*Protaetia brevitarsis*), and the green ant (*Oecophylla smaragdina*), began to be reported eight to ten years later, suggesting that some lesser-reported insects have begun to attract research attention.

**Emerging trends and future outlook**

The compilation and analysis of the available literature on the topic area of 'edible insects' has revealed the development of the literature over recent decades, in terms of the geographical source of the literature, the types of insects that have been investigated, and a structured sub-classification of information available. This analysis provides a means to
Fig. 6 Network visualization map of all the edible insect species studied, with a zoom in of the most studied insect species. The map was created using VOSviewer using data from Scopus.

Fig. 7 Overlay visualization map of all the edible insects reported in the literature. This map represents a timeline of the keywords from (2012–2022). The map was created using VOSviewer.
inform on emerging trends. A summary of the future outlook and key priority areas arising from the emerging trends is provided in Table 7.

Firstly, although a substantial proportion of the world population has the potential opportunity to include insects in their diets, generally, consumers in developed countries are not enamored by the prospect of the practice of entomophagy. Therefore, the accumulated knowledge and practices of indigenous cultures that have traditionally consumed insects need to be recognized and acknowledged to support the wider uptake of entomophagy as a food option. Acknowledgment of traditional indigenous knowledge on entomophagy can be promoted through policy directives of Governments (through acknowledging and documenting indigenous entomophagy practices in the country) and activities of food, agriculture, and nutrition-related professional organizations (through running of symposia, workshops, and conferences on the topic), and researchers and scientific journal publishers (through the editing of special issues on the topic).

Secondly, it has been recognized that it would also be useful to work towards international standardization of aspects such as the vernacular names, traditional collecting strategies, abundance and conservation, other uses (ethnomedical applications), health-promoting properties, and methods of processing and preparation of these insects for consumption (Jantzen et al. 2020). Developing processes that convert insect material into various products, such as powders, could provide an avenue for introducing insect material into various food products that consumers should consider more palatable. Such international co-operation would facilitate the development of various insects as feedstocks for alternative nutritional sources for both humans and farm animals. National, regional and international regulatory organizations have a role in developing and harmonizing standards that can allow the trading of edible insect materials across international markets.

The growing human population in the world is placing increasing demands on current animal- and plant-based food supplies, particularly concerning the provision of protein, which will likely soon become unsustainable. Therefore, edible insect farming can meet global future nutritional needs while working towards sustainable development goals. As is apparent from this bibliometric analysis, there has been a considerable escalation in interest in edible insects in the last decade. The expectation is that research into the nutritional value of various insects and the development of their farming and processing for use in various food products is anticipated. One way to advance this expectation is that research funding schemes (particularly those funding studies related to agriculture, food security, and nutrition) could include edible insect farming, processing, and nutrition as part of their priority areas.

**Variety and composition** As we can see from this study, there has been comprehensive research on some edible insects’ nutritional and functional aspects (especially mealworms). However, the composition of several other insect species consumed worldwide is still unknown. Also, due to the lack of standardized fractionation processes, studies on the techno-functionalities of insect proteins are still limited (Zielińska et al. 2017).

**Safety** As seen in this study, several research areas need future attention on risk assessment of insect-based products for both reared and wild-caught insects. In addition, attention should be given to the control and labelling requirements around the potential allergenicity of insects in the forms that they will be used or consumed. In addition, the microbial safety and the levels of heavy metals in insects (especially those that are wild-caught) need investigation. The risk assessment of insect products is at its initial stages, and the current bibliometric study has shown that research on this aspect is scant.

**Environmental impacts** Finally, as climate change and sustainability are global issues, a lot can be gained by leveraging indigenous and innovative insect rearing and farming practices that ensure food security and meet sustainable development goals (SDG# 2, 3, 12, 13). The aim is to broaden the scope of research and development and provide solutions to overcome the global food crisis.

**Limitations of study**

The present study used information from Scopus, which is considered a major compendium of peer-reviewed scientific literature. However, it should be recognized that there is also a substantial amount of information available from other sources, such as those produced by government, business, and industry, that are not included here. In addition, the literature reviewed was limited to that provided in English, and it should be recognized that valuable literature is available in languages other than English.

Secondly, there is a limitation posed by how the counting of documents for each country or author was carried out. Scopus makes the analysis based on the number of affiliations on the documents. Therefore, authors with different locations on the same article are counted once for each country. This counting method increased the researcher output of certain countries with high international research collaborations.

Another limitation of this study is that the citations in the present review may have included self-citations which could create bias in the total citations for countries, journals, and authors. Finally, the search query was built around ‘edible
Table 7  Some entomophagy priority areas stemming out of this study

| No | Priority area                                                                 | Potential stakeholders                                                                 | Potential activities                                                                 |
|----|------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| 1  | Need to acknowledge and learn from indigenous traditional knowledge of entomophagy | Government of nations                                                                   | Acknowledging and documenting indigenous practices of entomophagy                   |
|    |                                                                              | Professional organisations in the areas of agriculture, food, and nutrition             | Organisation of symposia, workshops, and conferences on indigenous practices in edible insects |
|    |                                                                              | Researchers and scientific journal publishers                                         | Establishing special issues and dissemination of research findings on this topic      |
| 2  | International standardization of aspects of entomophagy (e.g. safety, risk assessment, processing methods, uses, etc.) | National (e.g. FDA) and regional (e.g. EFSA), and international (e.g. FAO) regulatory agencies | Development and harmonization of standards on all aspects of entomophagy thus allowing trade of insect commodities across markets |
|    |                                                                              | Governments of nations                                                                  | Providing national data on any safety and epidemiologic (public health) incidences on the consumption of certain insects |
| 3  | Wider promotion of insects as sustainable food and feed with lower environmental impact | Governments of nations                                                                  | Celebrating and promoting the unique insect species consumed in that country          |
|    |                                                                              | Research funding organisations                                                           | Including edible insects in priority areas for funding                                |
|    |                                                                              | International organisations (e.g. FAO, WHO)                                             | Promoting edible insects as an effective strategy to improve food security of nations |
|    |                                                                              |                                                                                         | Including edible insect products in relief/humanitarian aid interventions             |
| 4  | Profiling the identities, chemical composition, and functional properties of lesser known edible insects | Governments of nations                                                                  | Make research on edible insects a priority, along with other food sources              |
|    |                                                                              | Research funding organisations                                                           | Including indigenous edible insects as part of priority areas for funding              |
|    |                                                                              | Researchers and scientific journal publishers                                         | Establishing special issues and dissemination of research findings on indigenous edible insects |

FAO Food and Agriculture Organisation, FDA Food and Drug Administration, EFSA European Food Safety Authority
insects' OR 'insects as food' OR 'entomophagy'. As the topic is broad and intensive, it is not easy to ensure that all literature is included. However, future research should focus on the nutritional aspect of insect material supplementation in the human diet compared to animal- and plant-based foods (Nowakowski et al. 2020).

Conclusion

To the best of our knowledge, this is the first comprehensive bibliometric study of published literature on 'edible insects' OR 'insects as food' OR 'entomophagy' covering several recent decades. It is evident from this bibliometric analysis that publication in this area has increased dramatically in the past few decades. There have been research contributions worldwide, but some countries have been more active than others. It is also evident that this topic area is highly interdisciplinary, and there has been substantial international collaboration. Collectively, this indicates an increasing recognition of the sustainability issues that the world faces, with a growing population, marked shifts in demographics of lifestyle, dietary choice, and income, with the expectation of enhanced lifestyle. Furthermore, there is a recognition that insect materials have huge potential to contribute to food security and sustainability for the world's future.

A considerable knowledge base exists with indigenous peoples, who have been utilizing insect material for a long time. Selection of suitable edible insect species, along with the development of industrial-scale insect farming and processing, with the involvement of traditional cultural knowledge, will be centrally important to introducing and bringing a currently reluctant, somewhat rejectionist, western world culture to the reality of insect material as an alternative food source. There are many unknowns about traditionally consumed insects worldwide; more research needs to be conducted to bridge the gap. Processing these insect materials and credible research providing information about the health-promoting value of such materials will be critically important to achieving acceptance. With the accelerating research drive apparent from this bibliometric study, there is a realistic expectation that edible insects will play a huge role in diversifying and meeting the world's future food needs.

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Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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References

Agea JG, Biriyumumaisho D, Buyinza M, Nabanoga GN (2008) Commercialization of Ruspolia nitidula (nsenene grasshoppers) in central Uganda. African J Food Agric Nutr Dev 8(3):319–332
Ahn MY, Hwang JS, Kim M-J, Park K-K (2016) Antipandemic effects and gene expression profiling of the glycosaminoglycans from cricket in rats on a high fat diet. Arch Pharm Res 39:926–936. https://doi.org/10.1007/s12272-016-0749-1
Ahn MY, Kim BJ, Kim HJ, Jin JM, Yoon HJ, Hwang JS, Lee BM (2019) Glycosaminoglycan derived from field cricket and its inhibition activity of diabetes based on anti-oxidative action. Preprints. https://doi.org/10.20944/preprints201903.0136.v1
Airyalat SAS, Malkawi LW, Momani SM (2019) Comparing bibliometric analysis using PubMed, Scopus, and Web of Science databases. J Vis Exp e58494. https://doi.org/10.3791/58494
Ayieko M, Oriaro V, Nyambuga I (2010) Processed products of termites and lake flies: improving entomophagy for food security within the Lake Victoria region. African J Food Agric Nutr Dev 10:2085–2098. https://doi.org/10.4313/ajfand.v10i2.
Belluco S, Losasso C, Maggioletti M, Alonzi CC, Paoletti MG, Ricci A (2013) Edible insects in a food safety and nutritional perspective: a critical review. Compr Rev Food Sci Food Saf 12:296–313. https://doi.org/10.1111/1541-4337.12014
Bodenheimer FS (1951) Insects as human food. In Insects as Human Food. Springer, pp 7–38
Bristowe WS (1953) Insects as food. Proceedings of the Nutrition Society 12(1):44–48. https://doi.org/10.1079/PNS19530012
Chantawannakul P (2020) From entomophagy to entomotherapy. Front Biosci 25;179–200. https://doi.org/10.2741/4802
Nowakowski AC, Miller AC, Miller ME, Xiao H, Wu X (2020) Potential health benefits of edible insects. Crit Rev Food Sci Nutr 1-10. https://doi.org/10.1080/10408398.2020.1867053

Okoli IC, Olobi WB, Ogbeuwe IP, Aladi NO, Okoli CG (2019) Nutrient Composition of African Palm Grub (Rhynchophorus phoenicis) Larvae Harvested from Raphia Palm Trunk in the Niger delta Swamps of Nigeria. Asian J Biol Sci 12:284–290

Omotoson OT, Adegbe CO (2007) Nutrient composition, mineral content and the solubility of the proteins of palm weevil, Rhynchophorus phoenicis f. (Coleoptera: Curculionidae). J Zhejiang 7:247–250.

Ledger J (1971) Arthropoda at Melville koppies useful as food for man. Proc Royal Soc b: Biological Sciences 278:2188. https://doi.org/10.1098/rspb.2016.2078

Payne P, Ryan A (2019) Insects as mini-livestock? A study of New Zealand attitudes toward insect consumption

Pihl S, Pohjanheimo T, Lähteenmäki-Uutela A, Kreekova Z, Otterbring T (2018) The effects of consumer knowledge on the willingness to buy insect food: An exploratory cross-regional study in Northern and Central Europe. Food Qual Prefer 70:1–10. https://doi.org/10.1016/j.foodqual.2019.01.016

Rhoods DW, Moses LM, Cunningham AA, Wood J, Jones KE (2016) Environmental-mechanistic modelling of the impact of global change on human zoonotic disease emergence: a case study of Lassa fever. Methods Ecol Evol 7:646–655. https://doi.org/10.1111/2041-210X.12549

Rho MS, Lee KP (2014) Geometric analysis of nutrient balancing in the mealworm beetle, Tenebrio molitor. (Coleoptera: Tenebrionidae). J Insect Physiol 71:37–45. https://doi.org/10.1016/j.jinsphys.2014.08.001

Rundlöf M, Andersson GK, Bommarco R, Engel KH (2017) Safety aspects of the production of foods and food ingredients from insects. Mol Nutr Food Res 61:1249968

Schlüter O, Rumpold B, Holzhauser T, Roth A, Vogel RF, Quasigroch W, Vogel S, Heinz V, Jäger H, Bandick N, Kulling S, Knorr D, Steinberg P, Engel KH (2017) Safety aspects of the production of foods and food ingredients from insects. Mol Nutr Food Res 61:1250020. https://doi.org/10.1002/mnr.201600520

Shaub W, Khan MS, Shahid H, Valdes EA, Alweis R (2015) Bibliometric analysis of the top 100 cited cardiovascular articles.
