ENTOMOLOGICAL
SOCIETY OF AMERICA
SHARING INSECT SCIENCE GLOBALLY

OXFORD

Plant-Insect Interactions

The food of life: which nectar do mosquitoes feed on?—An evidence-based meta-analysis

Eva Herreros-Moya[1,*,], Marianne Sinka[1], Angela F. Harris[2], Julian Entwistle[2], Andrew C. Martin[3], and Kathy J. Willis[1]

[1]Department of Biology, University of Oxford, Oxford, UK
[2]Innovative Vector Control Consortium, Liverpool School of Tropical Medicine, Liverpool, UK
[3]Scott Polar Research Institute, Department of Geography, University of Cambridge, Cambridge, UK

*Corresponding author. Department of Biology, University of Oxford, South Parks Road, Oxford OX1 3RB, UK (Email: eva.herreros-moya@biology.ox.ac.uk).

Nectar is an important source of food for adult mosquitoes, influencing their biological characteristics including longevity, fecundity, and flight range. Consequently, it can impact mosquitoes' survival and efficiency in transmitting disease. Different mosquito species are known to show preferences for flower nectar from certain plants, yet despite the importance of these plant–mosquito associations, knowledge of such biotic interactions is sparse. Here, we present a systematic map to address the question: "Which nectar do mosquitoes feed on?." The mapping process identified 49 articles (comprising 51 studies) meeting inclusion criteria, detailing 397 records of 74 mosquito species feeding on nectar from 145 plant species and 109 genera. Data extracted from the map were then analyzed to better understand if mosquitoes showed preferences for specific plant nectar. A key finding from this study is clear evidence supporting the hypothesis that mosquitoes exhibit preferences for nectar from particular plant species, including 77 species of plants and 58 genera for *Aedes* species, 18 species of plants and 17 genera for *Anopheles* species, and 16 species of plants and 16 genera for *Culex* species (all 3 genera belong in Diptera: Culicidae). Our study also highlighted the need for further field and laboratory work in time and space and using methods that randomly selects plant species for investigation. This would facilitate a better understanding of the relationship between mosquito feeding behavior and nectar seasonality and abundance; data that are critical for the development and improvement of new mosquito control methods to tackle vector-borne diseases.

Keywords: mosquito, nectar feeding, vector biology, vector control, meta-synthesis.

Introduction

Nectar is a critical source of food for adult mosquitoes of both sexes. Plant-derived sugar is the only source of food for male mosquitoes and is required for their overall survival, to fly and copulate. If sugar-deprived, male mosquitoes may not achieve reproductive success (Foster 1995). Female mosquitoes also feed on nectar, but in many species, they need blood meals to provide additional nutrients to complete egg maturation (Valzania et al. 2019, Harrison et al. 2021). Nectar from flowers (floral nectar) appears to be the preferred food for both male and female mosquitoes, although sometimes they also obtain sugar from other plant sources, including extrafloral nectaries, fruits, and plant tissue, as well as honeydew

from other sap feeding insects (Clements 1963, Foster 1995, Stone and Foster 2013).

Nectar is produced by the nectaries of plants present in the flower (flower nectaries) or outside the flower (extrafloral nectaries) and its composition can vary between different species of plants. While it primarily consists of water and sugars (sucrose, glucose, fructose), the exact ratio of these sugars, as well as the presence of other compounds like amino acids, vitamins, minerals, and secondary metabolites can differ significantly (Nicolson 2022). These variations can impact the attractiveness of nectar to specific insects. Both flower nectar and extrafloral nectar mainly attract and reward insects; however, they serve different ecological functions (González-Teuber

and Heil 2009). Flower nectar is present in the flower, close to the reproductive organs, and serves as a reward for pollinators when transferring pollen from flower to flower. Extrafloral nectaries are most often found on the leaves and petioles of the plant, and are suggested to work as an indirect defense of the plant as they attract herbivores' predators such as ants (Nepi et al. 2018).

Early studies of nectar feeding behavior usually linked the species of mosquitoes to the plants by observing where mosquitoes fed and rested in the field (Müller 1873, Knab 1907, Haeger 1955, Sandholm and Price 1962, Grimstad and DeFoliart 1974). However, recently developed laboratory techniques (Van Handel 1972, Schlein and Muller 1995, Burkett et al. 1999, Junnila et al. 2010) have also allowed the identification of the plant species and the part of the plant where mosquitoes have fed by analyzing the plant tissue and sugars in the mosquito's gut (Gary Jr and Foster 2004, Impoinvil et al. 2004, Manda et al. 2007b, Gouagna et al. 2010). These laboratory-based methods not only save researchers time in the field but also allow for more observations and better control of variables. The main focus of these latter studies has tended to be on understanding the mechanisms used by mosquitoes to identify their preferred flowering plants including visual (Orbán and Plowright 2014, Bernáth et al. 2016, Dieng et al. 2018, Peach et al. 2019), olfactory (Manda et al. 2007a, Nyasembe et al. 2012, 2018, Gouagna et al. 2014, Nikbakhtzadeh et al. 2014, Yu et al. 2017, 2018, Lahondère et al. 2020), and gustatory (Ignell et al. 2010, Chen and Kearney 2015, Kessler et al. 2015) cues.

Understanding whether there is a preference of mosquitoes for certain plant types is an important question for a number of reasons: First, given the critical role of plant nectar in a mosquito's life cycle, if there are particular species of plants that mosquitoes prefer to feed on, then a high concentration of these plants on a landscape could increase vector abundance (Russell et al. 2011, Moiroux et al. 2012, Padonou et al. 2012, Durnez and Coosemans 2013, Mwesigwa et al. 2017). Second, and equally important, the growing resistance to insecticides like pyrethroids and the shift in biting behavior reducing mosquito exposure to insecticide treated bednets or indoor residual spraying are challenging the effectiveness of these traditional control strategies (Moiroux et al. 2012, Durnez and Coosemans 2013, Hemingway et al. 2016, Ranson and Lissenden 2016, Mwesigwa et al. 2017, Van den Berg et al. 2021). As such, new mosquito control methods, such as attractive targeted sugar baits (ATSBs) (Müller and Schlein 2006, Schlein and Müller 2008, Müller et al. 2010, 2011, Sissoko et al. 2019), have been developed and are of interest in areas of high mosquito abundance. These novel interventions combine floral or fruit sugars with insecticide compounds targeted for mosquito control. As a method, this has shown successful results across multiple species of mosquitoes and in some environments (Schlein and Müller 2008, Müller et al. 2010, Gu et al. 2011, Traore et al. 2020). However, it is uncertain if large amounts of naturally occurring sugars in nectar from plant species that mosquitoes prefer to feed on, will influence the effectiveness of the ATSBs. Thus, it is important to better understand the impact

of potential competition from naturally occurring nectar resources across different landscapes.

The importance of understanding this relationship between nectar resource availability and mosquito abundance has been acknowledged many times (Gary Jr. and Foster 2001, Okech et al. 2003, Gary Jr and Foster 2004, Impoinvil et al. 2004, Müller and Schlein 2006, Manda et al. 2007a, Schlein and Müller 2008, Müller et al. 2010, Gu et al. 2011, Beier et al. 2012, Stone et al. 2012, Qualls et al. 2013, Yu et al. 2016, Sissoko et al. 2019, Nyasembe et al. 2021), and there are now many published studies that have looked at individual aspects of this functional relationship involving various plant/mosquito genera. However, to our knowledge, the evidence yielded from these studies has not yet been synthesized to investigate whether there is overall evidence to show that certain species of mosquito feed on particular plant species. The alternative hypothesis is that all mosquitoes are generalist feeders and feed on any available nectar on the landscape.

In this study, we therefore reviewed the studies to date that have examined the relationship between mosquitoes and plant feeding, both in field and laboratory studies, to ascertain if collectively the data they contain can provide a better understanding on whether mosquitoes exhibit feeding preferences for specific plant species.

Materials and Methods

Our study involved creating a systematic map to assimilate the current knowledge on mosquito nectar feeding (see the section "Visualization of the Systematic Map"), followed by meta-analysis of the data extracted to determine whether mosquitoes exhibit preferences for specific plant nectars (see sections "Risk of Bias Assessment to Study Mosquito Nectar Preferences" and "Data Handling and Meta-analysis").

Our systematic map followed the protocol published by the Collaboration for Environmental Evidence (CEE) (Pullin et al. 2022) and addressed the question: "*Which nectar do mosquitoes feed on?*" (see Supplementary Appendix 1). By following this protocol, we aimed to (i) identify relevant studies that contribute toward current knowledge on mosquito and plant nectar feeding and (ii) quantify knowledge gaps in the identified evidence. Key stages of the protocol are outlined below:

Searches

We conducted an initial bibliographic search in December 2020 and updated this with a later supplementary search in May 2022. We also conducted *snowballing*, whereby we identified earlier sources from the reference lists of selected papers (backward snowballing process) (Sayers 2007). To ensure that the search captured all literature pertaining to our research question, an iterative approach was applied and in accordance with systematic mapping practice, our research question was framed within the population (P), exposure (E) and outcome (O) (PEO) framework (Frampton et al. 2017), as shown in Table 1.

Table 1. PEO framework

Category	Definition	Description
P—Population	Populations of subject(s) of relevance to the review question.	Studies related to any mosquito species
E—Exposure	Environmental variable relevant to the Population.	Studies related to plant nectar (floral and extrafloral nectar)
O—Outcome	Documented record(s) of the Population and Exposure.	Studies including records of a mosquito feeding on a plant's nectar (including any plant in any geographical area)

We conducted searches across 3 bibliographic databases: Web of Science, Scopus, and CAB Abstracts (Table 2). The search terms were structured using the PEO framework and tested against a set of 19 relevant articles, known as the *test library*. Keywords were combined with Boolean operators (AND, OR) and iteratively refined until all articles from the test library were consistently retrieved. A full search was completed on 1 December 2020, and the retrieved articles were exported to the reference management software EndNote X9.3.3, where duplicates were removed. Finalized search terms and the test library are provided in Supplementary Appendix 1.

Screening

After deduplication, articles were uploaded into Colandr (https://colandrcommunity.com), an open-access platform that uses machine learning for screening and data extraction (Kahili-Heede and Hillgren 2021). Initial screening was done at the title-abstract level. To ensure consistency, 100 articles were randomly selected for double screening, and agreement between reviewers was measured using Cohen's Kappa (Cohen 1960), with a minimum score of 0.69 achieved (recommended threshold by CEE (Pullin et al. 2022) is > 0.6). Once consistency was evaluated, articles were divided into 3 batches for independent screening by reviewers, applying PEO eligibility criteria. Full-text screening was conducted by one reviewer, with details of exclusions provided in Supplementary Appendix 2.

Data Coding

The items outlined in Table 3 were extracted from the studies, and results are presented in Supplementary Appendices 2 and 3. If the plant species was not identified but the genus was provided followed by "sp.", it was treated as a species. However, when the genus was followed by "spp.", it was counted as a genus. Articles often included multiple studies on mosquito nectar feeding and, in such cases, we added suffixes (a, b, or c) to the article codes to differentiate between studies. Additionally, each study could report multiple records of mosquitoes feeding on nectar.

Visualization of the Systematic Map

We applied the final data from the systematic map to create an interactive map using the *Thalloo* mapping framework (Martin 2017). In this we included filters to allow different elements of data (for example, plant family, geographic location, study design, and purpose of the study) to be displayed separately allowing a better comprehension of the underlying information. Data from the United States (U.S.A.) were presented by state instead of for the whole country, as there was a large number of records from this country. Due to their relevance in transmission of vector-borne diseases, some mosquito species have traditionally been subject to a greater scrutiny than others and have notably more records. Therefore, where data allowed, these species were studied individually. The remaining mosquito records were at genus level.

Risk of Bias Assessment to Study Mosquito Nectar Preferences

While all studies retrieved from our mapping process reported instances of mosquitoes feeding on nectar, only those employing a rigorous method were included for the analysis of potential nectar preferences. To select this subset of studies, we investigated a risk of bias assessment based on 3 critical criteria as follows:

i) **Random plant selection:** This criterion resulted in the exclusion of those studies where plant selection was non-random, for example, when plants were chosen based on prior results or specific plant characteristics.

ii) **Multiple plant choices for mosquitoes:** The presence of more than one plant that mosquitoes could feed on in the study was considered essential for a comprehensive understanding of mosquito preferences on nectar. Single-choice assay is an example of tests that only used one plant.

iii) **Replication of studies:** The inclusion of replicates in the study design was considered crucial, as studies lacking replicates were susceptible to bias. The absence of replicates raised the possibility of other variables influencing mosquito preferences, such as the location of the plants in the study.

The risk of bias was defined as 'high' when the response to any of the 3 critical criteria was negative. Information on the calculation of the risk of bias is included in Supplementary Appendix 4.

Data Handling and Meta-analysis

Determination of Mosquito Preferences for Specific Plant Nectar

Details of the total number of plants included in the studies classified as low risk of bias (see Supplementary Appendix 4) was constructed, and the total number of plants that mosquitoes fed on from these studies was then used to determine if mosquitoes showed preferences for specific plant nectar.

To explore these preferences, we calculated the ratio between the number of preferred plants and the total number of plants investigated in each study classified as low risk of bias (see Supplementary Appendix 4). We then used this ratio as an indicator of whether mosquitoes exhibited preferences for specific plant species. While ideally, we could expect this ratio to be 1 (100%) when mosquitos show no preference for specific nectar types, this outcome is unlikely to be met in every such case. Hence, and as a rule of thumb, a ratio falling below 0.7 would indicate a tendency for mosquitoes to favor certain plants during their feeding activities. The same methodology was applied for the 3 genera of mosquitoes for which we obtained the most records in our analysis (*Aedes, Anopheles*, and *Culex*—Diptera: Culicidae) to explore if different mosquito genera showed preferences for a particular plant nectar.

Table 2. Database search

Database	Type of literature	Description of search
Web of Science	Platform of bibliographic databases	All records included in the 1945–2022 databases
Scopus	Bibliographic database	All records to 2022
Cab Abstracts	Bibliographic database	All records included in the 1910–2022 databases
Snowballing process	Grey literature	Relevant published articles cited and found in reference lists of our relevant studies (Sayers 2007) based on the assumption that these studies are relevant to our systematic map.

Table 3. Data extraction for studies that met the inclusion criteria in the full text.

Coded elements	Description
Study metadata	Authors, Title, Journal, DOI, Year of publication and Abstract (Supplementary Appendix 2)
Study area metadata	Location of the study (Supplementary Appendix 3)
Methodology	Information about the study methods—including study design (field/lab based/semi-field, observation/experimental) (Supplementary Appendix 3)
Mosquito data	Mosquito species and sex (Supplementary Appendix 3)
Plant data	Plant species and family—including number of plants studied and plant nectar where mosquitoes fed on (Supplementary Appendix 3)
Study data	Information about the study design (controlled/not controlled, number of repetitions and measurements taken in the study) (Supplementary Appendix 3)
Selection of the plants	Reasons that researchers used to select the plants of the study (Supplementary Appendix 3)
Outcomes	Purposes of the authors when carrying the study out (Supplementary Appendix 3)

Statistical Analysis

Chi-squared tests were conducted in R version 4.3.0 (2023-04-21) on those studies classified as low risk of bias and where the number of observations was sufficient. As a general guideline, we ran tests on all studies when the expected mosquito counts per plant species were 5 or greater (McHugh 2013). We also kept the analyses separate by study, as each included a different number of plants and mosquitoes (Supplementary Appendix 5).

Representation of Mosquito Genus—Plant Family Preferences

To visualize the interactions between different mosquito genera with plant families, 2 chord diagrams were created in R version 4.3.0 (2023-04-21) using the package *circlize* 0.4.16 (Gu et al. 2014). The first one included all the records of mosquitoes feeding on plant nectar in the systematic map. The second chord diagram specifically included records from studies registered as having low risk of bias (as stated in 'Determination of Mosquito Preferences for Specific Plant Nectar'), and thereby providing a representation of the preferences of different mosquito genera for particular plant families.

Results

Study Characteristics

The total number of articles retrieved from database searches was 1,671. After deduplication and title and abstract screening, 222 articles were selected. After reading the full text, 171 articles did not fulfill the PEO inclusion criteria and were not included in the systematic map. At the end of the selection process, 49 articles (all of them were journal articles) detailing 51 studies fulfilled all our inclusion criteria. These studies reported one or more records of mosquitoes feeding on plant nectar, amounting to a total of 397 records of different species of mosquitoes feeding on diverse plant species. The number of articles identified and included/excluded at each stage of the systematic mapping process is detailed in Figure 1. Individual records and their associated metadata may be viewed and filtered on the online visualization (Fig. 2): https://oxlel.github.io/evidencemaps/mosquito_map/. All references are included in Table 4.

The records included in our analyses (field and laboratory based) described observations of mosquitoes feeding on plant nectar in 17 different countries. The largest body of work on mosquito feeding behavior is found in North America (number of studies (n) = 24, 288 records). In comparison, far fewer studies have been carried out by researchers on the African continent (n = 13, 67 records), with studies in Kenya detailing the largest number of records of mosquito floral preferences in Africa (n = 6; 31 records). A total of 7 studies (29 records) were carried out in Europe, primarily reported from

Sweden (n = 3, 21 records). Four studies were performed in Eastern Asia (7 records) and several research publications have also been based in Israel (Western Asia, n = 3, 6 records). Figure 3 shows the temporal and spatial distribution of the total number of records retrieved in the systematic process.

Aedes was the most studied genus with 29 studies (233 records) and 30 different species. The most studied species were *Aedes vexans* (Meigen, 1830) (n = 5, 53 records), *Aedes aegypti* (Linnaeus, 1972) (n = 7, 19 records), *Aedes cinereus* (Meigen, 1818) (n = 4, 18 records), *Aedes provocans* (Walker, 1848) (n = 2, 21 records), *Aedes communis* (De Geer, 1776) (n = 3, 10 records) and *Aedes sollicitans* (Walker, 1856) (n = 2, 13 records). Note that genera *Stegomyia* and *Ochlerotatus* were also included as keywords in the search process to maximize the number of studies related to *Aedes* species, since these two genera names were formerly used to identify some *Aedes* species (eg *Ae. aegypti* was formerly known as *Stegomyia aegypti*, and *Aedes taeniorhynchus* (Wiedemann, 1821) was known as *Ochlerotatus taeniorhynchus*).

Twenty studies (60 records) were related to *Anopheles* species. A total of 11 species were found feeding on nectar of different plants, *Anopheles gambiae* Giles, 1900 being the most studied (n = 8, 34 records), followed by *Anopheles sergentii* (Theobald, 1907) (n = 3; 5 records).

Fourteen studies (47 records) reported a total of 13 *Culex* species feeding on different plants. *Culex pipiens* Linnaeus, 1972 was the most studied species (n = 7, 18 records), followed by *Culex restuans* Theobald, 1901 (n = 3, 15 records).

Other genera of mosquitoes that were observed feeding on plant nectar were: *Psorophora* (n = 3, 4 records); *Coquillettidia* (n = 3, 20 records), *Culiseta* (n = 4, 18 records), with *Culiseta inornata* (Williston, 1893) having the highest number of records within this genus (9 records), and *Uranotaenia* (n = 2, 2 records). Finally, the following mosquito genera were only reported in one study: *Mansonia* (n = 1, 7 records), *Eretmapodites* (n = 1, 1 record), *Ficalbia* (n = 1, 1 record), *Topomyia* (n = 1, 2 records), *Toxorhynchites* (n = 1, 1 record).

The selection of plants by researchers in the different studies was based on the following reasons: (i) plants were present and abundant in the study sites (n = 32, 327 records); (ii) specific characteristics of the plants (n = 7, 14 records); (iii) plants that other species of mosquitoes in previous studies fed on (n = 8, 24 records); (iv) observation of mosquitoes visiting different plants in the field (n = 2, 18 records); (v) observation of pollen on mosquitoes' bodies (n = 1, 4 records); and (iv) plant DNA identification in mosquitoes' guts (n = 1, 10 records). Studies that selected the plants based on previous studies without any additional information on the species of mosquitoes feeding on the plant were not included in the analysis.
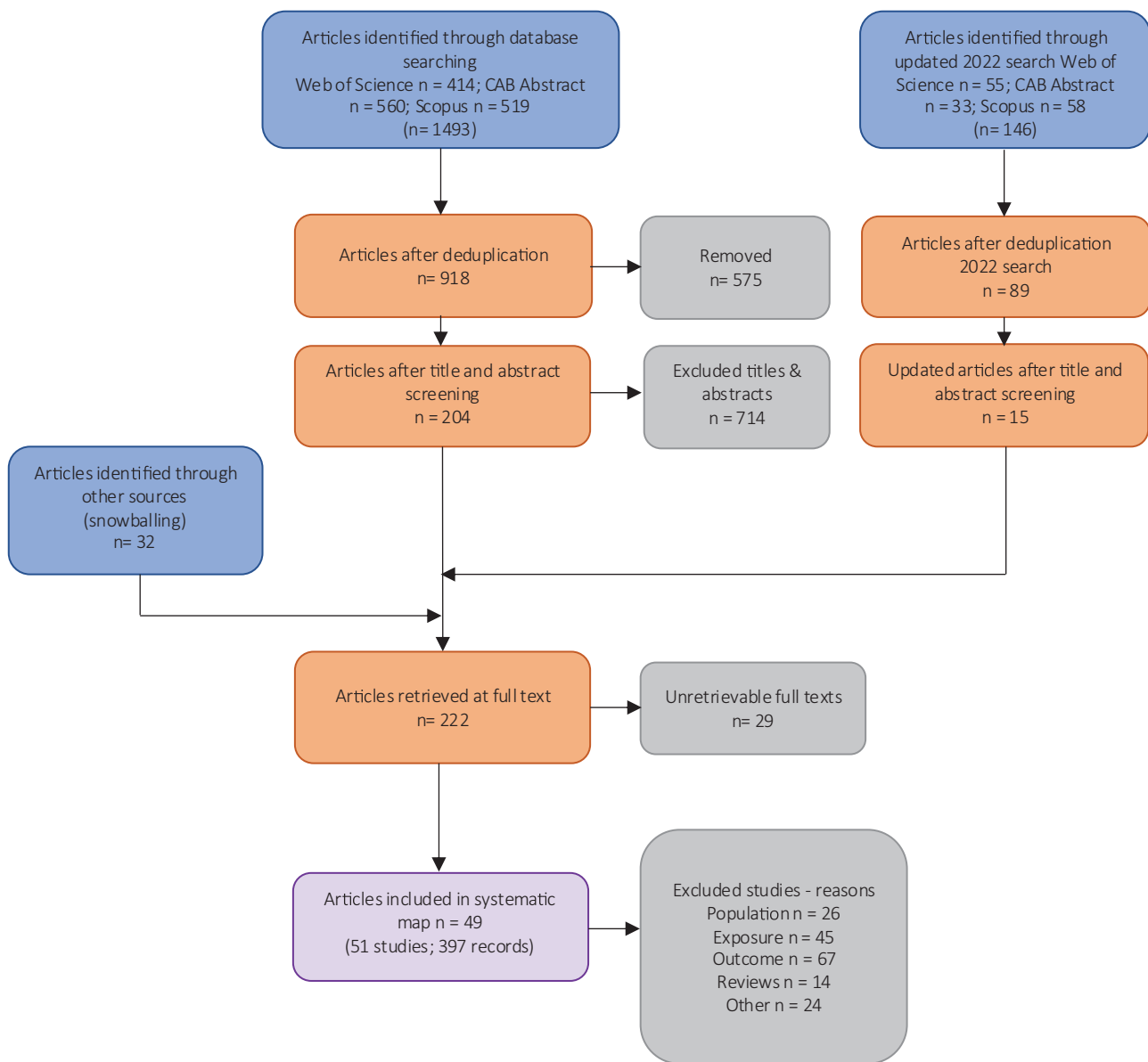
Fig. 1. Workflow of the systematic map showing number of sources identified at each stage of the mapping process.

Thirty published studies described results from field studies (320 records), most of them before the year 2000. Sixteen studies (55 records) were performed in laboratory conditions, mainly after the year 2000 with the development of new lab techniques. Three studies (17 records) used a combination of field and lab methodologies, and 2 studies (5 records) were carried out in semi-field conditions.

Most of the studies were based on observations of mosquitoes feeding on plant nectar (n = 29; 314 records). Other methodologies used by researchers were (i) a combination of single choice assay (mosquitoes only had one species of plant to feed on in the lab), with either the cold anthrone method to calculate the proportion of mosquitoes that have fed on the plant (n = 10; 32 records) or liquid/gas chromatography mass spectrometry (n = 2, 5 records), (ii) multiple choice assay where mosquitoes had different plants to choose to feed on (n = 2, 11 records), (iii) the use of markers on vegetation or on mosquitoes (n = 6, 22 records), (iv) detection of presence of pollen on the body of mosquitoes (n = 1; 4 records), and (vi) plant DNA extraction and identification from mosquitoes' guts (n = 1; 10 records).

Plants That Mosquito Genera Feed on

Our search found 74 different species of mosquitoes (12 genera) feeding on 145 plant species (109 genera). A list of all the records of mosquitoes feeding on plants can be found in Supplementary Appendix 2.

Asteraceae had the most records reporting *Aedes* (n = 13, 67 records) and *Culex* (n = 6, 20 records species feeding on them, followed by Rosaceae only for the *Aedes* species (8 studies, 36 records). Fabaceae (n = 10, 14 records), Asteraceae (n = 9, 15 records), and Euphorbiaceae (n = 6, 7 records) were the families with the most records of *Anopheles* species feeding on them. *Anopheles* species located in Africa showed clear preferences for Fabaceae plants (n = 7, 10 records); however, *Anopheles* species not located in Africa demonstrated preferences for plants pertaining to the Asteraceae family (n = 5, 11 records).

At the species level for plants, *Achillea millefolium* L. (Asterales: Asteraceae; 15 records), *Leucanthemum vulgare* Lam. (Asterales: Asteraceae; 13 records), and *Asclepias syriaca* L.
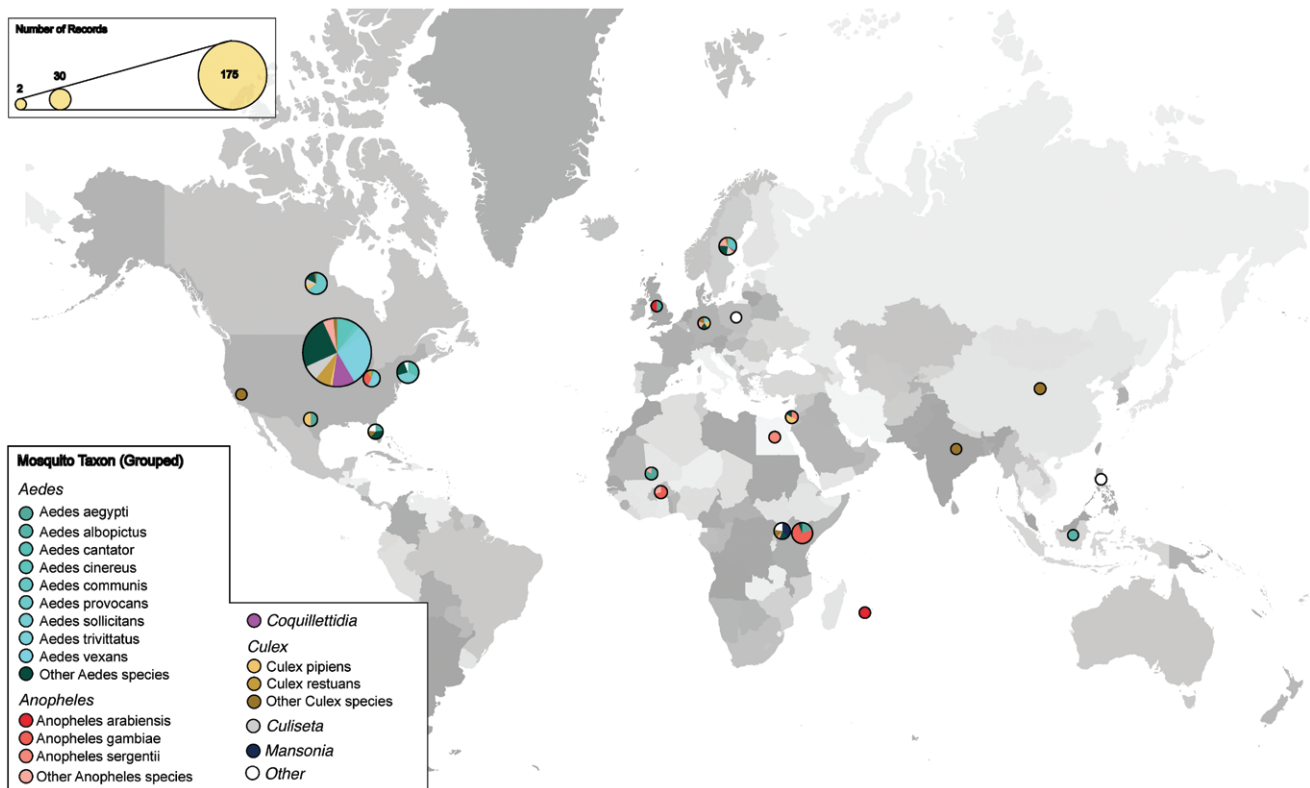
Fig. 2. Geographical map showing the spatial distribution of the 397 records of mosquitoes (field and laboratory studies) feeding on plant nectar that were included in the final systematic map dataset. The colors represent different species of mosquitoes, and the pie size is related to the number of studies found per country (or by state for U.S.A. records). More filters are available in the online version of the map: https://oxlel.github.io/evidencemaps/mosquito_map/

(Gentianales: Apocynaceae; 12 records) were the plants with the most records of *Aedes* species feeding on their nectar, followed by *Tanacetum vulgare* L. (Asterales: Asteraceae; 7 records), *Solidago canadensis* L. (Asterales: Asteraceae; 6 records), and *Solidago* spp. (5 records). The plants with the most records of *Anopheles* species feeding on them were *Ricinus communis* L. (Malpighiales: Euphorbiaceae; 6 records), *Parthenium hysterophorus* L. (Asterales: Asteraceae; 5 records), and *Senna didymobotrya* (Fresen.) H.S.Irwin & Barneby (Fabales: Fabaceae; 4 records). *Anopheles* species not located in Africa demonstrated preferences for plants pertaining to the Asteraceae family such as *T. vulgare* (3 records) and *A. millefolium* (3 records). *Tanacetum vulgare* (4 records), *A. millefolium* (3 records), *Solidago* spp. (3 records), and *Harungana madagascariensis* Poir. (Malpighiales: Hypericaceae; 3 records) were the species of plants with the most records of *Culex* species feeding on them.

Plants That Predominant Mosquito Vector Species Feed on

Aedes aegypti and *Ae. albopictus* are 2 key vectors of dengue, yellow fever, chikungunya, and Zika (Kraemer et al. 2019). Understanding which species they feed on is therefore of particular interest. Our analysis of the studies demonstrated that *Aedes aegypti* was observed feeding on 17 different plant species (19 records), with the Fabaceae family having the most records. *Impatiens walleriana* Hook.f. (Ericales: Balsaminaceae; 2 records) and *Pithecellobium dulce* (Roxb.) Benth. (Fabales: Fabaceae; 2 records) were the only plants with multiple records of *Ae. aegypti* feeding on them. In contrast, *Ae. albopictus* was recorded feeding on only 3 different plant species (3 records).

Among the main malaria vectors, *An. gambiae* was the most studied species and studies indicate that feed on at least 17 different plant species (34 records), with 7 belonging to the Fabaceae family. The plant species demonstrating the highest number of feeding observations of *An. gambiae* were *R. communis* (6 records), *P. hysterophorus* (5 records), *S. didymobotrya* (4 records), *Lantana camara* L. (Lamiales: Verbenaceae; 3 records), and *Tecoma stans* (L.) Juss. ex Kunth (Lamiales: Bignoniaceae; 3 records).

Other important malaria vectors include *Anopheles arabiensis* Patton, 1995 and *Anopheles coluzzi* Coetzee and Wilkerson, 2013 and again, interesting observations have been found. For example, *Anopheles arabiensis* was observed feeding on *A. millefolium* (1 record), *Duranta erecta* L. (Lamiales: Verbenaceae; 1 record), and *Stachytarpheta urticifolia* Sims (Lamiales: Verbenaceae; 1 record) and *An. coluzzi* showed preferences for *Barleria lupulina* Lindl. (Lamiales: Acanthaceae; 1 record) and *Cascabela thevetia* (L.) Lippold (Gentianales: Apocynaceae; 1 record). In comparison, no studies were found related to *Anopheles funestus* Giles, 1900 feeding behavior on plant nectar.

Culex pipiens, another significant vector known for transmitting West Nile virus, Saint Louis encephalitis, avian malaria, and filarial worms (Farajollahi et al. 2011), displayed a preference for plants from the Asteraceae family (5 records), particularly *A. millefolium* (2 records) and *T. vulgare* (2 records). Additionally, *Cx. pipiens* fed on 10 other plant species, with one record for each. See Supplementary Appendix 3 for more details.

Risk of Bias Assessment to Study Mosquito Nectar Preferences

The risk of bias assessment revealed that 36 studies (71%) were considered to have a high risk of bias, while 15 studies were classified as low risk. The results of the risk of bias assessments are available in Supplementary Appendix 4.

Only studies that selected the plants randomly, employed more than one plant where mosquitoes could feed on in the study, and

Table 4. List of references retrieved from the systematic review process

References	Location	Mosquito genera	Plant genera	Plant family
Twinn et al. (1948)	Canada	*Aedes*	*Platanthera*	Orchidaceae
Haeger (1955)	Florida, USA	*Aedes, Psorophora*	*Avicennia, Conocarpus*	Ancanthaceae, Combretaceae
Haeger (1960)	Florida, USA	*Aedes*	*Avicennia, Bidens, Eupatorium*	Ancanthaceae, Asteraceae
Sandholm and Price (1962)	Minnesota, USA	*Aedes, Coquillettidia, Culex, Culiseta*	*Apocynum, Aquilegia, Asclepias, Aster, Catalpa, Chrysanthemum, Cirsium, Cornus, Dasiphora, Echinocystis, Eutrochium, Fraxinus, Heracleum, Hydrangea, Lilium, Melilotus, Monarda, Nepeta, Pastinaca, Philadelphus, Phlox, Physocarpus, Rosa, Rudbeckia, Solidago, Spiraea, Symphoricarpos, Syringa, Tamarix, Tanacetum, Trifolium, Verbena*	Apocynaceae, Asteraceae, Bignoniaceae, Caprifoliaceae, Cornaceae, Cucurbitaceae, Fabaceae, Hydrangeaceae, Lamiaceae, Liliaceae, Oleaceae, Polemoniaceae, Ranunculaceae, Rosaceae, Tamaricaceae, Umbelliferae, Verbenaceae
Abdel-Malek (1964)	Egypt	*Anopheles*	*Alhagi, Juncus, Salicornia*	Fabaceae, Juncaceae, Amaranthaceae
Corbet (1964)	Canada	*Aedes*	*Dryas*	Rosaceae
McCrae et al. (1969)	Uganda	*Aedes, Anopheles, Culex, Eretmapodites, Ficalbia, Mansonia, Toxorhynchites, Uranotaenia*	*Harungana*	Hypericaceae
Thien (1969)	Wisconsin, USA	*Aedes*	*Platanthera*	Orchidaceae
Schaefer and Miura (1972)	California, USA	*Culex*	*Helianthus, Heterotheca*	Asteraceae
Grimstad and DeFoliart (1974)	Wisconsin, USA	*Aedes, Anopheles, Coquillettidia, Culex, Culiseta*	*Achillea, Apocynum, Asclepias, Cornus, Eupatorium, Euphorbia, Leucanthemum, Liatris, Maianthemum, Monarda, Prunus, Salix, Silene, Solidago, Spiraea*	Apocynaceae, Asparagaceae, Asteraceae, Caryophyllaceae, Cornaceae, Euphorbiaceae, Lamiaceae, Rosaceae, Salicaceae
Magnarelli (1977)	Connecticut, USA	*Aedes*	*Achillea, Daucus, Gerardia, Hieracium, Leucanthemum, Malva, Rosa, Solidago, Taraxacum*	Apiaceae, Asteraceae, Malvaceae, Orobanchaceae, Rosaceae
Magnarelli (1978)	Connecticut, USA	*Aedes*	*Achillea, Daucus, Hieracium, Leucanthemum, Malva, Rosa, Solidago*	Apiaceae, Asteraceae, Malvaceae, Rosaceae
Magnarelli (1979)	Connecticut, USA	*Aedes*	*Achillea, Daucus, Hieracium, Leucanthemum, Malva, Rosa, Solidago*	Apiaceae, Asteraceae, Malvaceae, Rosaceae
Magnarelli (1980)	Connecticut, USA	*Aedes*	*Achillea, Hieracium, Leucanthemum, Solidago*	Asteraceae
Magnarelli (1983)	Connecticut, USA	*Psorophora*	*Aster*	Asteraceae
Vargo and Foster (1984)	Ohio, USA	*Aedes, Culex*	*Ageratina, Solidago*	Asteraceae
Andersson and Jaenson (1987)	Sweden	*Aedes, Anopheles, Coquillettidia, Culex, Culiseta*	*Tanacetum*	Asteraceae
Healy and Jepson (1988)	UK	*Anopheles*	*Achillea*	Asteraceae
Jepson and Healy (1988)	UK	*Aedes*	*Leucanthemum*	Asteraceae
Mogi and Miyagi (1989)	Philippines	*Topomyia*	*Mucuna, Psidium*	Fabaceae, Myrtaceae
Andersson (1990)	Sweden	*Aedes*	*Achillea, Aegopodium, Anthriscus, Myosotis, Rubus, Vaccinium*	Apiaceae, Asteraceae, Boraginaceae, Ericaceae, Rosaceae
Jaenson and Ameneshewa (1991)	Sweden	*Anopheles*	*Achillea, Tanacetum*	Asteraceae

Table 4. Continued

References	Location	Mosquito genera	Plant genera	Plant family
Gadawski and Smith (1992)		*Aedes*	*Actaea, Amelanchier, Cornus, Crataegus, Leucanthemum, Prunus, Pyrus, Ranunculus, Rhamnus, Ribes, Rubus, Syringa, Taraxacum, Zanthoxylum*	Asteraceae, Cornaceae, Grossulariaceae, Oleaceae, Ranunculaceae, Rhamnaceae, Rosaceae, Rutaceae
Yee et al. (1992)	Ohio, USA	*Aedes*	*Apocynum, Asclepias, Daucus, Leucanthemum*	Apiaceae, Apocynaceae, Asteraceae
Smith and Gadawski (1994)	Canada	*Aedes*	*Prunus*	Rosaceae
Burkett et al. (1999)	Florida, USA	*Aedes, Culex, Psorophora, Uranotaenia*		Fabaceae
Gary Jr and Foster (2004)	Ohio, USA	*Anopheles*	*Manihot, Ricinus*	Euphorbiaceae
Impoinvil et al. (2004)	Kenya	*Anopheles*	*Ipomoea, Lantana, Ricinus*	Convolvulaceae, Verbenaceae, Euphorbiaceae
Müller and Schlein (2006)	Israel	*Aedes, Anopheles*	*Acacia*	Fabaceae
Manda et al. (2007b) (a)	Kenya	*Anopheles*	*Hamelia, Parthenium, Ricinus, Senna, Tecoma*	Asteraceae, Bignoniaceae, Euphorbiaceae, Fabaceae, Rubiaceae
Manda et al. (2007b) (c)	Kenya	*Anopheles*	*Hamelia, Lantana, Parthenium, Ricinus, Senna, Tecoma*	Asteraceae, Bignoniaceae, Euphorbiaceae, Fabaceae, Rubiaceae, Verbenaceae
Manda et al. (2007b) (b)	Kenya	*Anopheles*	*Parthenium, Ricinus, Senna, Tecoma*	Asteraceae, Bignoniaceae, Euphorbiaceae, Fabaceae,
Schlein and Müller (2008)	Israel	*Culex*	*Acacia, Polygonum, Tamarix*	Fabaceae, Polygonaceae, Tamaricaceae
Gouagna et al. (2010)	Burkina Faso	*Anopheles*	*Cassia, Delonix, Mangifera, Senna, Thevetia*	Anacardiaceae, Apocynaceae, Fabaceae
Gu et al. (2011)	Israel	*Anopheles*	*Acacia*	Fabaceae
Dötterl et al. (2012)	Germany	*Aedes, Anopheles, Culex*	*Silene*	Caryophyllaceae
Gouagna et al. (2014)	Reunion	*Anopheles*	*Duranta, Stachytarpheta*	Verbenaceae
Chen and Kearney (2015)	Texas, USA	*Aedes, Culex*	*Asclepias, Campis, Impatiens, Passiflora, Ricinus*	Asclepiadaceae, Balsaminaceae, Bignoniaceae, Euphorbiaceae, Passifloraceae
Hien et al. (2016)	Burkina Faso	*Anopheles*	*Barleria, Thevetia*	Acanthaceae, Apocynaceae
Nikbakhtzadeh et al. (2016)	Ohio, USA	*Anopheles*	*Lantana, Parthenium, Senna*	Asteraceae, Fabaceae, Verbenaceae
Peach and Gries (2016)	Canada	*Culex, Culiseta*	*Achillea, Leucanthemum, Tanacetum*	Asteraceae
Kenney et al. (2017)	West Virginia, USA	*Aedes*	*Cucurbita*	Cucurbitaceae
Müller et al. (2017)	Mali	*Anopheles*	*Prosopis*	Fabaceae
Rewicz et al. (2017)	Poland	*Culicidae*	*Epipactis*	Orchidaceae
Nyasembe et al. (2018)	Kenya	*Aedes, Anopheles*	*Hibiscus, Leonotis, Opuntia, Parthenium, Pithecellobium, Ricinus, Senna*	Asteraceae, Cactaceae, Euphorbiaceae, Fabaceae, Lamiaceae, Malvaceae
Yu et al. (2018)	China	*Culex*	*Abelia, Ligustrum, Nerium*	Apocynaceae, Caprifoliaceae, Oleaceae
Sissoko et al. (2019)	Mali	*Aedes*	*Acacia, Galphimia, Lantana, Prosopis*	Fabaceae, Malpighiaceae, Verbenaceae

Table 4. Continued

References	Location	Mosquito genera	Plant genera	Plant family
Pruett et al. (2020)	Florida, USA	*Aedes, Culex*	*Impatiens*	Balsaminaceae
Nyasembe et al. (2021)	Kenya	*Aedes*	*Leonotis, Opuntia, Pithecellobium*	Cactaceae, Fabaceae, Lamiaceae
Patil and Jagdale (2021)	India	*Culex*	*Luffa*	Cucurbitaceae
Rambey et al. (2021)	Indonesia	*Aedes*	*Amorphophallus*	Araceae

included experimental repetitions, were classified as low risk of bias. It was these studies that were included in our analysis to study mosquito preferences for specific plant nectar. Conversely, high-risk studies demonstrated a propensity to exclusively include plants known a priori to be attractive to mosquitoes and often conducted single-choice assays, limiting mosquitoes to feeding on a sole plant species. The high-risk category also included studies with the primary objective of observing variations in mosquito survival, fecundity, or vectorial capacity depending on the plants they fed on. In these cases, plant selection was not randomized but rather influenced by prior studies or inherent plant characteristics. To investigate mosquito preferences, it is essential to include a diverse selection of plants that reflects the variety mosquitoes encounter in their natural environment, or at least does not intentionally limit their choices to a few selected species.

Results of Meta-analysis

Do Mosquitoes Show Preferences for Specific Plant Nectar?

A detailed analysis was specifically conducted on studies classified as having low risk of bias to better understand whether mosquitoes showed preferences for particular plants and identify those preferences. Two of the 15 low risk of bias studies were excluded due to lack of information on the total number of plant species included. From these 13 studies, we obtained a ratio below 0.5 in 10 out of 13 studies, and a ratio between 0.5 and 0.7 in 2 out of 13 studies. Only one study obtained a ratio of 1, indicating no preference of mosquitoes for specific plant nectar. This suggests, therefore, that from the studies carried out to date, mosquitoes do appear to show a preference for the nectar of certain types of plants.

Do Different Mosquito Genera Show Preferences for Specific Plant Species?

Our analysis included 7 low risk of bias studies to investigate whether *Aedes* mosquitoes exhibited preferences for specific plant nectar. All demonstrated ratios below 0.7 and 5 of these obtained a ratio lower than 0.5 indicating that this mosquito species preferred to feed in particular plants, specifically, *Aedes* preferred to feed on 77 plant species.

Other 7 studies were involved in determining preferences in *Anopheles* species, and 6 out of 7 such studies obtained a ratio lower than 0.5, again demonstrating preferences for specific species of plants—in this case for 18 plant species.

Same conclusions in terms of plant preferences were obtained for *Culex* species, with ratios lower than 0.5 in all the studies (3 in total). In particular, this species showed preferences for 16 plant species.

The representation of these genera-specific interactions is shown in Fig. 4B and includes a total of 274 records of mosquitoes feeding on 100 distinct plant species (73 genera). From our analysis of the data would appear that at the plant family level, Asteraceae and Rosaceae dominated in terms of records of *Aedes* species feeding on them. In addition, studies with *Aedes* species based in Africa also showed preferences for plants within the Fabaceae family.

For *Anopheles* species, the families Asteraceae, Fabaceae, and Euphorbiaceae had the most feeding records. Finally, Asteraceae was the family with the highest number of records of *Culex* species feeding on them.

Similar results were obtained consistent with the previous analysis that incorporated all studies (and therefore potential bias) (Fig. 4A).

At the plant species level, our findings revealed distinct preferences among mosquito genera: *Aedes* species displayed a preference for
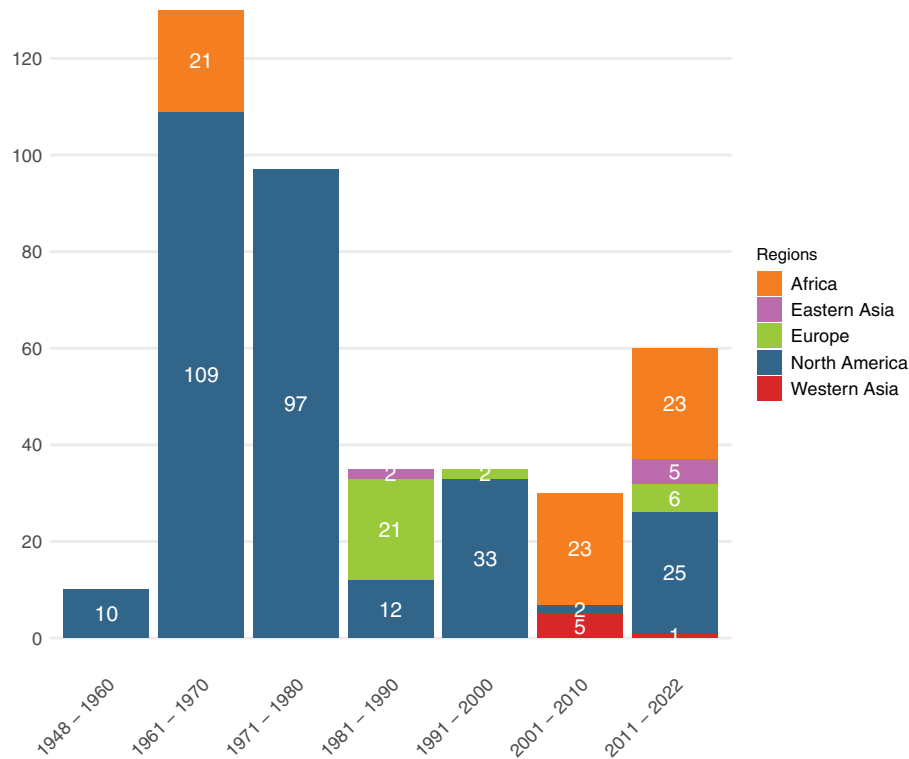
Fig. 3. Number of records of published studies that have examined floral nectar feeding behavior (field and laboratory) and the regions where this research was undertaken.

feeding on 77 species of plants pertaining to 58 genera (42 species of those were identified in the field by Sandholm and Price (1962); *A. millefolium* (*n* = 4, 12 records), *A. syriaca* (*n* = 3, 12 records, *L. vulgare* (*n* = 6, 11 records), and *S. canadensis* (*n* = 2, 5 records) were the plants with the most records of *Aedes* species feeding on them.

Anopheles species fed on 18 plant species (17 genera); *R. communis* (*n* = 4, 4 records), *P. hysterophorus* (*n* = 3, 3 records), and *S. didymobotrya* (*n* = 2, 2 records) remained the plants with the highest number of *Anopheles* feeding records, consistent with the previous analysis that included all records. For the studies on *Anopheles* species not conducted in Africa, *A. syriaca* (*n* = 1, 3 records), *A. millefolium* (*n* = 1, 2 records), and *Solidago* L. spp. (*n* = 1, 2 records) (Grimstad and DeFoliart 1974) were identified as the plants with highest number of *Anopheles* species feeding on them.

Finally, *Culex* species demonstrated preferences for 16 species of plants (16 genera); *Solidago* spp. (*n* = 1, 3 records) and *H. madagascariensis* (*n* = 1, 3 records) were the plants with more records of *Culex* species feeding on them. Following closely were *A. millefolium* (*n* = 1), *A. syriaca* (*n* = 2), and *S. canadensis* (*n* = 1) each with 2 records. These results can be found in Supplementary Appendix 4.

An interesting outcome arising from our analysis on mosquito nectar preferences is the discovery that several mosquito genera fed on nectar of certain plants. For example, 8 mosquito genera (15 species) fed on *H. madagascariensis*, 5 mosquito genera fed on *A. milefollium* (16 mosquito species), *A. syriaca* (16 mosquito species), and on *Solidago* spp. (14 mosquito species), and 4 mosquito genera fed on *Spiraea latifolia* (Aiton) Borkh. (Rosales: Rosaceae, 6 mosquito species) and *Philadelphus caucasicus* Koehne (Cornales: Hydrangeaceae, 6 mosquito species). Twenty more species of plants were attractive to several genera of mosquitoes.

Do Different Mosquito Species Present Specific Plant Preferences?

A total of 15 Chi-squared tests, involving 10 different mosquito species, were performed to statistically assess whether mosquito species exhibited preferences for specific plants. The tests were conducted using low-bias studies and only when the expected mosquito counts per plant species were 5 or greater. The results confirmed that different mosquito species showed preferences for specific plant traits (see Table 5 and Supplementary Appendix 5).

When studying the main mosquito vectors, our results indicated that, *Ae. aegypti* fed on *Hibiscus heterophyllus* Vent. (Malvales: Malvaceae; 1 record), *P. dulce* (1 record), and *Senna uniflora* (Mill.) H.S.Irwin & Barneby (Fabales: Fabaceae; 1 record) (Nyasembe et al. 2018). The feeding preferences of *An. gambiae* also showed consistent preferences with this species primarily feeding on *R. communis* (4 records), *P. hysterophorus* (3 records), *S. didymobotrya* (2 records), *L. camara* (2 records), and *T. stans* (2 records). Similarly, *Cx. pipiens* was observed feeding on a few different plants, demonstrating preferences for *Acacia saligna* (Labill.) Wendl. (Fabales: Fabaceae; 1 record), *Polygonum equisetiforme* Sm. (Caryophyllales: Polygonaceae; 1 record), and *Tamarix jordanis* Boiss. (Caryophyllales: Tamaricaceae; 1 record).

Discussion

When addressing the question '*Which nectar do mosquitoes feed on?*' using a systematic map, we found 74 mosquito species across 12 genera, feeding on 145 plant species (109 genera). Further analysis using a subset of studies with more stringent criteria to avoid potential bias demonstrated that mosquito families and genera, appear to show preferences for obtaining nectar from certain groups of plants. In particular, *Aedes* species exhibited preferences for 77 plant
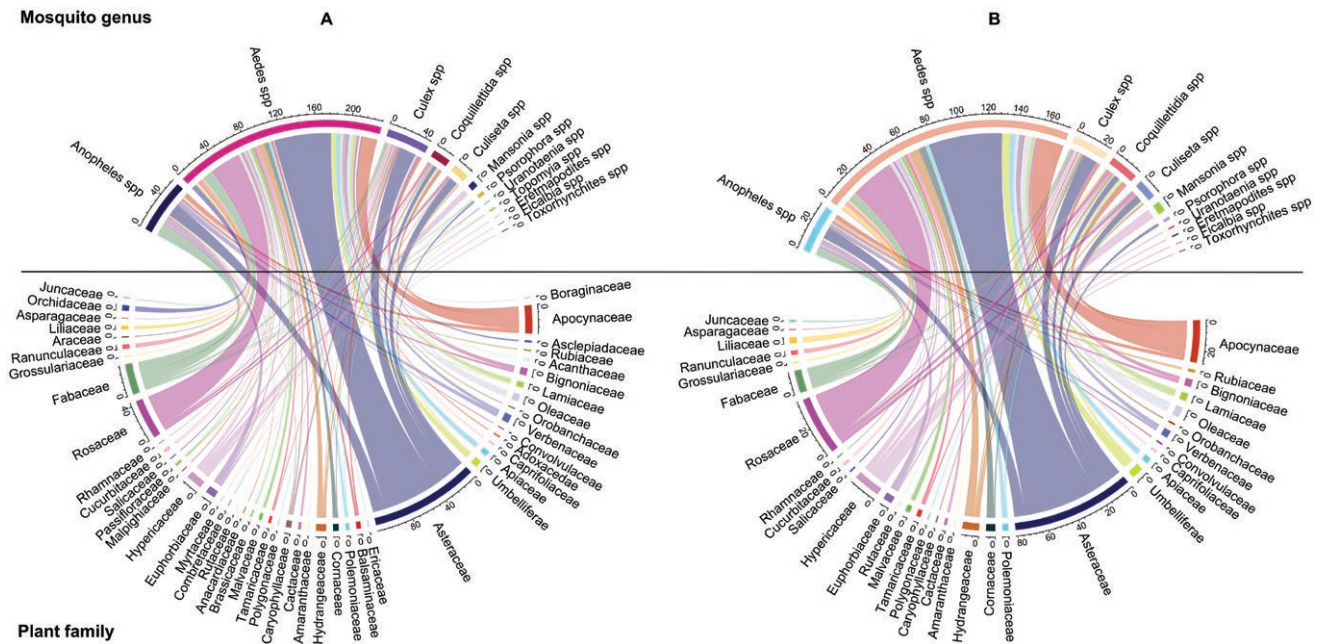
Fig. 4. Plant family preferences by different genera of mosquitoes. Panel (A) shows all records and Panel (B) records with low risk of bias.

species (58 genera), *Anopheles* species favored 18 plant species (17 genera), and *Culex* species displayed preferences for 16 plant species (16 genera).

Our meta-analysis of the data from the systematic map indicated that Asteraceae, Rosaceae and Fabaceae are the families with the most records of mosquitoes feeding on them and in these, there was a sub-set of 18 plant species in the Asteraceae, 20 plant species in the Rosaceae and 11 plant species in the Fabaceae that clearly demonstrated a feeding preference. Further research is now needed to understand whether there are common traits within these families and species that might make them more attractive to mosquitoes.

Some caution, however, must be taken when making assumptions about these preferred plant families. First, Asteraceae and Fabaceae are two of the most species-rich and abundant plant families globally (Panero and Crozier 2016). Second, mosquitoes' preferences in some cases seem to be country-specific, at least from the evidence available to date. For example, Asteraceae and Rosaceae emerged prominently in records of *Aedes* species feeding on them in North America (Sandholm and Price 1962, Grimstad and DeFoliart 1974, Magnarelli 1977, 1978, 1979, 1980, 1983, Gadawski and Smith 1992, Yee et al. 1992). In contrast, studies conducted in Africa with *Aedes* species did not show preferences for these two families (McCrae et al. 1969, Nyasembe et al. 2018). Also, while Asteraceae and Fabaceae were prevalent in records associated with *Anopheles* species, Fabaceae dominated for *Anopheles* species in Africa (Abdel-Malek 1964, Manda et al. 2007b, Nyasembe et al. 2018) (primarily *An. gambiae)*, whereas Asteraceae reported more records of *Anopheles* species feeding on them in other continents (Grimstad and DeFoliart 1974, Andersson and Jaenson 1987, Healy and Jepson 1988, Jaenson and Ameneshewa 1991).

The absence of findings regarding *Anopheles* species in Africa feeding on plants within the Rosaceae family could be attributed to the difference in abundance of this plant family in Africa (it is much more widespread as a family in northern temperate regions (Liu et al. 2021)) but this needs further investigation. These regional differences in the preferred plant families, however, also emphasizes the importance of considering geographical factors such as local vegetation in future work to understand mosquito-plant interactions.

When analyzing the plants preferred by major mosquito vectors, we identified several plants that these mosquitoes tend to feed on. First, *Anopheles gambiae*, the most extensively studied, displayed a preference for *R. communis, P. hysterophorus, T. stans, S. didymobotrya*, and *H. patens*. Previous work has suggested that *An. gambiae* may also have a preference for *L. camara*. Our analysis of the literature suggest that this remains controversial, with some studies suggesting it is one of *An. gambiae*'s preferred plants (Impoinvil et al. 2004) while others indicating the opposite (Manda et al. 2007b). In particular, these contrasting results suggest that attractiveness may depend on specific ecological contexts or experimental designs. Second, DNA extraction and sequencing techniques have identified *H. heterophyllus, P. dulce*, and *S. uniflora* as preferred plants of *Ae. aegypti* in the field in Kenya (Nyasembe et al. 2018). Finally, *Cx. pipiens* showed preferences for 3 out of 10 plant species, with *T. jordanis* being the most visited.

Our findings are also of relevance when considering future scenarios of climate change and globalization. With these changes occurring across the globe, it is widely expected that the disappearance of certain plant species from their natural habitats will occur, and they will be replaced by different species, especially those with invasive traits (Bhagwat et al. 2012, Agha et al. 2021, Tabe Ojong et al. 2021). It is likely therefore that certain of the plant species already identified as preferred to *An. gambiae*, such as *R. communis, P. hysterophorus, L. camara,* and *T. stans*, which are invasive and becoming widespread across landscapes (Emily et al. 2014, Nyasembe et al. 2015, Müller et al. 2017, Stone et al. 2018), could potentially increase their distribution and abundance, thereby increasing the availability of this nectar resource across mosquito-prone landscapes.

Limitations and Further Work

Our systematic map search included all the continents; however, we only included articles written in English. This might impact our results—especially those from gray literature. For example, no papers were found in South America related to our review question. Given that around 98% of peer-reviewed scientific studies are published in English nowadays (Gordin 2015), we believe the overall impact is low, although it could be regionally moderate.

Table 5. Chi-squared results using low risk of bias studies when the expected mosquito counts per plant species were 5 or greater.

Mosquito species	No Plant species	Study ID	Chi-squared results
Aedes canadensis	5	Grimstad_1974_112	X-squared = 32.375, df = 4, **P-value <0.001**
Aedes vexans	35	Sandholm_1962_66	X-squared = 6129, df = 34, **P-value <0.001**
Aedes sollicitans	17	Magnarelli_1977_105	X-squared = 313.56, df = 16, **P-value <0.001**
Aedes sollicitans	11	Magnarelli_1979_43	X-squared = 1898.3, df = 10, **P-value <0.001**
Aedes cantator	15	Magnarelli_1978_33	X-squared = 741.89, df = 14, **P-value <0.001**
Aedes cantator	11	Magnarelli_1979_43	X-squared = 1121.9, df = 10, **P-value <0.001**
Anopheles earlei	4	Grimstad_1974_112	X-squared = 8.6552, df = 3, **P-value <0.05**
Anopheles gambiae	8	Impoinvil_2004_206	X-squared = 212.51, df = 7, **P-value <0.001**
Anopheles gambiae	13	Manda_2007_42a	X-squared = 126.89, df = 12, **P-value <0.001**
Anopheles gambiae	13	Manda_2007_42b	X-squared = 124.15, df = 12, **P-value <0.001**
Anopheles sergentii	40	Abdel-Malek_1964_226	X-squared = 427.84, df = 39, **P-value <0.001**
Culex pipiens	10	Schlein_2008_13	X-squared = 6503.2, df = 9, **P-value <0.001**
Coquillettidia perturbans	10	Sandholm_1962_66	X-squared = 1012.7, df = 9, **P-value <0.001**
Coquillettidia perturbans	63	Grimstad_1974_112	X-squared = 146460, df = 62, **P-value <0.001**

We excluded studies on fruits, seedpods, plant tissue and honeydew, since our question was only related to nectar, the main sugar source of mosquitoes. We also excluded papers related to olfactory, gustatory, and visual attraction if they did not include observations of mosquitoes feeding on nectar. Several papers related to this topic were found during the review process. It would be interesting to build on our work further to carry out additional systematic reviews related to this topic.

Conclusion

Our systematic map includes 397 records of mosquitoes feeding on various plant species, retrieved from 51 studies. The interactive map provided details the temporal and spatial distribution of these studies, their methodologies, criteria for plant selection, study designs, and main objectives. This information is valuable for researchers planning future work in this field and for practitioners developing mosquito control methods. Our further meta-analysis of a selected set of studies confirmed that mosquitoes prefer certain plants. Asteraceae and Rosaceae were frequently associated with *Aedes* species, Asteraceae and Fabaceae with *Anopheles* species, and Asteraceae with *Culex* species. However, the number of studies is still low, and many are based on laboratory trials. More studies combining field observations with laboratory research are needed to identify mosquito preferences in various natural environments and assess changes over time and space depending on local vegetation.

Our study also highlighted a critical need for more long-term studies, planned according to the biology of the species of mosquito (nocturnal/diurnal and urban/peri-urban/rural). In particular, there is a need for greater observations and collections of mosquitoes feeding on plants in the field, including invasive species of mosquitoes and plants. This needs to be combined with robust sampling methods which include randomized selection of plants in the field, study replication, and multiple plant choice assays. Subsequent laboratory work, to confirm mosquito feeding on these plants and identify their nectar compounds are also crucial for better understanding mosquito feeding behavior in the field. This will help in the design and development of more targeted mosquito control methods, considering mosquito preferences as well as the spatial and temporal presence and abundance of their preferred plants.

Acknowledgments

Funding

Ethics Statement

The authors declare that approval by an ethics committee was not required for this study.

Supplementary material

Supplementary material is available at *Environmental Entomology* online.

Data Availability

The data underlying this article are available in the article and in its online supplementary material.

References

Abdel-Malek AA. 1964. Study of the feeding habits of male *Anopheles sergenti* Theo. at Siwa oasis using radiophosphorus. Bull. World Health Organ. 30:137–139.

Agha SB, Alvarez M, Becker M, et al. 2021. Invasive alien plants in Africa and the potential emergence of mosquito-borne arboviral diseases—a review and research outlook. Viruses 13, 32. https://doi.org/10.3390/v13010032

Andersson IH. 1990. Nectar feeding activity of *Aedes* mosquitoes, with special reference to *Aedes communis* females. *Journal of the American Mosquito Control Association*. 6:482–489.

Andersson IH, Jaenson TGT. 1987. Nectar feeding by mosquitoes in Sweden, with special reference to *Culex pipiens* and *Cx. torrentium*. Med. Vet. Entomol. 1:59–64. https://doi.org/10.1111/j.1365-2915.1987.tb00323.x

Beier JC, Müller GC, Gu W, et al. 2012. Attractive toxic sugar bait (ATSB) methods decimate populations of *Anopheles* malaria vectors in arid environments regardless of the local availability of favoured sugar-source blossoms. Malar. J. 11:31. https://doi.org/10.1186/1475-2875-11-31

Bernáth B, Anstett V, Guerin PM. 2016. *Anopheles gambiae* females readily learn to associate complex visual cues with the quality of sugar sources. J. Insect Physiol. 95:8–16. https://doi.org/10.1016/j.jinsphys.2016.08.011

Bhagwat SA, Breman E, Thekaekara T, et al. 2012. A battle lost? Report on two centuries of invasion and management of *Lantana camara* L. in Australia, India and South Africa. PLoS One 7:e32407. https://doi.org/10.1371/journal.pone.0032407

Burkett DA, Kline DL, Carlson DA. 1999. Sugar meal composition of five north central Florida mosquito species (Diptera: Culicidae) as determined by gas chromatography. J. Med. Entomol. 36:462–467. https://doi.org/10.1093/jmedent/36.4.462

Chen Z, Kearney CM. 2015. Nectar protein content and attractiveness to *Aedes aegypti* and *Culex pipiens* in plants with nectar/insect associations. Acta Trop. 146:81–88. https://doi.org/10.1016/j.actatropica.2015.03.010

Clements AN. 1963. The physiology of mosquitoes - adult feeding. In: Clements AN, editor. The physiology of mosquitoes. London: Pergamon Press, p. 128–150.

Cohen J. 1960. A coefficient of agreement for nominal scales. Educ. Psychol. Measurement. 20:37–46. https://doi.org/10.1177/001316446002000104

Corbet PS. 1964. Autogeny and oviposition in Arctic mosquitoes. Nature 203:669–669. https://doi.org/10.1038/203669a0

Dieng H, Satho T, Binti Arzemi NA, et al. 2018. Exposure of a diurnal mosquito vector to floral mimics: foraging responses, feeding patterns, and significance for sugar bait technology. Acta Trop. 185:230–238. https://doi.org/10.1016/j.actatropica.2018.05.019

Dötterl S, Jahreiß K, Jhumur US, et al. 2012. Temporal variation of flower scent in *Silene otites* (Caryophyllaceae): a species with a mixed pollination system. Bot. J. Linn. Soc. 169:447–460. https://doi.org/10.1111/j.1095-8339.2012.01239.x

Durnez L, Coosemans M. 2013. Residual transmission of malaria: an old issue for new approaches. In Manguin S, editor. *Anopheles mosquitoes—New insights into malaria vectors*. p. 671–704. https://doi.org/10.5772/55925

Emily W, Agnes L, Jenipher B, et al. 2014. A roadside survey of the invasive weed *Parthenium hysterophorus* (Asteraceae) in East Africa. J. East African Nat. Hist. 103:49–57. https://doi.org/10.2982/028.103.0105

Farajollahi A, Fonseca DM, Kramer LD, et al. 2011. 'Bird biting' mosquitoes and human disease: a review of the role of *Culex pipiens* complex mosquitoes in epidemiology. Infect. Genet. Evol. 11:1577–1585. https://doi.org/10.1016/j.meegid.2011.08.013

Foster WA. 1995. Mosquito sugar feeding and reproductive energetics. Annu. Rev. Entomol. 40:443–474. https://doi.org/10.1146/annurev.en.40.010195.002303

Frampton GK, Livoreil B, Petrokofsky G. 2017. Eligibility screening in evidence synthesis of environmental management topics. Environ. Evidence 6:27. https://doi.org/10.1186/s13750-017-0102-2

Gadawski RM, Smith SM. 1992. Nectar sources and age structure in a population of *Aedes provocans* (Diptera: Culicidae). J. Med. Entomol. 29:879–886. https://doi.org/10.1093/jmedent/29.5.879

Gary REJr., Foster WA. 2001. Effects of available sugar on the reproductive fitness and vectorial capacity of the malaria vector *Anopheles gambiae* (Diptera: Culicidae). J. Med. Entomol. 38:22–28. https://doi.org/10.1603/0022-2585-38.1.22

Gary REJr, Foster WA. 2004. *Anopheles gambiae* feeding and survival on honeydew and extra-floral nectar of peridomestic plants. Med. Vet. Entomol. 18:102–107. https://doi.org/10.1111/j.0269-283X.2004.00483.x

González-Teuber M, Heil M. 2009. Nectar chemistry is tailored for both attraction of mutualists and protection from exploiters. Plant Signal. Behav. 4:809–813. https://doi.org/10.4161/psb.4.9.9393

Gordin ME. 2015. Scientific Bable. The University of Chicago Press.

Gouagna LC, Poueme RS, Dabiré KR, et al. 2010. Patterns of sugar feeding and host plant preferences in adult males of *An. gambiae* (Diptera: Culicidae). J Vector Ecol. 35:267–276. https://doi.org/10.1111/j.1948-7134.2010.00082.x

Gouagna LC, Kerampran R, Lebon C, et al. 2014. Sugar-source preference, sugar intake and relative nutritional benefits in *Anopheles arabiensis* males. Acta Trop. 132:S70–S79. https://doi.org/10.1016/j.actatropica.2013.09.022

Grimstad PR, DeFoliart GR. 1974. Nectar sources of Wisconsin mosquitoes. J. Med. Entomol. 11:331–341. https://doi.org/10.1093/jmedent/11.3.331

Gu W, Müller G, Schlein Y, et al. 2011. Natural plant sugar sources of *Anopheles* mosquitoes strongly impact malaria transmission potential. PLoS One 6:e15996. https://doi.org/10.1371/journal.pone.0015996

Gu Z, Gu L, Eils R, et al. 2014. Circlize implements and enhances circular visualization in R. Bioinformatics 30:2811–2812. https://doi.org/10.1093/bioinformatics/btu393

Haeger JS. 1955. The non-blood feeding habits of *Aedes taeniorhynchus* (Diptera: Culicidae) on Sanibel Island, Florida. Mosquito News. 15:21–26.

Haeger JS. 1960. Behavior preceding migration in the salt-marsh mosquito, *Aedes taeniorhynchus* (Wiedemann). Mosquito News. 20:136–147.

Harrison RE, Brown MR, Strand MR. 2021. Whole blood and blood components from vertebrates differentially affect egg formation in three species of anautogenous mosquitoes. Parasites Vect. 14:119. https://doi.org/10.1186/s13071-021-04594-9

Healy TP, Jepson PC. 1988. The location of floral nectar sources by mosquitoes: the long-range responses of *Anopheles arabiensis* Patton (Diptera: Culicidae) to *Achillea millefolium* flowers and isolated floral odour. Bull. Entomol. Res. 78:651–657. https://doi.org/10.1017/s0007485300015509

Hemingway J, Ranson H, Magill A, et al. 2016. Averting a malaria disaster: will insecticide resistance derail malaria control? Lancet (London, England). 387:1785–1788. https://doi.org/10.1016/S0140-6736(15)00417-1

Hien DFS, Dabiré KR, Roche B, et al. 2016. Plant-mediated effects on mosquito capacity to transmit human malaria. PLoS Pathog. 12:e1005773. https://doi.org/10.1371/journal.ppat.1005773

Ignell R, Okawa S, Englund J-E, et al. 2010. Assessment of diet choice by the yellow fever mosquito *Aedes aegypti*. Physiol. Entomol. 35:274–286. https://doi.org/10.1111/j.1365-3032.2010.00740.x

Impoinvil DE, Kongere JO, Foster WA, et al. 2004. Feeding and survival of the malaria vector *Anopheles gambiae* on plants growing in Kenya. Med. Vet. Entomol. 18:108–115. https://doi.org/10.1111/j.0269-283X.2004.00484.x

Jaenson TGT, Ameneshewa B. 1991. Prehibernation diet and reproductive condition of female *Anopheles messeae* in Sweden. Med. Vet. Entomol. 5:243–252. https://doi.org/10.1111/j.1365-2915.1991.tb00547.x

Jepson PC, Healy TP. 1988. The location of floral nectar sources by mosquitoes: an advanced bioassay for volatile plant odours and initial studies with *Aedes aegypti* (L.) (Diptera: Culicidae). Bull. Entomol. Res. 78:641–650. https://doi.org/10.1017/s0007485300015492

Junnila A, Müller GC, Schlein Y. 2010. Species identification of plant tissues from the gut of *An. sergentii* by DNA analysis. Acta Trop. 115:227–233. https://doi.org/10.1016/j.actatropica.2010.04.002

Kahili-Heede M, Hillgren KJ. 2021. Colandr. Journal of the Medical Library Association 109:523–525. https://doi.org/10.5195/jmla.2021.1263

Kenney A, Cusick A, Payne J, et al. 2017. The potential for flower nectar to allow mosquito to mosquito transmission of *Francisella tularensis*. PLoS One 12:e0175157. https://doi.org/10.1371/journal.pone.0175157

Kessler S, Vlimant M, Guerin PM. 2015. Sugar-sensitive neurone responses and sugar feeding preferences influence lifespan and biting behaviours of the Afrotropical malaria mosquito, *Anopheles gambiae*. J. Comp. Physiol. A Neuroethol. Sens. Neural Behav. Physiol. 201:317–329. https://doi.org/10.1007/s00359-015-0978-7

Knab F. 1907. Mosquitoes as flower visitors. J. N. Y. Entomol. Soc. 15:215–219.

Kraemer MUG, Reiner RC, Brady OJ, et al. 2019. Past and future spread of the arbovirus vectors *Aedes aegypti* and *Aedes albopictus*. Nat. Microbiol. 4:854–863. https://doi.org/10.1038/s41564-019-0376-y

Lahondère C, Vinauger C, Okubo RP, et al. 2020. The olfactory basis of orchid pollination by mosquitoes. Proc. Natl. Acad. Sci. U.S.A. 117:708–716. https://doi.org/10.1073/pnas.1910589117

Liu M, Huang M, Cline AR, et al. 2021. Rosaceae, Brassicaceae and pollen beetles: exploring relationships and evolution in an anthophilous beetle lineage (Nitidulidae, *Meligethes*-complex of genera) using an integrative approach. Front. Zool. 18:9. https://doi.org/10.1186/s12983-021-00390-4

Magnarelli LA. 1977. Nectar feeding by *Aedes sollicitans* and its relation to gonotrophic activity. Environ. Entomol. 6:237–242. https://doi.org/10.1093/ee/6.2.237

Magnarelli LA. 1978. Bionomics of the salt-marsh mosquito, *Aedes cantator* (Diptera: Culicidae). Environ. Entomol. 7:512–517. https://doi.org/10.1093/ee/7.4.512

Magnarelli LA. 1979. Diurnal nectar-feeding of *Aedes cantator* and *A. sollicitans* (Diptera: Culicidae). Environ. Entomol. 8:949–955. https://doi.org/10.1093/ee/8.5.949

Magnarelli LA. 1980. Bionomics of *Psorophora ferox* (Diptera: Culicidae): seasonal occurrence and acquisition of sugars. J. Med. Entomol. 17:328–332. https://doi.org/10.1093/jmedent/17.4.328

Magnarelli LA. 1983. Nectar sugars and caloric reserves in natural populations of *Aedes canadensis* and *Aedes stimulans* (Diptera: Culicidae). Environ. Entomol. 12:1482–1486. https://doi.org/10.1093/ee/12.5.1482

Manda H, Gouagna LC, Foster WA, et al. 2007a. Effect of discriminative plant-sugar feeding on the survival and fecundity of *Anopheles gambiae*. Malar. J. 6:113. https://doi.org/10.1186/1475-2875-6-113

Manda H, Gouagna LC, Nyandat E, et al. 2007b. Discriminative feeding behaviour of *Anopheles gambiae* s.s. on endemic plants in western Kenya. Med. Vet. Entomol. 21:103–111. https://doi.org/10.1111/j.1365-2915.2007.00672.x

Martin AC. 2017. Thalloo Evidence-Mapping: A Jekyll Theme. Available online: https://github.com/AndrewIOM/thalloo

McCrae AWR, Ssenkubuge Y, Manuma P, Mawejje C, Kitama A. 1969. Mosquito and tabanid activity at plant sugar sources. Report of the East African Virus Research Institute. 18:96–102

McHugh ML. 2013. The chi-square test of independence. (1330-0962 (Print))

Mogi M, Miyagi I. 1989. Sugar feeding of *Topomyia pseudobarbus* (Diptera: Culicidae) in Nature. J. Med. Entomol. 26:370–371. https://doi.org/10.1093/jmedent/26.4.370

Moiroux N, Gomez MB, Pennetier C, et al. 2012. Changes in *Anopheles funestus* Biting Behavior Following Universal Coverage of Long-Lasting Insecticidal Nets in Benin. J. Infect. Dis. 206:1622–1629. https://doi.org/10.1093/infdis/jis565

Müller H. 1873. Befruchtung der Blumen durch Insekten. Wilhelm Engelmann.

Müller G, Schlein Y. 2006. Sugar questing mosquitoes in arid areas gather on scarce blossoms that can be used for control. Int. J. Parasitol. 36:1077–1080. https://doi.org/10.1016/j.ijpara.2006.06.008

Müller GC, Beier JC, Traore SF, et al. 2010. Field experiments of A*nopheles gambiae* attraction to local fruits/seedpods and flowering plants in Mali to optimize strategies for malaria vector control in Africa using attractive toxic sugar bait methods. Malar. J. 9:262–262. https://doi.org/10.1186/1475-2875-9-262

Müller GC, Xue R-D, Schlein Y. 2011. Differential attraction of *Aedes albopictus* in the field to flowers, fruits and honeydew. Acta Trop. 118:45–49. https://doi.org/10.1016/j.actatropica.2011.01.009

Müller GC, Junnila A, Traore MM, et al. 2017. The invasive shrub *Prosopis juliflora* enhances the malaria parasite transmission capacity of *Anopheles* mosquitoes: a habitat manipulation experiment. Malar. J. 16:237. https://doi.org/10.1186/s12936-017-1878-9

Mwesigwa J, Achan J, Di Tanna GL, et al. 2017. Residual malaria transmission dynamics varies across The Gambia despite high coverage of control interventions. PLoS One 12:e0187059. https://doi.org/10.1371/journal.pone.0187059

Nepi M, Grasso DA, Mancuso S. 2018. Nectar in plant-insect mutualistic relationships: from food reward to partner manipulation. Front. Plant Sci. 9:1063–1063. https://doi.org/10.3389/fpls.2018.01063

Nicolson SW. 2022. Sweet solutions: nectar chemistry and quality. Philos. Trans. R. Soc. London, Ser. B 377:20210163. https://doi.org/10.1098/rstb.2021.0163

Nikbakhtzadeh MR, Terbot Ii JW, Otienoburu PE, et al. 2014. Olfactory basis of floral preference of the malaria vector *Anopheles gambiae* (Diptera: Culicidae) among common African plants. J. Vector Ecol. 39:372–383. https://doi.org/10.1111/jvec.12113

Nikbakhtzadeh MR, Terbot JWII, Foster WA. 2016. Survival value and sugar access of four East African plant species attractive to a laboratory strain of sympatric *Anopheles gambiae* (Diptera: Culicidae). J. Med. Entomol. 53:1105–1111. https://doi.org/10.1093/jme/tjw067

Nyasembe VO, Teal PEA, Mukabana WR, et al. 2012. Behavioural response of the malaria vector *Anopheles gambiae* to host plant volatiles and synthetic blends. Parasites Vectors. 5:234. https://doi.org/10.1186/1756-3305-5-234

Nyasembe VO, Cheseto X, Kaplan F, et al. 2015. The invasive American weed *Parthenium hysterophorus* can negatively impact malaria control in Africa. PLoS One 10:e0137836. https://doi.org/10.1371/journal.pone.0137836

Nyasembe VO, Tchouassi DP, Pirk CWW, et al. 2018. Host plant forensics and olfactory-based detection in Afro-tropical mosquito disease vectors. PLoS Negl.Trop. Dis. 12:e0006185. https://doi.org/10.1371/journal.pntd.0006185

Nyasembe VO, Tchouassi DP, Muturi MN, et al. 2021. Plant nutrient quality impacts survival and reproductive fitness of the dengue vector *Aedes aegypti*. Parasites Vectors. 14:4. https://doi.org/10.1186/s13071-020-04519-y

Okech BA, Gouagna LC, Killeen GF, et al. 2003. Influence of sugar availability and indoor microclimate on survival of *Anopheles gambiae* (Diptera: Culicidae) under semifield conditions in western Kenya. J. Med. Entomol. 40:657–663. https://doi.org/10.1603/0022-2585-40.5.657

Orbán L, Plowright CMS. 2014. Getting to the start line: how bumblebees and honeybees are visually guided towards their first floral contact. Insectes Soc. 61:325–336. https://doi.org/10.1007/s00040-014-0366-2

Padonou GG, Gbedjissi G, Yadouleton A, et al. 2012. Decreased proportions of indoor feeding and endophily in *Anopheles gambiae* s.l. populations following the indoor residual spraying and insecticide-treated net interventions in Benin (West Africa). Parasites Vectors. 5:262. https://doi.org/10.1186/1756-3305-5-262

Panero JL, Crozier BS. 2016. Macroevolutionary dynamics in the early diversification of Asteraceae. Mol. Phylogenet. Evol. 99:116–132. https://doi.org/10.1016/j.ympev.2016.03.007

Patil AH, Jagdale S. 2021. Nocturnal insect pollinator diversity and species richness in Ridge gourd, Luffa acutangula. J Appl Nat Sci. 13:463–469. https://doi.org/10.31018/jans.v13i2.2625

Peach DAH, Gries G. 2016. Nectar thieves or invited pollinators? A case study of tansy flowers and common house mosquitoes. Arthropod Plant Interact. 10:497–506. https://doi.org/10.1007/s11829-016-9445-9

Peach DAH, Ko E, Blake AJ, et al. 2019. Ultraviolet inflorescence cues enhance attractiveness of inflorescence odour to *Culex pipiens* mosquitoes. PLoS One 14:e0217484. https://doi.org/10.1371/journal.pone.0217484

Pruett G, Hawes J, Varnado W, et al. 2020. The readily transformable *Impatiens walleriana* efficiently attracts nectar feeding with *Aedes* and *Culex* mosquitoes in simulated outdoor garden settings in Mississippi and Florida. Acta Tropica. (1873-6254 (Electronic)). 210:105624. https://doi.org/10.1016/j.actatropica.2020.105624

Pullin A, Frampton G, Livoreil B, Petrokofsky G. 2022. Collaboration for environmental evidence. Guidelines and standards for evidence synthesis in environmental management.

Qualls WA, Xue RD, Beier JC, et al. 2013. Survivorship of adult *Aedes albopictus* (Diptera: Culicidae) feeding on indoor ornamental plants with no inflorescence. Parasitol. Res. 112:2313–2318. https://doi.org/10.1007/s00436-013-3396-1

Rambey R, Rangkuti AB, Onrizal, Susilowaty A, Wijayanto N, Siregar IZ. 2021. Phenology of the bunga bangkai (*Amorphophallus gigas*) in North Padang Lawas, North Sumatra Province, Indonesia. IOP Conf Series. 782:032019. https://doi.org/10.1088/1755-1315/782/3/032019

Ranson H, Lissenden N. 2016. Insecticide resistance in African *Anopheles* mosquitoes: a worsening situation that needs urgent action to maintain malaria control. Trends Parasitol. 32:187–196. https://doi.org/10.1016/j.pt.2015.11.010

Rewicz A, Jaskuła R, Rewicz T, Tończyk G. 2017. Pollinator diversity and reproductive success of *Epipactis helleborine* (L.) Crantz (Orchidaceae) in anthropogenic and natural habitats. (2167-8359 (Print))

Russell TL, Govella NJ, Azizi S, et al. 2011. Increased proportions of outdoor feeding among residual malaria vector populations following increased use of insecticide-treated nets in rural Tanzania. Malar. J. 10:80. https://doi.org/10.1186/1475-2875-10-80

Sandholm HA, Price RD. 1962. Field observations on the nectar feeding habits of some Minnesota mosquitoes. Mosquito News. 22:346–349.

Sayers A. 2007. Tips and tricks in performing a systematic review. (0960-1643 (Print))

Schaefer CH, Miura T. 1972. Sources of energy utilized by natural populations of the mosquito, *Culex tarsalis*, for overwintering. J. Insect Physiol. 18:797–805. https://doi.org/10.1016/0022-1910(72)90204-1

Schlein Y, Muller G. 1995. Assessment of plant tissue feeding by sand flies (Diptera: Psychodidae) and mosquitoes (Diptera: Culicidae). J. Med. Entomol. 32:882–887. https://doi.org/10.1093/jmedent/32.6.882

Schlein Y, Müller GC. 2008. An approach to mosquito control: using the dominant attraction of flowering *Tamarix jordanis* Trees Against *Culex pipiens*. J. Med. Entomol. 45:384–390. https://doi.org/10.1603/0022-2585(2008)45[384:aatmcu]2.0.co;2

Sissoko F, Junnila A, Traore MM, et al. 2019. Frequent sugar feeding behavior by *Aedes aegypti* in Bamako, Mali makes them ideal candidates for control with attractive toxic sugar baits (ATSB). PLoS One 14:e0214170. (). https://doi.org/10.1371/journal.pone.0214170

Smith SM, Gadawski RM. 1994. Nectar feeding by the early-spring mosquito Aedes provocans. Med. Vet. Entomol. 8:201–213. https://doi.org/10.1111/j.1365-2915.1994.tb00499.x

Stone CM, Jackson BT, Foster WA. 2012. Effects of plant-community composition on the vectorial capacity and fitness of the malaria mosquito *Anopheles gambiae*. Am. J. Trop. Med. Hyg. 87:727–736. https://doi.org/10.4269/ajtmh.2012.12-0123

Stone CM, Foster WA. 2013. Plant-sugar feeding and vectorial capacity. In: Takken W, Koenraadt CJM, editors. Ecology of parasite-vector interactions. Wageningen Academic Publishers. p. 35–79.

Stone CM, Witt ABR, Walsh GC, et al. 2018. Would the control of invasive alien plants reduce malaria transmission? A review. Parasites & Vectors 11:76. https://doi.org/10.1186/s13071-018-2644-8

Tabe Ojong MP, Jr., Alvarez M, Ihli HJ, Becker M, Heckelei T. 2021. Action on invasive species: control strategies of *Parthenium hysterophorus* L. on Smallholder Farms in Kenya. (1432-1009 (Electronic))

Thien LB. 1969. Mosquito pollination of *Habenaria obtusata* (Orchidaceae). Am. J. Bot. 56:232–237. https://doi.org/10.2307/2440711

Traore MM, Junnila A, Traore SF, et al. 2020. Large-scale field trial of attractive toxic sugar baits (ATSB) for the control of malaria vector mosquitoes in Mali, West Africa. Malar. J. 19:72. https://doi.org/10.1186/s12936-020-3132-0

Twinn CR, Hocking B, McDuffie WC, et al. 1948. A preliminary account of the biting flies at Churchill, Manitoba. Can. J. Res. 26d:334–357. https://doi.org/10.1139/cjr48d-025

Valzania L, Mattee MT, Strand MR, et al. 2019. Blood feeding activates the vitellogenic stage of oogenesis in the mosquito *Aedes aegypti* through inhibition of glycogen synthase kinase 3 by the insulin and TOR pathways. Dev. Biol. 454:85–95. https://doi.org/10.1016/j.ydbio.2019.05.011

Van den Berg H, da Silva Bezerra HS, Al-Eryani S, et al. 2021. Recent trends in global insecticide use for disease vector control and potential implications for resistance management. Sci. Rep. 11:23867. https://doi.org/10.1038/s41598-021-03367-9

Van Handel E. 1972. The detection of nectar in mosquitoes. Mosquito News. 32:458–458.

Vargo AM, Foster WA. 1984. Gonotrophic state and parity of nectar-feeding mosquitos. Mosquito News. 44:6–10.

Yee WL, Foster WA, Howe MJ, et al. 1992. Simultaneous field comparison of evening temporal distributions of nectar and blood feeding by *Aedes vexans* and *Ae. trivittatus* (Diptera: Culicidae) in Ohio. J. Med. Entomol. 29:356–360. https://doi.org/10.1093/jmedent/29.2.356

Yu BT, Ding YM, Mo XC, et al. 2016. Survivorship and fecundity of *Culex pipiens pallens* feeding on flowering plants and seed pods with differential preferences. Acta Trop. 155:51–57. https://doi.org/10.1016/j.actatropica.2015.12.015

Yu BT, Huang SQ, Ding YM, et al. 2017. Laboratory evaluation of differential attraction of *Culex pipiens pallens* to the volatiles of flowers, fruits, and seed pods. J. Asia-Pac. Entomol. 20:1372–1376. https://doi.org/10.1016/j.aspen.2017.06.010

Yu BT, Hu Y, Ding YM, et al. 2018. Feeding on different attractive flowering plants affects the energy reserves of *Culex pipiens pallens* adults. Parasitol. Res. 117:67–73. https://doi.org/10.1007/s00436-017-5664-y