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Review

A Systematic Review of the Bioactivity of *Jatropha curcas* L. (Euphorbiaceae) Extracts in the Control of Insect Pests

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Abstract: The use of botanical extracts of the plant *Jatropha curcas* (Euphorbiaceae) represents a valuable alternative to control insect pests and avoid the detrimental effects on the environment and health that arise due to synthetic chemical insecticides. Thus, we conducted a systematic review to summarize the published evidence on the bioactivity of *J. curcas* against insect pests. Electronic databases were searched to identify studies that assessed *J. curcas* extracts against insect pests in various types of crops. We included 39 articles that reported the insecticidal and insectistatic activity of several botanical extracts from *J. curcas* against insects of eight different taxonomic orders. The evidence demonstrates that aqueous and methanolic extracts from seeds and leaves, seed oil, and petroleum ether seed extracts were effective against insect pests of stored grains, aphids of cabbage and sorghum, fruit flies, and desert locusts. The extracts caused high mortality, controlled the populations, reduced oviposition, diminished hatchability, and increased the antifeedant effect. However, the type of solvent used to obtain the botanical extract and the method of application (contact or food) are fundamental to increase its bioactivity. Therefore, botanical extracts from seeds and leaves of *J. curcas* should be considered as an alternative against insect pests and may be incorporated into integrative and sustainable management for insect control.

Keywords: botanical extracts; sustainable management of pests; insecticide activity; insectistatic activity; insect pests

Citation: Valdez-Ramirez, A.; Flores-Macias, A.; Figueroa-Brito, R.; Torre-Hernandez, M.E.d.l.; Ramos-Lopez, M.A.; Beltran-Ontiveros, S.A.; Becerril-Camacho, D.M.; Diaz, D. A Systematic Review of the Bioactivity of *Jatropha curcas* L. (Euphorbiaceae) Extracts in the Control of Insect Pests. *Sustainability* **2023**, *15*, 11637. https://doi.org/10.3390/su151511637

Academic Editors: Fathiya Mbarak Khamis, Inusa Jacob Ajene and Mustafa O. Jibrin

Received: 5 July 2023
Revised: 24 July 2023
Accepted: 26 July 2023
Published: 27 July 2023

1. Introduction

Globally, the environment is sprayed every year with over 4.6 million tons of synthetic chemical pesticides that include insecticides, fungicides, and plant regulators, among others [1]. Although developing countries account for only 25% of the global use of pesticides, 99% of all deaths due to these groups of substances occur in these countries [2]. Given that land use intensification in developing countries is based on an intensive and extensive use of synthetic pesticides as the pest-management approach, there is an ongoing

alarming growth of their use across several regions of the world [3]. Additionally, highly hazardous pesticides (defined as biologically active compounds acknowledged for causing high levels of health and environmental damage) represent a global health concern because occupational or accidental exposure to these substances may cause acute or chronic toxic effects [4]. Moreover, environmental contamination with highly hazardous pesticides is common and occurs mainly during the consumption of pesticide residues in food and water. In addition, children are at a higher risk of exposure due to their behavior and are more sensitive because of their reduced size [5].

Insecticides of synthetic origin are intended to control and eliminate insect pests that cause damage in agriculture and livestock, insects that cause damage to ornamental plants and animals, and organisms that serve as disease vectors. Furthermore, insecticides contribute to food security because they are used on insect pests to protect crops and avoid postharvest losses [1]. Nevertheless, the excessive use of synthetic chemical insecticides in recent decades has been partly responsible for various health and environmental problems, contamination of surface and groundwater, and increased cost of production [6,7]. Indeed, environmental contamination with insecticide residues in soil, food, and water generates serious consequences for human health, including blindness, cancer, and liver diseases, as well as long-term effects that reduce fertility, increase cholesterol levels, produce high infant mortality rates, and cause various metabolic/genetic disorders [8,9].

Although the mechanism of action of insecticides varies, most commercial products contain neurotoxic active ingredients [10]. Therefore, exposure to residues of chemical insecticides such as rotenone, DDT, endosulfan, organophosphates, carbamates, and pyrethroids is highly toxic. For instance, chlorpyrifos is a highly mobile and toxic organophosphate insecticide frequently detected in soils, sediments and groundwater in many areas and is considered an endocrine-disrupting chemical that poses a potential risk to human health [11]. Among the main neurological issues caused by pesticide residues are neuronal damage, Alzheimer's, Parkinson's, and defects in neurotransmitter synthesis [12]. Additionally, chronic exposure to residues of highly hazardous pesticides may cause cancer in both children and adults [4].

Globally, there is a growing demand for food produced without the use of synthetic chemicals and the adoption of organic, agroecological, or environmentally sustainable agriculture [13]. For these reasons, more effective strategies for the control of insect pests are continually being sought. In addition to being more efficient, the new compounds should be implemented in an integrated pest-management strategy and have a favorable ecotoxicological profile that includes a short persistence in the environment [14]. In the search for new pest-insect control alternatives, plant extracts have different effects against different pest insect species because they are toxic, repellent, anti-feedant, oviposition deterrent, and reproductive behavior suppressant, degrade rapidly in the environment, are less costly and less toxic to natural enemies, are more selective in action, and reduce pest insects from acquiring resistance [15]. Consequently, botanical extracts represent a sustainable alternative in the control of insect pests in comparison to synthetic chemical insecticides.

Although the efficacy of synthetic chemical insecticides lies in their rapid control of pest insects, their intensive use has brought environmental problems such as rapid development of resistance, suppression of parasitoids and predators, changes in ecosystem balances, adverse effects on nontarget organisms, and the dispersion and accumulation of chemical residues that impact human health through food, water, and soil contamination [16]. In contrast, botanical insecticides are characterized by their low persistence and bioaccumulation in the environment, including low selectivity toward beneficial insects and reduced toxicity toward humans [17]. In this regard, several studies have demonstrated the insecticidal and deterrent potential of the plant *Jatropha curcas* L. (Euphorbiaceae) on pest insects through the use of its extracts, oils or compounds isolated from different parts of the plant, including its seeds, whose toxicity to insects is attributed to several components, including saponins, lectins, curcine, phytates, protease inhibitors, curcalonic acid and phorbol esters, among others [18,19].

The plant *J. curcas* belongs to the Euphorbiaceae family. Although most of its botanical extracts are not toxic to human health [20], the consumption of the seeds from this plant could be toxic because they contain phorbol esters that reach up to 6 mg/g in toxic varieties in regions of México, Africa, and Asia [21]. However, in some regions of Mexico, nontoxic varieties of this plant exist, which contain 0.27 mg/g and are used for human and livestock consumption [22]. The seeds of *J. curcas* contain between 32 and 40% of valuable oil that is used to produce biofuels. It is a plant that requires little water and grows in arid and semiarid regions, being used in the market for the production of bioenergy [23]. The use of botanical extracts from *J. curcas* aids producers in controlling insect pests while reducing the consumption of synthetic chemical insecticides, allowing them to produce food in a sustainable way while reducing their impact on the environment. Therefore, botanical extracts of *J. curcas* represent an alternative to achieve sustainable management in pest control, as they have nematicidal, fungicidal, and antifeedant effects [24], as well as molluscicidal, insecticidal, and acaricidal activities [25].

Although there is evidence on the potential use of the plant *J. curcas* in the control of insect pests, to date there has been no systematic and orderly summary of the bioactivity of its botanical extracts against the groups of insects on which these extracts are effective and thus prevent damage in the main crops affected by such insects. Consequently, in the present study, a systematic review was carried out to synthesize the global evidence published regarding the use of botanical extracts of *J. curcas* on plague insects. The objectives of the present systematic review were (1) to identify and map the body of scientific evidence published on the use of botanical extracts of *J. curcas* against insect pests in different crops, (2) to summarize the body of evidence, and (3) to identify the main chemical compounds with insecticidal and insectistatic bioactivity extracted from the plant. The information generated from this study will be useful in guiding evidence-based decisions for any actor seeking alternatives for sustainable pest management control.

The analysis and summary of the articles included in our study allowed us to determine the bioactivity of the extracts obtained from different parts of the plant *J. curcas* on different species of insect pests in different regions of the world. The evidence generated could help researchers make decisions in the development of new studies aimed at evaluating their bioactivity under greenhouse and field conditions, as well as developing more efficient application methodologies for greater control of insect pests and sustainable management of plant genetic resources that could help small producers make more efficient decisions, protecting agroecosystems and taking care of their economy.

2. Materials and Methods

2.1. Protocol and Guidelines Followed

The topic addressed in this systematic review was established using an a priori protocol following the methodology proposed in the Preferred Reporting Items for Systematic Reviews and Meta-analysis protocol (PRISMA-P) statement [26], which is available upon request by contacting the corresponding author. The protocol described the outline of the methodological approach and contained 15 out of the 17 items of the PRISMA-P, including the predefined eligibility criteria, search strategy, data items, outcomes, risk of bias assessment, and data synthesis. The preparation of the protocol ensured careful planning of the systematic review and served to document an explicit methodological description before the review started. The consequent required consistency between the final report and the protocol allows research integrity and transparency [26].

To define the information and methods outlined in the protocol, we used the Cochrane Handbook for Systematic Reviews, adapting all the necessary content as a guiding tool to design and prepare our systematic review [27]. In addition, the study was reported in adherence to the PRISMA [28] statement, which consists of a 27-item checklist and a 4-phase flow diagram (identification, screening, eligibility, and inclusion of evidence sources), both of which are essential for transparent reporting of a systematic review.

Appendix A Figure A1 depicts the required PRISMA checklist, whereas Figure 1 shows the PRISMA flow diagram.

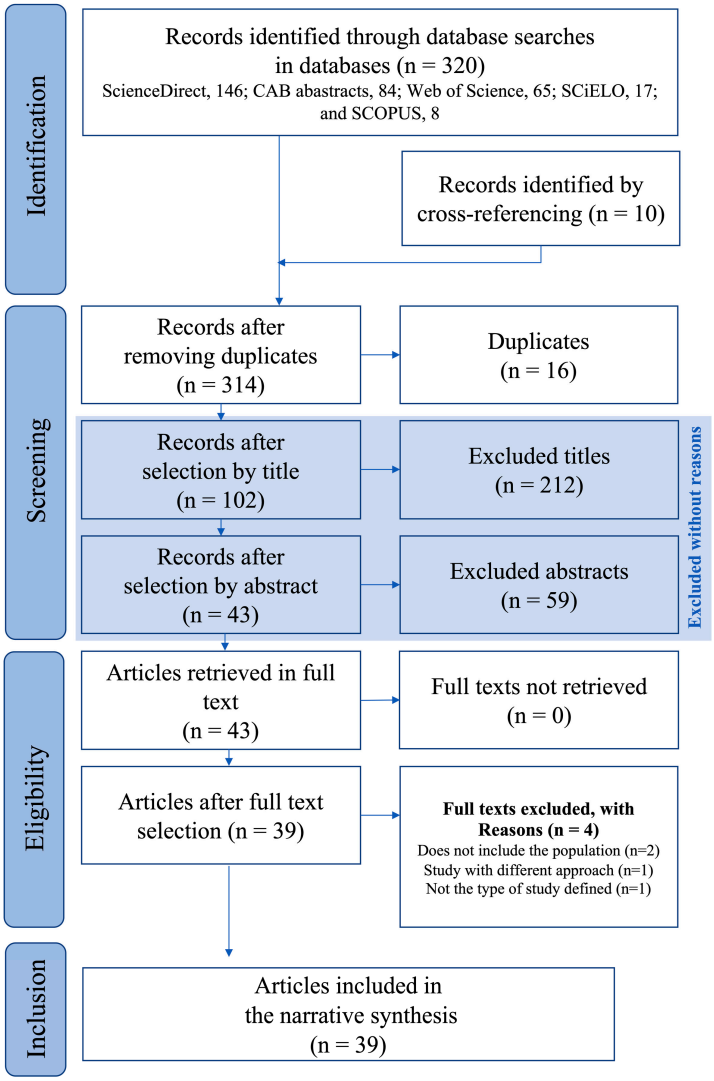

Figure 1. PRISMA flow diagram for the selection of the studies included in the synthesis.

2.2. Inclusion Criteria

To define inclusion criteria, we used the PIOS (Population, Intervention, Outcomes, and Study) approach of the PRISMA statement, as summarized in Table 1.

Table 1. Definitions of eligibility criteria for the studies.

Acronym	Definition	Search Term
(P) Population	We included studies that reported results on the use of botanical extracts from the plant *J. curcas* in which their bioactivity was assessed either as insecticidal or insectistatic against insect pests of different crops	*Jatropa curcas* OR *J. curcas* OR physic nut
(I) Intervention	We included studies that assessed any type of botanical extract (including hexanic, acetonic, methanolic, aqueous, ethanolic, or petroleum ether, among others) or secondary metabolite extracts from the plant *J. curcas* under in vitro, field, or greenhouse conditions	extracts OR botanical extracts OR hexanic OR acetonic OR methanolic OR aqueous OR ethanolic OR petroleum ether OR secondary metabolites

Table 1. *Cont.*

Acronym	Definition	Search Term
(O) Outcome	The studies should include at least one of the following outcomes: *Insecticidal activity*, considered as the primary outcome and defined as the control of the number of insects or colonies reported as the absolute value or percentage of mortality or larval and pupal viability reduction after exposure to the botanical extracts *Insectistatic activity*, considered as the secondary outcome and defined as an effect on the growth or reproduction of the insect, anti-feeding effect, including a reduction in larval and pupal weight, lower fecundity and fertility, anti-oviposition effect, reduced hatching and hatchability of eggs, altered development, morphological malformations, and altered physiology	crop pest insects OR insect control OR insecticide OR insectistatic OR bioactivity
(S) Study	We included only primary experimental studies published from 2012 to 2022 the last 10 years as full text articles in English, Spanish, or Portuguese in peer-reviewed journals. We excluded all nonpublished evidence (gray literature) to ensure optimal methodological comparability [29]	

2.3. Information Sources and Search Strategy

The search for studies was carried out exhaustively from September to November 2022 using different databases included in the Digital Library System of the Metropolitan Autonomous University (BIDI-UAM) and included the main search engines Scopus, ScienceDirect, Web of Science, SCiELO, and CAB Direct. To perform the specific electronic searches, we defined and used the search terms presented in Table 1, which were derived from our inclusion criteria defined in the PIOS approach. We used the search terms in conjunction with Boolean operators (AND, OR, and NOT) according to the population AND intervention AND outcome structure as follows: (*Jatropha curcas* OR *J. curcas* OR physic nut) AND (extracts OR botanical extracts OR hexanic OR acetonic OR methanolic OR aqueous OR ethanolic OR petroleum ether OR secondary metabolites) AND (crop pest insects OR insect control OR insecticide OR insectistatic OR bioactivity).

Due to the broad variation in the search engines of each database, we used all the methodological filters available to constrain the search. For instance, in SCOPUS we used the following search command: (jatropha AND curcas OR j AND curcas OR physic AND nut) AND (extracts OR botanical AND extracts OR hexanic OR acetonic OR methanolic OR aqueous OR ethanolic OR petroleum AND ether OR secondary AND metabolites) AND (crop AND pest AND insects OR insect AND control OR insecticide OR insectistatic OR bioactivity) AND (LIMIT-TO (SUBJAREA, "AGRI")) AND (LIMIT-TO (DOCTYPE, "ar")), where we limited the search according to the subject area and type of document.

In Web of Science, we set up the filter to include the search terms in all sections within a document and used the NOT operator to exclude reviews in our search. We used the search command ALL = ((*Jatropha curcas* OR *J. curcas* OR physic nut) AND (extracts OR botanical extracts OR hexanic OR acetonic OR methanolic OR aqueous OR ethanolic OR petroleum ether OR secondary metabolites) AND (crop pest insects OR insect control OR insecticide OR insectistatic OR bioactivity)) NOT Document types: Review Article.

The records found in each database were downloaded as separate RIS files for compiling with EndNote 20 (Clarivate, Philadelphia, PA, USA), which was used to manage the bibliographic records by a single reviewer who created independent libraries through the four-phase selection process depicted in the PRISMA flow diagram.

2.4. Study Selection Process

To select the studies included in our systematic review, we used the four-phase approach of the PRISMA statement (identification, screening, eligibility, and inclusion).

Once the records were identified through electronic database searching, a single reviewer screened the studies. First, the reviewer removed duplicates by searching both manually within the EndNote library and automatically using the "Find duplicates" tool included in the software. Next, the same reviewer concluded the screening process, first removing studies based on the title and then reading the abstract to check if the record was related to our reviewed topic, taking the inclusion criteria as a reference. All nonrelated studies were removed. Given that this screening removed the highest number of records, the individual reasons for exclusion were not specified. After the screening, the studies were retrieved in full text to assess their eligibility using a standardized format that was pilot tested in a random sample of 10% of the studies. The questionnaire included four questions based on the definitions of the PIOS approach (one question for each definition) and was used to check if individual studies fulfilled each criterion before being selected. In this case, the reasons for exclusion were annotated. Finally, the studies that included PIOS information were selected for final inclusion in the narrative synthesis.

2.5. Data Extraction

The studies included in the systematic review were extracted using a standardized format that was pilot tested in 10% of the studies to find their meta-data, which refers to the main information that describes a study, including its methodology. As previously reported [30], the meta-data were used for data charting in an Excel spreadsheet and included author, year of publication, objective and methodology of the study, geographical region where the study was conducted, parts of the plant used and type of extract obtained, type of insect pests and agricultural crops assessed, type of sample evaluated (eggs, larvae, pupae, or adult insects), and identification of secondary metabolites. Within the Excel database, we coded the extracted information by creating categories of the sets of variables, which were used to construct informative charts and tables that allowed for summarizing and visualizing the results.

2.6. Risk of Bias Assessment

One reviewer assessed the risk of bias in individual studies using an adapted version of the Cochrane Collaboration's risk of bias tool [31]. Given that the Cochrane risk of bias tool was developed for intervention studies in clinical research, we modified the original tool to assess the following domains in our study: (1) adequate description of the botanical extract assessed in the study, which was defined as the report of exact part of the plant and type of extract assessed; (2) clear specification of the method used in the bioassay, defined as the explicit methodological description of the experimental conditions, dose, administration form, crop or fruit assessed, and insect pest; (3) consistency of report, defined as the presentation of results without discrepancies; (4) adequate analysis of the insecticidal and insectistatic activity, defined as the explicit description of how the outcomes were analyzed and presented; (5) clear description of the method used for obtaining extracts, defined as the explicit methodological description of how botanical extracts were obtained from the plan; and (6) selective presentation of results, defined as the omission of missing data without tracking or explaining the discrepancies or differences. Each study was assessed for having a low (clearly exclude bias), high (clearly indicates bias), or unclear (insufficient information to allow a proper judgment) risk of bias in each of the defined domains. The results from this evaluation are presented as the percentage of studies in each category of bias per domain.

2.7. Summary of Evidence

Starting from the Excel database, we obtained the absolute and relative frequency of each extracted category of the meta-data from the studies and created contingency tables to summarize the information as well as a cumulative histogram to show the distribution of studies by year of publication, stacked bars for the region of publication and the risk of bias assessment, and a Sankey diagram to depict the distribution of publications by

species of insects according to their taxonomic order. Graphs were constructed with Prisma 10 (GraphPad Inc., San Diego, CA, USA), whereas the Sankey diagram was constructed with the Sankeymatic online tool at https://sankeymatic.com, accessed on 7 June 2023.

3. Results

3.1. Studies included in the Evidence Synthesis

The initial search yielded a total of 320 documents, with ScienceDirect and CAB abstracts being the electronic databases that contributed 71.8% of the records, while SCOPUS only contributed 2.5%. Additionally, 10 more records were added by cross-referencing to generate a total of 330 identified records, of which 16 duplicates were removed. Of the 314 remaining records, 212 were excluded after reviewing the title, and 59 more documents were excluded after reading the abstract. Thus, 43 documents passed the eligibility process and were retrieved in full text. Of these, after applying the inclusion criteria, 4 studies were eliminated for the reasons presented in the flow diagram depicted in Figure 1. In total, 39 publications were included in the narrative synthesis.

3.2. Main Characteristics of the Studies included in the Systematic Review

Among the 39 studies included in our review, 24 were published in English, followed by 3 and 2 studies published in Portuguese and Spanish, respectively. The studies were from 14 different countries distributed across three continents, with Africa contributing the highest number of publications (18), followed by the Americas (11) and Asia (10) (Figure 2a). In conjunction, Nigeria (9), India (7), Brazil (7), Sudan (4), and Mexico (3) provided 78.94% of the studies, whereas the remaining nine countries contributed one study each (Appendix A Table A1). According to Figure 2b, 52.63% of the studies (20) were published from 2015 to 2021, thus indicating a high interest in the topic in recent years.

As summarized in Appendix A Table A1, the 39 studies included in the systematic review assessed the insecticidal and insectistatic activity of a variety of botanical extracts from *J. curcas* against different insect pests. These studies reported mortality, population number, anti-feeding activity, anti-oviposition, hatchability of eggs, morphological/developmental effects, repellency, and physiological effects as the main outcomes. The studies assessed the bioactivity of botanical extracts of *J. curcas* on eight different taxonomic orders of insect pests that included 44 individual bioassay results for different insect pest species from these orders (Figure 2d). Lepidoptera, Coleoptera, and Hemiptera were the main taxonomic orders, as these included 36/44 bioassays.

3.3. Risk of Bias within the Studies

As summarized in Figure 2c, among the 39 studies assessed for risk of bias, 23.07% showed a high risk of bias in the selective presentation of results. However, 15.38 and 17.94% of the studies were rated as having an unclear risk of bias for not presenting a clear description of the method used for obtaining the botanical extract and the selective reporting of results, respectively. In the remaining domains, between 94.87 and 100% of the studies were rated as having a low risk of bias.

3.4. Summary of Evidence by Order of Plague Insects

3.4.1. Lepidoptera

1. *Plutella xylostella*

Amoabeng et al. [32] evaluated the aqueous extract of *J. curcas* leaves sprayed on cabbage (*Brassica oleracea* (L.)) plants at a concentration of 3% (*w*/*v*) under open field conditions. The plants contained third instar larvae of *Plutella xylostella* (L.) (Lepidoptera: Plutellinae), which were reduced by 66% with the treatment. Ingle et al. [33] evaluated methanolic extracts of leaves, seeds, seed hulls, bark, and root of *J. curcas* at a concentration of 5% (*w*/*v*) against third instar larvae of *P. xylostella* in bioassays of ingestion in cabbage leaf discs. After 72 h, the methanolic extract of seed husk was more effective, causing 100% mortality. In another study, the aqueous latex extract obtained from *J. curcas* stems was

evaluated at concentrations of 25 and 50% (*v*/*v*) sprayed on experimental plots of cabbage crops for controlling *P. xylostella* larvae infestation. The treatment showed a minimal reduction of 11% in the number of larvae at the higher concentration [34].

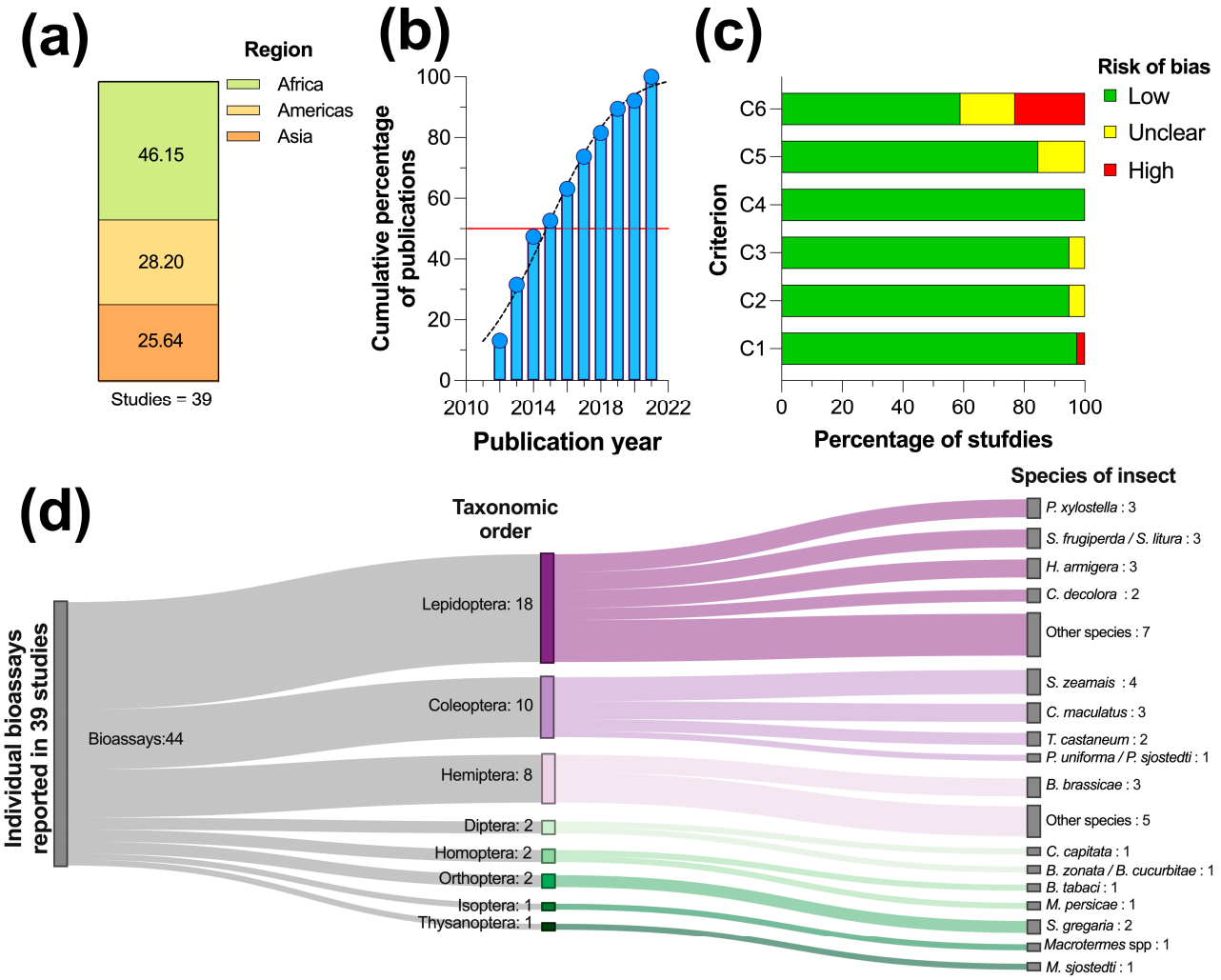

Figure 2. (**a**) Geographical region where the study was published, (**b**) publications per year, (**c**) risk of bias assessment, and (**d**) distribution of individual bioassays per taxonomic order. C1, Adequate description of the extract; C2, Clear specification of the bioassays; C3, Consistency of the report; C4, Adequate analysis of the bioactivity; C5, Clear description of the method used for obtaining extracts; and C6, Selective presentation of results.

2. *Spodoptera frugiperda*

Devappa et al. [35] assessed phorbol ester-enriched fractions of *J. curcas* seed oil against *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), the main pest of the maize crop. Two bioassays were performed against third instar larvae of the insect, one of topical toxicity (0.0313, 0.0625, 0.125, 0.25, 0.5, 1, and 20 mg/mL^{-1}) and the other by ingestion (0.0625, 0.125, and 0.25 mg/mL^{-1}). The treatment induced toxicity by contact with an LC_{50} of 0.83 mg/mL^{-1}, and the treated corn leaves (0.25 mg/mL^{-1}) showed decreased feed consumption by 33% and reduced growth by 42% and feed conversion efficiency by 38%. Ribeiro et al. [36] assessed seven methanolic leaf extracts of different accessions (PM-2, PM-7, PM-10, PM-11, PM-12, PM-14 and EMB) of *J. curcas* against neonate larvae of *S. frugiperda* in an ingestion bioassay (1000 mg/kg^{-1}). The EMB accession extract showed the best result for larval mortality (range 56.67–60%). Ingle et al. [37] examined methanolic extracts of leaves, bark, seeds, and seed hulls of *J. curcas* against third instar larvae of

S. litura in ingestion bioassays at 5% (*w*/*v*). After 72 h, the methanolic extract from the leaves showed 60% mortality of the larvae compared to the other extracts.

3. *Helicoverpa armigera*

Diabaté et al. [38] used an aqueous extract of *J. curcas* seeds sprayed at 50 and 80 g/L on tomato plots to control *Helicoverpa armigera* (H.) (Lepidoptera; Noctuidae) larvae in field trials and reported a similar reduction in the number of larvae in comparison to chemical pesticides. One study reported the effect of methanolic extracts from different parts of *J. curcas* used in an ingestion bioassay of cotton leaves at 5, 10, and 15% (*w*/*v*) against third instar larvae of *H. armigera*. The extracts showed antifeedant activity and reduced the weight of larvae by 42% after 48 h, whereas 15% of the extract caused the highest mortality (60%) of larvae [33]. Jagdish et al. [39] included *J. curcas* oil alone or in combination with Neem to control *H. armigera* and *Thysanoplusia oleracea* (I.) (Lepidoptera: Noctuidae) in a chickpea–cilantro intercropping system. Two treatments that included *J. curcas* oil were the most effective in reducing the larval population of both insect pests.

4. *Copitarsia decolora*

Figueroa-Brito et al. [40] used an aqueous extract of *J. curcas* seed powder in bioassays of ingestion at 1 and 5% (*v*/*v*) against *Copitarsia decolora* (G.) (Lepidoptera: Noctuidae) and reported a 46% reduction in larval viability when 5% of the aqueous extract was used. Additionally, Figueroa-Brito et al. [41] assessed the use of *J. curcas* acetone seed extracts (shell, kernel, and almond nut) against neonate larvae of *C. decolora* in experimental bioassays (250, 500, 1000, 1500 and 2000 ppm) and greenhouse tests (250, 500 and 1000 ppm) on *B. oleracea* plants. The acetonic extracts from almond nut and kernel plus shell at 500 and 1500 ppm, respectively, caused the highest percentage of deformations in pupae and adults and induced a 50% mortality of larvae. In greenhouse tests, 250 ppm almond nut showed the highest reduction (33.8%) in damage to the plant.

5. Other species

Guerra-Arévalo et al. [42] evaluated five concentrations (10, 20, 30, and 40% (*v*/*v*)) of *J. curcas* resin on leaf discs of *Swietenia macrophylla* (K.) mahogany (Meliaceae) to control the third instar larvae of *Hypsipyla grandella* (Z.) (Lepidoptera: Pyralidae). At a 40% concentration, the resin caused 67% larval mortality and 30% larval activity. Ishag and Osman [43] reported the effect of aqueous and oily extracts of *J. curcas* seeds on the hatchability of *Erias insulana* (B.) (Lepidoptera: Noctuidae) eggs in a contact bioassay at 5, 10, 15, and 20% (*v*/*v*) concentrations, in which the highest concentration reduced the hatchability of the eggs by 64%.

Sharma [44] assessed the effect of an acetone extract (0.0, 0.625, 1.25, 2.5, 5.0, and 10.0 (*v*/*v*)) obtained from leaves of *J. curcas* on the growth and development of *Spilarctia oblicua* (R.) (Lepidoptera: Noctuidae) larvae. The concentration of 5.0% produced the highest larval mortality (33.3%) and the largest reduction in pupation (36.6%). Kona et al. [45] investigated the effect of petroleum ether extract of *J. curcas* seeds against eggs and larvae of the tomato leafminer *Tuta absoluta* (M.) (Lepidoptera: Gelechiidae) in contact bioassays at 62.5, 125, 250, 500, and 1000 mg/L for freshly laid eggs and 2000, 4000, 6000, and 8000 mg/L for larvae. The highest mortality of eggs (25%) was found at 125 mg/L of the plant extract, whereas larval mortality was 85 and 100% at 4000 and 8000 mg/L, respectively.

Ugwu [46] evaluated a petroleum ether extract of *J. curcas* seeds against the legume pod borer *Maruca vitrata* (F.) (Lepidoptera: Crambidae). The extract was sprayed at 10 mL/L water on cowpea (*Vigna unguiculata* (L.)) seedlings in which the treatment reduced the larval population by 59.12%. De Oliveira et al. [47] reported the effect of a 3% aqueous extract of *J. curcas* oil on the hatching of *Diatraea saccharalis* (F.) (Lepidoptera: Pyralidae) caterpillars in a contact toxicity bioassay. After applying the treatment, only 60% hatching was observed in conjunction with an increase in the embryonic period. Khani et al. [48] examined the efficacy of a petroleum ether extract of *J. curcas* seeds against third instar larvae and eggs of the rice moth larvae *Corcyra cephalonica* (S.) (Lepidoptera: Pyralidae).

The extract was tested at 2, 4, 6, 8, and 10% (*w*/*v*) in contact bioassays in which an LC_{50} of 13.22 µL/mL was found, with 12 and 20 µL/mL of the extract causing a mortality of 66.5 and 98%, respectively, whereas 10 µL/mL reduced hatchability by 92% and inhibited adult emergence.

3.4.2. Coleoptera

1. *Sitophilus zeamais*

Silva et al. [49] conducted two bioassays against adult insects of *Sitophilus zeamais* (M.) (Coleoptera: Curculionidae) and *Rhyzorpertha dominica* (S.) (Coleoptera: Bostrychidae) using 5 and 10% (*w*/*v*) aqueous extracts and powders from seeds and pericarps from *J. curcas*. The higher concentration induced the highest mortality of *S. zeamais* and *R. dominica* insects by 75 and 100%, respectively. Babarinde et al. [50] evaluated oils from *J. curcas* seeds pretreated with different extraction methods (roasting, cooking, and crude extract) against adult insects of the corn weevil *S. zeamais*. After fumigation (50, 100, 150 and 200 µL/L) and contact toxicity (0.30, 0.60, 0.90, 1.20, and 1.50 µL/cm^2) bioassays, 200 µL/L of the oil from roasted seeds increased mortality by 84.68%, which was the highest among the treatments. Jide-Ojo [51] assessed aqueous leaf extract and seed oil from *J. curcas* on *S. zeamais* at 0, 5, 10, 50, and 100 ppm concentrations. Seed oil at 100 ppm increased protection against grain damage by 93%, inhibited oviposition by 90%, decreased adult hatching by 92.3%, and caused 90% mortality. Finally, seed powders from *J. curcas* were used for controlling adult insects of *S. zeamais* at 0.0, 2.5, 5.0, 7.5, and 10.0 g through an ingestion bioassay. Treatment with 10 g of seed powder caused an increase in the number of dead insects in comparison to the control group, which showed no mortality [52].

2. *Callosobruchus maculatus*

Opuba et al. [53] exposed adult insects of the stored cowpea seed beetle *Callosobruchus maculatus* (F.) (Coleoptera; Chrysomeloidea) to an aqueous extract of *J. curcas* leaves in an ingestion bioassay. The extract was sprayed at 1.0, 2.0, and 3.0% (*w*/*v*) on cowpea seeds containing adult insects, and the results showed that all the treatments induced high mortality (range 94–98%) and that 1% of the extract reduced the oviposition rate by 81.04%. Uddin Ii and Abdulazeez [54] used powder and aqueous extract of *J. curcas* seeds in the control of *C. maculatus*. The treatments were applied by contact at different filtrations (1.5, 2.0, and 2.5% (*w*/*v*)) on cowpea seeds containing newly emerged adult insects. The extract at 2.5% for 48 h increased mortality, reduced oviposition, and decreased adult emergence. Finally, Kolawole and Kolawole [55] performed an ingestion bioassay using cowpea seeds infected with adult insects of *C. maculatus* to assess the effect of an ethanolic extract of *J. curcas* seeds at 0, 5000, 10,000, 15,000, and 20,000 ppm. The highest concentration of the extract increased oxidative stress by 22.42% and lipid peroxidation, which are indicative of damage to the vital organs of the insects.

3. *Triboleum castaneum*

Pant et al. [56] examined a combined aqueous extract of *J. curcas* and *Pongamia glabra* (L.) (Fabaceae) for the control of *Triboleum castaneum*, an insect pest of stored grains. The extract was mixed with eucalyptus oil to obtain a nanoemulsion that was used in direct contact bioassays at 300, 600, 900, 1200, and 1500 ppm. The LC_{50} was 0.1646 mg/L, with 300 and 1500 ppm causing insect mortality between 88 and 100%. Another study assessed methanolic, chloroformic, petroleum ether, and n-hexane extracts of *J. curcas* leaves in toxicity bioassays at 5, 10, and 15% (*v*/*v*) against adult insects of *T. castaneum* and *R. dominica*. At 72 h posttreatment, 15% of the methanolic extract induced the highest mortality in *T. castaneum* and *R. dominica* (37.32 and 49.17%, respectively) [57].

4. *Podagrica uniforma*

Onunkun [58] reported the effect of an aqueous extract of *J. curcas* seeds on adult insects of *Podagrica uniforma* (Jac.) and *P. sjostedti* (Jac.) (Coleoptera: Chrysomeloidea), which are two species of flea beetles that infest okra crops (*Abelmoschus esculentus* (L.))

(Malvaceae). An ingestion bioassay using 10% (*w*/*v*) of the extract showed a reduction in beetle populations of 64%.

3.4.3. Hemiptera

1. *Brevicoryne brassicae*

Botti et al. [59] evaluated an aqueous seed oil extract of *J. curcas* at different concentrations (0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0% (*v*/*v*)) for the management of a major cabbage pest, the aphid *Brevicoryne brassicae* (L.) (Hemiptera: Aphididade). The extract was sprayed on cabbage leaf discs containing adult aphids of *B. brassicae,* with 40 and 60% mortality of aphids in the first 24–48 h after application at a concentration of 3.0%. Another study used an aqueous latex extract from *J. curcas* extracts against *B. brassicae*. The extract was evaluated at 25 and 50% (*v*/*v*) and sprayed on experimental plots of *B. oleracea* cabbage crops, where a moderate reduction was observed at the 50% concentration [34]. Finally, another study reported the effect of a 3% (*w*/*v*) aqueous extract of *J. curcas* leaves against adult aphids of *B. brassicae* in mesh cages containing *B. oleracea* cabbage plants, where the extract showed a reduction in aphid infestation [32].

2. Other species

Orozco-Santos et al. [60] used different types of oils and plant extracts of *J. curcas* to control *Diaphorina citri* (K.) (Hemiptera: Liviidae) nymphs on lime trees *Citrus aurantifolia* (L.) (Rutaceaer). The extract and seed oil were evaluated in an ingestion bioassay at 1 and 4% (*v*/*v*). At 2–6 days posttreatment, the seed oil reduced the nymph number by between 76.3 and 92.5%. Sumantri et al. [61] assessed an aqueous extract of *J. curcas* seeds on adult insects of *Nezara viridula* (L.) (Hemiptera: Pentatomidae), the main insect pest of soybean *Glycine max* (L.) (Fabaceae). Using an ingestion bioassay with 0.25 and 0.5% (*v*/*v*) of the extract, the LC_{50} was 0.026% with an insect mortality of 80 and 100% per treatment.

Holtz et al. [62] reported the insecticidal potential of different parts and seed oil of *J. curcas* against nymphs and adult insects of *Planococcus citri* (R.) (Hemiptera; Pseudococcidae). In contact and ingestion bioassays with 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0% (*w*/*v*) of the extracts, there was a high mortality (>90%) at 1.5, 2.0, and 3.0% concentrations. Yadav et al. [63] investigated the effect of a methanolic extract of *J. curcas* leaves on aphids of *Melanaphis sacchari* (Z.) (Hemiptera: Aphididade) in ingestion bioassays using sorghum leaves. The extract showed a mortality rate of 68.35% and a control efficiency of 56.57%. Ugwu [64] used crude and aqueous extracts of *J. curcas* against *Phytolyma fusca* (A.) (Hemiptera: Homotomidae) under laboratory and field conditions. Using a bioassay of residual action and contact toxicity with 75 and 100% (*w*/*v*) of the extract, the treatment had a residual effect of 3.33 and 4.33 at 40 min and a 1.67 contact effect on *P. fusca*.

3.4.4. Diptera

Silva et al. [65] evaluated the toxicity of a 10% (*w*/*v*) aqueous extract of *J. curcas* leaves on larvae of the fruit fly *Ceratitis capitata* (W.) (Diptera: Tephritidae) using an ingestion bioassay and found that the treatment was toxic and effective because it caused a high larval mortality of 95.6%. Rampadarath et al. [66] tested the larvicidal activity of ethyl acetate extract with methanol from bark, roots, leaves, and seeds of *J. curcas* against *Bactrocera zonata* (S.) and *B. cucurbitae* (C.) larvae (Diptera: Tephritidae). Ingestion bioassays using 200, 400, and 800 mg/L (*w*/*v*) of the extract were performed on larvae, and the results showed a significant effect because larval mortality ranged between 66.67 and 70%.

3.4.5. Homoptera

Diabaté, Gnago, Koffi, and Tano [38] assessed an aqueous extract of *J. curcas* seeds sprayed at 50 and 80 g/L on tomato plots for the control of adult insects of *Bemisia tabaci* (G.) (Homoptera: Aleyrodidae) in field trials. The treatment at 80 g/L reduced the number of insects by between 0.13 and 2.26 among the experimental conditions. Another study reported the effect of green fruit seed extracts and seed oils from fresh and dry fruits of

J. curcas on adult green aphids *Myzus persicae* (S.) (Homoptera: Aphididae). Cabbage leaves (*B. oleracea* (L.) treated with 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0% (*w*/*v*) of the extract in an ingestion bioassay were tested, with 61 and 71% mortality after 48–72 h at 2.5% [67].

3.4.6. Isoptera

Addisu et al. [68] reported the use of an aqueous seed extract of *J. curcas* for controlling the worker termite *Macrotermes* spp. (H.) (Isoptera: Termitidae), an insect pest that attacks timber tree crops. A topical application bioassay using 10, 20, 30, and 35% (*w*/*v*) of the extract showed a total mortality of 100% 72 h after treatment with 20 and 35%.

3.4.7. Othoptera

Bashir and El Shafie [69] evaluated the insecticidal and antifeedant efficacy of *J. curcas* oil against third instar nymphs of the desert locust *Schistocerca gregaria* (F.) (Orthoptera: Acrididae), a phytophagous insect of great economic importance. The seed oil at 5, 10, 15, and 20% (*v*/*v*) concentrations was tested in bioassays in which all the concentrations caused nymph mortality ranging from 22.4 to 59.2%. In addition, 10% of the extract delayed the development time and reduced the percentage of egg hatching, whereas 5% of the extract caused an antifeeding effect of 50%. Bashir and El Shafie [70] reported the effect of 10% (*v*/*v*) *J. curcas* seed oil against third instar nymphs and adult development of *S. gregaria* in a contact bioassay, whereas 5% (*v*/*v*) of the extract was assessed for its phage-deterrent effect. The 5% extract produced an antifeedant effect of 78.92%, with a nymphal mortality of 43.39% and 42.2% reduction in female fecundity found at 10% of the extract.

3.4.8. Thysanoptera

Ugwu [46] examined the insecticidal efficacy of petroleum ether extracts of *J. curcas* seeds against legume flower thrips *Megalurothrips sjostedti* (T.) (Thysanoptera: Tripidae). The extract was sprayed at a concentration of 10 mL/L on cowpea seedlings in experimental plots at one-week intervals for six weeks. After this period, the treatment produced a 52.07% reduction in the percentage of *M. sjostedti* thrips.

3.5. Chemical Compounds Identified in the Botanical Parts of Jatropha curcas

In total, six studies reported the main chemical compounds identified in the botanical extracts of *J. curcas*. Two studies using gas chromatography and mass spectrometry found fatty acids such as palmitic acid, palmitoleic acid, oleic acid, linoleic acid, stearic acid, octadecenal, and vaccenic acid as the main compounds in seeds of the plant [41,50]. Another study identified sterols, diterpenic alcohol, and hydrocarbons in fractions of aqueous extracts from fresh and dried leaves of *J. curcas* through gas chromatography-mass spectrometry and nuclear magnetic resonance spectroscopy (H^1 y C^{13}) [36]. In one study, fractions enriched with phorbol esters from seed oil of *J. curcas* were obtained and purified using ultrafast chromatography and high-performance liquid chromatography [35]. Another two studies used phytochemical screening on seeds and leaves of *J. curcas* to identify secondary metabolites that included alkaloids, tannins, saponins, flavonoids, terpenoids, steroids, and phenols in leaves and seeds from the plant [51,52].

4. Discussion

The analysis of the information from the studies included in this systematic review allowed us to summarize the published body of evidence on the bioactivity of several botanical extracts from *J. curcas*. Our results demonstrate that these extracts represent an alternative for the biological control of different species of insect pests in some regions of the world where alternatives to synthetic chemical pesticides are needed. Additionally, because of their natural origin, the botanical extracts from *J. curcas* are environmentally friendly and may provide producers with a low cost, safer, and more efficient option for being added to sustainable pest management. The summary of evidence presented herein

allowed us to achieve our three objectives. Thus, the discussion will be presented according to the results and implications of each of them.

4.1. Objective 1—Identify and Map the Body of Evidence Published on the Use of J. curcas against Insect Pests

In our study, we identified 39 publications that described the bioactivity of botanical extracts from different parts of *J. curcas* for controlling insect pests. These studies were conducted in different parts of the world, with East and West Africa accounting for 46% of the studies, followed by Latin America with 28% and South Asia with 25%. The studies reviewed reported the effect of botanical extracts against insect pest species distributed across eight taxonomic orders, with Lepidoptera species accounting for most of the individual bioassays reported in the studies (18/44), mainly in the Noctuidae genus, followed by Coleoptera (10/44) and Hemiptera (8/44). In contrast, Isoptera and Thysanoptera were less frequently included in the bioassays.

J. curcas is a small drought-resistant tree that thrives in many parts of tropical and subtropical regions [71]; thus, we found no studies from Europe, North America, and North Asia. The studies that included stored grain pest insects from Coleoptera were found mainly in East and West Africa, where people make their living from agriculture, which is largely traditional, and grains constitute the major part of their diet, such as sorghum, maize, rice, wheat, millet, cowpea, beans, chickpea, and groundnut [72]. Therefore, the introduction and dissemination of exotic pest insects into new habitats where they inflict damage on stored agricultural products represents a serious burden [73]. Consequently, producers are looking for new low-cost alternatives for controlling insect pests of stored grains. This growing interest in exploring botanical extracts from plants with insecticidal and insectistatic activity, such as *J. curcas*, helps explain the fact that 20/39 studies included in our review were published during a six-year period (2015–2021).

4.2. Objective 2—Summarize the Body of Evidence

In Table 2, we present a summary of the significant results of the insecticidal and insectistatic activity of *J. curcas* extracts on insect pests and the main crops in which the bioassays were conducted. This information may be used to guide evidence-based decisions on the use of botanical extracts from *J. curcas* as an alternative for sustainable pest management control. Accordingly, seed oil and the aqueous and methanolic extracts from seeds and leaves of *J. curcas* showed both effective insecticidal and insectistatic activity against postharvest pests such as *C. maculatus* and *S. zeamais*, polyphagous pests such as *E. insulana*, *S. frugiperda*, *H. armiguera*, *C. decolora*, *C. cephalonica,* and *D. saccharalis*, and the desert locust *S. gregaria* (Table 2).

Table 2. Summary of the studies that reported significant bioactivity of the *J. curcas* botanical extracts.

Activity/Botanical Extract	Affected Crop or Grain	Treatment	Main Finding
		Insecticidal activity	
(1) Aqueous seed extract	Stored grains	10% (*w*/*v*)	60–100% mortality of *S. zeamais*, *R. dominica*, and *T. castaneum*
	Eucalyptus	20 to 35% (*w*/*v*)	100% mortality of *Macrotermes* spp.
	Stored grains	300 and 1500 ppm	88–100% mortality of *T. castaneum*
	Soybeans	0.25% (*v*/*v*)	100% mortality of *N. viridula*
	Okra	10% (*w*/*v*)	64% reduction in the populations of *P. uniforma* and *P. sjostedti*
(2) Seed oil	Corn	20 mg/mL^{-1} phorbol esters	80% mortality of *S. frugiperda*
	Coffee	1 and 4% (*v*/*v*)	76.3 and 92.5% reduction in the nymphal number of *D. citri*
	Stored grains	200 µL/L	84% mortality of *S. zeamais*
	Cabbage	2.5% (*v*/*v*)	61–71% mortality of *M. persicae*
	Cabbage	3% (*v*/*v*)	60% mortality of *B. brassicae*

Table 2. *Cont.*

Activity/Botanical Extract	Affected Crop or Grain	Treatment	Main Finding
(3) Methanolic seed extract	Cabbage	5% (*w*/*v*)	100% mortality of *P. xylostella*
(4) Petroleum ether seed extract	Rice, corn, cocoa, and coffee	20 µL/mL	98% mortality of *C. cephalonica*
(5) Methanolic leaf extract	Sorghum	Amla + Drumstick + Jatropha + Neem + Water (1:1:1:1:1)	68% mortality of *M. sacchari*
	Cotton, rice, tobacco	5% (*w*/*v*)	60% mortality of *S. litura*
	Corn	1000 mg/kg^{-1} fresh and dried leaves	60 and 56.67% larval mortality of *S. frugiperda*
(6) Aqueous leaf extract	Cabbage	3% (*w*/*v*)	66% mortality of *P. xylostella* and reduced infestation of *B. brassicae*
	Cowpea	1% (*w*/*v*)	98% mortality of *C. maculatus*
	Fruit	10% (*w*/*v*)	95.6% mortality of *C. capitata*
	Insectistatical activity		
A. Development			
(1) Seed oil	Gramineae and legumes	10% (*v*/*v*)	Delayed nymphal instar development by 5 days in *S. gregaria*
B. Eggs			
(1) Aqueous leaf extract	Cowpea	1% (*w*/*v*)	81.04% reduction in oviposition rate in *C. maculatus*
(2) Aqueous seed extract	Okra	20% (*w*/*v*)	64% decrease in hatchability of eggs in *E. insulana*
(3) Seed oil	Stored grains	100 ppm	Inhibited 90% oviposition and reduced 92.3% hatching in *S. zeamais*
	Gramineae and legumes	10% (*v*/*v*)	42.2% reduction in female fecundity in *S. gregaria*
	Sugar cane	3% (*v*/*v*)	40% decrease in egg hatching in *D. saccharalis*
(4) Petroleum ether seed extract	Rice, corn, cocoa, and coffee	2 µL/mL	58% decrease in hatchability in *C. cephalonica*
C. Anti-feeding			
(1) Seed oil	Corn	0.125 mg/mL^{-1} phorbol ester enriched fractions	45% reduction in relative consumption rate in *S. frugiperda*
	Corn	0.25 mg/mL^{-1} phorbol ester enriched fractions	42% decrease in relative growth in *S. frugiperda*
	Gramineae and legumes	5% (*v*/*v*)	50–78.92% anti-feedant effect on *S. gregaria*
(2) Methanolic leaf extract	Cotton, chickpea	15% (*w*/*v*)	42% reduction in larval weight in *H. armiguera*
(3) Petroleum ether seed extract	Rice, corn, cocoa, and coffee	6 µL/g	48.08% anti-feedant effect on *C. cephalonica*
D. Malformations in adult insects			
(1) Acetonic seed extract	Cabbage	500 ppm	60% deformed insects of *C. decolora*

The insecticidal bioactivity of the botanical extracts from *J. curcas* induced a higher mortality and a greater reduction in the colonies or number of insect pests, whereas the insectistatic bioactivity was characterized by an increased antifeedant activity, decreased oviposition, reduced hatching of eggs, low hatchability, higher percentage of malformation of adult insects, and developmental defects of larvae and pupae (Table 2). These results coincide with previous reports that concluded that seed oil, petroleum ether, and acetonic extracts from *J. curcas* seeds and leaves presented biocidal activity, including insecticidal effects against different species of insects, mainly from the orders Lepidoptera, Homoptera, and Coleoptera [74–76].

The importance of controlling the different insect pest species summarized in Table 2 using botanical extracts from *J. curcas* relies on the significant economic losses caused by these insects in crops of grasses, legumes, stored grains, fruit products, and timber trees. It is estimated that annually up to 40% of the world's crop production is lost to insect pests, and each year, insect pests cost the global economy more than $70 billion [77]. Crop losses due to these insect pests can be substantial and preventable. According to our summary of evidence, botanical extracts obtained from different parts of *J. curcas* can be a promising alternative in the biological control of insect pests, as well as a less costly, environmentally friendly, and conducive way to sustainably manage agroecosystems. The different extracts obtained from seeds, seed powders, seed oil, and fresh/dried leaves of *J. curcas* showed greater bioactivity in the control of the different insect pests.

4.3. Objective 3—Identify the Main Chemical Compounds with Insecticidal and Insectistatic Bioactivity

The aqueous and methanolic extracts from seeds and leaves and the seed oil of *J. curcas* showed the greatest insecticidal and insectistatic activity against polyphagous pests, insect pests of stored grains, grain flea beetles, aphids of cabbage and sorghum, citrus crops, and fruit flies, among others. Additionally, our systematic review showed that both the type of solvent used to obtain the botanical extract of *J. curcas* and the method of application (contact or food) are fundamental to increase the insecticidal and insectistatic bioactivity on different species of insect pests. In a previous review by Muniz et al. [78], the authors concluded that although all organs of the *J. curcas* plant are toxic, the degree of toxicity varies according to the formulation of the extract, the nature of the active substance, the administration procedure, and the individual sensitivity of the insect pest. On the other hand, it is of vital importance to know how secondary metabolites affect the behavior, development and reproduction of pest insects [79].

The identification of the major chemical compounds found in the different extracts obtained from the botanical parts of the *J. curcas* plant is an important first step in understanding the effect they have on insect life at the molecular level. Other studies have reported that aqueous extracts of seeds and leaves obtained from plants belonging to the Euphorbiaceae family are also effective against plague insects of the orders summarized in this review. In one study, *R. comunis* (Euphorbiaceae) at a concentration of 20% (*w*/*v*) caused 67% mortality in *P. xylostella* larvae [80]. An aqueous extract of *Euphorbia thymifolia* (Euphorbiaceae) showed a 100% antifeedant effect at a concentration of 10% (*w*/*v*) on the stored grain pest insect *R. dominica* [81]. Our results and those from other studies that show a higher efficacy of the aqueous extracts of seeds and leaves of plants from the Euphorbiaceae family suggest that these botanical extracts should be used as a new alternative for the control and agroecological management of insect pests by producers from different parts of the world. Additionally, as leaves and seeds are more abundant for collection and obtaining aqueous extracts, they tend to benefit producers because of the easy method for obtaining them, without requiring the purchase of other chemical solvents that could cause toxic problems for producers, which makes them a new alternative in an integrated pest-management program that is easy to apply, environmentally friendly, sustainable, and low-cost [82].

In the present systematic review, major chemical compounds such as oleic, linoleic, and palmitoleic fatty acids were identified from *J. curcas* seeds [41,50]. Some studies have shown that these fatty acids produced mortality and neuronal cell inhibition by inducing apoptosis in AW1 cells on *Helicoverpa zea* (B.) [83]. In another study on *S. frugiperda* (Sf-21) cells, linoleic acid and linoleic mono-epoxides had transient uncoupling effects, decreasing the rate of respiration by increasing the amount of oligomycin, while linoleic acid diols inhibited the electron transport chain [84].

4.4. Perspectives and Future Research on the Botanical Extracts of J. curcas

According to our summary of evidence, most of the studies reviewed were conducted under laboratory conditions, and there are only a few studies that have evaluated the bioactivity of *J. curcas* extracts against insect pests under greenhouse and field conditions. Furthermore, a reduced number of studies have identified the main chemical compounds present in botanical extracts. In the light of these results, it is recommended that future research should be directed toward the identification of the major compounds and metabolites found in the extracts, as well as to perform bioassays under greenhouse and field conditions to scale up the application of botanical extracts and analyze the underlying mechanisms of action (humoral, metabolic, and molecular) that regulate the differential outcomes against the control of insect pests when different botanical extracts are used.

5. Limitations

Our study is not devoid of several limitations. First, we included only published studies found in major electronic databases, which could have biased the body of evidence because of the exclusion of gray literature. Second, we included only studies published in English, Spanish, and Portuguese, which could cause a language bias because some important studies are not published in peer-reviewed journals in these languages. Third, the different studies analyzed showed methodological and experimental differences for both obtaining the extracts and assessing their effects, thus affecting the generalization of results. Fourth, in some cases, the results arising from the bioassays were not tested under open field conditions, which may cause a lack of applicability of these results. Fifth, some studies presented selective reports of results, presenting omissions of outcomes that did not provide significance within the study. Sixth, due to the limited availability of data from field conditions, the extrapolation of results from experimental studies may be taken with caution, as more studies are needed to draw solid conclusions. Seventh, according to the GRADE scale [85], the overall rate of evidence was rated as moderate mainly due to the results of the risk of bias assessment, which highlighted some discrepancies and selective reporting in some studies, as well as inconsistencies regarding the effect of the botanical extracts against some species of insect pests.

6. Conclusions

Our systematic review allowed us to obtain a body of evidence and thus evaluate the scope and nature of the scientific publications reporting the use of botanical extracts obtained from different parts of *J. curcas*, which present bioactivity in the control of insect pests of different taxonomic orders. In addition, our summary of evidence allowed us to analyze, synthesize, and disseminate the main characteristics and findings of these studies. The body of evidence summarized in our study adds to the growing interest in controlling insect pests in an effective, economically profitable, and environmentally friendly manner. We found that aqueous and methanolic extracts obtained from leaves, seeds, and seed oil of *J. curcas* provide an alternative in the control of insect pests, showing increased insecticidal activity in the different taxonomic orders of insect pest species. The results summarized in this review can support future experimental work and inform evidence-based technical decision-making by agricultural producers. However, future research is needed to evaluate the bioactivity of the main secondary metabolites of *J. curcas* and their main mechanisms of action (humoral, metabolic, and molecular) that regulate the control of insect pests of different taxonomic orders worldwide.

Author Contributions: Conceptualization, A.V.-R. and A.F.-M.; methodology, A.V.-R., R.F.-B. and M.E.d.l.T.-H.; software and visualization, A.V.-R., M.A.R.-L. and D.D.; writing—original draft preparation, A.V.-R., A.F.-M., and R.F.-B.; investigation and writing—review and editing, A.V.-R., M.A.R.-L., S.A.B.-O., D.M.B.-C. and D.D.; data curation, A.V.-R.; project administration, A.F.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data used to perform the present study are available from the corresponding author upon reasonable request.

Acknowledgments: The first author gratefully acknowledges the Scholarship provided by Consejo Nacional de Humanidades Ciencias y Tecnología (CONAHCYT) and Universidad Autónoma Metropolitana, Unidad Xochimilco for performing this systematic review.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	1-2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	3
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	4
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	4
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	5
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	5
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	5
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	NA
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	5
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	NA
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	NA
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	6
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	NA
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NA
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NA
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA

Figure A1. *Cont.*

Section and Topic	Item #	Checklist item	Location where item is reported
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	6-7
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	NA
Study characteristics	17	Cite each included study and present its characteristics.	19-21
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	7
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	NA
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	NA
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NA
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NA
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	13-15
	23b	Discuss any limitations of the evidence included in the review.	16
	23c	Discuss any limitations of the review processes used.	NA
	23d	Discuss implications of the results for practice, policy, and future research.	16
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	3
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	3
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	16
Competing interests	26	Declare any competing interests of review authors.	17
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	16

Figure A1. PRISMA checklist.

Table A1. Individual characteristics and results of the 39 studies included in the systematic review.

Study/Country	Botanical Extract	Methods	Bioactivity
Addisu et al. [68]/ Ethiopia	Aqueous extract of *J. curcas* seeds	The extract was evaluated at four concentrations (10, 20, 30, and 35% (*w*/*v*)) on *Macrotermes* ssp. worker termites by topical application. The percentage of mortality and repellency was evaluated	The aqueous extract caused 100% mortality on worker termites at a concentration of 20 to 35% 72 h after application
Amoabeng et al. [32]/ Ghana	Aqueous extract of *J. curcas* leaves	The extract was sprayed (3% (*w*/*v*)) on cabbage plants containing *P. xylostella* larvae in open field. In a mesh cage experiment, adult aphids of B. brassicae were transferred. The percentage mortality rate was calculated	The 3% aqueous extract showed a 66% larval mortality of *P. xylostella*, while the infestation reduction score of *B. brassicae* was 0 (colonies absent)
Babarinde et al. [50]/ Nigeria	Seed oil from toxic varieties of *J. curcas*	The seed oil was obtained by roasting one portion, cooking in distilled water, and the last was used raw. Two bioassays of fumigation (50, 100, 150, and 200 µL/L) and contact toxicity (0.30, 0.60, 0.90, 1.20, and 1.50 µL/cm^2) evaluated the percentage of mortality on adult insects of *S. zeamais*	Exposure of *S. zeamais* to 200 µL/L of roasted seed oil showed a mortality of 84.68% at 24 h, compared to 40.28 and 47.80% observed in cooked and raw seed oil

Table A1. *Cont.*

Study/Country	Botanical Extract	Methods	Bioactivity
Bashir et al. [69]/ Sudan	Hexanic extract of *J. curcas* seed oil	Concentrations of *J. curcas* seed oil (5, 10, 15, and 20% (*v*/*v*)) were tested through a contact and ingestion toxicity bioassay on *S. gregaria* nymphs. Effects on development, mortality, antifeedant activity and hatchability of eggs were evaluated	All concentrations caused nymph mortality (range 22.4 to 59.2%). The 10% concentration delayed development time and reduced the percentage of egg hatching. The 5% concentration caused an anti-feeding effect of 50%
Bashir et al. [70]/ Sudan	Hexanic extract of *J. curcas* seed oil	The extract was evaluated in a contact bioassay, sprayed at 10% (*v*/*v*) on *S. gregaria* nymphs. The outcomes included mortality, percentage of deformed adults, affectations in development, effect on fecundity, and hatchability of eggs. The phagodisuasive effect was recorded at a concentration of 5% (*v*/*v*)	The 5% extract produced an anti-feeding effect of 78.92%, a nymphal mortality of 43.39% at the 10% concentration and significantly reduced female fecundity by 42.2%
Botti et al. [59]/ Brazil	*J. curcas* seed oil	0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0% (*v*/*v*) of *J. curcas* seed oil were sprayed on cabbage leaf discs containing green aphids *B. brassicae* and mortality was evaluated at 24, 48, and 72 h	The oil caused a mortality of between 40 and 60% of the aphids in the first 24 and 48 h after application at 3.0%
de Oliveira et al. [47]/ Brazil	Aqueous extract of *J. curcas* seed oil	A 3% aqueous seed oil extract was applied in a contact toxicity bioassay on *D. saccharalis* eggs. Its effect on egg hatching was evaluated	With the treatment, only 60% hatched and an increase in the embryonic period of 7 days was observed
Diabaté et al. [38]/ Ivory Coast	Aqueous extract of *J. curcas* seed	The extract was sprayed at different concentrations (50 and 80 g/L) on rural, randomized and experimental plots of tomato for the control of adult insects of *B. tabaci* and larvae of *H. armiguera* in field efficiency trials evaluating their presence or absence	The extract at 80 g/L reduced the number of *B. tabaci* insects between 0.13 and 2.26 among the plots. A moderate reduction in the number of *H. armiguera* larvae was observed (range 0.0 to 0.03)
Devappa et al. [35]/ India	Phorbol ester fractions of *J. curcas* seed oil	The phorbol ester fractions and the phorbol ester-rich extract were applied topically (0.0313, 0.0625, 0.125, 0.25, 0.5, 1, and 20 mg/mL^{-1}) and by ingestion (0.0625, 0.125 and 0.25 mg/mL^{-1}) on third instar larvae of *S. frugiperda* per treatment, calculating the percentage of mortality, consumption, and weight	The enriched fraction showed contact toxicity with a LC_{50} of 0.83 mg mL^{-1}. The extract decreased feed consumption by 33%, relative growth by 42%, and feed conversion efficiency by 38% at 0.25 mg mL^{-1}. Feed intake reduction was the highest (39 and 45%) with 0.0625 and 0.125 mg
Figueroa-Brito et al. [40]/ Mexico	Aqueous extract of *J. curcas* seed powder	The aqueous extract of seed powder was tested at 1 and 5% (*v*/*v*) in artificial diet on *C. decolora* larvae through an ingestion bioassay in a completely randomized design, evaluating the percentage of mortality and insectatic activity	Aqueous seed extract at 5% ppm reduced larval viability of *C. decolora* by 46%

Table A1. *Cont.*

Study/Country	Botanical Extract	Methods	Bioactivity
Figueroa-Brito et al. [41]/ Mexico	Acetone extract of shell, kernel, and almond nut from *J. curcas* seeds	Acetone extracts of shell, kernell, and almond nut were obtained from the seeds. Ingestion bioassays were performed under laboratory (250, 500, 1000, 1500, and 2000 ppm) and greenhouse (250, 500 and 1000 ppm) conditions against *C. decolora* in cabbage plants. Insecticidal and insecticidal activity was evaluated	The extracts of almond nut and shell plus kernell at 500 and 1500 ppm caused the highest percentage of deformations in pupae and adults, causing a mortality of 50% in larvae. Almond nut was active in greenhouse test (250–1000 ppm)
Guerra-Arevalo et al. [42]/ Peru	Resin of *J. curcas*	Five resin treatments (10, 20, 30, and 40% (*v*/*v*)) were evaluated in *H. grandella* larvae on *S. macrophylla* leaf discs. Disc consumption, survival, mortality and larval activity were measured.	The resin at a concentration of 40% caused a mortality of 67% and a larval activity < 30% in *H. grandella* larvae
Habib-ur-Rehman et al. [57]/ Pakistan	Methanolic, chloroformic, petroleum ether, and n-hexane of *J. curcas* leaves	The extracts were evaluated at different concentrations (5, 10, and 15% (*v*/*v*)) through a toxicity bioassay on adult insects of *T. castaneum* and *R. dominica*. The percentage of mortality was evaluated 24, 48 and 72 h after application of the treatments	Methanolic extract at a concentration of 15% caused 37.32% mortality on *T. castaneum* after 72 h of application, as well as 49.17% mortality on *R. dominica*
Holtz et al. [62]/ Brazil	Green fruit seed and green and dried fruit seed oil of *J. curcas*	The extracts were applied in ingestion bioassays (0.0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% (*w*/*v*)) on cabbage leaves with green aphids M. persicae, evaluating mortality over time periods of 24, 48 and 72 h	The best results were obtained 48 h after the application of nut oil at 2.5% and 72 h with a mortality between 61 and 71% on *M. persicae*
Holtz et al. [67]/ Brazil	Leaves, stem with or without bark, fruit and seeds of *J. curcas*	Aqueous extract and seed oil were evaluated on nymphs and adult insects of *P. citri* through contact and ingestion bioassays on coffee leaf discs at different concentrations (0.0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% (*w*/*v*))	All aqueous extracts in contact application showed satisfactory insecticidal activity, reaching 91.6% mortality at three concentrations (1.5, 2.0 and 3.0% (*w*/*v*))
Ingle et al. [37]/ India	Leaves, bark, seeds, and seed hulls of *J. curcas*	The crude methanolic extracts were evaluated through an ingestion bioassay on *S. litura* larvae at a concentration of 5% (*w*/*v*), evaluating the insecticidal activity by counting dead insects in a period of 72 h after application	The leaf extract showed a 60% mortality compared to the other parts of the plant 72 h after application
Ingle et al. [33]/ India	Leaves, bark, seeds, seed hulls, and root of *J. curcas*	Methanolic extracts were evaluated at 5% (*w*/*v*) on *P. xylostella* larvae and 5, 10 and 15% (*w*/*v*) was used on *H. armigera* larvae by means of bioassays of ingestion by immersion of cabbage leaf discs. Larval mortality at 72 h and antifeedant activity were determined on treated cotton leaves	The 15% leaf extract showed antifeedant activity against *H. armigera* by reducing larval weight by 42% and causing 60% mortality. Seed husk extract caused 100% mortality at 5% against *P. xylostella*
Ishag et al. [43]/ Sudan	Aqueous extract and oil of *J. curcas* seeds	The extract was evaluated at 5, 10, 15 and 20% (*v*/*v*) through a contact toxicity bioassay on *E. insulana* eggs	The aqueous extract reduced the percentage of egg hatching, with the 10% concentration being the most effective

Table A1. *Cont.*

Study/Country	Botanical Extract	Methods	Bioactivity
Jagdish et al. [39]/ India	*J. curcas* seed oil	Different combinations of biopesticide and *J. curcas* seed oil treatments were applied in experimental plots over a period of three years for the control of *H. armiguera* and *T. orichalcea*, evaluating the percentage of damage to the ear	Treatments that included *J. curcas* seed oil were the most effective in reducing the number of larval populations of both pest insects
Jide-Ojo et al. [51]/ Nigeria	Aqueous extract of leaves, oil and juice of *J. curcas* seeds	The oviposition-deterrent activity and corn grain-protective activity of the different treatments (0, 5, 10, 50, and 100 ppm) of the extracts against *S. zeamais* were evaluated	Seed oil at 100 ppm produced 93% protection against grain damage, inhibited oviposition by 90%, decreased adult hatching by 92.3% and caused 90% mortality
Khani et al. [48]/ Malasya	Pretoleum ether extract of *J. curcas* seeds	The extract was tested at different concentrations (2, 4, 6, 8, and 10% (*w*/*v*)) through food and contact bioassays on third instar larvae and eggs of *C. cephalonica*. The percentage of mortality, the anti-feeding activity and its effect on egg hatchability were evaluated	The extract produced larval susceptibility, with a LC_{50} of 13.22 µL/mL. While at 12 and 20 µL/mL it caused a mortality of 66.5 and 98%, respectively, with an anti-feeding action of 48.08% at 6 µL/g and hatchability of 58% at 2 µL/mL
Kolawole et al. [55]/ Nigeria	Ethanolic extract of *J. curcas* seeds	The extract was used at 0, 5000, 10,000, 15,000, and 20,000 ppm in an ingestion bioassay with cowpea seeds infested with adult *C. maculatus* insects. Oxidative stress, lipid peroxidation and antioxidant glutathione enzymes were evaluated	The extract at 20,000 ppm increased oxidative stress, lipid peroxidation. While at 5000 ppm it increased glutathione reductase, indicating the extent of damage to vital organs
Kona et al. [45]/ Sudan	Petroleum ether extract from *J. curcas* seeds	The extract was applied in contact bioassay on tomato leafminer *T. absoluta* eggs at 62.5, 125, 250, 250, 500, and 1000 mg/L. The larvae were exposed to 2000, 4000, 6000, and 8000 mg/L. Mortality of eggs and larvae was recorded	The concentration of 125 mg/L showed the highest mortality (25%) in eggs and a higher larval mortality of 85 to 100% was observed at 4000 and 8000 mg/L, respectively
Mwine et al. [34]/ Uganda	Latex from *J. curcas* stems	Aqueous latex extract obtained from stems was evaluated at 50 and 25% (*v*/*v*) and sprayed on experimental plots of cabbage crops, evaluating the efficiency in controlling infestation numbers of *P. xylostella* larvae and colonies of *B. brassicae* aphids	The 50% extract showed a moderate reduction in *B. brassicae* infestation, while the same concentration produced a slight 11% reduction in the number of *P. xylostella* larvae
Onunkun et al. [58]/ Nigeria	Aqueous extract of *J. curcas* seeds	The extract was tested in a 10% (*w*/*v*) ingestion bioassay on okra plants infested with adult insects of *P. uniforma* and *P. sjostedti*. The reduction in the number of insects was determined	The extract at 10% concentration reduced flea beetle populations of *P. uniforma* and *P. sjostedti* by 64%
Opuba et al. [53]/ Nigeria	Aqueous extract of *J. curcas* leavess	The aqueous extract was evaluated through an ingestion bioassay by spraying 1.0, 2.0, and 3.0% (*w*/*v*) on cowpea seeds containing adult *C. maculatus* insects	All concentrations showed insecticidal activity. The lowest concentration produced 94–98% mortality and reduced the oviposition by 81.04%

Table A1. *Cont.*

Study/Country	Botanical Extract	Methods	Bioactivity
Orozco-Santos et al. [60]/ Mexico	*J. curcas* seed oil	The extract was evaluated in a 1 and 4% (*v*/*v*) ingestion bioassay on the Asian citrus psyllid *D. citri*. The population of live immatures before and after treatment was quantified.	The treatment was effective in reducing the number of nymphs between 76.3 and 92.5% in relation to the initial population
Pant et al. [56]/ India	*J. curcas* seed oil with or without eucalyptus and *P. glabra*	The evaluation of the insecticidal activity was carried out in direct contact bioassays (300, 600, 900, 1200, and 1500 ppm) of the nanoemulsion of eucalyptus alone and with aqueous filtrate of *P. glabra* and *J. curcas* on *Tribolium* spp.	The 300 and 1500 ppm nanoemulsion produced 88–100% mortality against insects with LC_{50} for the nanoemulsions with and without the aqueous filtrate were 0.1646 and 5.4872 mg L^{-1}
Rampadarath et al. [66]/ Mauritius	Bark, leaves, roots, and seeds *J. curcas* seeds	Crude ethyl acetate extracts were tested by ingestion bioassays (200, 400, and 800 mg/L (*w*/*v*)) on larvae of two insects, *B. zonata* and *B. cucurbitae*. Larval mortality was determined	The bark extract after 24 h produced a mortality ranging between 66.67 and 70% for both larvae of *B. cucurbitae* and *B. zonata*, respectively
Ribeiro et al. [36]/ Brazil	Methanolic extract of *J. curcas* fresh and dry leaves	Fractions of methanolic extracts of seven accessions were evaluated. The extracts were evaluated through a bioassay of ingestion of fresh and dried leaves (1000 mg/kg^{-1}) on *S. frugiperda* larvae. Insecticidal and insecticidal activity was evaluated	Extracts of EMB accessions of fresh and dried leaves showed the best result for larval mortality of *S. frugiperda* with (range 60 and 56.67%).
Sharma et al. [44]/ India	Acetonic extract of *J. curcas* seeds	Dilutions were made with water of the extract at 0.00, 0.625, 1.25, 2.50, 5.00 and 10.00% (*v*/*v*). Treatments were tested in an ingestion bioassay against *S. oblicua* larvae fed on treated resin leaves. Larval and pupal weight, percentage mortality, pupation and adult emergence were evaluated	The 5.0% concentration increased the percentage of larval mortality by 33.3%, as well as a decrease in pupation from 26.66% to 1.25%.
Silva et al. [49]/ Brazil	Aqueous extract and powder of *J. curcas* seeds	Two bioassays were used, the first with plant seeds and the second with aqueous extracts and seed and pericarp powder at 5 and 10% (*w*/*v*) on adults of *S. zeamais*, *R. dominica*, *T. castaneum*, and *O. surinamensis*	The aqueous extracts were active at 10%, causing 75, 100, 60, and 90% mortality on *S. zeamais*, *R. dominica*, *T. castaneum*, and *O. surimanensis*, respectively
Silva et al. [65]/ Brazil	Aqueous extract of *J. curcas* leaves	The aqueous extract was evaluated through an ingestion bioassay (10% (*w*/*v*)) on neonate larvae of *C. capitata*. Larval mortality and control efficiency were evaluated	The aqueous extract was toxic and effective in the control of *C. capitata* larvae causing 95.6% mortality at 10%
Sumantri et al. [61]/ Indonesia	Aqueous extract of *J. curcas* seeds	The experiment was conducted using residual toxicity, by applying 0.5 and 0.25% (*v*/*v*) aqueous extract solution on adults of *N. viridula* per treatment. The mortality rate was recorded daily	The extracts showed 80 to 100% mortality on *N. viridula*, and were highly toxic with an LC50 of 0.026%
Uddin li et al. [54]/ Nigeria	Aqueous extract of *J. curcas* seeds	The extract was applied by contact at 1.5, 2.0, and 2.5% (*w*/*v*) on cowpea seeds infested with newly adult insects of *C. maculatus*, evaluating mortality, oviposition and emergence of the progeny	The 2.5% treatment increased mortality by 2.25 times, decreased oviposition and decreased adult emergence by 0.75 times

Table A1. *Cont.*

Study/Country	Botanical Extract	Methods	Bioactivity
Ugwu et al. [46]/ Nigeria	*J. curcas* seed oil	Petroleum ether extract of seeds was sprayed at 10 mL/L on cowpea seedlings. The number of *M. sjostedti* thrips and *M. vitrata* larvae, as well as damage to cowpea pods, was evaluated	The treatment reduced the population of thrips of M. sjostedti by 52.07% and 59.12% for the pod borer *M. vitrata*
Ugwu et al. [64] /Nigeria	Aqueous and ethanolic extract of *J. curcas* seeds	The aqueous and ethanolic seed extract were evaluated at concentrations of 75 and 100% (*w*/*v*) through a bioassay of residual action and contact toxicity on adult insects of *P. fusca*. Mortality was evaluated for 24 h	Aqueous and ethanolic extracts of seeds at 75% and 100% concentrations had a residual effect of 3.33 and 4.33 at 40 min and 1.67 contact effect on *P. fusca*
Ukpai et al. [52] /Nigeria	Seed powder of *J. curcas*	Seed powders were evaluated at different doses (2.5, 5.0, 7.5 and 10.0 g) through an ingestion bioassay on adult *S. zeamais* insects. The number of insects killed per treatment was evaluated	Treatment with 10 g of seed powder caused significant mortality of adult *S. zeamais* insects.
Yadav et al. [63]/ India	Methanolic extract of *J. curcas* leaves	The extract was tested in nine concentrations in combination with different plants through an ingestion bioassay, using sorghum leaves with *M. sacchari* aphids. Mortality and reproductive rates were measured	The methanolic extract formulation that included *J. curcas* showed a mortality rate of 68.35% and 56.57% efficiency in controlling aphids of *M. sacchari*

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