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Biological control of fruit flies: bibliometric analysis on the main biocontrol agents

Controle biológico de moscas das frutas: análise bibliométrica sobre os principais agentes de biocontrole

Control biológico de moscas de la fruta: análisis bibliométrico de los principales agentes de biocontrol

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Abstract
The Tephritidae family has many fruit fly species responsible for causing direct and indirect damage to economically important fruit trees worldwide. Biological control has been sought as a method for the management of these insects, mainly because it does not cause adverse damage to the environment. Thus, this review sought information on what is currently being published in the scientific field about the main biological agents that are used to control fruit flies. The information was obtained through surveys between the months of June and August 2020, in bases such as the Web of Science, Scopus, ScienceDirect, Taylor & Francis, Springer, and Scielo. The inclusion of the articles followed criteria such as publication language English, Portuguese and Spanish, available in full, from categories A1 to B1, related to the biological agents used in the control of fruit flies and published in the last five years. A total of 2,362 studies were found, of which 105 articles were selected for this review. Regarding the years of publication, only 27% of the studies correspond to references from the years 2019 and 2020, with a greater number of research on parasitoids and developed in the laboratory. The largest concentration of research was in countries like Brazil, Mexico, and Spain.
Keywords: *Ceratitis*; *Anastrepha*; Parasitoids; Predators; Entomopathogens.

Resumo
A família Tephritidae apresenta diversas espécies de moscas-das-frutas responsáveis por ocasionar danos diretos e indiretos em frutíferas de importância econômica em todo o mundo. O controle biológico tem sido um método bastante procurado para o manejo desses insetos, principalmente por não ocasionar danos adversos ao meio ambiente. Desta forma procurou-se nesta revisão informações sobre o que está sendo publicado atualmente no campo científico sobre os principais agentes biológicos que são utilizados no controle das mosca-das-frutas. As informações foram obtidas através de pesquisas entre os meses de junho e agosto de 2020, em bases como a Web of science, Scopus, ScienceDirect, Taylor & Francis, Springer e Scielo. A inclusão dos artigos obedeceu a critérios como: idioma de publicação inglês, português e espanhol, disponíveis na íntegra, de qualis A1 a B1, relacionados aos agentes biológicos utilizados no controle de mosca-das-frutas e publicados nos últimos cinco anos. Ao todo 2.362 estudos foram encontrados, destes 105 artigos foram selecionados para esta revisão. Em relação aos anos de publicação apenas 27% dos estudos correspondem a referências dos anos de 2019 e 2020, com maior número de pesquisas sobre

parasitóides e desenvolvidas em laboratório. A maior concentração de pesquisas foi em países como Brasil, México e Espanha.
Palavras-chave: *Ceratitis*; *Anastrepha*; Parasitóides; Predadores; Entomopatógenos.

Resumen
La familia Tephritidae tiene varias especies de moscas de la fruta responsables de causar daños directos e indirectos a árboles frutales de importancia económica en todo el mundo. El control biológico ha sido un método popular para el manejo de estos insectos, principalmente porque no causa daños adversos al medio ambiente. Así, esta revisión buscó información sobre lo que se está publicando actualmente en el campo científico sobre los principales agentes biológicos que se utilizan para el control de la mosca de la fruta. La información se obtuvo a través de encuestas entre los meses de junio y agosto de 2020, en bases como Web of Science, Scopus, ScienceDirect, Taylor & Francis, Springer y Scielo. La inclusión de los artículos siguió criterios como: idioma de publicación inglés, portugués y español, disponibles en su totalidad, de las categorías A1 a B1, relacionados con los agentes biológicos utilizados en el control de la mosca de la fruta y publicados en los últimos cinco años. Se encontraron un total de 2.362 estudios, de los cuales se seleccionaron 105 artículos para esta revisión. En cuanto a los años de publicación, solo el 27% de los estudios corresponden a referencias de los años 2019 y 2020, con un mayor número de investigaciones sobre parasitoides y desarrolladas en el laboratorio. La mayor concentración de investigación se dio en países como Brasil, México y España.
Palabras clave: Queratitis; Anastrepha; Parasitoides; Depredadores; Entomopatógenos.

1. Introduction

The flies are the fruit pest insects belonging to the family *Tephritidae*, a major pest of world fruit production (Gava et al., 2020). According to Norrbom et al., 1999, among the representatives of the *Tephritidae* family, the genera *Bactrocera*, *Rhagoletis*, *Toxotrypana*, *Anastrepha*, and *Ceratitis* stand out, the latter two being the ones that are considered of greatest economic relevance.

The genus *Anastrepha* (Schiner, 1868) has the largest number of species in the tropics and subtropics of the Americas with more than 250 described, constituting the most important genus at the level of pests in these regions (Norrbom & Korytkowsk, 2011). The species of greatest economic importance are *A. obliqua* (Macquart), A. *ludens* (Loew), *A. suspensa* (Loew), *A. grandis* (Macquart), *A. serpentina* (Wiedemann), *A. striata* (Schiner), and *A fraterculus* (Wiedemann) with emphasis on the latter, known as South American fruit flies, which is highly polyphagous and widely distributed in the Americas, from the southern United States to Argentina (Norrbom et al., 1999).

The genus *Ceratitis*, on the other hand, is composed of approximately 78 species (De Meyer, 2001). Being the *Ceratitis capitata* Wied 1824 considered one of the main worldwide pests of fruit production, presenting the widest range of hosts among the other fruit flies, responsible for the infestation of about 300 species of fruits, vegetables, and cultivated nuts and wild and causing losses of up to 100% of production (Leftwich et al., 2014; Goldshtein et al., 2017).

In general, the direct damages caused by fruit flies is related to the fruits perforation by the females in the oviposition act, as well as by the galleries formed by the larvae when feeding on their pulp, including the direct losses in productivity and the increase in production costs, mainly due to the insecticides usage in order to control this (Grové et al, 2019).

According to Soliman et al. (2020), due to the fact that the main control tool for this pest is the pesticides usage, a great barrier was formed in fresh fruits exportation to countries that restrict agricultural products with agrochemical residues entry, causing a negative economic impact for producing countries.

However, there are other control strategies that must be used for the fruit flies management, one of the tools indicated by the integrated management programs is biological control, as it is economically viable and environmentally safer (Colmenarez et al., 2016). For an organism to be used in biological control, it must be considered as a natural enemy of the interest species, which may be other beneficial insects, predators, parasitoids, and microorganisms, such as fungi, viruses, and bacteria (Berti-Filho & Macedo, 2011).

Therefore, performing this study becomes of paramount importance, since it reviews current information from the scientific field about the main biological agents that are used in the fruit flies control. Thus, we sought to conduct a systematic literature review in order to analyze bibliometric parameters for fruit flies biological control.

2. Methodology

In the first moment, a literature review was carried out, based on the search for results on the main biological controllers used in fruit flies management. This information was obtained between June and August 2020 in the following databases: Web of Science, Scopus, ScienceDirect, Taylor & Francis, Springer, Scielo.

The inclusion criteria were articles written in English, Portuguese and Spanish language, which were published in the last five years and that was available in full, having grades from A1 to B1 and were related to biological agents used in the fruit flies control. In order to perform the search, the following keywords were used: " *Ceratitis*", " *Anastrepha* ", "biological control", "parasitoids", "predators" and "entomopathogens", searched in both Portuguese and English. The Boolean operators used were AND and OR.

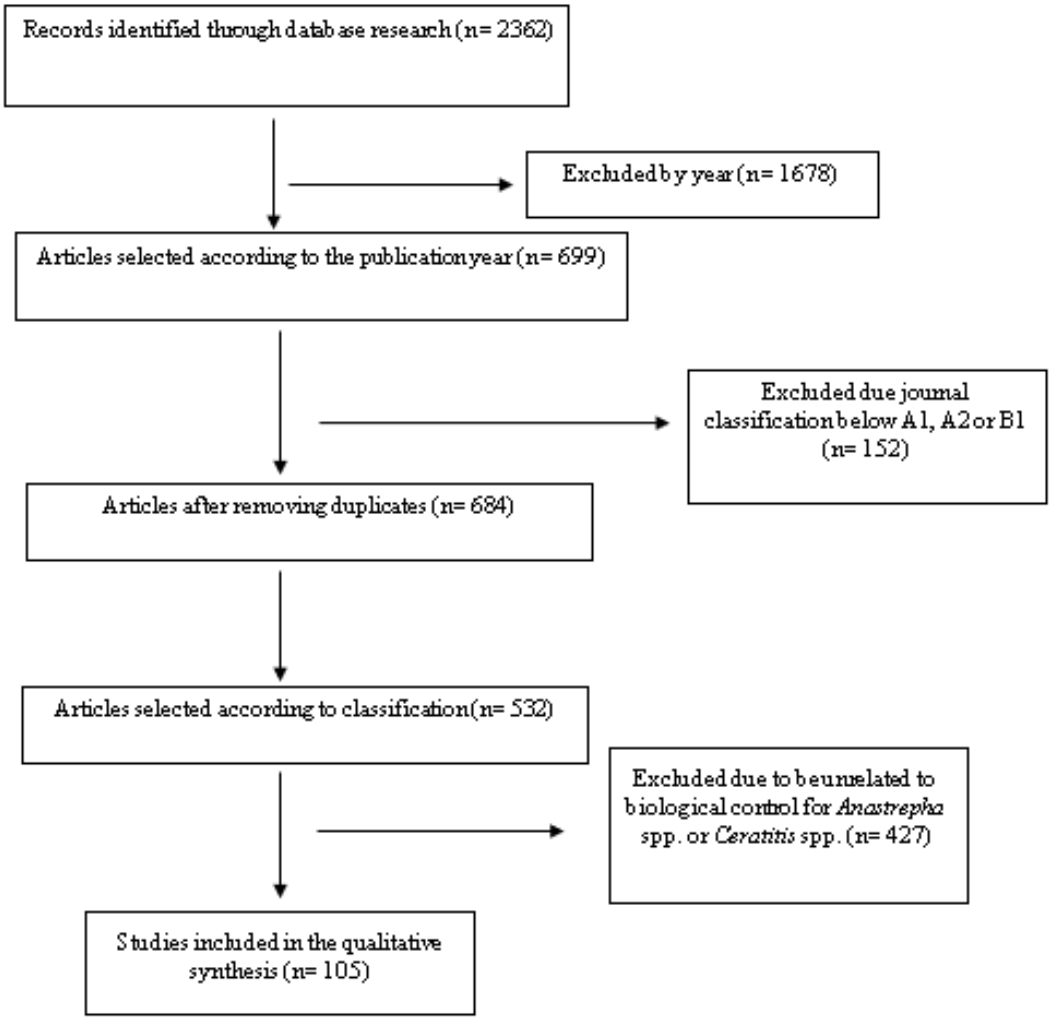
The search was carried out in the databases previously mentioned through the combination of keywords, the last access date being: August 28, 2020, and the results were imported into a Mendeley library, reference manager, where duplicates were removed. Research in form of a Monograph, dissertation, thesis, and research project was considered inadequate to compose the present study. The remaining records were retrieved in full text and inspected in detail for inclusion in the study, where they were initially analyzed by their titles following by abstracts reading. Those papers that meet the research inclusion and exclusion criteria were read in full.

In order to organize the data collected in the articles, a spreadsheet was created on Microsoft Excel containing the following information: database names, journal names, publication year, control agent, target insect, researched area, and geographical distribution.

3. Results

Based on the eligibility criteria, of 2,362 studies found in the database search, 532 articles were selected for a full reading. After reading, 105 articles were selected for this review Figure 1.

Figure 1. Flowchart based on the PRISMA model with the article selection results.

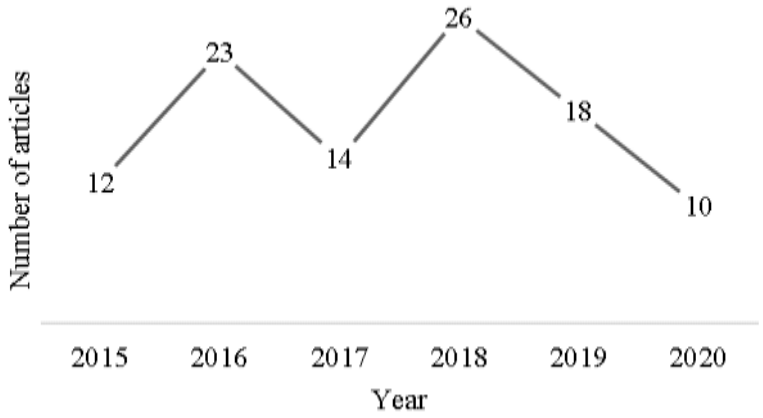


Source: Authors.

3.1 Publishijng years

Regarding the publication distribution per year about biological control for fruit flies an irregular behavior was observedj (Fig 2). A total of 105 articles that addressed this theme were found in the last five years, where just 27% of the found studies correspond to current references (2019 and 2020). The highest number of publications was in 2018, with a total of 24.7% of the total published articles.

Figure 2. Time trend of research on biological control for fruit fly species (*Anastrepha* spp. And *Ceratitis* spp.) In the period from 07/24/2020 to 08/28/2020.



Source: Authors.

3.2 Geographic distribution

The spatial research distribution involving fruit flies illustrated in Figure 3 demonstrates that studies on these insects are concentrated especially in Brazil, Mexico, and Spain, as well as in Argentina, the United States of America (USA), Italy and others outnumbered.

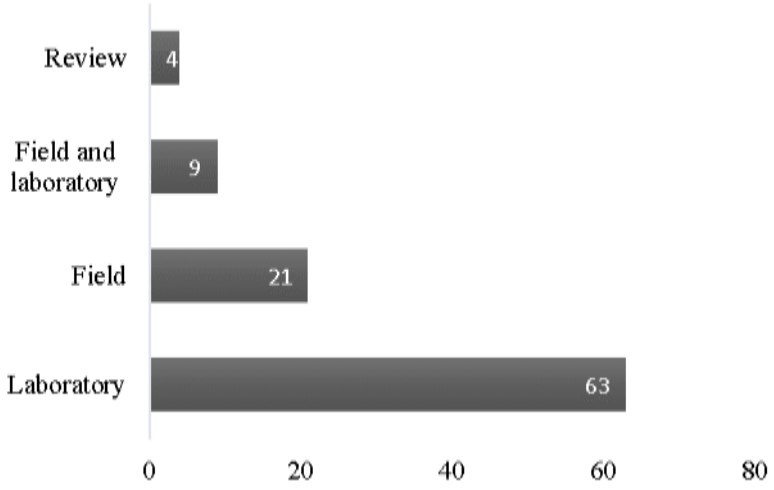
Figure 3. Geographic distribution of the research on biological control for the fruit fly species (*Anastrepha* spp. And *Ceratitis* spp.) In the period from 07/24/2020 to 08/28/2020.

Source: Authors.

3.3 Research application area

Regarding the research carrying area, according to Figure 4, most of the studies took place under laboratory conditions, followed by field, field and laboratory studies, and bibliographic reviews.

Figure 4. Survey of the research application area on biological control for fruit fly species (*Anastrepha* spp. And *Ceratitis* spp.) In the period from 07/24/2020 to 08/28/2020.



Source: Authors.

3.4 Fruit fly species

For the *Anastrepha* genus, the species *A. fraterculus* was the most cited in the research, with a total of 19 studies. Of the four species of *Ceratitis*, *C. capitata* was the most relevant with 59 citations. It is also observed that the species *A. striata*, *A. zenildae* and *C. rosa* were the least mentioned.

Table 1. Number of studies by species in the research on biological control for fruit flies (*Anastrepha* spp. And *Ceratitis* spp.) In the period from 08/24/2020 to 08/28/2020.

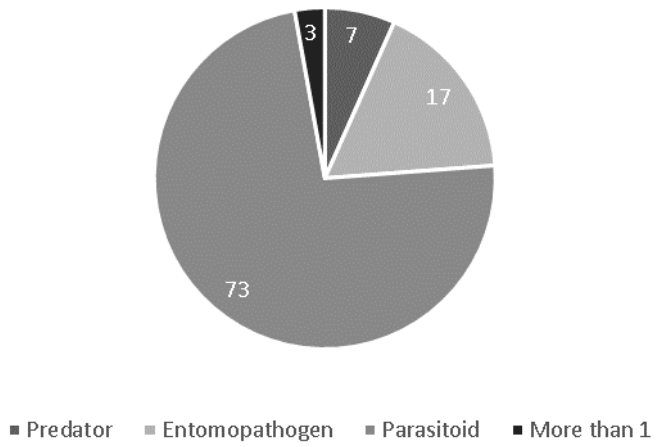
Anastrepha	n° articles	*Ceratitis*	n° articles
Anastrepha fraterculus	19	*Ceratitis capitata*	59
Anastrepha obliqua	10	*Ceratitis cosyra*	7
Anastrepha sp.	10	*Ceratitis* sp.	4
Anastrepha ludens	9	*Ceratitis rosa*	1
Anastrepha suspensa	4		
Anastrepha sororcula	2		
Anastrepha striata	1		
Anastrepha zenildae	1		

Source: Authors.

3.5. Control agents

Those articles that met the predetermined requirements, 73% were related to parasitoids, 17% entomopathogens, 7% predators, and 3% of the articles grouped more than one of these biological control classes for the fruit fly species (*Anastrepha* spp. And *Ceratitis* spp.) (Figure 5).

Figure 5. A percentage representation of the agent categories found in the research on biological control for the fruit fly species (*Anastrepha* spp. And *Ceratitis* spp.) In the period from 08/24/2020 to 08/28/2020.



Source: Authors.

A total of 58 species of biocontrol organisms were listed through this review and grouped according to their categories (Table 2). 120 studies were about parasitoids and of these, two species stand out (*Diachasmimorpha longicaudata, Doryctobracon areolatus*) comprising 38.3% of this total. Only 9 works were about predators, in entomopathogens, 18 studies of these were listed, standing out three species (*Beauveria bassiana, Wolbachia*, and *Bacillus thuringiensis*) total 33.3%.

Table 2. Number of studies referring to the biological agent categories of the research on biological control for fruit fly species (*Anastrepha* spp. And *Ceratitis* spp.) In the period from 07/24/2020 to 08/28/2020.

Parasitoids	**N° articles**	**Predators**	**N° articles**
Diachasmimorpha longicaudata	33	*Araniella cucurbitina*	1
Doryctobracon areolatus	13	*Calathus granatensis*	1
Utetes anastrephae	8	Formigas	1
Doryctobracon crawfordi	6	*Orius naivashae* (Poppius)	1
Aganaspis daci	5	*Orius thripoborus* (Hesse)	1
Aganaspis pelleranoi	5	*Phidippus audax*	1
Fopius arisanus	5	*Pterostichus globosus*	1
Doryctobracon brasiliensis	4	*Synema globosum*	1
Nysius ericae	4	*Tapinoma nigerrimum*	1
Psyttalia concolor	4	**Entomopathogens**	**N° articles**
Steinernema sp.,	4	*Beauveria bassiana*	2
Coptera haywardi	3	*Wolbachia*	2
Fopius caudatus	3	*Bacillus thuringiensis*	2
Opius bellus	3	*Beauveria bassiana*	1
Aryscapus silvestrii	1	Ceratitis capitata iflavirus 1	1
Asobara japonica	1	Ceratitis capitata iflavirus 2	1
Bacillus cereus	1	Ceratitis capitatanoravírus	1
Beauveria bassiana	1	*Fusarium sp.*	1
Diachasmimorpha kraussi	1	*Heterorhabditis bacteriophorae*	1
Ganaspis cf. brasiliensis	1	*Heterorhabditis indica*	1
Heterorhabditis bacteriophora	1	*Metarhizium*	1
Heterorhabditidae sp.	1	*Metarhizium brunneum (Petch)*	1
Leptopilina heterotoma	1	*M. guizhouense*	1

Leptopilina japonica	1	*Steinernematids*	1
Opius hirtus	1	*Steinernema feltiae*	1
Pachycrepoideus vindemmiae (Rondani)	1		
Providencia rettgeri	1		
Pseudoophonus rufipes	1		
Spalangia cameroni	1		
Spalangia gemina Boucek	1		
Spalangia impunctata Howard	1		
Spalangia leiopleura Gibson	1		
Spalangia simplex Perkins	1		
Tetrastichus giffardianus	1		

Source: Authors.

4. Discussion

4.1 Publishing years

The scientific production negative performance found in our results in recent years must be related to the number of investments and resources earmarked for this purpose, considering that one of the main setbacks of scientific production is the availability of resources for the development of research (Kang & Liu, 2021).

4.2 Geographic distribution

From the distribution, it is possible to observe that the studies concentrated on the countries that are considered centers of fruit production. In addition, other factors that may contribute to the greater number of research in these countries are climatic conditions, the availability of financial resources, and investment in research in this sector (Frighetto et al., 2019).

4.3 Research application area

The occurrence of a greater number in laboratory research is due to the ease of raising these insects under controlled conditions. In addition, there is still a need to understand the biology about the agents used for control, and from this to outline study plans in the field so that later on, their insertion in integrated pest management is facilitated (Meirelles et al., 2016). It is also worth emphasizing the importance of applying these works developed in the laboratory to be extended to the field so that the real efficiency of the results obtained when subjected to environmental conditions can be assessed (Dias et al., 2019).

4.4 fruit fly species

The largest number of studies for *A. fraterculus* is due to the fact that the species is cosmopolitan and highly polyphagous, being reported as an important fruit crop pest in several countries, with a wide distribution in the Americas (Norrbom et al., 1999). Regarding *Ceratitis capitata* this is due to the greater variety of hosts, responsible for the infestation in large varieties of vegetables and wild and cultivated nuts (Leftwich et al., 2014; Goldshtein et al., 2017).

4.5 Control agents analyzed by categories

Most studies on biological control for fruit flies, *Anastrepha* spp. and *Ceratitis* spp. genera, focused on studies with parasitoids for the effectiveness of these organisms since they present specificity to the target organism and can be released inundated (Cancino et al., 2019; Cruz et al., 2018).

Direct and indirect damage is caused by *Anastrepha* and *Ceratitis*, thus the biological control of fruit flies has great economic and environmental importance, providing increased research aimed at the use of the organisms *Diachasmimorpha*

longicaudata, Doryctobracon areolatus, Beauveria bassiana, Wolbachia, and B*acillus thuringiensis*, who are responsible for controlling this pest (Harbi et al., 2019).

5. Conclusion

Scientific production on fruit flies biological control is in decline worldwide, although Brazil outnumbers the number of articles published on biological control agents, with the majority of studies carried out under laboratory conditions. The surveyed species *A. fraterculus* and C. *capitata* are the most studied, with the parasitoids *Diachasmimorpha longicaudata* and *Doryctobracon areolatus* being the main control agents and the main species representing this class.

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