Methods for the control of whitefly (Aleyrodidae) in citrus: a systematic review

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ABSTRACT

Objective: To carry out a systematic review of original articles published from 1950 to 2021 about the methods used to control whitefly on citrus crops and the biological control organisms.

Design/Methodology/Approach: The study was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. The reference works were retrieved from electronic databases. The Mendeley Bibliography Manager was used to create a new data base which, in its turn, was used to analyze the information.

Results: Two groups were identified as control methods: 1) chemical control, and 2) biological control. The latter was used with greater frequency than the former. Several genera of the family Aphelinidae were the parasitoids most frequently used for biological control. *Aleurothrixus floccosus* was the most frequent pest in citrus orchards.

Study Limitations/Implications: The information is limited and scattered. There is no information about the efficiency of the methods.

Findings/Conclusions: The use of antagonistic organisms used as a biological control method is of utmost importance, given the impact those organisms have on pests. They make a contribution to the natural regulation of the population levels of harmful insects in citrus crops.

Keywords: Whitefly parasitoids, biological control, citrus pests.

Citation: Rodas-Martínez, C. E., Galindo-Alcántara, A., Ruiz-Acosta, S. del C., &Sánchez-Hernández, R. (2023). Methods for the control of whitefly (Aleyrodidae) in citrus: a systematic review. *Agro Productividad*. https://doi.org/10.32854/agrop.v16i9.2372

Academic Editors: Jorge Cadena Iñiguez and Lucero del Mar Ruiz Posadas

Received: September 03, 2022.
Accepted: August 17, 2023.
Published on-line: November 03, 2023.

Agro Productividad, 16(9). September. 2023. pp: 37-45.

INTRODUCTION

Citrus are one of the main crops worldwide; they are in high demand and are grown in tropical and subtropical regions, across more than 140 countries (Vu *et al.*, 2018). The main producers are Brazil, China, India, Spain, the USA, and Mexico (FAO, 2017). In 2019, 9,898,643 ha were used for the worldwide production of citrus, reaching a production of 99,410,000 t —*i.e.*, a 17.78% increase in production from 2012 to 2019 (FAOSTAT, 2022; Knoema, 2021). Nevertheless, the crop faces phytosanitary problems, as a result of pests and diseases. The following diseases have particularly devastating effects: huanglongbing

(citrus green disease), leprosis, and variegated chlorosis. They are transmitted by the Asian citrus psyllid (*Diaphorina citri*), mites from the genera *Brevipalpus* spp., and the whitefly (*Aleurothrixus floccosus*). Whiteflies include approximately 1,556 species, divided into 161 accepted genera (SENASICA, 2020).

Whiteflies cause direct and indirect damage to the plants, hindering respiration and reducing photosynthesis and nitrogen levels. Nymphs produce molasses and a waxy secretion, weaking buds, causing defoliation, and enabling the development of *negrilla* (sooty mold) and other saprophytic fungi that have a direct repercussion on citrus production per surface unit and its commercial value (Sáenz-Pérez *et al.*, 2019). Mexico is the fourth largest citrus producer in the world (Knoema, 2021) and the losses in lemon, orange, and grapefruit cultivation caused by the said pest can reach up to 40% of the total harvest (Agroasemex, 2019).

The scientific texts that discuss the methods used to control whitefly in citrus orchards are scarce and scattered. Therefore, the objective of this work was to carry out a systematic review of the said methods, along with the number of whitefly species recorded, and the organisms used for their biological control. This research was based on original articles published from 1950 to 2021. The purpose of this analysis was to group the existing information, make contributions to the subject matter, and lay the foundations for future research. As far as it can be determined, no previous systemic reviews have been carried out regarding this issue.

MATERIALS AND METHODS

Search strategy and reference management

The work complied with the conditions established by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Urrútia y Bonfill *et al.*, 2010). To guarantee its exhaustiveness, a bibliographical search was made on the Scopus y ScienceDirect electronic databases, as well as in Google Scholar, Dialnet, and SciELO (Figure 1). The starting point was the research question: What methods are used to control whiteflies in citrus? A general search route was established combining terms through Boolean operators and the time period was limited to the years 1950 to 2021.

Inclusion and exclusion criteria

The structure of the information source of the study was managed based on original articles published in Spanish or English. Only studies from the time range established

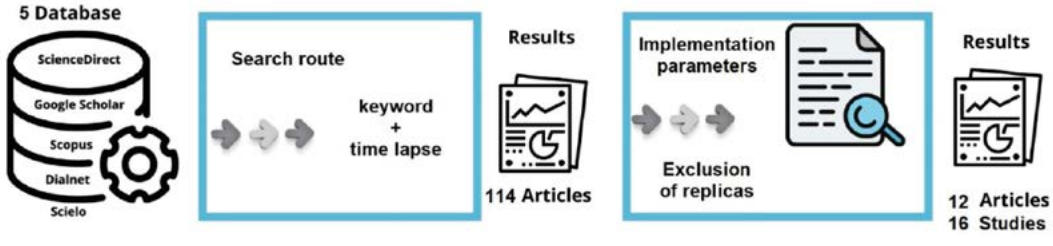

Figure 1. Methodology. Figure developed by the authors.

and which included the description of the control method, the whitefly species, and the control organisms were considered to be eligible. Duplicate articles were excluded through the Mendeley Reference Manager. An Excel database was developed and it included the information to be evaluated. Percentages were calculated and graphs and tables were developed for descriptive purposes.

RESULTS AND DISCUSSION

One-hundred-fourteen articles were published during the established time range. Having applied inclusion and exclusion criteria and eliminated duplicates, the resulting sensitivity was 12 publications, based on which 16 studies were extracted and used in the systematic review.

Spatial and Temporal Distribution of the Publications

Regarding their point of origin, 37.5% of the studies were developed in Europe, while the Americas, Africa-Asia, and Oceania accounted for 31.2%, 12.5%, and 6.5%, respectively. Most researches were carried out in Spain, the USA, and Chile (Figure 2). Regarding the publication period, over 40% of the studies were carried out from 1998 to 2002, which matches the increase in whitefly reports in citrus orchards in the early 1990s, resulting from the lack of efficiency of the usual pesticides. The *Parabemysia myricae* populations diminished in Spain from 1995, but *Dialeurodes citri*, *Aleurothrixus floccosus*, and *Trialeurodes vaporariorum* decreased slowly and their levels were still considerable in 1999 (Soto *et al*., 2001).

The introduction and establishment of *Eretmocerus debachi* in Spain's citrus zones, along with the natural control exercised by the abundant population of *Cales noacki* (a parasite of *Aleurothrixus floccosus*), drastically diminished the populations of *Parabemisia myricae*. This phenomenon could be related to the decrease in publications about the subject, since it was the only fly species that damaged citrus orchards during those periods (Soto *et al*., 1999). Santaballa *et al*. (1980) published the first study about the application of a method to control whitefly in citrus.

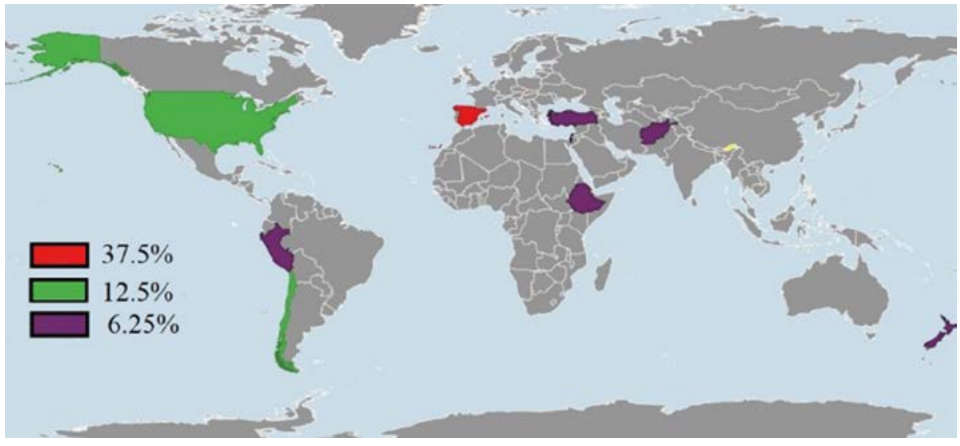

Figure 2. Spatial distribution of publications per country. Figure developed by the authors.

Objectives of the studies

One-quarter (25%) of the studies evaluated the effectiveness of insecticides —12.5% of which were contact products, while the rest were systemic or applied on the leaves. The evaluation of agrochemicals is a major element in pest control. Employing an adequate control, applying the product only where pests have been detected, using adequate doses, time, and schedule, providing a good cover technique, and rotating active ingredients with other modes of action improve the quality of the crop production, as these practices reduce sooty mold and avoid resistance or efficiency loss (Ripa *et al.*, 2006). The effectiveness of parasitoids was evaluated in 18.75% of the studies. In most cases, parasitoids were used to control whiteflies, because this "key pest" does not only colonize whiteflies on the release site; it can also scatter to up to 60 km away from the original area. Therefore, it can cover a wider area of the citrus cultivation zone, achieving a greater impact in the control of whitefly (Santaballa *et al.*, 1980). Other objectives include the evaluation of the effectiveness of predators and of the infestation degree on the whitefly stages (12.5%). The remaining studies had various objectives, represented a lower percentage, and were grouped as "others."

Identification of control methods

Two control method groups were identified: 1) chemical control and 2) biological control. The latter group was the subject of the highest percentage of reports (68.75%), revealing the interest in the use of methods with a lower environmental impact (Table 1). Biological control is a major strategy that not only helps to reduce the population density of pests, but also diminishes environmental degradation and the imbalance in the natural control of agricultural pests resulting from the use of agrochemicals (SENASICA, 2020).

The use of parasitoids is an outstanding biological control method (Table 1). These natural antagonists have a major impact on whiteflies, causing damage that conditions any intervention on the remaining pests and diseases that attack citrus (Santaballa *et al.*, 1980). Several authors have reported the suppression of whiteflies populations in citrus as a result of the introduction and release of parasitoids and their subsequent establishment and spreading (Ulusoy *et al.*, 2003). However, there are remarkable variations in the abundance indexes and the infestation rate by larvae and adults, which mainly depend on the growth of foliage and the regional meteorological conditions (Mahmoudi *et al.*, 2018). Entomopathogenic fungi were also used, despite their sensitivity to weather conditions —which impact their stability and persistence— and their slower action rate (Table 1). They are an alternative for the intensive application of agrochemicals to combat citrus pests —including the Asian citrus psyllid, the major citrus pest worldwide (Pucheta-Diaz *et al.*, 2006).

Chemical control accounted for 31.25% of the methods employed, and they were divided in insecticides and detergents (Table 1). Two sulfonate-based commercial detergents were used: SU-120 (liquid presentation) and SU-143 (powder). Overall, organic insecticides were the most frequently used chemical control method (53%, out of which organophosphates account for 40%); systemic insecticides and pyrethrum were used in a lower rate (27% and 13%, respectively), while natural control methods were the least used. Agrochemicals are

Table 1. Methods used for whitefly control.

Control	Used Method	Usage (%)
Biological	Parasitoids	43.75
	Entomopathogenic fungi	12.5
	Predators	6.25
	Plantation management	6.25
Chemical	Detergents	6.25
	Contact insecticides	25

the most efficient and quick way to control a pest. However, the constant use of insecticides made from chemical synthesis disturbs and destabilizes the agroecosystem, potentially affecting populations that act as a natural pest control (Castresana, 2016). Nevertheless, when biological control fails, a chemical intervention or using a strategy that includes chemicals is recommended (Santaballa *et al.*, 1980; Xu *et al.*, 2013).

Biological control organisms

Several genera of the family Aphelinidae were some of the parasitoids used for biological control. The two most represented genera were *Eretmocerus* (41%) and *Cales* (33%). *Cales noacki* and *Eretmocerus debachi* were the species with the highest use percentage (Table 2). Since it was introduced to citrus orchards, *Cales noacki* has controlled the nymphs of *Aleurothrixus floccosus*, significantly decreasing the application of phytosanitary treatments. This hymenopteran parasitoid was introduced in Spain in 1970, achieving a better adaptation than the two other genera of the same family that were introduced at the same time. For their part, *Cales noacki*, *Eretmocerus paulistus*, and other species had been used in Mexico and the USA before they were introduced in Spain, obtaining good results as a biological control (Myartseva *et al.*, 2017). In 25% of the analyzed sources, the genus *Encarsia* (25%) was found to be less efficient as a pest control (Foltyn and Gerling, 1985; Gerling *et al.*, 2001). The use of parasitoids is an efficient method for the control of *Aleurothrixus floccosus* in citrus; however, its action must not be disturbed by the application of incompatible phytosanitary treatments.

Beauveria bassiana was the only entomopathogenic fungi species reported. Its entomopathogenic function has been known since 1835 (Commonwealth Mycological Institute, 1979). It has been used to control members of the Aleyrodoidea superfamily,

Table 2. Employment of organisms as biological control against whitefly.

Organism	Specie	%	Organism Type	Specie	%
Parasitoid	*Cales noacki*	20	Parasitoid	*Eretmocerus* spp.	5
Parasitoid	*Eretmocerus debachi*	15	Predator	*Conwentzia psociformis*	10
Parasitoid	*Encarsia lahorensis*	5	Predator	*Coccinella seprempunctata*	5
Parasitoid	*Encarsia strenua,*	5	Predator	*Clitostethus arcuatus*	5
Parasitoid	*Encarsia lutea*	5	Predator	*Chrysoperla carnea*	5

including *Bemisia tabaci* (Genn.), *Dialeurodes citri* (Ashm.), and *Trialeurodes vaporariorum* (Westw.) (Ruiz *et al.*, 2009; Santamaría *et al.*, 1998). The most frequently used predator was *Conwentzia psociformis*, from order Neuropetara (Table 2). Predators can reduce pest populations. Nevertheless, there are used less frequently than parasitoids as an exclusive control method, because being generalists they feed on various phytophagous species in citrus, hindering an efficient control of the whitefly (García-Marí, 2012).

Whitefly species

Seventy-five percent of the studies were carried out with hybrids from the genus *Citrus*: *Citrus maxima* (31.5%), *Citrus medica* (31.2%), and *Citrus reticulata* (12.5%). Out of this total, 25% were *Citrus*×*sinensis* and a similar percentage was reported for a non-specified lemon hybrid. Five whitefly species were detected (Figure 3). *Aleurothrixus floccosus* was reported in 54.5% of the studies and in the 3 citrus species. Table 3 shows that orange was the citrus most affected by *A. floccosus*, which was found in the two reported hybrids (22.7%), mainly in *Citrus*×*sinensis*. The non-identified citrus group was affected in a similar percentage, along with the non-specified lemon hybrid, although the latter recorded a lower percentage (Table 3). In countries like Spain, *Aleurothrixus floccosus* is considered the most important fly species, because it has colonized the greatest surface and causes major health and economic problems to the citrus industry (Garrido, 1994; Xu *et al.*, 2013).

The frequency of the *A. floccosus* reports could be related to its apparent high potential in areas with favorable weather conditions, mainly where winter temperature is higher than 14 °C a condition which allows a constant oviposition throughout the period, severely damaging the harvest (Tello-Mercado and Zarzar-Maza, 2021). Weather variations in the environment favor the acclimatization of the fly to the environmental conditions of places that it had found formerly unfavorable (Beingolea, 1959).

Citrus×*sinensis* is a hybrid that is usually affected by whiteflies (including *A. floccosus*). Whiteflies feed and lay their eggs on the abaxial surface of young leaves (Giliomee and Millar, 2009; Ripa *et al.*, 2006), taking advantage of weather conditions, particularly high temperatures (Tello-Mercado and Zarzar-Maza, 2021). The molasses and wax secretion produced during the advanced nymph stages have a significant impact on the yield and quality of the product; they protect such pests as woodlouse and mites

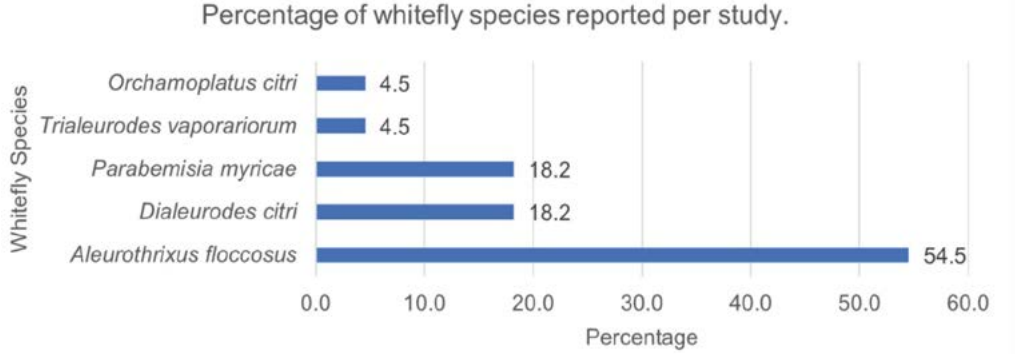

Figure 3. Whitefly species detected. Figure developed by the authors.

Table 3. Percentage of whitefly species by citrus in the studies.

Whitefly species	Plant	%
Aleurothrixus floccosus	*Citrus* spp.	18.2
Dialeurodes citri		13.6
Parabemisia myricae		13.6
Aleurothrixus floccosus	Limón N/E	9.1
Dialeurodes citri		4.5
Parabemisia myricae		4.5
Trialeurodes vaporariorum	*Citrus limon*	4.5
Orchamoplatus citri	Mandarina N/E	4.5
Aleurothrixus floccosus	*Citrus reticulata* blanco	4.5
Aleurothrixus floccosus	*Citrus sinensis*	18.2
Aleurothrixus floccosus	*Citrus aurantium* L.	4.5

against phytosanitary treatments and the action of their natural enemies, consequently encouraging their development. Molasses and wax secretion also generate diseases (*e.g.*, sooty mold), which cover the leaves and interfere with photosynthesis (Ceceña-Durán *et al.*, 2017). Other species with similar report percentages were identified, including *Dialeurodes citri* and *Parabemisia myricae* (Figure 3). They mainly affected the group made of non-identified species (Table 3). Both whitefly species were found in an expansive state in Spain in 1994; since their detection, they have become resistant to a wide range of insecticides, including organophosphates (OP) and carbamates (CBs) (Garrido, 1994; Xu *et al.*, 2013).

The three fly species with the greatest presence in this review cause major problems to citrus orchards. Severe yearly attacks by *Dialeurodes citri* can affect fruit quality, because sooty mold —which grows as a result of the molasses produced during the immature phases— indirectly influences plant vigor and, consequently, its productivity. Severe attacks by *Parabemisia myricae* do not only lead to the development of sooty mold, they also, as a consequence of the darkening of the tree, prevent an adequate photosynthesis; this phenomenon stops the growth and fruition of the tree, which has a direct influence on production (Garrido, 1994).

CONCLUSIONS

The use of antagonistic organisms to combat the various whitefly species (whether native or introduced to the environment) is a highly important matter. Given the effect they have on pests, they contribute to the natural regulation of the population levels of harmful insects in citrus orchards. This study lays the foundations for the development of new research that evaluate the effect and efficiency that beneficial organisms used as biological control methods have on the various Aleyrodidae species that affect citrus.

REFERENCES

Agroasemex, S.A. (2019). Las plagas producen pérdidas de un 40 por ciento en la producción agrícola, revela estudio de la FAO.

Beingolea, O. (1959). El problema de "la mosca blanca lanuda" de los citricos, en el Perú *Aleurothrixus floccosus* (Homop.: Aleurodidae). *Revista Peruana de Entomologia*. Vol. 2,65-68.

Ceceña-Durán, C., González-Mendoza, D., Grimaldo-Juárez, O., Ruvalcaba, S. P., Tzintzun, C. O., & Durán-Hernández, D. (2017). Eficacia de entomopatógenos en el control de mosca blanca (*Bemisia argentifolli*, Bellows y Perring), en algonodero en el DDR 014. *OmminiaSciencie*. 1-68. DOI: https://doi.org/10.3926/oms.366

FAOSTAT (Organización de las Naciones Unidas para la alimentación y la Agricultura) (2022). Escenario actual de la producción citrícola en México.

Foltyn, S., & Gerling, D. (1985). The parasitoids of the aleyrodid *Bemisia tabaci* in Israel: development, host preference and discrimination of the aphelinid wasp Eretmocerus mundus. *Entomologia Experimentalis et Applicata, 38*(3), 255-260.

García-Marí, F. (2012). Plaga de los cítricos: Gestión integrada en países de clima mediterraneo. *Phytoma*.

Garrido, V.A. (1994). Problemas actuales de las moscas blancas en el cultivo de los cítricos (I). *Revista PHYTOMA España*. Vol. 58,48-54.

Gerling, D.; Alomar, O.; Arno, J. 2001. Biological control of *Bemisia tabaci* using predators and parasitoids. *Crop Protection 20*(9): 779-799.

Giliomee, J.H., & Millar, I.M. (2009). The wolly whitefly, *Aleurothrixus floccosus* (Maskell) (Hemiptera: Aleyrodidae), a potentially serious citri pest, recorded from south Africa. *Revista Entomología africana*. 17, 232-233. DOI: http://dx.doi.org/10.4001/003.017.0216

Knoema, E. (2021). World Data Atlas. Producción de cítricos en toneladas. https://knoema.es/atlas/topics/Agricultura/Producci%c3%b3n-de-Cultivos-Cantidad-toneladas/C%c3%adtrico

Mahmoudi, A., Allal, B.L., Yigit, A., & Goosen, M.F. (2018). An assessment of population fluctuations of citrus pest wolly whitefly *Aleurothrixus floccosus* (Maskell, 1896) (Homoptera, Aleyrodidae) and its parasitoid *Cales noacki* Howard, 1907 (Hymenoptera, Aphelinidae): A case study from Northwestern Algeria. *Acta agriculturae Slovenica*. 111, 407-417. DOI:10.14720/aas.2018.111.2.15

Myartseva, S. N., Ruíz-Cancino, E., & Coronado-Blanco, J. M. (2017). Aphelinidae (Hymenoptera) parasitoides de los principales hemípteros plaga (Hemiptera: Aleyrodoidea: Coccoidea) de los cítricos en México. *Folia Entomológica Mexicana (nueva serie), 3*(2), 32-41.

Pucheta-Diaz, M., Flores-Macias, A., Rodriguez, Navarro, S., & De la Torre, MM. (2006). Mecanismo de acción de los hongos entomopatogenos. *Interciencia*.

Ripa, S.R., Rodríguez, A.F., Larral, D.P., & Luck, R.F. (2006). Evaluación de un detergente en bases a benceno sulfonato de sodio para el control de la mosquita blanca *Aleuthrixus floccosus* (Maskell) (Hemiptera: Aleyrodidae) y de la arañita roja *Panonychus citri* (McGregor) (Acarina: Tetranychidae) en naranjos y mandarinos. *Revista de agricultura técnica (Chile).* 66, 115-123.

Ruiz, E., Rosado, A., Chan, W., Cristobal, J., & Munguia, R. (2009). Patogenicidad de *Beauveria bassiana* (Bals.) Vuillemin sobre estados inmaduros de mosquita blanca (*Bemisia tabaci* Genn). *Fitosanidad*. 13, 89-93.

Santaballa, E., Borras, C., & Colomer, P. (1980). Lucha contra la mosca blanca de los cítricos *Aleurothrixus floccosus* Mask. *Bol. Serv. Plagas*. 6, 109-118.

Santamaría, A., Costa-Comelles, J., Alonso, A., M. Rodríguez, J., & Ferrer, J. (1998). Ensayo del hongo entomopatógeno *Beauveria bassiana* (Balsamo) Vuillemin para el control de la mosca blanca de los cítricos *Aleurothrixus floccosus* (Maskell) (Homoptera: Aleyrodidae) y su acción sobre el parásito *Cales noacki* (howard) (Hymenoptera: Aphelinidae). *Bol. San. Veg. Plagas*. 24, 695-706.

SENASICA (Servicio Nacional de Sanidad Inocuidad y Calidad Agroalimentaria) (2020). Plagas reglamentadas de los cítricos. https://www.gob.mx/senasica/documentos/plagas-reglamentadas-de-los-citricos-110863

Soto, A., Ohlenschlager, F., & García-Marí, F. (2001). Dinámica poblacional y control biológico de las moscas blancas *Aleurothrixus floccosus*, *Dialeurodes citri* y *Parabemisia myricae* (Homoptera: Aleyrodidae) en los cítricos valencianos. *Boletín de Sanidad Vegetal. Plagas, 27*(1), 3-20.

Soto, A., Ohlenschläger, F., & García-Marí, F. (1999). Situación del control biológico de las moscas blancas de cítricos *Aleurothrixus floccosus*, *Parabemisia myricae* y *Dialeurodes citri* en la comunidad valenciana. *Revista Levante agrícola*. 475-484.

Tello-Mercado, V., & Zarzar-Maza, M. (2021). Fluctuación poblacional y parasitismo de *Aleurothrixus floccosus* (Hemiptera: Aleyrodidae) en cítricos del Desierto de Atacama, Chile. *Revista Colombiana de Entomología*. Vol. 47,1-10. https://doi.org/10.25100/socolen.v47.i1.7806

Ulusoy, M.R., Vatansever, G., Errilic, L., & Uygun, N. (2003). Studieson *Aleurothrixus floccosus* (Maskell) (Homoptera, Aleyrodidae) and parasitoid, *Cales noacki* Howard (Hymenoptera, Aphelinidae) in the East Mediteranean Region of Turkey. *Journal of pest science*. 76, 163-169. https://doi.org/10.1007/s10340-003-0014-5

Vu, X.T., Ngo, T.T., Mai, D.L.T., Bui, T.T., Le, D.H., Bui, V., Nguyen, Q.H., Ngo, Xuan, B., & Tran, V.T. (2018). A Highly efficient Agrobacterium tumefaciens-mediated transformation system for the postharvest pathogen penicillium digitatum using DsRed and GFP to visualize citrus host colonization. *Journal of microbiological methods*. 144, 134-144. https://doi.org/10.1016/j.mimet.2017.11.019.

Xu, Q.U.I., Chai, F., An, X., & Han, S. (2013). Optimization of bioassay method for specific activity of acetylcholinesterase of B Biotype *Bemisia tabaci* (Hemiptera: Aleyrodidae). *Magazine Florida Entomologist*. 96, 160-165. https://www. jstor.org/estable/23608886