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Fruit fly management research: A systematic review of monitoring and control tactics in the world

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ABSTRACT

Several fruit fly species are invasive pests that damage quality fruits in horticultural crops and cause significant value losses. The management of fruit flies is challenging due to their biology, adaptation to various regions and wide range of hosts. We assessed the historical and current approaches of fruit fly management research worldwide, and we established the current knowledge of fruit flies by systematically reviewing research on monitoring and control tactics, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. We performed a systematic review of research outputs from 1952 to 2017, by developing an a priori defined set of criteria for subsequent replication of the review process. This review showed 4900 publications, of which 533 publications matched the criteria. The selected research studies were conducted in 41 countries for 43 fruit fly species of economic importance. Although 46% of the studies were from countries of North America, analysis of the control tactics and studied species showed a wide geographical distribution. Biological control was the most commonly studied control tactic (29%), followed by chemical control (20%), behavioral control, including SIT (18%), and quarantine treatments (17%). Studies on fruit flies continue to be published and provide useful knowledge in the areas of monitoring and control tactics. The limitations and prospects for fruit fly management were analyzed, and we highlight recommendations that will improve future studies.

1. Introduction

Horticultural crops constitute a significant segment of the global agricultural production. The importance of horticulture can be substantiated by its high export value, high yield and returns per unit area (Ravichandra, 2014). Several species of fruit flies (Diptera: Tephritidae) are invasive pests of horticultural crops worldwide, due to their adaptation to various regions, high polyphagia and rapid reproduction (Sarwar, 2015).

Fruit flies cause direct damage to fruits and vegetables by the puncture for oviposition by the female and the larval development inside the fruit (Aluja, 1994). These pests cause direct damage to important export crops leading to losses of 40% up to 80%, depending on locality, variety and season (Kibira et al., 2010). The presence of these pest species limits access to international markets due to quarantine restrictions imposed by importing countries (Lanzavecchia et al., 2014).

Few insects have greater impact on the international marketing of horticultural produce than tephritid fruit flies (Hendrichs, 1996). Countries that harbor these important pests spend millions of dollars each year on control and have trade sanctions imposed by rigorous treatments of products prior to export. Such treatments are effective, but the volume of imported horticultural produce into countries free of these pests raises biosecurity concerns (Dhami et al., 2016). To remain free of fruit flies, New Zealand, for example, spends approximately NZ $1.4 million each year in post-border surveillance alone (Dhami et al., 2016). However, in fruit fly-free countries, such as Chile, this status contributes to the export of up to 50% of fruit production (Retamales and Sepúlveda, 2011).

The management of fruit flies is challenging because third-instar larvae leave decaying fruits and drop to the ground to pupate in the soil; consequently, both larvae and pupae in fruits and soils are protected from surface-applied insecticides (Heve et al., 2016). The control

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of fruit flies is becoming increasingly difficult in many countries, as formerly effective broad-spectrum and systemic-acting insecticides are removed from the market (Böckmann et al., 2014).

Due to progressively more stringent restrictions on the use of insecticides and the increasing demand for healthy food around the world, new environmentally friendly techniques for fruit fly control are arising (Navarro-Llopis et al., 2011). In addition, given the dependence of fruit fly distribution and abundance on climate variables, there are also concerns about the intensification of the climate changes that will facilitate the occurrence of more frequent outbreaks in horticultural regions (Sultana et al., 2017).

In fruit fly management, more than one tactic is frequently required. Each of these tactics has different advantages and disadvantages, and its adoption may or not be available for every case (Suckling et al., 2016). For example, the Male Annihilation Technique (MAT) is applied for some *Bactrocera* species but not for other species, owing to the lack of suitable lures. Additionally, the Sterile Insect Technique (SIT) requires the mass rearing of the target pest and geographic isolation of the release zone (Suckling et al., 2016).

Therefore, it is important to examine the current and historical approaches to fruit fly management research worldwide to enable researchers to evaluate the effectiveness of current research approaches and, if needed, develop more appropriate research protocols. The objective of the present study was to establish the current knowledge on fruit fly management by systematically reviewing research on monitoring and control tactics used for local and regional management of these pests. There is one overarching research question in the present systematic review that can be divided into a series of more focused questions: How has monitoring and control tactics research been conducted worldwide?

- What fruit fly control tactics have been/were studied?
- What methodological approaches were examined?
- What fruit fly species were targeted?
- What localities were studied?
- What are the challenges for fruit fly management?
- What are the prospects for fruit fly management?
- What are the potential knowledge gaps in fruit fly research?

2. Material and methods

2.1. Database sources

We used Web of Science Core Collection, Science Direct, PubMed and Scopus to generate a database of publications that assess fruit fly monitoring and control tactics efforts in a pest management context. The search was limited to these four databases because they contained research articles that were available in full text and had undergone peer-review by scientists. The search was limited to publications written in English, Spanish and Portuguese published in journals from 1952 to 2017.

2.2. Search term

We divided fruit fly monitoring and control tactics into nine categories: 1) monitoring and detection; 2) control with natural product insecticides; 3) bioinsecticides; 4) chemical control; 5) biological control; 6) behavioral control; 7) mechanical control; 8) quarantine; and 9) genetic control. The description of each category is shown in Supplementary information (Supplementary Material 1). We used the following search terms: (“fruit fly” AND “monitoring”), (“fruit fly” AND “natural products”), (“fruit fly” AND “bait”), (“fruit fly” AND “insecticide control”), (“fruit fly” AND “biological control”), (“fruit fly” AND “sterile insect technique”), (“fruit fly” AND “male annihilation technique”), (“fruit fly” AND “mass-trapping”), (“fruit fly” AND “quarantine control”), (“fruit fly” AND “irradiation”) and (“fruit fly” AND “RNAi”).

2.3. Article screening

The search generated 4900 records (last access date: 13 December 2017), and the results were imported into a library of Mendeley Reference Manager. We removed duplicates, reviews, conference proceedings, editorial material and book chapters. The remaining records were retrieved in full text and inspected in detail. For study inclusion, three criteria were determined: 1) studies with Tephritidae fruit fly species; 2) fruit fly monitoring studies (excluding faunal analysis studies), and 3) studies that used one or more tactics for fruit fly control and assessed effects on biology, physiology and/or behavior (excluding studies of rearing techniques).

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Moher et al., 2009) (PRISMA statement and Checklist) guidelines in including or excluding publications during screening stages. A checklist of the systematic review is shown in Supplementary Material 2.

2.4. Data extraction

For each publication, we collected the full reference and extracted information on the monitoring and control tactics used, the fruit fly species studied, the methodological approach used and the country where the study was performed. Studies that included the species *Bactrocera invadens* (Drew, Tsuruta and White), *Bactrocera papayae* (Drew and Hancock) and *Bactrocera philippinensis* (Drew and Hancock) were added to studies of *Bactrocera dorsalis* (Hendel), the current synonymized species (Hendrichs et al., 2015; Schutze et al., 2015). The methodological approaches used in each study were categorized into laboratory, semifield, field or combined approaches. The combined approach used more than one methodology (e.g., field and laboratory). For studies lacking information on where the research was performed, we used the location of the first author's institution.

2.5. Data analysis

The extracted data were subjected to descriptive analysis (proc UNIVARIATE) and principal component analysis (PCA) (proc PRINCOMP). The PCA was performed to examine any intrinsic variation in the fruit fly studies and whether any clustering was presented. The PCA was performed on the countries (41 variables), species (43 variables), methodological approaches (4 variables) and monitoring and control methods (9 variables) extracted from the studies dataset (Supplementary Material 3). The data for each category were transformed by standardized Euclidean distance analysis prior to PCA, to stabilize the variance of the measured variables and thus give the variables approximately equal weight in the PCA. The statistical analysis was performed using SAS (version 9.0, SAS Institute Inc., Cary, NC, USA) and the results were fitted using Sigma Plot®.

3. Results

A total of 533 publications matched the criteria and were included in the analysis. Full references for all publications and extracted data are presented in Supplementary Material 3. Fig. 1 shows the flow diagram for the systematic review.

3.1. Publication years

A significant increase in the number of published studies has been observed since the 1990s (Fig. 2). However, more than half of the studies were published within the last seven years (n = 290 studies), demonstrating a rapid expansion of fruit fly research since 2010.