Chapter 9

A focus on Morocco's sterile insect technique initiative

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9.1 INTRODUCTION

In Morocco, the citrus industry is an important component of the national agricultural sector. It contributes to the value added of the agricultural sector with a value of 489 million US dollars. Citrus production occupies a total area of 105,000 ha, with the Sous-Massa region being the most important production area accounting for 32% of the total area, followed by Rabat-Sale-Kenitra accounting for 20% (MMAFRDWF 2023).

In addition to water scarcity, one of the main challenges in Morocco, the citrus industry must face pest management requirements, due to the high-quality standards demanded by the market, and in some cases quarantine restriction. Many key citrus pests are present in Morocco such as *Ceratitis capitata* (Wiedemann), *Aonidiella aurantii* Maskell, *Panonychus citri* McGregor, and *Phyllocnistis citrella* Stainton. However, *C. capitata* is the most damaging pest with both direct and indirect economic impacts and is regarded as a critical threat to fruit production, diversification, and export (Mazih 2015; Elaini and Mazih 2018; Assouguem et al. 2021).

9.2 MEDFLY STATUS IN MOROCCO

The Mediterranean fruit fly (Medfly) (*C. capitata*) is the primary tephritid pest in Morocco, remaining present year-round. Its spatiotemporal occurrence and phenology are determined by suitable environmental conditions, host plants, and fruit availability (Elaini and Mazih 2018). Medflies are active nearly all year, completing up to ten generations annually if host fruits are available. With increasing global temperatures, the species may soon expand its host range and infestation period to spring, early summer, and even winter (Boulahia-Kheder 2021). Medfly populations in Morocco display substantial genetic diversity, particularly at higher altitudes, with marked differentiation between populations (Alaoui et al. 2010). Besides citrus, other fruit crops such as pears, apples, peaches, nectarines, plums, and pomegranates are notably impacted by Medflies, especially in Northern Morocco (Elaini and Mazih 2018). In the Souss valley within the Sous-Massa region of Central Morocco, a major citrus production area, citrus orchards are adjacent to Argan forests (*Argania spinosa*), which serve as significant reservoirs for Medfly individuals (Sacantanis 1957). Infestation rates in Argan fruits vary seasonally, remaining low from February to May but rising sharply in June and July, with ripe fruits being most vulnerable (Mazih and Debouzie 1996). Additionally,

DOI: 10.1201/9781003644330-12

while *Opuntia ficus-indica* was once a potential reservoir, its density in Morocco has drastically declined due to infestations by *Dactylopius opuntiae* (El Aalaoui et al. 2019).

In Morocco, citrus is one of the crops most severely affected by Medfly-related losses. Despite extensive efforts to control the Medfly population, this pest remains a significant threat to the national citrus industry, impacting both exports and production (Boulahia-Kheder 2021). Farmers must closely monitor Medfly prevalence during fruit maturation phases and may need to apply multiple pesticide treatments to manage the pest. However, even with these control measures, fruit infestation levels can still average between 10% and 20%, sometimes reaching even higher levels (Elaini and Mazih 2018). In the Berkane region (northeast Morocco), notably high infestation rates have been recorded resulting in a temporary ban on the commercialization of certain products, including clementines, tangerines, mandarins, and sweet oranges produced or shipped from this area (APHIS 2016).

9.3 CONVENTIONAL PEST CONTROL METHODS

Chemical control is the most widely employed method against Medflies and other pests (Assouguem et al. 2021). Typically, treatments involve full-cover spraying with various broad-spectrum pesticides, which are highly detrimental to natural pest enemies, including beneficial insects, birds, and bats (Berni et al. 2021). Alternatively, foliar spot spray using hydrolyzed protein baits, applied to one row out of every three or four, constitute the other primary chemical application method currently in use (Elaini and Mazih 2018).

Adult Medfly prevalence and fruit infestation levels determine the timing and frequency of chemical sprays. The trigger threshold for initiating spraying is 3–5 adult males per trap per day from a trapping grid network of 50–100 traps/km^2. However, in smaller farms, sprays are typically applied every 8–10 days during late summer and autumn for early citrus varieties and from the end of winter to spring for late varieties, depending on the region (Mazih 2015). To meet the requirements of certain international markets, such as the Russian market, some farmers lower the chemical spray threshold to 1 male or 0.5 female per trap per day (Assouguem et al. 2021).

As farmers prioritize economic benefits over health and environmental considerations, chemical pesticide treatments remain the most common control method. However, there are growing concerns about pesticide residues and their impact on human health and the environment (Aberkani et al. 2022; Khfif et al. 2022). Furthermore, exceeding the maximum residue limits would impede adherence to international standards for Moroccan citrus exports (Addi et al. 2013; Choubbane et al. 2022).

In this context, the demand for biopesticides has increased as a safer alternative to hazardous chemical pesticides. Consequently, biopesticides such as *Beauveria bassiana*, Azadirachtin, and Spinosad have been approved for use (Mokrini et al. 2020). In particular, Spinosad-based products have become more preferred for chemical treatments, especially during the harvest period, due to their short environmental persistence and a preharvest interval of just one day (Elaini and Mazih 2018).

Increasingly, more environmentally friendly approaches are being adopted within the framework of integrated pest management, such as mass trapping. This method relies on a highly selective and potent combination of three chemical compounds (putrescine, trimethylamine, and ammonium acetate) designed to attract female Medflies (Bakri et al. 1998; Epsky et al. 1999; Assouguem et al. 2021).

9.4 STERILE INSECT TECHNIQUE

Based on the previously cited problems with conventional control methods of the Medfly, it becomes imperative to employ a control strategy that not only effectively manages the target pest population but also minimizes its environmental impact. The sterile insect technique (SIT) emerges as a highly promising method capable of satisfying these criteria adeptly. SIT is based on mass production, reproductive sterilization using ionizing radiation, and the release of the target sterile insect into infested areas. Within these environments, sterile males mate with wild females, resulting in the inability to produce viable offspring and consequently lowering pest populations (Knipling 1955; Dyck et al. 2021).

Globally, this technique is employed for containing, excluding, suppressing, and eradicating a significant variety of pests, including various species of flies, mosquitoes, moths, and beetles (Vreysen et al. 2006; Bakri et al. 2021; Bourtzis and Vreysen 2021). Its extensive use is due to several advantages it offers. It is species-specific, targeting only the intended pest species without affecting the population of nontarget insects. In addition, it preserves the genetic integrity of the target species by not introducing foreign genetic material into the population. Moreover, the method minimizes the reliance on hazardous chemicals, thereby mitigating potential environmental and health risks associated with their use. Furthermore, this technique is compatible with other control measures, such as the bait application technique and augmentative biological control (Knipling 1955; Nagel and Peveling 2005; Toledo et al. 2017; Montoya et al. 2020).

SIT programs have been implemented in several countries (Figure 9.1) in North, Central, and South America, Europe, the Middle East, Asia, Africa, and Australia (Enkerlin 2005) and have become an essential measure to control the Medfly population worldwide. Currently, the different fruit fly factories are weekly producing several

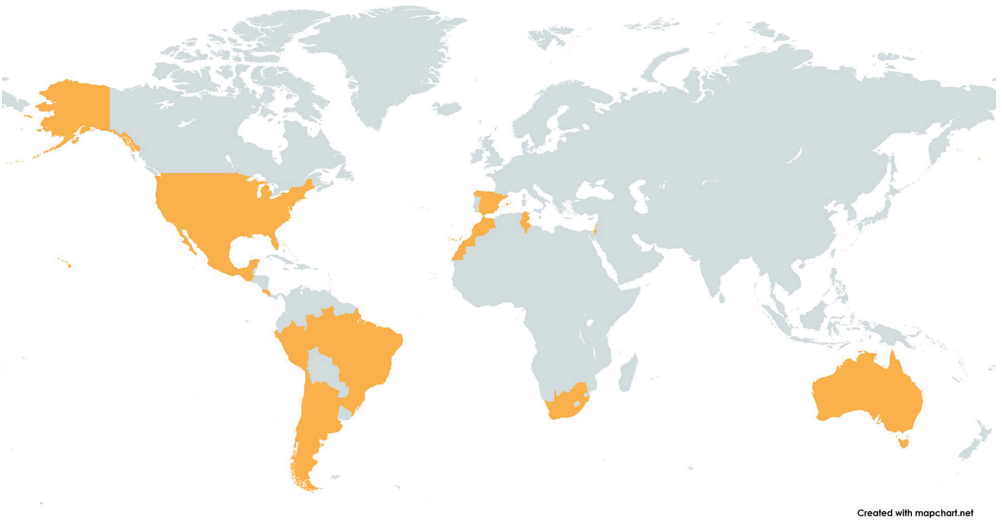

Figure 9.1 Medfly SIT units in the world based on Bakri et al. (2022). Countries having units mass-rearing sterile Medflies are shown on the map (dark grey).

billion sterile Medfly males that are released in the field to mate with wild females (Llopis-Giménez et al. 2017; Bakri et al. 2020, 2022).

SIT, incorporated in an area-wide integrated pest management approach, has been a successful Medfly control strategy in many countries around the world. For example, in Mexico, this strategy has helped maintain a pest-free status for over 30 years and proved to be highly cost-effective (Enkerlin et al. 2015). Also, Spain's Valencian Community implemented an area-wide integrated pest management program in 2007, with SIT as the main control method, resulting in a 90% reduction in aerial insecticide use (Plá et al. 2021). Also, Argentina successfully applied an integrated area-wide SIT program against Medflies in the Patagonia and Cuyo regions. This achievement redefined the phytosanitary status of these regions, enabling exports to previously closed markets without the need for postharvest treatments (Guillén and Sánchez 2007). Additionally in Peru, the released Medflies in the Santa Anita district and along the coastal areas led to the eradication of Medflies in the Tacna and Moquegua regions (Pérez-Staples et al. 2021). Similarly, in Chile, the continued releases of sterile Medflies prevented outbreaks in northern Chile (Arica province) and southern Peru (Tacna Valley) (Gonzalez and Troncoso 2007).

9.5 SIT IMPLEMENTATION IN MOROCCO

The first implementation of SIT in Morocco began in 2006, with imported sterile males released in the pilot area of 4,864 ha of citrus orchards with a 1 km buffer zone around this area within the Ouled-Berhil commune in the Souss-Massa region. The releases were at a density of 2,000 sterile males per hectare and managed by ALBRA (Association de Lutte Biologique Contre les Ravageurs des Agrumes et Primeurs). After three years of releases, despite favorable environmental conditions for Medflies between 2010 and 2011, the abundance of female Medflies in the examined zone declined compared to previously recorded levels. Consequently, chemical sprays were reduced by 25%–75% in conjunction with this approach (ALBRA 2015).

Another pilot area in the Moulouya perimeter in northeastern Morocco underwent sterile male releases in 2017 to test the effectiveness of SIT combined with trapping in an area of 1,200 ha of citrus orchards. The results confirmed its effectiveness, showing a reduction in citrus infestation rates from 5% in areas with no sterile male release to 2.4% and 1.6% in fields where sterile males were released at densities of 1,000 and 3,000 males per hectare, respectively (Yazid et al. 2020).

Recognizing the many advantages of SIT as an effective method of Medfly control, the Moroccan Ministry of Agriculture, Fisheries, Rural Development, Water and Forests (MMAFRDWF) decided to establish a Medfly mass-rearing facility to meet national needs of sterile males. The application of this technique on a national scale will benefit the citrus sector by improving fruit quality, decreasing pesticide use, protecting the environment and the consumers, and preserving the current export markets and exploration of other potential international markets. In collaboration with the International Atomic Energy Agency (IAEA), the unit was established in 2020 with a budget exceeding six million dollars. Partial equipment was sourced from the previous unit in the Madeira Islands, while the remaining materials were supplied by the National Office of Food Safety (ONSSA) with support from the IAEA.

The facility, located on an 8,340 m² site in the municipality of Tikiouine, prefecture of Agadir Ida-Outanane, includes several buildings for administration, mass rearing,

filter and quality control, sterile adult emergence, and an area for future production capacity extension (Figure 9.2a and b). The unit was built to have an estimated production capacity of 130 million pupae per week, making it the largest SIT Medfly production facility in Africa.

Currently, the facility is utilizing the Vienna-8 FDF strain (Porras et al. 2020) and has recently been equipped with a Cobalt-60 irradiator model Foss-812 (Figure 9.2c). The planned radio-sterilization dose is set at 100 Gy. The facility's infrastructure is sufficient to provide sterile males to cover the entire Souss area, encompassing approximately 40,000 hectares of citrus-producing zones and neighboring regions. The ultimate goal is to implement the SIT as a nationwide program, covering all citrus-producing areas in the country.

Currently, the infestation rate of the Medfly in citrus orchards is being assessed in the Souss Valley, particularly in the Ouled-Aissa area, which spans approximately 6,000 hectares of citrus orchards. Using GIS software, the area was delineated and divided into equal sections of roughly 100 hectares each (Figure 9.3). Then, in each section

Figure 9.2 SIT facility in Agadir: (a) 3D plan of the unit, (b) photo inside the unit, (c) Co60 irradiator model Foss-812.

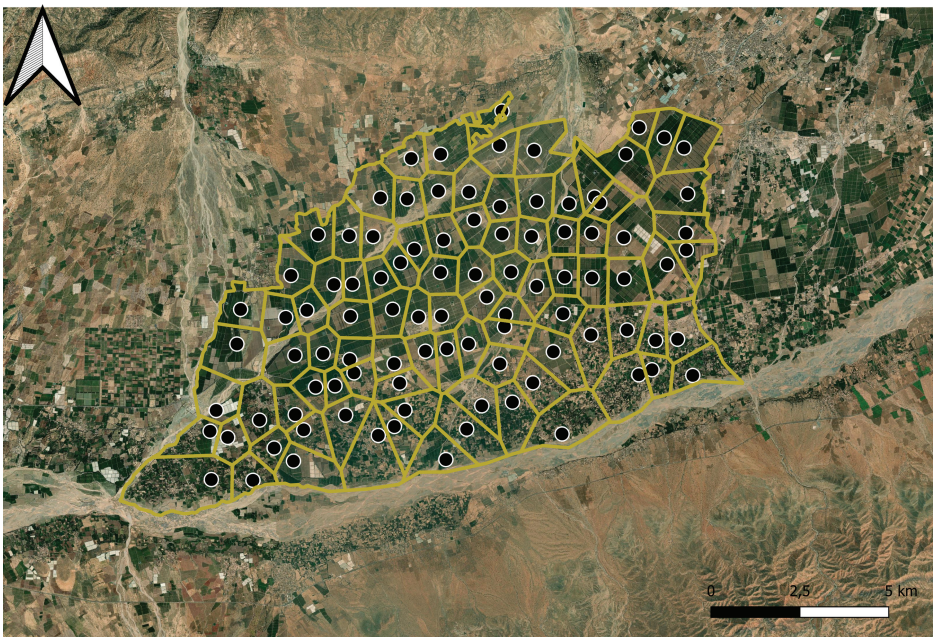

Figure 9.3 Trap positions in the monitoring area.

were placed Net-traps baited with a food attractant dispenser composed of a mixture of three components: ammonium acetate, trimethylamine, and diaminopentane. The trap's transparent lid was impregnated with deltamethrin insecticide on the inner surface. Data were recorded every 14 days since December 2023. This monitoring program aims to understand the population dynamics within the area, to help with a better optimization of sterile male releases in the future.

9.6 CONCLUSION

It is anticipated that the implementation of SIT will significantly reduce economic losses caused by the Medfly, thereby mitigating one of the major threats to the citrus industry in Morocco. By lowering the pest population through environmentally friendly and species-specific methods, SIT will reduce reliance on chemical pesticides, leading to healthier ecosystems and safer agricultural practices.

REFERENCES

Aberkani, K., F. Z. Briache, H. Ghazal, et al. 2022. Knowledge about pesticides use and consumption of fruit and legumes in growers and consumers in the Province of Nador, Morocco. Results from a survey study. *Revista Española de Nutrición Humana y Dietética* 26(4):268–276. DOI:10.14306/renhyd.26.4.1708

Addi, E. H., A. A. Addi, and F. Achemchem. 2013. Evaluation of four pesticides residues contents in the citrus fruits from Souss-Massa area (Morocco). *Environmental Engineering and Management Journal* 13:663–667. DOI: 10.30638/eemj.2014.070

Alaoui, A., A. Imoulan, Z. El-Alaoui-Talibi, et al. 2010. Genetic structure of Mediterranean fruit fly (*Ceratitis capitata*) populations from Moroccan endemic forest of *Argania spinosa*. *International Journal of Agriculture and Biology* 12:291–298.

ALBRA. 2015. Projet pilote d'introduction de la technique des insectes steriles (tis) contre la ceratite dans la plaine du souss, 78. Agadir: ALBRA.

APHIS. 2016. APHIS prohibits the importation of certain citrus fruits from Morocco due to Mediterranean fruit fly (*Ceratitis capitata*). https://www.aphis.usda.gov/import_export/plants/plant_imports/federal_order/downloads/2016/2016-10.pdf.

Assouguem, A., M. Kara, S. Benmessaoud, et al. 2021. *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) in Moroccan Citrus orchards: Chemical and sustainable control methods and priorities for future research. *Tropical Journal of Natural Product Research* 5:1703–1708.

Bakri, A., W. Enkerlin, R. Pereira, et al. 2020. Tephritid-related databases: TWD, IDIDAS, IDCT, DIR-SIT. In Area-Wide Management of Fruit Fly Pests, ed. D. Pérez-Staples, F. Díaz-Fleischer, P. Montoya, and M. T. Vera, 369–385. Boca Raton: CRC Press.

Bakri, A., H. Hadis, N. D. Epsky, R. R. Heath, and J. Hendrichs. 1998. Female *Ceratitis capitata* (Diptera: Tephritidae) capture in a dry trap baited with food-based synthetic attractant in an argan forest in Morocco. Part I: Low population field test. *The Canadian Entomologist* 130(3):349–356. DOI:10.4039/Ent130349-3

Bakri, A., K. Mehta, and D. R. Lance. 2021. Sterilizing insects with ionizing radiation. In *Sterile Insect Technique: Principles and Practice in Area-Wide Integrated Pest Management*, ed. V. A. Dyck, J. Hendrichs, and A. S. Robinson, 355–398. Boca Raton: CRC Press.

Bakri, A., R. Pereira, W. Enkerlin, et al. 2022. Status of the tephritid fruit fly production worldwide for the sterile insect technique application. The 11th ISFFEI, 13–18 November 2022, Sydney, Australia.

Berni, I., A. Menouni, I. G. El, et al. 2021. Understanding farmers' safety behavior regarding pesticide use in Morocco. *Sustainable Production and Consumption* 25(1):471–483. DOI:10.1016/j.spc.2020.11.019

Boulahia-Kheder, S. 2021. Review on major fruit flies (Diptera: Tephritidae) in North Africa: Bio-ecological traits and future trends. *Crop Protection* 140:105416. DOI:10.1016/j.cropro.2020.105416

Bourtzis, K., and M. J. Vreysen. 2021. Sterile insect technique (SIT) and its applications. *Insects* 12(7):638. DOI:10.3390/insects12070638

Choubbane, H., A. Ouakhssase, A. Chahid, et al. 2022. Pesticides in fruits and vegetables from the Souss Massa region, Morocco. *Food Additives & Contaminants* 15:79–88. DOI:10.1080/19393210.2022.2028196

Dyck, V. A., J. Hendrichs, and A. S. Robinson. 2021. *Sterile Insect Technique: Principles and Practice in Area-Wide Integrated Pest Management*. Boca Raton: CRC Press/Taylor & Francis. DOI:10.1201/9781003035572

El Aalaoui, M., R. Bouharroud, M. Sbaghi, et al. 2019. Predatory potential of eleven native Moroccan adult ladybird species on different stages of *Dactylopius opuntiae* (Cockerell) (Hemiptera: Dactylopiidae). *EPPO Bulletin* 49:374–379. DOI:10.1111/epp.12565

Elaini, R., and A. Mazih. 2018. Current status and future prospects of *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) control in Morocco. *Journal of Entomology* 15:47–55. DOI:10.3923/je.2018.47.55

Enkerlin, W. R. 2005. Impact of fruit fly control programmes using the sterile insect technique. In *Sterile Insect Technique: Principles and Practice in Area-Wide Integrated Pest Management*, ed. V. A. Dyck, J. Hendrichs, and A. S. Robinson, 651–676. Dordrecht: Springer Netherlands. DOI:0.1201/9781003035572-30

Enkerlin, W., J. M. Gutiérrez-Ruelas, A. V. Cortes, et al. 2015. Area freedom in Mexico from Mediterranean fruit fly (Diptera: Tephritidae): A review of over 30 years of a successful containment program using an integrated area-wide SIT approach. *Florida Entomologist* 98(2):665–681. DOI:10.1653/024.098.0242

Epsky, N. D., J. Hendrichs, B. I. Katsoyannos, et al. 1999. Field evaluation of female-targeted trapping systems for *Ceratitis capitata* (Diptera: Tephritidae) in seven countries. *Journal of Economic Entomology* 92(1): 156–164. DOI:10.1093/jee/92.1.156

Gonzalez, J., and P. Troncoso. 2007. The fruit fly exclusion programme in Chile. In *Area-Wide Control of Insect Pests: From Research to Field Implementation*, ed. M. J. B. Vreysen, A. S. Robinson, and J. Hendrichs, 641–651. Dordrecht: Springer Netherlands. DOI:10.1007/978-1-4020-6059-5_59

Guillén, D., and R. Sánchez. 2007. Expansion of the national fruit fly control programme in Argentina. In Area-Wide Control of Insect Pests: From Research to Field Implementation, ed. M. J. B. Vreysen, A. S. Robinson, and J. Hendrichs, 653–660. Dordrecht: Springer Netherlands. DOI:10.1007/978-1-4020-6059-5_60

Khfif, K., J. Benyazid, R. Bouharroud, et al. 2022. Study of the control methods practiced against the Mediterranean fruit fly (*Ceratitis capitata* Wiedemann, 1824) in citrus orchards of the Moulouya region. *AFRIMED AJ –Al Awamia* 135:192–207. DOI: 10.34874/IMIST.PRSM/afrimed-i135.33456

Knipling, E. F. 1955. Possibilities of insect control or eradication through the use of sexually sterile males. *Journal of Economic Entomology* 48:459–462. DOI:10.1093/jee/48.4.459

Llopis-Giménez, A., R. M. González, A. Millán-Leiva, et al. 2017. Novel RNA viruses producing simultaneous covert infections in *Ceratitis capitata*. Correlations between viral titers and host fitness, and implications for SIT programs. *Journal of Invertebrate Pathology* 143:50–60. DOI:10.1016/j.jip.2016.11.014

Mazih, A. 2015. Status of citrus IPM in the Southern Mediterranean basin Morocco, North Africa. *Acta Horticulturae* 1065:1097–1103. DOI:10.17660/ActaHortic.2015.1065.138

Mazih, A., and D. Debouzie. 1996. Infestation rate of argan fruit (*Argania spinosa*) by the Mediterranean fruit fly (*Ceratitis capitata*) in relation to phenology and maturation of the fruit. *Entomologia Experimentalis et Applicata* 81:31–38. DOI:10.1111/j.1570-7458.1996.tb02011.x

MMAFRDWF. 2023. Filière agrumicole | Ministère d'agriculture. https://www.agriculture.gov.ma/fr/filiere/agrumicole#:~:text=Une%20gamme%20diversifi%C3%A9e%20de%20vari%C3%A9t%C3%A9s,32%20%25%20(40%20344%20Ha) (accessed January 31, 2025).

Mokrini, F., S. E. Laasli, Y. Benseddik, et al. 2020. Potential of Moroccan entomopathogenic nematodes for the control of the Mediterranean fruit fly *Ceratitis capitata* Wiedemann (Diptera: Tephritidae). *Scientific Reports* 10:1–11. DOI:10.1038/s41598-020-76170-7

Montoya, P., S. Flores, S. Campos, et al. 2020. Simultaneous use of SIT plus disseminator devices of *Beauveria bassiana* enhance horizontal transmission in *Anastrepha ludens*. *Journal of Applied Entomology* 144:509–518. DOI:10.1111/jen.12766

Nagel, P., and R. Peveling. 2005. Environment and the sterile insect technique. In *Sterile Insect Technique: Principles and Practice in Area-Wide Integrated Pest Management*, ed. V. A. Dyck, J. Hendrichs, and A. S. Robinson, 499–524. Dordrecht: Springer Netherlands. DOI:10.1201/9781003035572-23

Pérez-Staples, D., F. Díaz-Fleischer, and P. Montoya. 2021. The sterile insect technique: success and perspectives in the Neotropics. *Neotropical Entomology* 50(2):172–185. DOI:10.1007/s13744-020-00817-3

Plá, I., J. García de Oteyza, C. Tur, et al. 2021. Sterile insect technique programme against Mediterranean fruit fly in the Valencian Community (Spain). *Insects* 12(5):415. DOI:10.3390/insects12050415

Porras, M. F., J. S. Meza, E. G. Rajotte, et al. 2020. Improving the phenotypic properties of the *Ceratitis capitata* (Diptera: Tephritidae) temperature-sensitive lethal genetic sexing strain in support of sterile insect technique applications. *Journal of Economic Entomology* 113(6):2688–2694. DOI:10.1093/jee/toaa220

Sacantanis, K. B. 1957. La forêt d'arganier. Le plus grand foyer de *Ceratitis capitata* (Wied.) connu dans le monde. *Bollettino del Laboratorio di Entomologia. Agraria* 15:1–53.

Toledo, J., S. Flores, and S. Campos, et al. 2017. Pathogenicity of three formulations of *Beauveria bassiana* and efficacy of autoinoculation devices and sterile fruit fly males for dissemination of conidia for the control of *Ceratitis capitata*. *Entomologia Experimentalis et Applicata* 164:340–349.

Vreysen, M. J., J. Hendrichs, and W. Enkerlin. 2006. The sterile insect technique as a component of sustainable area-wide integrated pest management of selected horticultural insect pests. *Journal of Fruit and Ornamental Plant Research* 14:107–131.

Yazid, J. B., Z. Chafik, I. Bibi, et al. 2020. Effectiveness of sterile insect technique for medfly (*Ceratitis capitata*, Wiedemann, 1824) control in citrus orchards of Moulouya perimeter North East of Morocco. *ISPEC Journal of Agricultural Sciences* 4(3):405–421. DOI:10.46291/ispecjasvol4iss3pp405-421