Mini-review

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In Focus: Spotted wing drosophila, *Drosophila suzukii*, across perspectives

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Abstract

In August 2008, the first detection of the spotted wing drosophila, *Drosophila suzukii*, to the North America mainland in California caused great concern, as the fly was found infesting a variety of commercial fruits. Subsequent detections followed in Oregon, Washington, Florida and British Columbia in 2009; in Utah, North Carolina, South Carolina, Michigan, and Louisiana in 2010; and in Virginia, Montana, Wisconsin, Pennsylvania, New Jersey, Maryland and Mexico in 2011. In Europe, it has been detected in Italy and Spain in 2009 and in France in 2010. Economic costs to the grower from *D. suzukii* include the increased cost of production (increased labor and materials for chemical inputs, monitoring and other management tools) and crop loss. An effective response to the invasion of *D. suzukii* requires proper taxonomic identification at the initial phase, understanding basic biology and phenology, developing management tools, transferring information and technology quickly to user groups, and evaluating the impact of the research and extension program on an economic, social, and environmental level. As *D. suzukii* continues to expand its range, steps must be initiated in each new region to educate and inform the public as well as formulate management tactics suitable for the crops and growing conditions in each.

Keywords: *Drosophila suzukii*; North America; Europe; Mexico

1 INTRODUCTION

Unlike other vinegar or pomace flies that are considered a nuisance, *Drosophila suzukii* Matsumura (Diptera: Drosophilidae) is an economically damaging pest because the females have a serrated ovipositor enabling them to infest ripening fruit before harvest. Moreover, *D. suzukii* exhibits a wide host range in its introduced and native range, infesting blackberries, blueberries, cherries, peaches, raspberries, strawberries, grapes (wine and table) and various wild fruiting plants, as well as fruits that are damaged, dropped or split such as apples, apricots, loquat, greenhouse mandarins, persimmons and tomatoes.[1–3] *D. suzukii*, was first observed on cherries in 1916 in Japan, and by the 1930s infestations had worsened, leading to rejections of cherries by buyers.[1] Infestations also occurred in parts of China, Korea and Russia (southeast Siberia). With the recent detection of *D. suzukii* in many new regions of the continental United States and Europe, this *In Focus* collection of papers has been gathered to provide an overview of some key aspects of this insect's biology, economic impact and management, and the steps being taken to educate stakeholders about how to respond to arrival of this invasive insect in some new regions of the world.

In North America, *D. suzukii* was first reported from Hawaii in 1980,[4] without raising much alarm. In August 2008, the first detection from the mainland in California caused great concern, as the fly was found infesting strawberries and caneberries. Subsequent detections followed in Oregon, Washington, Florida and British Columbia in 2009; in Utah, North Carolina, South Carolina, Michigan and Louisiana in 2010; and in Virginia, Montana, Wisconsin, Pennsylvania and New Jersey and Mexico in 2011.[5–7] In Europe, it has been detected in Italy and Spain in 2009, and in France in 2010. Misidentification of the first *D. suzukii* specimens led to a delay in responding to reported infestations. The first paper of this issue's *In Focus* by Hauser[8] chronicles the invasion of *D. suzukii* in the US mainland, with a feature on taxonomic characteristics.

There are also recent *D. suzukii* findings made from three European countries (geographical coordinates: latitude 40–47 °N, longitude 02–12 °E), and some larvae were detected in infested raspberry fruits in Trentino, Italy, in September 2009. Detailed monitoring of fruit damage throughout the region revealed other infested plantations, both of raspberry and blueberry. Subsequent surveys revealed that the fly was spread throughout Italy (Trentino-Alto Adige, Piemonte, Toscana, Campania). It was also found on cherry and strawberry in southern France (Montpellier, Languedoc-Roussillon, Provence-Alpes-Cote-d'Azur, Corsica)[9] and collected

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from trap catches in Spain (e.g. Rasquera, Barcelona, Malaga, Valencia, Catalonia). In addition, infestations were confirmed from Mexico in 2011.

Considerable damage has been reported in the most relevant soft fruit and cherry production areas in Italy and France in 2010. In Italy, eggs and larvae were detected in fruits of sweet cherry, apricot, blueberry, strawberry, raspberry, blackberry, fig and wine grape, and also in fruits of wild hosts (*Lonicera* spp., wild blackberry, *Sambucus nigra, Frangula alnus*) (Grassi A, private communication, 2011).

2 BIOLOGY

Most of the known basic biology of *D. suzukii* is from the Japanese literature, as studies in the United States and Europe have only recently been initiated. *D. suzukii* develops through three larval instars, and development from egg to adult has taken from 8 days 2 h to 10 days 3 h at 25 °C/77 °F, and from 21 days 8 h to 25 days 2 h at 15 °C/59 °F (number of individuals $n = 7$ and 3 respectively).[2] Males court females by fanning their wings and tapping their legs. Mating ranges between 2 min and 1 h 25 min, with an average of 26.6 min ($n = 56$),[2] and females start ovipositing between 1 day and 4 days 20 h after pupal emergence, with an average of 1 day 23 h ($n = 79$).[1] Female *D. suzukii* are fecund and can lay 161.1 ± 23.9 eggs over a lifetime on cherries and 105.8 ± 15.8 eggs on Concord grapes ($n = 17$ and 17),[1] with averages of between 219 and 563 eggs over a lifetime among ten generations on cherries from another study (n = unknown).[2] Females oviposit between 10 °C/50 °F and 32 °C/90 °F,[10] and will lay eggs in single clutches randomly on fruit.[11] Adult activity is reduced above 30 °C/86 °F.[2] In Japan, only the adult stage was noted to overwinter in pebbles or leaves, starting in late November, when minimum temperatures fell below 5 °C/41 °F (n = unknown).[2] Walsh *et al.*[5] also provide other information not described here on *D. suzukii* life stages, host range, overwintering and degree-day models based on Japanese literature and recent observations made in the United States. Calabria *et al.*[12] describe the first records of *D. suzukii* in Europe, as well as monitoring and biological observations.

This issue's *In Focus* includes two laboratory studies on basic biology. Lee *et al.*[13] exposed various fruit cultivars and ripeness stages to *D. suzukii* adults in the laboratory. They demonstrated that the color-changing stages of blackberry, blueberry, cherry, raspberry and strawberry in no-choice and choice arenas are more susceptible to *D. suzukii* oviposition and development than the green and overripe stages. Dalton *et al.*[14] examined the overwintering survivorship of *D. suzukii* under constant temperatures in laboratory bioassays, and demonstrated very poor survival at 7 °C/45 °F or less.

3 PEST MANAGEMENT

Effective management of this pest is a challenge owing to the wide host range and short generation time. In Japan, *D. suzukii* is primarily controlled by pesticide sprays on fruit at the coloring stage before harvest.[10] In North America, the immediate management response to this new invasive pest has included monitoring for adult activity with yeast or apple cider vinegar traps, monitoring fruit for larval infestation and application of insecticides. In this issue's *In Focus*, Bruck *et al.*[15] evaluate pesticides for immediate and residual activity in the laboratory and field among small fruits: blueberry, raspberry, strawberry and wine grapes. Beers *et al.*[16] evaluate pesticide efficacy in sweet cherries. These trials emphasize that three classes of registered pesticides, organophosphates, pyrethroids and spinosyns, have demonstrated good contact or residual activity, while there is a pressing need to identify more organic alternatives, as there are few effective products available. In Europe, the European and Mediterranean Plant Protection Organization (EPPO) made a pest risk assessment (PRA) after the first detection in Europe. In the result of the PRA, the EPPO put *D. suzukii* on the alert list and distributed a fact sheet for all member states immediately. Detection of *D. suzukii* is reported in many regions of southern Europe, and it has become the first priority for soft fruits and cherry growers in Italy. Besides the monitoring for adult activity with vinegar traps and for larval infestation of the fruits of different crops, extensive field and laboratory trials were carried out to evaluate the insecticide efficacy. Efficacy trials are needed for the registration of new pesticides. In non-infested countries such as Germany, official monitoring by the Plant Protection Service will start in 2011.

While pesticides have been the focus in 2010 studies to provide growers with immediate chemical options, other management practices are critical to developing a sustainable *D. suzukii* integrated pest management program. Longer-term research is under way on the use of other methods, including mass trapping, sanitation, semiochemicals, biological control, landscape management and post-harvest treatment. For cultural control, covering blueberries with a mesh with a grid size of 0.98 mm provided 100% control in Japan.[17] For mass trapping, placing 24–40 traps per hectare (60–100 traps per acre) reduced *D. suzukii* field populations in China.[18,19] While this labor-intensive approach would not be possible for most growers, it could provide a non-pesticide alternative for homeowners or small-acreage farms. For sanitation, preliminary small-scale trials in Oregon suggest that bagging infested blueberries in clear/black plastic bags or solarizing fruit piles with tightly sealed 1–2 mm clear plastic can eliminate *D. suzukii* larvae, whereas crushing fruit is more effective under sunny conditions, and burying fruit is not effective, as *D. suzukii* adults find their way to the surface (Dreves AJ, unpublished data). In-field sanitation to limit the amount of fruit on the ground is also critical for mitigating *D. suzukii* populations. For biological control, projects in the United States are currently evaluating cynipid and pteromalid parasitic wasps of *D. suzukii* larvae or pupae and *Orius* predators of *D. suzukii* eggs or larvae (Miller JC, Dreves AJ, Shearer PW and Lee JC, unpublished data). Landscape and habitat choices of *D. suzukii* are being investigated to help understand movement and *D. suzukii* distribution for better design of alternative management practices (Dreves AJ, unpublished data). Furthermore, post-harvest treatment for *D. suzukii*-infested grapes is being studied in California. Prior storage of infested cherries at −1.6–2.2 °C/36 °F for 96 h caused 100% mortality of eggs and neonate larvae in Japan.[2]

4 ECONOMICS

Economic costs of *D. suzukii* include yield losses, increased labor and chemical input costs for monitoring and management, and the loss of foreign markets if fruit from *D. suzukii*-infested regions is banned from trade. Based on 2008 production values, a yield loss of 20% could lead to $US 33.4 million in revenue losses for strawberries, $US 56.7 million for blueberries, $US 156.6 million for caneberries and $US 174.8 million for cherries in California, Oregon and Washington combined.[20] In this issue, Goodhue *et al.*[21] present an economic analysis of *D. suzukii* in California strawberries and raspberries. Their analysis finds that the benefits of *D. suzukii* management well outweigh the costs of not controlling this pest.

In Europe in 2010, losses of up to 80% occurred in strawberry crops of the Alpes Maritimes region of southern France (Reynaud P, private communication, 2010). Important crop losses (30–40%) in Italy were reported by the most significant growers association, especially on highbush blueberry, blackberry and raspberry. Besides the crop loss in the field, an additional economic impact occurs owing to cost-intensive secondary selection of fruits in the storage facilities after harvest, as well as to losses due to the shorter shelf life of fruit containing eggs of *D. suzukii*. An expert working group of the EPPO for *D. suzukii* in 2010 concluded that the potential for economic consequences due to *D. suzukii* incursions in Europe were 'high'. The strongest factor determining this decision was the fact that there is already evidence of extremely high crop yield losses where *D. suzukii* is already established.

5 EXTENSION AND EVALUATION

With this high-priority invasive fruit pest, a plethora of research is currently being conducted on its biology, phenology, distribution and management. A critical step is to manage all the new information and efficiently disseminate it to the various user groups. In this issue's *In Focus*, Dreves[22] describes the formulation of outreach programs and events covering *D. suzukii* in the western United States. The plan makes use of the mapping of rapidly accessible area-wide pest incidence data, as well as digital online information on monitoring and management. Information including several university websites, hands-on workshops for growers, weekly updates and news releases are being tailored for agricultural professionals, Extension agents, farm advisors, backyard fruit growers, packers and the public. Efforts are focused on helping these main user groups to understand *D. suzukii* and ultimately increase adoption of recommended practices. Developing a unified message for stakeholders and managing the message to the media also became important priorities while developing Extension programs.

In Europe, the EPPO reacted quickly to the introductions of *D. suzukii*, put it on an alert list and elaborated a PRA. Part of the PRA is pest risk management. The monitoring and general measures are described in a fact sheet summarized by the expert working group of the EPPO that was issued for the member states by the EPPO. This was the trigger to start monitoring intensively in countries, and, where *D. suzukii* has been detected, high alert has been declared. Chemical treatments will be made according to adult flight and field scouting for oviposition. In spite of these efforts, further specific investigations for Europe are necessary, as well as for other non-endemic regions.

An effective response to the invasion of *D. suzukii* requires proper taxonomic identification at the initial phase, understanding of its basic biology and phenology, the development of management tools, the transfer of information and technology quickly to user groups and evaluation of the impact of the research and Extension program on an economic, social and environmental level.

REFERENCES

1 Kanzawa T, Research into the fruit-fly *Drosophila suzukii* Matsumura (preliminary report). Yamanashi Prefecture Agricultural Experiment Station, Kofu, Japan (1935).
2 Kanzawa T, Studies on *Drosophila suzukii* Mats. Yamanashi Prefecture Agricultural Experimental Station, Kofu, Japna (1939).
3 Biology and control of *Drosophila suzukii*. Agric Policies Div Ext Instruction, distributed at an extension meeting in Gunma Prefecture (2005).
4 Kaneshiro KY, *Drosophila* (Sophophora) *suzukii* (Matsumura). *Proc Hawaiian Entomol Soc* **24**:179 (1983).
5 Walsh DB, Bolda MP, Goodhue RE, Dreves AJ, Lee J, Bruck DJ, *et al*, *Drosophila suzukii* (Diptera: Drosophilidae): invasive pest of ripening soft fruit expanding its geographic range and damage potential. *J Integrated Pest Manag* **2**:1–7 (2010).
6 *Spotted Wing Drosophila (Fruit Fly) Pest Alert.* [Online]. Ministry of Agriculture and Lands. Available: http://www.agf.gov.bc.ca/cropprot/swd.htm 8 August 2011.
7 *Pest Tracker, Reported Pest Status of Spotted Wing Drosophila –* Drosophila suzukii. [Online]. National Agricultural Pest Information System. Available: http://pest.ceris.purdue.edu/pestlist.php [8 August 2011].
8 Hauser M, A historic account of the invasion of *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae) in the continental United States, with remarks on their identification. *Pest Man Sci* **67**:1352–1357 (2011).
9 Mandrin JF, Weydert C and Trottin-Caudal Y, Un nouveau ravageur des fruits: *Drosophila suzukii*. Premiers dégâts observés sur cerises. *Infos CTIFL* **266**:26–33 (2010).
10 Sakai M, Cherry *Drosophila suzukii*, in *Primary Color Pest and Disease Encyclopedia. Vol. 2. Apples, Cherries, European Pears and Walnuts*, 2nd edition. Rural Culture Association Japan, Tokyo, Japan, pp. 489–492 (2005).
11 Mitsui H, Kazui H, Takahashi M and Kimura T, Spatial distributions and clutch sizes of *Drosophila* species ovipositing on cherry fruits of different stages. *Popul Ecol* **48**:233–237 (2006).
12 Calabria G, Máca J, Bächli G, Serra L and Pascual M, First records of the potential pest species *Drosophila suzukii* (Diptera: Drosophilidae) in Europe. *J Appl Entomol* DOI: 10.1111/j.1439.2010.01583.x (2010).
13 Lee JC, Bruck DJ, Curry H, Edwards D, Haviland DR, Van Steenwyk RA *et al*, The susceptibility of small fruits and cherries to spotted-wing drosophila, *Drosophila suzukii*. *Pest Man Sci* **67**:1358–1367 (2011).
14 Dalton DT, Walton VM, Shearer PW, Walsh DB, Caprile J and Isaacs R, Laboratory survival of *Drosophila suzukii* under simulated winter conditions of the Pacific Northwest and seasonal field trapping in five primary regions of small and stone fruit production in the United States. *Pest Man Sci* **67**:1368–1374 (2011).
15 Bruck DJ, Bolda M, Tanigoshi L, Klick J, Kleiber J, DeFrancesco J *et al*, Laboratory and field comparisons of insecticides to reduce infestation of *Drosophila suzukii* in berry crops. *Pest Man Sci* **67**:1375–1385 (2011).
16 Beers EH, Van Steenwyk RA, Shearer PW, Coats WW and Grant JA, Developing *Drosophila suzukii* management programs for sweet cherry in the Western US. *Pest Man Sci* **67**:1386–1395 (2011).
17 Kawase S, Uchino K and Takahashi K, Control of cherry Drosophila, *Drosophila suzukii*, injurious to blueberry. *Plant Prot* **61**:205–209 (2007).
18 Wu SR, Tai HK, Li ZY, Wang X, Yang SS, Sun W, *et al*, Field evaluation of different trapping methods of cherry fruit fly, *Drosophila suzukii*. *J Yunnan Agric Univ* **22**:776–778 (2007).
19 Wu SR, Tai HK, Li ZY, Wang X, Yang SS, Sun W, *et al*, A comparative study on control effects of fruit flies by different methods in red bayberry orchard. *J Mountain Agric Biol* **26**:365–368 (2007).
20 Bolda M, Goodhue RE and Zalom FG, Spotted wing drosophila: potential economic impact of a newly established pest. *Agricultural and Resource Economics Update* **13**:5–8 (2010).
21 Goodhue RE, Bolda M, Farnsworth D, Williams JC and Zalom FG, Spotted wing drosophila Infestation of California strawberries and raspberries: economic analysis of potential revenue losses and control costs. *Pest Man Sci* **67**:1396–1402 (2011).
22 Dreves AJ, IPM program development for an invasive pest: coordination, outreach and evaluation. *Pest Man Sci* **67**:1403–1410 (2011).

