Evaluation of Fruit Wastes as Off-Season Potential Breeding Sources for Spotted-Wing Drosophila in Michigan

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The spotted-wing drosophila (SWD), *drosophila suzukii* (Matsumura), is an invasive pest from eastern Asia and is a major threat to the US small fruit industry. Since its first detection in California in 2008, SWD has spread throughout all of the fruit-producing regions of the US. Spotted-wing drosophila was first detected in Michigan in late September 2010 and can be found throughout the state. In Michigan and the northeastern US, SWD has become an unprecedented threat to the blueberry, cranberry and cherry industries. It has caused tremendous economic damage and has had a major impact on IPM programs (Bolda et al. 2010; eFly Working Group 2012). Growers now rely on calendar-based sprays of broad-spectrum insecticides that often continue throughout the harvest (Beers et al. 2011; Van Timmeren and Isaacs 2013), resulting in secondary pest outbreaks (Williams et al. 2003; Biondi et al. 2012). Chemical management of SWD is difficult for crops without insecticides having short pre-harvest intervals (PHIs) and late season applications put crops at risk of violating maximum residue limits (MRLs) maintained for international trade. Thus, there is an increasing interest in the development of cultural, physical and biological pest management tactics.

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Cultural management tactics, including crop sanitation and reduction of alternate breeding sites, may reduce over-dependence on chemical management, or help in maintaining SWD numbers at more manageable levels. Removal of such potential breeding sites would presumably reduce SWD populations. In addition to the cultivated ripening soft fruit hosts, several non-cultivated plants such as honeysuckle, autumn olive, spicebush, elderberry, pokeweed, etc., have been reported to be susceptible to SWD during the fruit production season, as well as during other periods of the year when no cultivated fruit crop is available (Lee et al. 2015).

While it has been hypothesized that SWD could utilize fruit wastes, including dropped, over-ripe and compromised fruit and processing by-products, as a reproductive resource, little research has been done in this area. In temperate climates, dropped and unharvested apples, pears and other "durable" fruits can remain undecomposed on the orchard floor during the winter, and fruit wastes such as apple or grape pomace can also be found in or near farms with cideries or winemaking facilities. If SWD can utilize these resources, they might provide an off-season (early or late season) reproductive resource for SWD in the absence of susceptible cultivated fruit crops that serve as "fresh" hosts for this pest during the crop season. Thus, our goal was to determine the potential for dropped fruit and fruit wastes to be reproductive resources for SWD in Michigan. We focused on the autumn months, with the hypothesis that these fruit wastes will provide off-season breeding resources for SWD during the absence of its fruit crop hosts. We assessed this hypothesis through a pair of experiments: the first determining the presence of wild SWD in a range of fruit wastes collected from farms, and the second determining reproductive suitability of specific fruit wastes by exposing them to SWD in the laboratory. The findings shared in this article come from a recently published study (Bal et al. 2017).

Fruit waste collection

We collected dropped fruits including apples, grapes, pears, peaches, plums, raspberries, and cherries from 15 fruit farms distributed across the lower peninsula in Michigan from 13–28 Oct 2016 (Figures 1, 2). We collected fruit compost/pomace and abandoned pumpkins from farms with cideries or winemaking facilities (Farms 2–6, 8 and 14, Figure 3). We also collected cherries and peaches from trees at Farm 7 and wood chip mulch from a heap at Farm 5. All the fruit waste samples were refrigerated at 5°C before any experimentation.

Fruit waste assessment

Assessment of the fruit waste included two experiments: 1) natural SWD emergence from the fruit wastes and 2) host

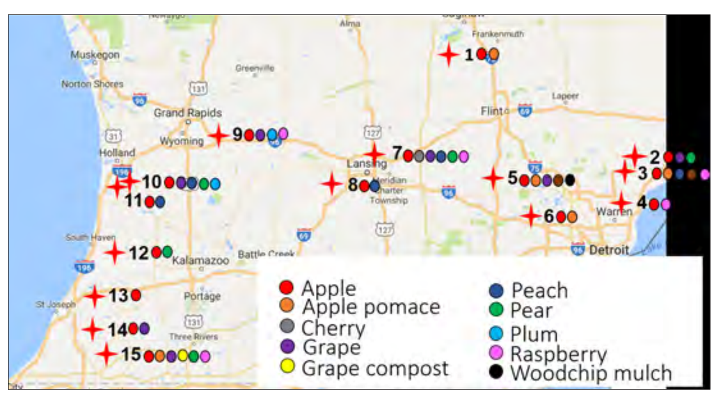

Figure 1. Map of the lower peninsula in Michigan showing 15 different fruit farms from which different fruit wastes (dropped fruits and fruit composts) were collected in Fall 2016. Farms 2-6, 8, and 14 had attached cider mills and Farms 3, 5, 7, 9, 10, and 15 had more than three fruit crops.

suitability of fruit wastes using laboratory-reared SWD. Our lab SWD colony was reared on SWD solid food diet in 50-ml polystyrene vials (Genesee Scientific, San Diego, CA) held in a growth chamber at 24°C, 45% relative humidity, and a photoperiod of 16:8 h (L:D) cycle using the protocol described by Dalton et al. (2011). All the fruit waste assessment was done within 24 h of refrigeration to ensure fly survival in the samples (Aly et al. 2017).

1) Natural fruit fly emergence: 2–5 fruit waste subsamples were collected from one or more 0.1-ha fruit waste areas such as orchard, vineyard, berry planting, or pomace waste pile from each farm, depending on the availability of fruit waste at a given farm. Natural fruit fly emergence was observed in 100 g of each fruit waste subsample placed in individual 950-ml emergence cages, as described by Bal et al. (2017) (Figure 4). To allow adult fruit fly development for species identification, emergence cages were held at 25°C for 3 wk under a 16:8 h (L:D) cycle. Flies were identified as SWD males or females or other *drosophila* species. Mean density of male and female SWD for each farm/fruit waste combination was obtained by pooling the number of flies from each subsample from each farm/fruit waste combination. We also calculated mean ± SEM number of male, female, and total SWD and other *drosophila* species for each fruit waste type.

2) Spotted-wing drosophila host suitability: This experiment was conducted in emergence cages with 20 g of each fruit waste sample per cage, replicated five times (Figure 4). Adult SWD used in this experiment were lightly anesthetized with CO_2 after being removed from the rearing vials, sorted by sex, counted, and immediately released on the fruit waste samples. Each 5 g of fruit waste sample was exposed to a single mated 3–5-d old adult female SWD. Samples were frozen for at least 1 wk prior to experimentation to eliminate any natural drosophilid population. Samples were then thawed at room temperature for 24 h, followed by treatment with 2% propionic acid for 5 s and air drying for 12 h to eliminate any mold growth during experimentation. Samples were held at 25°C for 14 d or until flies started emerging under a 16:8 h (L:D) cycle. The number of male and female SWD progeny was counted to confirm host utilization/reproduction and compared among fruit waste types using an analysis of variance ($\alpha = 0.05$) after $\log_{10}(x)$

Figure 2. Dropped A) apples and B) pears collected from 15 and 5 different farms, respectively, for fruit waste assessment in Fall 2016.

Figure 3. Apple pomace/compost collected from the A) farm grounds and B) pomace piles near fruit plantation for fruit waste assessment in Fall 2016.

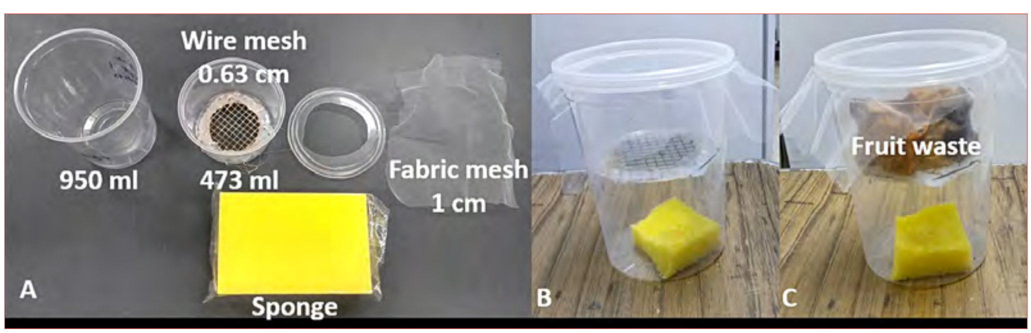

Figure 4. Emergence cage: A) materials, B) empty cage, and C) cage containing a fruit waste sample. An emergence cage consisted of a 473-ml plastic deli cup with a wire mesh base (0.63 cm mesh size) contained in a 950-ml plastic deli cup with a mesh top (1 cm mesh size) and a piece of sponge (5.08 cm x 5.08 cm x 2.54 cm) placed at the bottom of each cage to prevent flies from drowning in fruit juices.

Table 1. **Mean ± SEM male, female, and total spotted-wing drosophila (SWD) and other *drosophila* species recovered from each sample containing different fruit wastes (dropped fruits and fruit composts) collected from 15 different fruit farms across the lower peninsula in Michigan. Farm number corresponds to Figure 1. Table modified from Bal et al. (2017).**

Crop	Farms	% farms infested with SWD	Number of samples across all farms	Mean ± SEM male SWD/ sample	Mean ± SEM female SWD/ sample	Mean ± SEM total SWD/ sample	Mean ± SEM other drosophila/sample
Grape	2,5,7,9,10,14,15	100	18	0.49 ± 0.38	277.58 ± 115.73	278.07 ± 115.83	17.28 ± 5.59
Pear	2,7,10,12,15	100	11	0.10 ± 0.10	186.20 ± 112.69	186.30 ± 112.66	104.47 ± 46.51
Apple	1-15	100	61	0.24 ± 0.10	40.57 ± 7.58	40.81 ± 7.60	23.11 ± 7.24
Raspberry	3,4,7,9,15	100	9	11.70 ± 5.12	21.80 ± 11.84	33.50 ± 14.80	6.70 ± 3.35
Peach	3,7,8,10,11	40	12	0.67 ± 0.67	18.30 ± 15.72	18.97 ± 16.38	3.37 ± 2.55
Grape compost	15	100	4	0.25 ± 0.0	21.75 ± 0.0	17.0 ± 0.0	22.0 ± 0.0
Apple pomace	1,3,5,6,15	40	15	0.06 ± 0.06	9.33 ± 6.05	9.33 ± 5.67	3.60 ± 2.13
Plum	9,10	50	6	0	0.37 ± 0.37	0.37 ± 0.37	0
Pumpkin	3,5	50	7	0.17 ± 0.17	0	0.17 ± 0.17	57.33 ± 13.33
Cherry	7	0	3	0	0	0	0
Woodchip mulch	5	0	2	0	0	0	0

transforming the values to obtain normality and equality of variance (SAS Release 9.4).

Natural SWD infestation in fruit wastes

We recorded 100% SWD infestation in dropped apples, pears, grapes, and raspberries collected from the farms surveyed (Table 1). While dropped peaches and plums, and abandoned pumpkins were infested with SWD in ≤ 50% farms surveyed, we did not record any SWD infestations in dropped cherries and wood chip mulch from any of the farms sampled. Apple and grape pomace was infested by SWD in 40% and 100% of farms surveyed, respectively (Figure 5). On comparing the means of total SWD recovered from different dropped fruit types, we recorded numerically higher numbers from dropped grapes and pears, compared with other fruit wastes. Other *drosophila* species were numerically higher in dropped pears compared with other fruit wastes. These results suggest that fruits such as apples and pears that are not typically associated with SWD may serve as important alternate reproductive hosts when fallen on the ground and compromised (damaged and soft) during the fall.

SWD numbers also differed among the farms across all fruit waste types (Figure 6). SWD infestation was numerically higher on farms with on-site cider mills (Farms 5, 8, and 14) and with multiple cultivated fruit crops (Farms 7 and 9) than farms with no cider mills and only one cultivated fruit crop. This suggests that fruit waste piles near cider mills and availability of multiple fruit crops at a farm may serve as off-season SWD reproductive reservoirs.

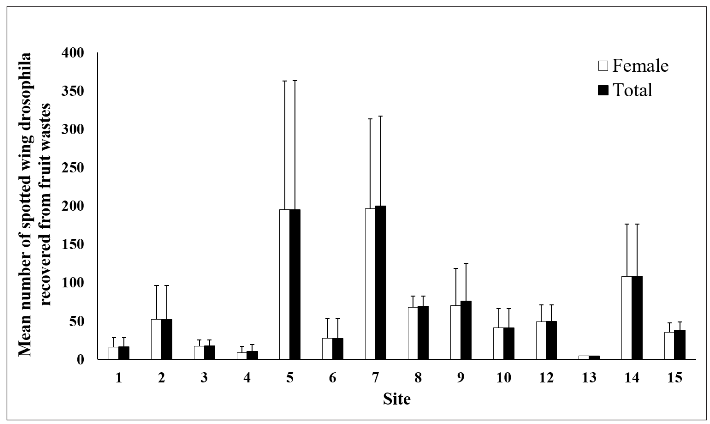

Figure 6. Mean ±SEM female and total spotted-wing drosophila recovered from all fruit waste (dropped fruits and fruit composts) samples collected from different fruit farms represented as farms corresponding to Figure 1 across the lower peninsula in Michigan (Figure from Bal et al. 2017).

Figure 5. Field-collected apple pomace sample infested with fruit flies including spotted-wing drosophila and other *drosophila* species.

SWD sex ratio varied among fruit wastes and farms. Male SWD infestation was very low in all fruit waste samples except dropped raspberries. Female SWD infestation was numerically higher in dropped grapes and pears compared with other fruit wastes. Female SWD previously have been reported to survive lower temperatures than males during the overwintering stage of this pest, which could explain the female-biased sex ratio in fall-collected fruit wastes (Dalton et al. 2011; Tochen et al. 2014; Rossi-Stacconi et al. 2016). Even among farms with on-site cider mills, female numbers infesting fruit wastes differed numerically. Greater numbers of females were recovered from fruit wastes collected from Farm 5 than Farms 3 and 4. We suspect these differences could be correlated with differences in geographical location or pest management strategies used at the farms.

SWD host suitability of fruit wastes

We evaluated the host suitability of 11 different fruit waste types for SWD reproduction in the laboratory and found the following fruit wastes to be the most suitable hosts for SWD: raspberry, pear and apple pomace, with reproduction in 100% of samples tested, and grapes and grape compost, with reproduction in 80% of samples tested. SWD progeny production was highest in raspberries and least in peaches, with no differences between grapes, apples, and grape compost ($F = 6.99$; $df = 6{,}27$; $p < 0.01$) (Table 2). Both male and female SWD offspring were recovered in higher numbers in raspberries than grapes and apples ($F = 4.11$; $df = 4{,}21$; $p = 0.01$), and grape compost, apples, and peaches ($F = 5.89$; $df = 6{,}26$; $p < 0.01$), respectively. Thus, dropped raspberries emerged as one of the most important reproductive sources for SWD. Raspberries have also been reported previously to be among the most preferred cultivated hosts (Lee et al. 2011). SWD did not utilize any of the following wastes for reproduction: plum, blueberry, pumpkin, and wood chip mulch collected from the ground, and cherries and peaches collected from trees. These fruit waste samples were likely too dry to support oviposition or egg and larval development (Atallah et al. 2014).

Implications

The major outcome of our study is that it demonstrated that fruit wastes, including dropped berry, pome and stone fruits, and fruit pomace at farms with attached cideries and winemaking facilities, may be important late season reproductive resources for SWD. Our results also support the ecological hypothesis that SWD is a saprophyte utilizing rotting fruit wastes for reproduction, in addition to being a frugivore infesting cultivated soft-skinned fruits. Interestingly, the rotting fruit wastes evaluated in our study include fruits such as apples and pears that are typically not attacked by SWD during growth and development. These conclusions, however, require further confirmation with long-term evaluation of different types of fruit wastes as potential SWD breeding resources in different regions.

These results also suggest future research on evaluation of postharvest crop sanitation in pome fruit and grapes for area-wide management of this economically important pest. Recent work by Leach et al. (2017) found that bagging and solarizing infested berries for 32 h reduced SWD larval survival by 99%. There was no significant difference in larval mortality after 32 h between clear, white, and black bags, though fruit in the clear bags reached the highest temperatures and remained at temperatures lethal to SWD for the longest periods of time. While this method of disposal is effective against culled berries, it is difficult to translate to pome and stone fruit wastes (Haye et al. 2016). Composting or burial of susceptible fruit wastes are additional options but have not been fully explored.

We have begun evaluating composting in the laboratory, with initial results suggesting that compost feedstocks containing chicken manure may reduce the suitability of apple pomace. Mated females were exposed to feedstocks composed of either a vegetable base or a chicken manure base mixed with 0, 10, 30, 70% or 100% apple pomace. For vegetable-based compost blends, SWD reproduction was reduced by 95%, 77% and 32% on 10, 30, and 70% apple pomace blends compared with pomace alone, respectively. Chicken manure-based compost feedstocks reduced reproduction by 100% in 10% pomace blends with 30 and 70% manure blends, performing similarly to the vegetable compost blends. However, juvenile development was delayed in all of the pomace/manure blends compared with vegetable compost blends (Hooper et al. unpublished). In a trial where juvenile SWD were covered in pure chicken manure, we observed a 100% reduction in the number of emerging adults compared with larvae and pupae buried in soil (Hooper et al. unpublished).

We have also begun to evaluate burial as a way to dispose of fruit wastes. SWD pupae were buried at depths of 0, 1, 3, 10, and 30 cm in two soil textures, sandy and loamy. We found that a burial depth of only 3 cm reduced emergence by 50% in sandy soil and 73% in loamy soil, with no SWD emerging from depths of 10 cm or below (Hooper et al. unpublished). Other recommended options for fruit waste disposal include burning, freezing, or use as animal feed. Future research on which fruit wastes need to be disposed of, and effective methods for disposal of fruit, would be useful to generate recommendations for growers.

Table 2. Mean ± SEM number of total spotted-wing drosophila (SWD) adults (males and females) reproduced from mated females added to each fruit type (dropped fruits and fruit composts) collected from different fruit farms across the lower peninsula in Michigan. Means sharing the same letters within a column are not significantly different between fruit waste types based on Tukey's test comparisons at p > 0.05. Table modified from Bal et al. (2017).

Fruit	Mean ± SEM male SWD offspring (adults)/ 5 g fruit sample	Mean ± SEM female SWD offspring (adults)/ 5 g fruit sample	Mean ± SEM total SWD offspring (adults)/ 5 g fruit sample
Raspberry	5.71 ± 1.44 a	8.82 ± 1.98 a	14.53 ± 3.25 a
Pear	1.91 ± 0.49 ab	1.70 ± 0.33 ab	3.61 ± 0.82 ab
Apple pomace	1.29 ± 0.33 ab	1.35 ± 0.37 ab	2.63 ± 0.70 abc
Grapes	0.77 ± 0.48 b	1.21 ± 0.79 ab	1.98 ± 1.27 bc
Apple	0.26 ± 0.15 b	0.20 ± 0.11 b	0.47 ± 0.26 bc
Grape compost	0 b	0.31 ± 0.10 b	0.31 ± 0.10 bc
Peach		0.04 ± 0.02 b	0.04 ± 0.02 c
Plum		0 b	0 bc
Blueberry			
Pumpkin			
Woodchips			
Cherry (on tree)			
Peach (on tree)			

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- Promoting the industry
- Representing the industry in matters of public policy

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- sponsor trade shows
- cooperate with and encourage others to provide educational opportunities

Promoting the Fruit Industry by:
- promoting ideas which will benefit the economic health of the fruit industry
- educate the general public about the New York fruit industry

Representing the New York fruit industry by:
- Have cemented our role as legislative voice in both Albany and Washington, DC for the fruit industry
- representing the industry's interest as well as other agencies and institutions

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- **Agricultural Labor and Immigration**
- **Fruit Industry Economic Development**
- **Cornell Research and Extension**
- **Education Public Officials**
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— See page 36 for membership details —