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Efficacy of food-based attractants for monitoring *Drosophila suzukii* (Diptera: Drosophilidae) in berry crops

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ABSTRACT

Spotted-Wing Drosophila (SWD), *Drosophila suzukii* Matsumura is an invasive fruit fly pest of soft-skinned fruits that causes serious economic losses in the berry growing areas of central Mexico. Effective attractants are necessary to detect its presence, to monitor populations where established, and to explore new strategies for pest control. The capture of *D. suzukii* in four food-based attractants was compared with apple cider vinegar (ACV) as the reference attractant in blackberry, raspberry, and blueberry crops. An active yeast-based lure, Fly Buster Powder®, resulted the most effective attractant capturing SWD flies in blackberry and blueberry. However, this attractant was similar to SuzukiiTrap® Max Captures, ACV and Pherocon® SWD, but less effective than a two-component attractant (2C trap) in raspberry. The specificity of attractants was variable among crops and experiments but Fly Buster Powder® tends to be highly selective in the capture of SWD with up to 70% of *D. suzukii* from all drosophilids captured. Fly Buster Powder® and 2C trap attractants were more effective trapping *D. suzukii* when aged for 7 days than when aged for 1 or 15 days. The specificity of both yeast-based attractants was significantly reduced when aged for 15 days than when aged for 1 or 7 days.

1. Introduction

Drosophila suzukii Matsumura (Diptera: Drosophilidae), also called Spotted Wing Drosophila (SWD), is a pest native to Southeast Asia that has currently established itself in America and Europe (Asplen et al., 2015) causing large economic losses due to the direct damage of females that oviposit on host fruits. Substantial indirect impacts include closures of markets because of quarantine due to SWD detections and postharvest fumigation of fruit shipped from *D. suzukii* infested regions (Farnsworth et al., 2017). It is a major pest of soft fruit crops such as raspberries, blackberries, blueberries, strawberries, cherries, grapes, and apricots (Asplen et al., 2015; Farnsworth et al., 2017; Walsh et al., 2011). In Mexico, *D. suzukii* was firstly detected in Los Reyes, Michoacán in 2011 (DGSV, 2011) and quickly spread through the country. The loss or damage caused by *D. suzukii* in Mexico is high, particularly for berry crop production where severe outbreaks of this pest have prompted efforts to forecast and control adult populations. Management pest programs to control and mitigate the dispersal of this fly in Mexico were subsequently extended to growers, which include the gathering and concealing of infested fruits, trapping and the use of pesticides (DGSV, 2011; DOF, 2014). Monitoring recommendations to growers in Mexico mainly involve the use of artisanal plastic traps baited with food attractants such as apple cider vinegar (ACV) (SAGARPA-SENASICA, 2014). ACV has been the most commonly used attractant to capture *D. suzukii* adults because it is cheap, widely available and is moderately effective. However, it is a non-specific attractant and captures other non-target species (Lee et al., 2012). In addition to ACV and other vinegars (Clymans et al., 2019; Lasa et al., 2020; Lee et al., 2013; Willbrand and Pfeiffer, 2019), other attractants have been investigated, including fermenting yeasts (Frewin et al., 2017; Hampton et al., 2014; Iglesias et al., 2014; Lasa et al., 2017a) or different mixtures of yeast, wine and vinegar (Huang et al., 2017; Landolt et al., 2012a, 2012b; Tonina et al., 2018) (Huang et al., 2017; Landolt et al., 2012a,b; Tonina et al., 2018). Artificial mixtures of volatile compounds produced naturally during the fruiting season or fermentation lures have also been tested (Abraham et al., 2015; Cha et al., 2013, 2014, 2018; Feng et al., 2018), with some

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commercial products containing a mixture of acetic acid, ethanol, acetoin, and methionol, such as Pherocon® SWD, Z-Kinol® and Scentry® Lure (Cloonan et al., 2018; Lasa et al., 2019a). However, studies on monitoring systems have shown highly variable efficacy in trap captures due the trap-attractant used and other interacting factors such as the berry crop, crop phenology and population demography that lead to efficacy inconsistencies among berry geographical production areas (Shawer et al., 2018). Thus, specific studies to find better attractants for each crop and region is justified to improve the detection, monitoring and management control strategies to reduce the economic injury of this pest.

Previous research in Mexico revealed that ACV provided similar capture rates to other commercial attractants such as the Suzukii Trap® and Z-Kinol® (Lasa et al., 2019a) but was less effective than fermenting attractants such as yeast-sugar mixture used in a two-component trap device (2C trap) (Lasa et al., 2017a) or a mixture of raspberry fruits with sugar (Lasa et al., 2019a). It has been shown that active yeasts are more effective in attracting *D. suzukii* flies than other attractants with fermentation by products (Frewin et al., 2017; Iglesias et al., 2014; Lasa et al., 2017a). However, their use in berry crops such as blackberry, raspberry, and blueberry have not been well documented. Recently, three new attractants have been used in Mexico for monitoring and/or control of *D. suzukii*: 1) a new improved formulation of organic acids and peptides, Suzukii Trap® Max Captures; 2) an active yeast fermenting powder, Fly Buster Powder®, mixed with water and that was developed to trap the house fly, *Musca domestica* L. (Diptera: Muscidae), and 3) an artificial attractant mixture of four components, Pherocon® SWD.

As there is no evidence of the efficacy to date of these products to trap *D. suzukii* flies, this study compared the efficacy of these three commercial attractants under polytunnel bioassays and compared them with ACV or the previously evaluated 2C trap attractants during the fruiting season in the three most important hosts, blackberry (*Rubus fruticosus* L.), raspberry (*Rubus idaeus* L.) and highbush blueberry (*Vaccinium corymbosum* L.). As active yeasts outperformed the capture of SWD flies with respect to the other attractants, the efficacy and specificity for *D. suzukii* of both active yeast attractants were evaluated under laboratory and field conditions after aging for periods ranging from 1 to 15 days.

2. Materials and methods

2.1. Study sites

All field experiments were carried out in multi-span polytunnels of blackberry, raspberry, and blueberry in the berry production state of Michoacán, Mexico. The multi-span polytunnel is a group of tunnels in a row (6.6 m height, 6 m wide and variable in length), that are typically made from steel and covered with white polyethylene (Fig. 1). Experiment type, berry crop, locality, dates and GPS coordinates of all trials are shown in Table 1.

2.2. Trap and attractants

A similar translucent plastic cup of 1000 ml (118 mm internal diameter × 146 mm height) with a flat pressure lid (Fig. 1) was selected for all experiments because it is recommended by the Mexican Secretary of Agriculture and Rural Development (SADER) for surveillance of *D. suzukii* populations in Mexico (SAGARPA-SENASICA, 2014). As recommended, the cup was drilled with 10 lateral holes of 3.2 mm diameter around the container below the middle height of the cup and 20–30 mm above the upper level of the attractant. This trap was also modified with a hole in the lid into which a 50 ml ventilated plastic centrifuge tube was inserted with an additional yeast-sugar attractant when used with the 2C trap attractants (Fig. 1B).

Five attractants were evaluated: i) Suzukii Trap® Max Captures (Bioibérica, Barcelona, Spain), an improved mixture of peptides (2% w/w) and organic acids (5% w/w), pH 4.3 and density of 1.04 g/ml; ii) Pherocon® SWD (Trécé Inc., Adair, OK), a broad spectrum four-component lure with acetic acid, acetoin, ethanol, and methionol, packed in a multi-component controlled release PEEL-PAK™ and reported as an effective attractant for *D. suzukii* (Cloonan et al., 2018); iii) Fly Buster Powder® (Flybuster, 2021), an active yeast based attractant prepared with 50 g of a mixture of yeasts and sodium bicarbonate in 1 l of water and that proved attractive to *M. domestica*; iv) apple cider vinegar (ACV) (Clemente Jacques®, 5% acidity, Sabormex de México, Puebla, Mexico), used as a reference attractant following recommendations by SADER and; v) 2C trap attractants, a combination of ACV + 10% ethanol used as the drowning solution and a tube device inserted into the lid that was baited with a sugar-yeast mixture composed in 20 ml of water, 1.1 g of sugar and 0.417 g of baker's yeast (*Saccharomyces cerevisiae* Hansen, Tredi-Pan, Safmex SA CV, Mexico-Toluca, Mexico). This attractant combination proved attractive to *D. suzukii* adults in Michoacán (Lasa et al., 2017a).

Fig. 1. Clear plastic trap baited with the attractants: Pherocon® SWD (A), 2C trap attractant (B), Suzukii Trap® Max Captures (C), ACV (D), FlyBuster Powder® (E) and water (F).

2.3. Field trials of food-based attractants efficacy

The efficacy of different attractants for *D. suzukii* capture under blackberry, raspberry, and blueberry polytunnels was determined using a similar trap design on different dates during the fruiting season (Table 1). Along this period, only botanical extracts and some fungicides (mainly microbial fungicides) were applied to the crops for the control of aphids, lygus bugs, fungus gnats and phytophagous mites. Two independent polytunnels of a similar multi-span model (replicate trials A and B for blackberry, C and D for raspberry and, E and F for blueberry crops) were carried out to evaluate attractants for each crop (Table 1). Each trial involved the evaluation of five different attractants: i) Suzukii Trap Max Captures, ii) Fly Buster Powder, iii) ACV; iv) Pherocon® SWD; and v) 2C trap. A control trap with water was also used. All attractants were evaluated in a similar clear plastic trap design (Fig. 1). This trap was modified to hang the Pherocon® SWD patch and to allow the insertion of the additional tube device of the 2C trap.

All traps were baited with 200 ml of the attractant. The Pherocon® SWD attractant was used with 200 ml of water as the drowning solution. All treatments, except Suzukii Trap® Max Captures and Fly Buster Powder®, contained a drop (12–15 μl) of odorless detergent (ML-100, Beta®, Procesos S.A. de C.V., Celaya, Guanajuato, Mexico) to reduce the surface tension of the liquid and improve the likelihood of fly drowning. All attractants were prepared 1 h before being placed in the field except the Fly Buster Powder® that was prepared the day before following the manufacturer's specifications. Traps were hung at 1.7 m above the ground in metal stakes within the plant vegetation in four different blocks. The traps within a block were deployed 25 m apart in a liner row

Table 1
Experiment type, crop, coded variety, region, crop surface, dates and GPS coordinates of multi-span polytunnels used in this study.

Experiment	Crop	Variety	Trial	Locality	Surface (Ha)	Dates	GPS Coordinates (altitude in masl[a])
Attractant efficacy	Blackberry	082D60	A	Zamora	11.5	Oct–Nov 2018	20°1′32.33″N, 102°14′13.83″W (1573)
		082D60	B	Los Reyes	2.6	May–Jun 2019	19°54′25.11″N, 102°12′15.85″W (1280)
	Raspberry	025E75	C	Jacona	5.1	Oct–Nov 2018	20°1′32.33″N, 102°14′13.83″W (1573)
		025E75	D	Los Reyes	3.8	Feb–Apr 2019	19°32′31.43″N, 102°26′57.29″W (1430)
	Blueberry	A70267	E	Tingüindín	3.3	May–Jun 2019	19°45′44.97″N, 102°25′35.42'' W (2023)
		A70267	F	Los Reyes	4.7	Dec 2019–Jan 2020	19°35.363′N, 102°29.982′W (1172)
Attractant age	Blackberry	086K2312		Los Reyes	3.2	Dec 2019	19°34′11.50″N, 102°29′39.97″W (1290)

[a] Meters above sea level.

and blocks separated 36 m. Traps were checked every 7 days and trapped flies were transferred to a vial covered with mesh and transported in Ziploc® plastic bags (33 × 38 cm) to the laboratory where the total number of drosophilid flies were counted and *D. suzukii* were separated and sorted by sex. After that, traps were rotated to the next position within each block for a new replicate.

Suzukii Trap® Max Captures, Fly Buster Powder® and Pherocon® SWD were replaced after four weeks of use in the field according to the manufacturer's specifications, whereas ACV, 2C trap attractants and water used as control were replaced weekly on inspection. The experiment was done in four replicate blocks by trial (A to F) and lasted five weeks after which all attractants had been placed in all positions within a block.

2.4. *Laboratory and field trials of aged yeast-based attractants*

Following favorable results of Fly Buster Powder® and 2C trap attractant, an additional experiment was carried out to evaluate the effect of the attractant age on its efficacy to trap *D. suzukii* flies under laboratory and field conditions.

2.4.1. *Laboratory bioassays*

A colony of *D. suzukii* was established at the insectary (Driscoll's company, Jacona, Michoacán, Mexico), from infested fruits collected in the field. Pupae were kept in plexiglass cages (30 × 30 × 30 cm) until adult emergence and adults were allowed to oviposit in a cornmeal-based artificial diet (Dalton et al., 2011), dispensed into 300 ml plastic cups and covered with a fine nylon gauze under laboratory conditions, 24 ± 1 °C temperature, 70 ± 10% relative humidity and a 12:12 h (light: darkness) photoperiod. Both sexes were collected daily from emergence cups and kept together in cages until required for experiments. The efficacy of the attractant age was evaluated independently for Fly Buster Powder® and 2C trap attractants. Each attractant was aged for 1, 7 and 15 days under the same laboratory conditions using polystyrene foam cups of 1000 ml simulating a trap with 20 lateral holes (3.2 mm diameter) but covered with a 0.2 mesh to prevent the entrance of insects. A volume of 200 ml of the attractant of the three aged periods (1, 7 and 15 d) was placed in clear plastic traps and hung equidistantly (50 cm apart and 30 cm above the base) from the ceiling of a nylon cage (60 × 60 × 100 cm, 0.2 mesh). Only in the case of the 2C trap attractants, a drop of odorless detergent was used in the ACV-ethanol to reduce the surface tension of the liquid. The cage contained a potted single 75 cm high blackberry plant as a resting site for adult flies. One hundred adults, 50 females and 50 males, of *D. suzukii* (4 days-old and not starved) were released inside the cage using an entomological aspirator. Twenty-three hours later, the total numbers of flies captured in each trap were counted and sorted by sex. A set of 100 new adult flies were used for each replicate. A total of three replicates were performed by changing the position of the trap sequentially so that each trap was tested for a 23 h period in all positions within the cage. Three cages were used simultaneously (n = 9).

2.4.2. *Field trials*

This trial was carried out in a blackberry crop (Table 1). Following a similar methodology (2.4.1), both Fly Buster Powder® and 2C trap attractants were aged for 1, 7, and 15 days in the laboratory. Aged Fly Buster Powder® and 2C trap attractants were tested independently in three different blocks within the same multi-span polytunnel. Plastic traps were baited with 200 ml of each of the three aging periods (1, 7 and 15 d) and hung randomly within each block at 1.7 m above the ground in metal stakes as described above. The traps were randomly distributed in a crop line at 30 m between traps and 36 m between blocks. Traps were checked every 24 h and trapped flies were transferred to the laboratory where the total number of drosophilid flies were counted and *D. suzukii* adults were sorted by sex. After inspection, attractants were replaced, and traps rotated to the next position within each block to minimize the position effect. The experiment lasted three days so each attractant was tested in all positions (n = 9).

2.6. *Data analysis*

A high variation was observed among crops and trials, so they were analyzed independently. The mean number of *D. suzukii* flies trapped with different food attractants was subjected to a two-way analysis of variance (ANOVA) with attractants and fly sex as fixed effects and blocks as random effects. The water control trap was not included in the analysis due to the null capture of flies in all trials. The specificity of attractants, measured as the ratio of *D. suzukii* flies divided by the total number of drosophilids captured per trap, was subjected to a one-way ANOVA with attractant as fixed effect. The mean numbers of SWD trapped with aged attractants evaluated under laboratory and field conditions were analyzed by a two-way ANOVA with treatment and sex as fixed effects. Female and male flies trapped with aged attractants were compared by Student t-test. For ANOVA, means separation was performed by a Tukey HSD test. Box-Cox transformation was applied to solve problems of normality and homoscedasticity when required. All analyses were performed using the software R v3.6.3 (R Core Team, 2020).

3. Results

3.1. *Field trials of food-based attractants efficacy*

On blackberry (Fig. 2A), a total of 35,908 drosophilid flies were captured, of which 8294 (23.1%) were *D. suzukii*, with 3939 were captured in trial A and 4355 in trial B. Significant differences in the mean number of total *D. suzukii* flies among attractants were found for trial A ($F = 11.91$; $df = 4, 190$; $P < 0.0001$) and trial B ($F = 23.31$; $df = 4, 182$; $P < 0.0001$) (Fig. 2A). In both tests, Fly Buster Powder® captured a significantly higher number of flies than the 2C trap, Suzukii Trap® Max Capture, ACV and Pherocon® SWD. No statistical differences were observed in the trial A for sex ($F = 0.33$; $df = 1, 190$; $P = 0.56$), with no significant sex*attractant interaction ($F = 1.38$; $df = 4, 190$; $P = 0.23$). In contrast, significant differences between sexes ($F = 74.82$; $df = 1, 182$; $P < 0.0001$), but not for the interaction of attractant*sex ($F = 1.55$; $df = 4, 182$; $P < 0.18$), were recorded in trial B. In this trial 2, 48.7% females were trapped in comparison to 51.3% males.

In raspberry (Fig. 2B), a total of 22,516 drosophilid adult flies were

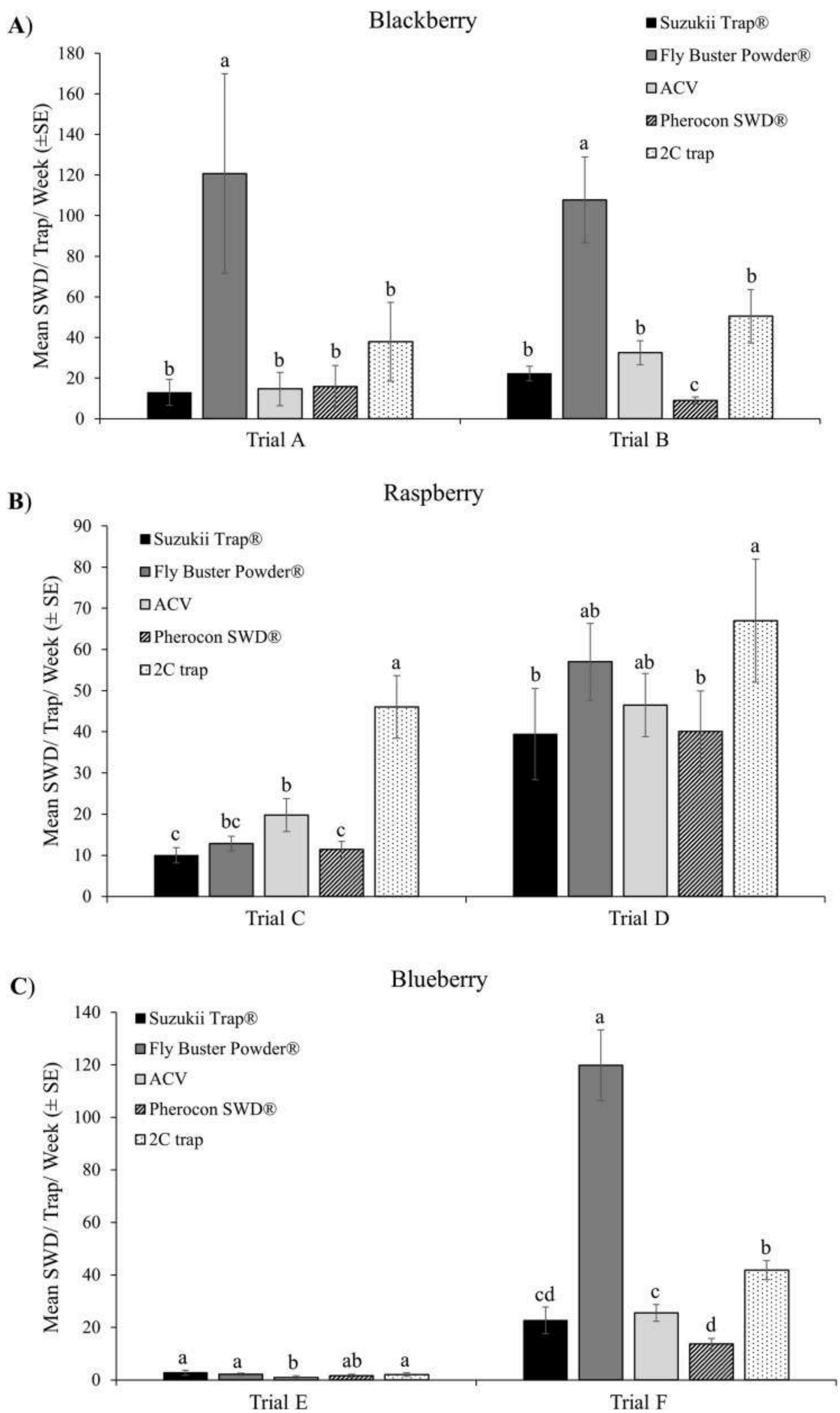

Fig. 2. Mean of *D. suzukii* capture with the five different attractants in blackberry (A), raspberry (B), and blueberry (C). Columns with the same letter within each test are not significantly different (Tukey's test, $P > 0.05$). Suzukii Trap® = SuzukiiTrap® Max Captures.

captured, of which 6946 were *D. suzukii*, with 4943 in trial C and 2003 in trial D. In trial C, 2C trap captured a significantly higher mean number of flies than all attractants evaluated ($F = 3.86$; $df = 4, 188$; $P < 0.01$), while in trial D, 2C trap captured a significantly higher mean number of flies than only the Suzukii Trap® Max Capture and Pherocon® SWD attractant ($F = 26.63$; $df = 4, 190$; $P < 0.0001$). In trial C, statistical differences between sexes were recorded ($F = 22.13$; $df = 1, 188$; $P < 0.0001$) with no significant sex*attractant interaction ($F = 1.45$; $df = 4,$

188; P = 0.216). In this trial, 36.3% females and 63.7% males were trapped. In trial D, there were no statistical differences between sexes (F = 0.01; df = 1, 190; P = 0.901), with no significant interaction of sex*attractant (F = 0.22; df = 4, 190; P = 0.923).

For blueberry (Fig. 2C), a total of 12,657 drosophilids adult were captured, of which 4659 (36.8%) were *D. suzukii*, with 189 were captured in trial E, and 4470 in trial F. In trial E, an unusually low number of *D. suzukii* flies were captured. Fly Buster Powder®, 2C trap, and Suzukii Trap® Max Captures trapped a significantly higher mean number of flies than ACV, with Pherocon® SWD having intermediate

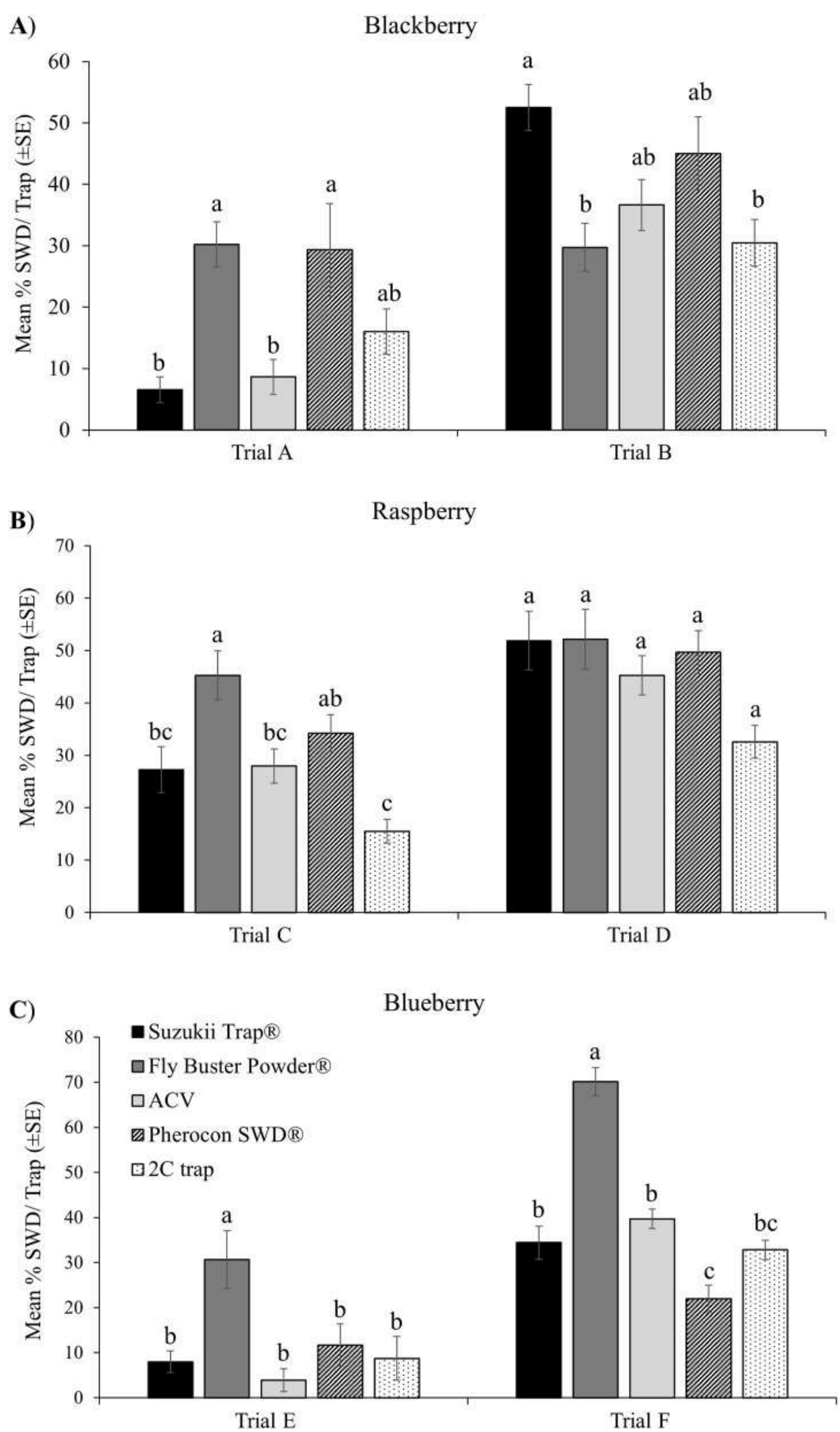

Fig. 3. Mean percentage of *D. suzukii* in relation to the total number of drosophilid flies captured with the five different attractants in blackberry (A), raspberry (B) and blueberry (C). Columns with the same letter within each test are not significantly different (Tukey's test, P > 0.05). Suzukii Trap® = SuzukiiTrap® Max Captures.

captures ($F = 5.17$; df = 4, 190; $P < 0.001$). No statistical differences between sexes ($F = 1.14$; df = 1, 190; $P = 0.28$) were observed and no significant interaction of sex*attractant ($F = 0.30$; df = 4, 190; $P = 0.87$) were detected. In contrast in trial F, Fly Buster Powder® captured a significantly higher mean number of flies than all other attractants evaluated ($F = 70.0$; df = 4, 190; $P < 0.001$) and statistical differences were observed between sexes ($F = 8.35$; df = 1, 190; $P = 0.04$), but the number of captures by sex was not related to the attractant type ($F = 4.23$; df = 4, 190; $P = 0.08$). In this trial, 47% females and 53% males were trapped.

In blackberry crops (Fig. 3A), significant differences were observed in the specificity among attractants in both trials (trial A: $F = 6.48$; df = 4, 95; $P < 0.0001$ and trial B: $F = 4.88$; df = 4, 91; $P < 0.001$). In trial A, Fly Buster Powder®, Pherocon® SWD and Suzukii Trap® Max Captures have greater specificity, while in trial B, Pherocon® SWD, SuzukiiTrap® Max Captures, and ACV showed the most specificity.

In raspberry crops (Fig. 3B), significant differences were observed in the specificity among attractants in both trials (trial C: $F = 8.55$; df = 4, 95; $P < 0.0001$ and trial D: $F = 3.16$; df = 4, 94; $P < 0.001$). In trial C, Fly Buster Powder® and Pherocon® SWD showed the greatest specificity, while in trial D the major specificity was observed in Fly Buster Powder® and Suzukii Trap® Max Captures.

Finally, significant differences were also observed in specificity among attractants in both trials carried out in blueberry crops (trial E: $F = 5.54$; df = 4, 95; $P < 0.001$ and trial F: $F = 39.8$; df = 4, 95; $P < 0.001$). Fly Buster Powder® significantly recorded the highest percentage of SWD in both trials with 30.1% in trial E and 69.6% in trial F (Fig. 3C).

In general, except for trial B in blackberry, Fly Buster Powder® attracted the greatest proportion (30–70%) of *D. suzukii* (Fig. 3), followed by Pherocon® SWD, Suzukii Trap® Max Captures, 2C trap and ACV.

3.2. Laboratory bioassays and field trials of aged yeast-based attractants

3.2.1. Laboratory bioassays

The capture of D. suzukii adults with Fly Buster Powder® was significantly higher when it was aged for 7-days than when aged for 1 or 15-days ($F = 33.55$; df = 2, 24; $P < 0.001$) (Fig. 4A). The capture of D. suzukii with the 2C trap attractants was significantly higher when aged for 7-days and 15 days ($F = 36.86$; df = 2, 24; $P < 0.001$) than when aged for 1-day (Fig. 4B). For 2C trap attractants, no significant differences for sexes were observed for any of the aging periods ($F = 2.6$; df = 1, 84; $P = 0.10$), with no significant interaction of attractant age*sex ($F = 1.59$; df = 2, 84; $P = 0.20$). For Fly Buster Powder®, a significant difference was observed between sexes ($F = 50.44$; df = 1, 84; $P < 0.001$) with significant attractant age*sex interaction ($F = 4.88$; df = 2, 84; $P = 0.02$). Fly Buster Powder® aged for 7-days captured 2.5-times more females (total = 196, mean = 21.7 flies per trap) than males (total = 78, mean =

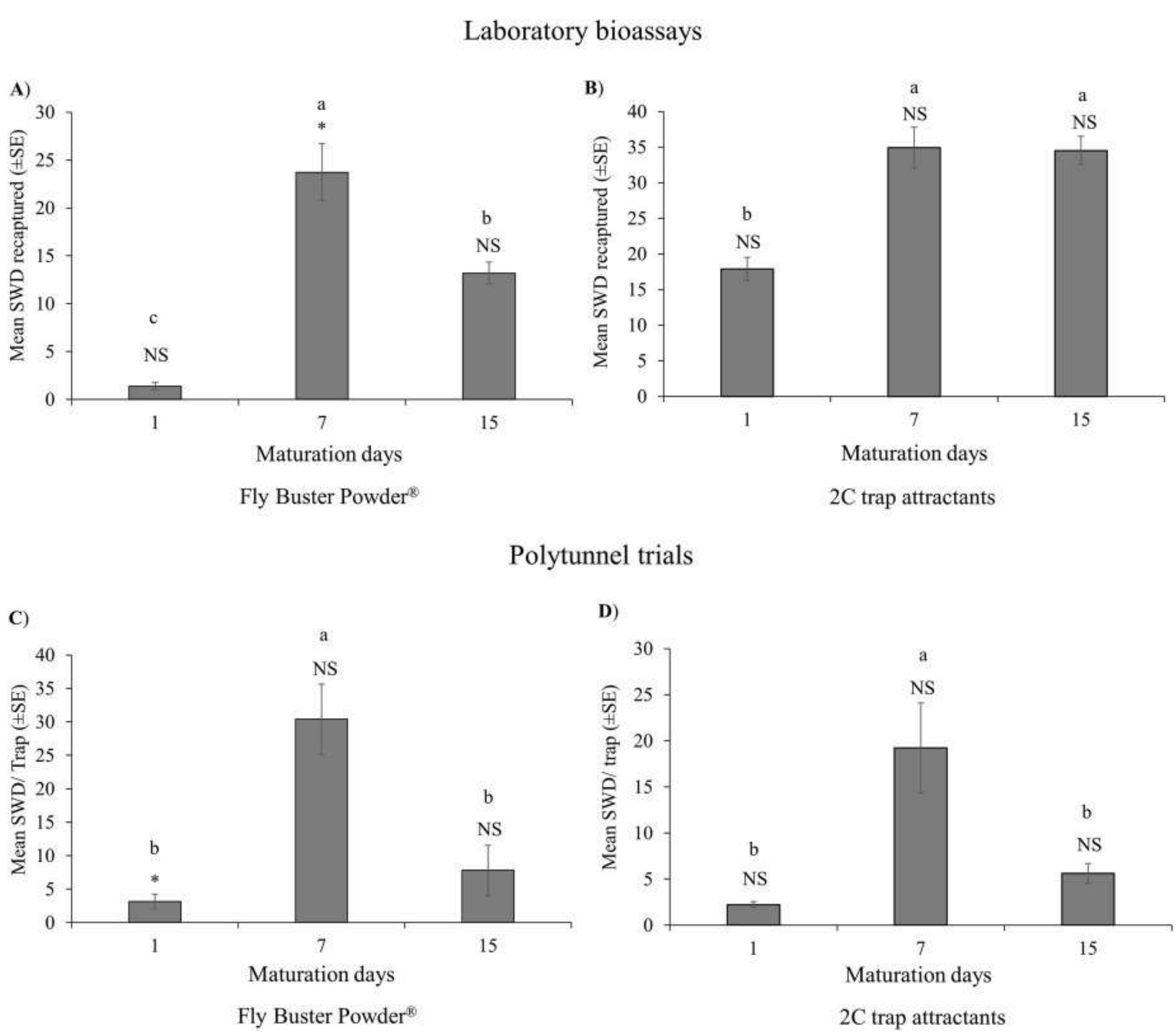

Fig. 4. Mean of *D. suzukii* captured with Fly Buster Powder® (A and C) and 2C trap attractants (B and D) when aged for 1, 7 and 15 days. A) and B) correspond to laboratory bioassays and C) and D) to blackberry polytunnel trials. Columns with different letters are significantly different (Tukey's test, $P < 0.05$). Asterisks above the bars indicate statistical differences between sexes and NS, no significant differences (Student *t*-test, $P > 0.05$).

8.6 flies per trap) ($t = 2.26$, $df = 22.06$, $P = 0.034$) (Fig. 4A). No significant differences were observed between the mean number of males and females trapped with Fly Buster Powder® aged for 1-day or 15-days.

3.2.2. Field trials

Under polytunnel conditions, Fly Buster Powder® aged for 7 days had also a significantly higher SWD capture than when aged for 1 or 15 days ($F = 19.50$; $df = 2, 24$; $P < 0.0001$, Fig. 4C). In a similar way, the 2C trap attractant had significantly higher capture of D. suzukii flies when aged for 7 days in comparison with the attractant aged for 1 and 15 days (Fig. 4D, $F = 14.01$; $df = 2, 24$; $P < 0.001$). Significant differences between sexes were observed for aged Fly Buster Powder® ($F = 6.60$; $df = 1, 48$; $P = 0.01$) with no significant attractant age*sex interaction ($F = 1.58$; $df = 2, 48$; $P = 0.21$). No significant differences between males and females were observed after 2C trap attractants were aged for 1, 7 and 15 days in the field ($F = 2.31$; $df = 1, 48$; $P = 0.13$), with no significant attractant age*sex interaction ($F = 1.14$; $df = 2, 48$; $P = 0.32$) (Fig. 4D).

The specificity for Fly Buster Powder® ($F = 3.36$; $df = 2, 24$; $P = 0.05$) and 2C trap attractant ($F = 3.99$; $df = 2, 24$; $P = 0.03$) varied with maturation days (Fig. 5). A higher specificity to *D. suzukii* was recorded for Fly Buster Powder® when aged for 7 day (71.7%) than when aged for 15 days (32.6%), with intermediate specificity when aged for 1 day (53.6%) (Fig. 5A). For the 2C trap attractants, a similar higher specificity was recorded when aged for 1 (75.4%) than when aged for 15 days (49.7%), with intermediate specificity when aged for 7 days (71.0%) (Fig. 5B). For both attractants, the lowest specificity was recorded after 15 days of maturation.

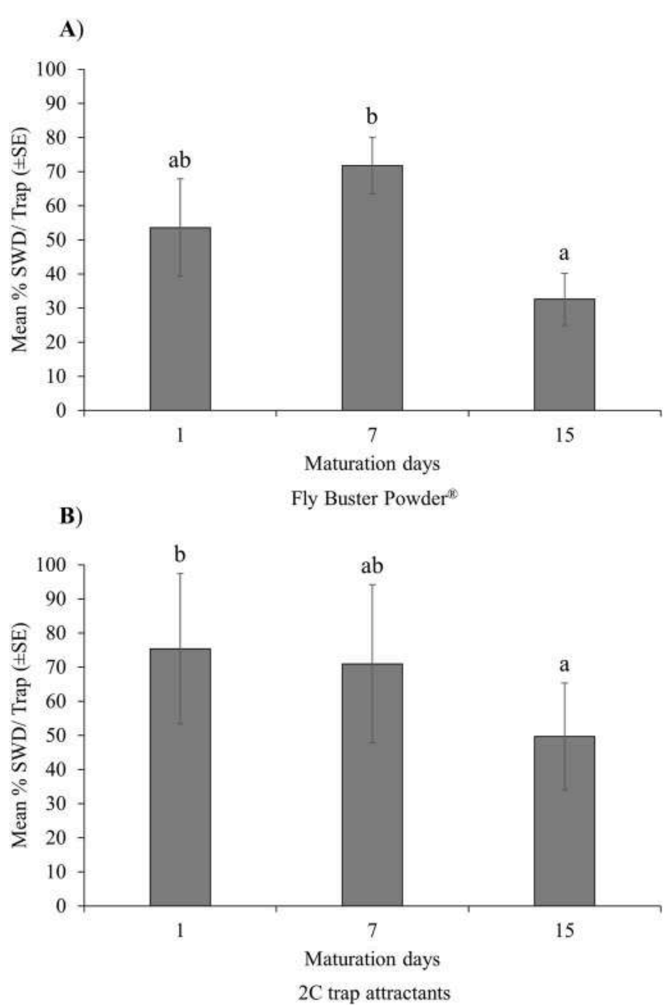

Fig. 5. Mean percentage of *D. suzukii* in relation to the total number of drosophilid flies captured with Fly Buster Powder® (A) and 2C trap attractants (B) aged for 1, 7 or 15 days. Columns with the same letter within each trial are not significantly different (Tukey's test, $P > 0.05$).

4. Discussion

In this study, we found a variable response in the attraction of flies to different food attractants depending on crops and trials, but two active yeast based-attractants, Fly Buster Powder® and 2C trap attractants, were in general more effective in the capture of *D. suzukii* flies than Suzukii Trap® Max Captures, Pherocon® SWD or the standard ACV. The two component 2C trap attractants were more effective in capturing *D. suzukii* adults than ACV and Suzukii Trap® in previous experiments carried out in blackberry crops of this growing area (Lasa et al., 2017a). Here, Fly Buster Powder® was more effective than the 2C trap attractants in blackberry and blueberry crops, but not in raspberry crops, where the 2C trap attractants had a similar or even better capture of *D. suzukii* flies. Why 2C trap attractants and Fly Buster Powder® attracted differently in blackberry and raspberry crops are unknown but reinforce previous experiments in which the crop species and location significantly interact with the efficacy of attractants (Burrack et al., 2015; Lee et al., 2012; Marcus, 2014). Volatile compounds of blackberry and raspberry fruits are quite different (Abraham et al., 2015; Dewitte et al., 2021), which influences the complex crop volatile environment, causing this discrepancy of attraction. However, despite the variability observed in our experiments, in general our data support previous studies in which attractants based on active baker's yeast (*S. cerevisiae*), were more attractive for *D. suzukii* during the fruit harvest period than ACV, Suzukii Trap® and other artificial mixture attractants such as Pherocon® SWD or Scentry® Lure (Iglesias et al., 2014; Jaffe et al., 2018; Lasa et al, 2017a, 2019a). Frewin et al. (2017) showed that Scentry® Lure and Pherocon® SWD captured similar numbers of *D. suzukii* flies than active yeasts earlier in the growing season in blueberry and raspberry, but the captures with active yeast based-attractants outperformed both commercial lures throughout the harvest period in blueberry. In contrast, Harmon et al. (2019) found that yeast-based attractants were attractive to *D. suzukii* early in the season during fruit development in the field, while Scentry® Lure and Pherocon® SWD captured more *D. suzukii* flies throughout the season in blueberry and blackberry.

In Central Mexico, active yeast-based attractants seem to be the best option to capture SWD adults, at least throughout the harvest period. Fermentation products serve as attractants because yeasts are involved as a food source for larval development and positively interact with adult courtship and female egg production (Hamby et al., 2012). A raspberry pulp + sucrose solution used by growers and fermented with their own raspberry yeasts present on fruits was also significantly more effective in the capture of *D. suzukii* adults than traps baited with ACV (Lasa et al., 2019a). However, additional experiments revealed that specific strains of *S. cerevisiae* and *H. uvarum* isolated from blackberry and raspberry fruits do not outperform standard baker yeast *S. cerevisiae* under polytunnel field conditions (Lasa et al., 2019b).

In addition to the efficacy, the specificity of attractants for *D. suzukii* under different environmental crop conditions is a critical component considered by growers to adopt a certain trapping system for SWD fly monitoring (Cha et al, 2013, 2018; Cloonan et al., 2018). Our study showed high SWD specificity of Fly Buster Powder® in almost all crops and experiments, with SWD percentages varying between 30 and 70% of the total number of drosophilids adults captured. In almost all experiments, the specificity of Fly Buster Powder® was also significantly higher than for the other attractants tested, even after not being renewed for 4 weeks. However, the specificity of attractants for *D. suzukii* is reported to be variable and is difficult to compare among studies because a lower relative prevalence could sometimes be related to the presence of fallen damaged fruits that were rapidly exploited by other drosophilid species (Lasa et al., 2017b), something that is dependent on several factors including crop, damage, and orchard management. In some studies on different trap-attractant combinations, *D. suzukii* comprised less than 33% of trapped drosophilid flies (Basoalto et al., 2013; Iglesias et al., 2014; Lee et al., 2012) or above 50% (Landolt et al., 2012a,b; Lasa et al., 2017a). Although these differences make specificity comparison difficult among studies, both Suzukii Trap® and Pherocon® SWD have been considered very selective attractants when compared with other attractants such as ACV (Frewin et al., 2017; Tonina et al., 2018). In our experiments, Fly Buster Powder® was also more selective than ACV and similar or even more selective than Suzukii Trap® Max Captures and Pherocon® SWD.

When Fly Buster Powder® or 2C trap attractants were aged for 7 days, they were significantly more attractive under field conditions than when attractants were aged for one day or 15 days. After 15 days deployed in the field, both Fly Buster Powder® and 2C trap attractants also reduced specificity to *D. suzukii*. A particularly putrefied odor (to the human nose) was noted for Fly Buster Powder® at this time probably due to the presence of sodium bicarbonate as a catalyst, something that could be responsible for that characteristic odor.

To our knowledge, this is the first study that has evaluated Fly Buster Powder® as a *D. suzukii* attractant. Our results indicate that Fly Buster Powder® and 2C trap attractants are effective and partially selective for this pest in the neotropics when compared with standard ACV. However, the capture rate and specificity were significantly reduced after 15 days aged under laboratory conditions. This suggest that captures of this pest may be highly variable using these attractants under different climatic conditions. As the use of time-stable attractants improves the reliability of monitoring over time and generally reduces costs, future studies should focus on improving the stability of these attractants under field conditions. Additionally, future experiments could explore the use of this attractants to reduce this pest with other control strategies, such as mass trapping (Hampton et al., 2014) attract-and-kill (Rice et al., 2017), push-pull scheme (Wallingford et al., 2018) or the auto-dissemination of entomopathogenic fungi (Yousef et al., 2018).

Declaration of competing interest

The authors declare that they have no financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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