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Article

Evaluation of Mass Trapping Devices for the Control of the European Cherry Fruit Fly [*Rhagoletis cerasi* (L.)]

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Abstract: *Rhagoletis cerasi* (L.) is the most damaging pest of cherries in Europe and Western Asia and it has been recently introduced in North America. Females sting the ripening cherries and tolerance of damaged fruit is very low (<2%). The management of this pest is mainly based on insecticide applications near harvest. Only a few insecticides are authorized for this use in Europe, and repeated use of them likely entails environmental risks, resistance to insecticides and residues in the fruit. Therefore, alternative tools are needed. Trap-attractant combinations were compared on searching an efficient and economical device for a viable mass trapping method against *R. cerasi* on a large-scale use. A folded yellow sticky trap with a homemade ammonium acetate dispenser was the most efficient and also the cheapest one. The efficacy of mass trapping using this device was evaluated in farm-scale trials. With low pest pressure, mass trapping was sufficient to obtain commercially acceptable fruit. With high pest pressure, mass trapping reduced the number of insecticide (spinosad) applications while keeping damage below the economic threshold. Therefore, mass trapping can be a useful tool for managing *R. cerasi* and reducing insecticide application.

Keywords: *Rhagoletis cerasi*; mass trapping; cherry; ammonium acetate

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1. Introduction

The European cherry fruit fly, *Rhagoletis cerasi* (L.) (Diptera: Tephritidae), is the most damaging pest of sweet cherry crops [*Prusus avium* L. (Rosaceae)] in Europe and Western Asia [1]. Recently, *R. cerasi* has been introduced in North America [2] and it is likely to spread in most of the cherry producing areas of the USA, as well as to other cherry growing countries and regions such as China, Japan, the Koreas, Australia, New Zealand, South America, South Africa, Mexico, and Canada [3]. *Rhagoletis cerasi* is an oligophagous and univoltine species with a biological cycle synchronized with cherry tree phenology. Larvae pupate into the soil where they undergo a marked diapause, adults emerge in spring and females are ready for oviposition when fruits are ripening. The female of this species lays the egg under the cherry cuticle and the larva feeds in the mesocarp and spoil the fruit [1,4]. Only 2% of attacked fruits in a lot is enough for it to be rejected for the market and, without adequate control, the whole production may be lost [5].

Currently, control of *R. cerasi* in conventional cherry production is based on chemical insecticide treatments. Dimethoate spraying was the most common practice in Europe against this pest and since its recent prohibition other chemical insecticides, mainly the neonicotinoid acetamiprid and the pyrethroids lambda-cyhalothrin and deltamethrin, have replaced it [1]. Anyway, it is not easy to carry out a rational control of this pest since several insecticide applications close to harvest are often required to ensure the low infestation rates tolerated. Meanwhile to maintain a low level of residues in the fruit is needed [6]. Hence, growers tend to make preventive insecticide applications, therefore using a control strategy which does not fit well with IPM principles [1,7]. In organic cherry orchards, management of *R. cerasi* is more challenging since chemical insecticides are not authorized and hardly any other effective control tools are available.

Several cultural, mechanical, and biological tools for managing this pest have been developed. However, these practices are sometimes not enough to limit damage to the fruit or their use is very limited due to practical or economic disadvantages [1,8–14]. Bait sprays based on the naturally derived insecticides neem and spinosad showed promising results in field cages trials [15]. In some European countries as Italy, a spinosad-based adulticide bait [Spintor-Fly® (spinosad 0.024%)] that is authorized against *R. cerasi* has proved to be very effective in controlling the pest, although its large-scale use could be limited by its low persistence [16]. On the contrary, in Spain and other European countries, spinosad bait formulations are not registered for *R. cerasi*, but conventional total sprays of spinosad [Spintor 480 SC (spinosad 48%)] are authorized against this pest, to a maximum of two applications per season [17].

Mass trapping is used against various fruit flies, especially in organic fruticulture and many different traps are available on the market. The efficacy of this method is often based on high trap density and therefore, mass trapping will only be applicable if the device used achieves high capture efficiency at a low cost. Despite its high cost, mass trapping is the most applied practice against this pest in organic cherry orchards due to the lack of other authorized alternatives [1]. After several studies to determine the most efficient type of trap for detection and monitoring of *R. cerasi*, it was found that yellow traps bearing a sharp increase of reflectance in the 500 to 520 nm region were found to be the most attractive for adults of this species. Based on this knowledge, the three-dimensional, cross-shaped Rebell® Amarillo trap was developed in the 1970s and has been used in many places as reference for mass trapping and monitoring of *R. cerasi* [18,19]. Later on, Katsoyannos et al. [20] carried out comparison trials of various traps and attractants, showing that the Rebell® Amarillo traps were the most effective for monitoring *R. cerasi* and also that their effectiveness was improved when combined with an ammonium acetate dispenser. For the control of *R. cerasi*, some authors have recommended the hanging, in the southeast side of the canopy, from 1 to 8 traps per tree, depending on the size of the trees, what makes implementation of mass trapping using the Rebell-type trap hardly affordable [1]. Looking for more efficient and economical traps, Daniel et al. [21] tested yellow panels of various hues together with traps with different shapes and found out that traps with a strong increase in reflectance at 500–550 nm and a secondary peak in the UV region at 300–400 nm captured significantly more flies than the standard Rebell® Amarillo trap. They also observed that the shape of the trap was of minor importance, provided it was three-dimensional and visible from all directions. Accordingly, and based on economic and practical considerations, they developed the cylinder-shaped trap "UFA-Samen Kirschenfliegenfalle". Recently Bayer CropScience has developed the ready-to-use device Decis® Trap Cerasi for monitoring and mass trapping *R. cerasi*. In this trap, the transparent top part is internally impregnated with the insecticide deltamethrin as killing agent and the hemispherical, orange coloured lower part carries an attractant dispenser (filled in with ammonium carbonate). According to published results of large-scale field trials with this device, a density of 100 traps/ha reduced damage drastically even under high pest pressure [22]. Some other recent studies have been aimed to the search for more effective attractants for *R. cerasi*. Thus, satisfactory control results have been obtained in field trials with yellow Rebell traps combined with a dispenser containing a mixture of ammonium acetate and ammonium carbonate, as well as putrescine (added in a separate container) [23]. On the other hand, the production of a sexual male pheromone attractive for females has been known since the 70s, but its exact composition has not yet been established [24,25]. Ongoing research in this regard has shown promising results on field trials with male volatile compounds [26,27].

This study undertakes the comparison of 14 trap-attractant combinations, over four years of field trials, to select the best mass trapping method for *R. cerasi* according to its cost-effectiveness ratio. These trials included both effective devices against other fruit flies available in the market and cheaper combinations of homemade traps and attractants. Subsequently, that device best meeting the cost and efficiency requirements was subject of larger-scale field tests to verify the usefulness of the mass trapping method in reducing the damage caused by this pest in cherry orchards.

2. Materials and Methods

2.1. Comparison of Traps and Attractants

The capacity to capture *R. cerasi* adults of different traps and attractants was compared in 4 different field trials, during the flight periods (June–July) of the years 2014, 2015, 2016 and 2017. These trials were carried out in a commercial cherry orchard located in Lagunilla (Salamanca, Spain) (40°20′03′′ N 5°57′02′′ W, approximately 930 m a.s.l.) which was selected for its record of high incidence of this pest. The cherry trees (*P. avium*) in the test orchard were 11–15 years old and of the late varieties "Sweet Heart" and "Lapins". The following capture devices were tested (Figure 1):

1. Folded yellow sticky trap: "Econex Cromática Amarilla" (20 × 25 cm) roof shape like, exposing its glued surface on the underside (Econex, Murcia, Spain). The baits were hung, with a wire, in the center of the trap underside. Approximate price: 0.5 €/trap. Two different baits were combined with this trap:
    a. Econex *Rhagoletis cerasi* 90 days: Food attractant dispenser of unknown composition (Econex, Murcia, Spain). Approximate duration: 90 days. Price: 4.8 €/dispenser.
    b. Homemade ammonium acetate dispenser: Two 3 mm hole perforated polythylene Ziploc® bag (6 × 4 cm), filled in with 15 g of ammonium acetate (Labkem, Barcelona, Spain). Approximate duration: 60 days. Price: 0.3 €/dispenser.
2. Decis® Trap Cerasi: A ready-to-use dry trap with a transparent top part internally impregnated with deltamethrin as a killing agent (Bayer CropScience International, Monheim am Rhein, Germany). The attractant is placed in the lower part, which is hemispherical, orange in color and bearing four lateral holes. Appoximated price: 3.5 €/trap. Two different baits were combined with this trap:
    a. Econex Rhagoletis cerasi 90 days.
    b. Homemade ammonium acetate dispenser.
3. Cera Trap® bottle trap: 1.5 L plastic bottle with four 8 mm diameter equidistant holes in the upper third of the bottle and baited with its own attractant Cera Trap® (hydrolysed proteins 5.5%) (Bioibérica, Barcelona, Spain). Approximate duration: 90 days. Price: 3.5 €/trap.
4. Magnet® MED: Attract-and-kill device consisting of a deltamethrin impregnated paper envelope that incorporates two membrane dispensers with trimethylamine and ammonium acetate as attractants (Suterra Europe, Valencia, Spain). Approximate duration: 6 months. Price 5.2 €/trap. In order to evaluate and compare the effectiveness of this trap, its outer shell was covered with insect glue. In this way, the attracted insects remained stuck in the trap and were counted.
5. Easy trap®: Made up of two rectangular plastic halves (one yellow and the other transparent), each bearing one of the two 12 mm holes, placed one in front of the other (Sorygar, Madrid, Spain). Price: 1.5 €/trap. This trap was tested with three different attractants:
    a. Biocebo®: Liquid attractant (hydrolyzed protein 30%) (Bioibérica, Barcelona, Spain), at 9%. Price: 4 €/l.
    b. Econex *Rhagoletis cerasi* 90 days.
    c. Homemade ammonium acetate dispenser.

    Econex *Rhagoletis cerasi* 90 days and homemade ammonium acetate dispensers were placed inside the trap, hanging down from the upper end by means of a wire. The trap contained some water with a few drops of detergent to prevent scape of incoming flies.
6. Tephri-trap ecological®: A yellow cylindrical trap with a funnel at the botton and four lateral holes (Sorygar, Madrid, Spain). The inlet holes are provided with nets (6 mm mesh size) to prevent the entry of larger beneficial insects. Price: 2.5 €/trap. Two baits were evaluated with this trap:

   a. Econex Rhagoletis cerasi 90 days.
   b. Homemade ammonium acetate dispenser.

   In both cases, baits were hung inside the trap, which was filled with soapy water to trap incoming flies.

7. Olipe trap: 1.5 L PET bottle with five 6 mm diameter lateral holes, set and equidistant around the middle of the bottle height. Price: 0.5 €/trap. Inside the trap, a homemade ammonium acetate dispenser was hung and some water with a few drops of detergent was put in order to retain captured flies.
8. Econex Bottle Trap: 1 L PET bottle with four 12 mm diameter lateral holes provided with yellow and truncated-cone shaped inserts helping flies enter while making it difficult find an a way out (Econex, Murcia, Spain). Price: 2.5 €/trap. Two baits were evaluated with this trap:
   a. Econex Diammonium Phosphate RC: Diammonium phosphate dosed in 25 g sachets. The content of each sachet works in solution with 250 mL of water. Price: 0.6 €/sachet.
   b. Ceratinex®: Food attractant (45% Torula yeast, 45% Borax) in the form of water-soluble tablets (to solve 4 or 5 tablets with 500 mL of water) (Econex, Murcia, Spain). Price: 0.4 €/tablet.

Figure 1. Traps tested for *Rhagoletis cerasi* mass trapping: Folded yellow sticky trap (**1**), Decis® Trap Cerasi (**2**), Cera Trap® bottle trap (**3**), Magnet® MED (**4**), Easy trap® (**5**), Tephri-trap ecological® (**6**), Olipe trap (**7**) and Econex Bottle Trap (**8**).

The prices provided for traps and attractants are those found in August 2022. When several offers were found, the average was taken. The traps containing liquids were refilled every two weeks.

At every trial, 4–6 repetitions of each trap and attractant combination (Table 1) were distributed following a random block design. Each block consisted of a repetition of each device placed along a row of cherry trees, every third tree, being 5 m the separation between rows and 4 m the distance between trees of the same row. Traps were hung from cherry tree branches SE oriented (since it is the area of the tree canopy most frequently visited by the adults of this species) and at an approximate height of 1.5 m. Test rows (blocks) were placed every other row of cherry trees. Traps were checked every two weeks to count and remove the captured insects and then refill the traps with the solutions, if necessary. Due to the different duration of the trials (Table 1), in 2014, 2015 and 2016, three intermediate inspections were carried out between the placement and removal of the traps, while only two intermediate inspections were carried out in 2017.

Table 1. Characteristics of field trials to compare the efficacy of traps and attractants for mass trapping European cherry fruit fly.

Trials (Dates [1])	**Devices [2]**	**N [3]**
2014 (29/05–28/07)	Cera Trap® bottle trap Magnet® MED Easy trap® + Biocebo® Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days Folded yellow sticky trap + Homemade AmAc. dispenser	6
2015 (29/05–27/07)	Cera Trap® bottle trap Easy trap® + Biocebo® Decis® trap + Econex *Rhagoletis cerasi* 90 days Decis® trap + Homemade AmAc. dispenser Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days Folded yellow sticky trap + Homemade AmAc. dispenser	4
2016 (03/06–29/07)	Cera Trap® bottle trap Olipe trap + Homemade AmAc. dispenser Easy trap® + Econex *Rhagoletis cerasi* 90 days Easy trap® + Homemade AmAc. dispenser Tephri-trap ecological® + Econex *Rhagoletis cerasi* 90 days Tephri-trap ecological® + Homemade AmAc. dispenser Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days Folded yellow sticky trap + Homemade AmAc. dispenser	5
2017 (26/05–07/07)	Econex Bottle Trap + Econex Diammonium Phosphate RC Econex Bottle Trap + Ceratinex® Folded yellow sticky trap + Homemade AmAc. dispenser	6

[1] In brackets, the dates of placement and removal of traps. [2] AmAc.: Ammonium acetate. [3] Number of replicates in each trial.

To estimate the cost of the mass trapping method with each tested device, both the prices of traps and attractants as well as the handling costs have been taken. These handling costs include the costs associated with the preparation of the attractant diffusers, the assembly of the traps and the placement, maintenance and removal of the devices. The estimated times for these tasks are based on our own experience and that of the farmers who collaborated in these trials. For these works, a cost of 8 €/h has been taken (the average in the test areas). The total costs per hectare are calculated for one trap hung from each tree, with a density of 500 trees per ha (average in the field trial areas).

2.2. Evaluation of Mass Trapping Efficacy

The efficacy of the mass trapping method for controlling the European cherry fruit fly was evaluated in four field trials held on commercial cherry orchards of three cherry-growing Spanish regions (Table 2).

One trap per tree was hung in the south-eastern side of the canopy at a height of approximately 1.5 m. Traps were placed one week before the predicted dates of fly emergence and removed right after harvest time (throughout June and July, depending on the location, year and cultivar). Plots contiguous and with similar characteristics to each of the mass trapping ones were used as controls.

To monitor *R. cerasi* populations, every week, the captured flies were counted in five traps of the mass trapping plots and in another five traps, of the same type, that had been placed in each control plot for this purpose. When the threshold of one adult captured/trap and week (average of the five monitored traps) was exceeded at one plot, a spinosad treatment (Spintor 480 SC (48%)) (Corteva Agriscience) was carried out, with a maximum of two annual treatments per plot. At harvest time, the damage produced by *R. cerasi* was evaluated in each plot, obtaining the percentage of attacked fruits, from around 400 cherries that were collected in each plot from 20 different trees (all of them standing both at the perimeter and inside the plots). The sampled cherries were examined in the laboratory under a stereomicroscope and those that presented at least one oviposition hole were counted as damaged fruits, regardless of whether or not they had larvae inside.

Table 2. Characteristics of the field trials evaluating the efficacy of mass trapping against the European cherry fruit fly.

Trial	Location (Coordinates) Altitude [1]	Dates [2]	Trap + Attractant [3]	Number of Trees (Area)
Rozas	Lagunilla (Salamanca) (40°20′00″ N 5°57′06″ W) 916 m a.s.l.	2017 (26/05–07/07)	Folded yellow sticky trap + Homemade AmAc. dispenser	450 (0.7 ha)
Cruz vieja	Lagunilla (Salamanca) (40°19′50″ N 5°57′04″ W) 923 m a.s.l.	2017 (26/05–07/07)	Folded yellow sticky trap + Homemade AmAc. dispenser	320 (0.6 ha)
Cañadilla	El Torno (Cáceres) (40°07′16″ N 5°56′19″ W) 449 m a.s.l.	2021 (6/05–08/07)	Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days	112 (0.4 ha)
Barrachina	La Almunia (Zaragoza) (41°27′07″ N 1°23′59″ W) 455 m a.s.l.	2021 (13/05–18/06)	Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days	106 (0.4 ha)

[1] a.s.l.: above sea level. [2] In parentheses, the dates of placement and removal of traps. [3] AmAc.: Ammonium acetate.

2.3. Statistical Analysis

To compare the efficacy of the different mass-trapping devices, data on fly captures were analyzed by a two-way ANOVA with "device" and "block" as factors. The Tukey post hoc test was used for mean separation. To evaluate the efficacy of the mass-trapping strategy, data on fly captures and percentages of attacked cherries were analyzed by a General Linear Model with "treatment" as fixed factor and "trial" as random factor. When necessary, data were previously transformed by ln(x + 1) for normality and homogeneity of variances. The level of significance was $p < 0.05$ in all cases. These tests were performed using the Statgraphics® Centurion XV software.

3. Results

3.1. Comparison of Traps and Attractants

Statistical analysis of the data on captures found significant differences among the different devices in all the trials ($F_{4, 20} = 11.44$, $p = 0.0001$ in 2014; $F_{5, 15} = 18.90$, $p < 0.0001$ in 2015; $F_{7, 28} = 9.02$, $p < 0.0001$ in 2016 and $F_{2, 17} = 19.75$, $p = 0.0003$ in 2017) (Table 3).

The folded yellow sticky trap registered the best results of *R. cerasi* captures in all trials and no significant differences were found between the two baits with which it was combined: Econex *Rhagoletis cerasi* 90 days and homemade ammonium acetate dispenser. Differences in catches between the folded yellow sticky trap and the other devices were generally very large (Table 3). However, in the 2016 trial, numbers of *R. cerasi* captured with this trap were not significantly different to those obtained with Tephri-trap ecological®, using the same two attractants, and with Easy trap®, using the homemade ammonium acetate dispenser. No significant differences were observed in the proportion of females captured by the different devices in any of the trials.

Table 4 provides the estimated costs of implementing mass trapping by using each of the compared devices (trap + attractant). The price of the different devices ranges between 0.8 and 8.3 €/unit, the lowest price corresponding to Folded yellow sticky trap + Homemade AmAc. dispenser and Olipe trap + Homemade AmAc. dispenser. Handling costs of the different devices were between 0.15 and 0.40 € per trap, the highest corresponding to devices containing liquids, which due to the evaporation, should be replenished. Considering a density of one trap per tree and 500 trees per ha, the estimated total cost ranges between 575 and 4250 €/ha. The lowest total costs also correspond to Folded yellow sticky trap + Homemade AmAc. dispenser and Olipe trap + Homemade AmAc. dispenser with 575 and 600 €/ha respectively.

Table 3. Flies captured in field trials to evaluate traps and attractants for mass trapping of the European cherry fruit fly.

Trials	Temperature and Rain [1]	Devices	Flies/Trap [2] ($\overline{X} \pm SE$)	% ♀
2014	20.5 °C 28 mm	Cera Trap® bottle trap	0.67 ± 0.42 a	75.0 ± 25.0 a
		Magnet® MED	0 a	-
		Easy trap® + Biocebo®	0.67 ± 0.33 a	50.0 ± 35.4 a
		Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days	4.00 ± 1.63 b	55.1 ± 16.2 a
		Folded yellow sticky trap + Homemade AmAc. dispenser	4.50 ± 1.09 b	52.4 ± 13.2 a
2015	24.1 °C 17 mm	Cera Trap® bottle trap	2.00 ± 0.41 a	45.8 ± 20.8 a
		Easy trap® + Biocebo®	0 a	-
		Decis® trap + Econex *Rhagoletis cerasi* 90 days	2.00 ± 0.82 a	58.3 ± 22.1 a
		Decis® trap + Homemade AmAc. dispenser	1.25 ± 0.48 a	66.7 ± 16.7 a
		Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days	26.25 ± 10.52 b	52.5 ± 4.2 a
		Folded yellow sticky trap + Homemade AmAc. dispenser	13.00 ± 2.16 b	49.8 ± 5.9 a
2016	23.6 °C 35 mm	Cera Trap® bottle trap	0 a	-
		Olipe trap + Homemade AmAc. dispenser	1.80 ± 0.73 ab	44.4 ± 17.2 a
		Easy trap® + Econex *Rhagoletis cerasi* 90 days	1.30 ± 0.93 ab	66.7 ± 29.1 a
		Easy trap® + Homemade AmAc. dispenser	5.40 ± 2.84 bc	40.7 ± 15.2 a
		Tephri-trap ecological® + Econex *Rhagoletis cerasi* 90 days	4.60 ± 1.89 bc	52.6 ± 20.5 a
		Tephri-trap ecological® + Homemade AmAc. dispenser	5.40 ± 1.36 bc	54.5 ± 6.7 a
		Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days	10.60 ± 3.20 c	49.1 ± 4.4 a
		Folded yellow sticky trap + Homemade AmAc. dispenser	15.60 ± 3.75 c	47.4 ± 4.6 a
2017	21.2 °C 94 mm	Econex Bottle Trap + Econex Diammonium Phosphate RC	0.50 ± 0.34 a	41.7 ± 0.73 a
		Econex Bottle Trap + Ceratinex®	0.67 ± 0.49 a	25.0 ± 0.73 a
		Folded yellow sticky trap + Homemade AmAc. dispenser	13.17 ± 3.24 b	33.3 ± 0.73 a

[1] Average temperature and accumulated rain along the trials; [2] Accumulated *R. cerasi* adults captured along de trial. In each trial, data followed by a different letter are significantly different (two-way ANOVA, α = 0.05).

Table 4. Estimated costs of the mass trapping strategy with the tested capture devices.

Devices	Price [1] (€/Device)	Handling Costs (€/Device) [2]			Total Cost [4] (€/ha)
		Preparation	Placement and Removal	Maintenance [3]	
Folded yellow sticky trap + Econex *Rhagoletis cerasi* 90 days	5.3	0.1	0.15	-	2775
Folded yellow sticky trap + Homemade AmAc. dispenser	0.8	0.2	0.15	-	575
Decis® trap + Econex *Rhagoletis cerasi* 90 days	8.3	0.05	0.15	-	4250
Decis® trap + Homemade AmAc. dispenser	3.8	0.15	0.15	-	2050
Cera Trap® bottle trap	3.5	-	0.15	-	1825
Magnet® MED	5.2	-	0.15	-	2675
Easy trap® + Econex *Rhagoletis cerasi* 90 days	6.3	0.05	0.15	0.1	3300
Easy trap® + Homemade AmAc. dispenser	1.8	0.15	0.15	0.1	1100
Easy trap® + Biocebo®	2.5	0.07	0.15	0.1	1410
Tephri-trap ecological® + Econex *Rhagoletis cerasi* 90 days	7.3	0.05	0.15	0.1	3800
Tephri-trap ecological® + Homemade AmAc. dispenser	2.8	0.15	0.15	0.1	1600
Olipe trap + Homemade AmAc. dispenser	0.8	0.15	0.15	0.1	600
Econex Bottle Trap + Econex Diammonium Phosphate RC	3.1	0.07	0.15	0.1	1710
Econex Bottle Trap + Ceratinex®	4.1	0.07	0.15	0.1	2210

[1] Total price of trap + attractant (August 2022). When several offers were found, the average was taken. [2] For a cost of 8 € per hour of work. [3] Refilling of liquid attractants, when necessary. [4] For one trap/tree and 500 cherry trees/ha.

3.2. Evaluation of Mass Trapping Efficacy

Flies captured in the monitoring traps, applications of spinosad and percentages of attacked fruits in the field trials to evaluate the efficacy of mass trapping against the European cherry fruit fly are showed in Table 5. At first glance, large differences are observed in cherry flies captured in the different tests ($F_{3,3}$ = 306.66, p = 0.0003). Besides, captures of *R. cerasi* were significantly lower at mass trapping plots than at the control ones ($F_{1,3}$ = 18.70, p = 0.0228), even though two spinosad applications were carried out both at two of the control plots (Rozas and Cruz Vieja) because the treatment threshold was exceeded, whereas only one treatment was necessary at the corresponding mass trapping plots. Figure 2 shows the evolution over time of the captures of *R. cerasi* and the timing of spinosad applications in two of the trials. A more rapid initial increase in the number of captures was observed in the control plots and this remained greater also in the controls until the end of the trials, despite a further application of spinosad. In the other two trials, these data have not been represented, due to the low catch values observed.

Table 5. Flies captured and percentages of attacked fruits in the field trials to evaluate the efficacy of mass trapping against *R. cerasi*.

Trial	Treatment	Captures (Flies/Trap) [1] $\overline{X} \pm$ SE	Spinosad Applications per Year	Damaged Cherries (%) $\overline{X} \pm$ SE (*n*) [2]
Rozas	Mass trapping	11.20 ± 2.44	1	0.99 ± 0.46 (421)
	Control	16.20 ± 2.76	2	2.03 ± 0.61 (432)
Cruz vieja	Mass trapping	6.80 ± 1.50	1	0.79 ± 0.43 (383)
	Control	11.20 ± 1.60	2	1.98 ± 0.56 (403)
Cañadilla	Mass trapping	0.20 ± 0.20	0	0.74 ± 0.40 (415)
	Control	0.60 ± 0.24	0	1.83 ± 0.70 (391)
Barrachina	Mass trapping	0.00 ± 0.00	0	0.20 ± 0.20 (494)
	Control	0.20 ± 0.20	0	0.47 ± 0.32 (443)

[1] Average accumulated captures of *R. cerasi* adults in the five traps of each plot. [2] Total number of cherries collected from each plot.

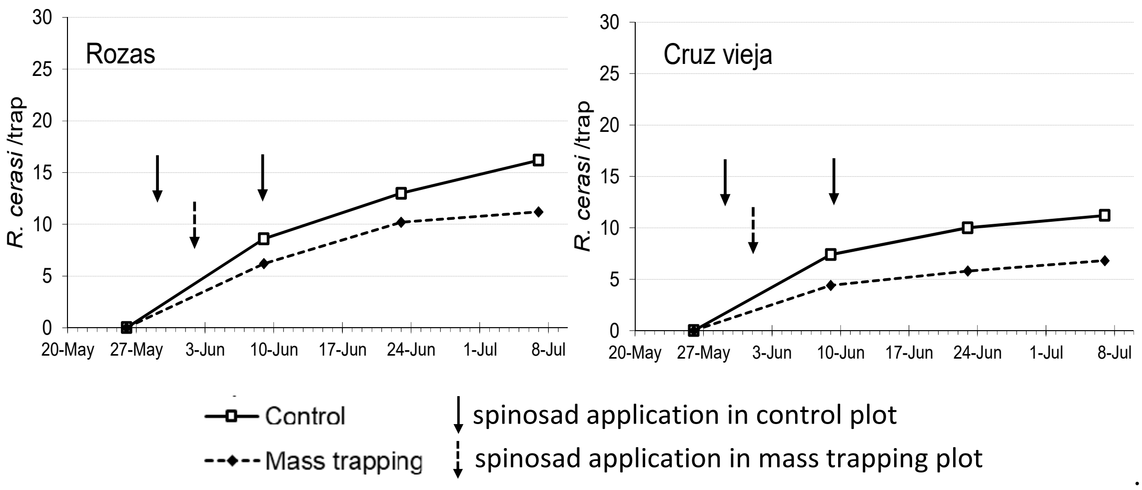

Figure 2. Cumulative adult catches of *R. cerasi* adults and spinosad applications in trials to evaluate efficacy of mass trapping.

On the other hand, percentages of damaged fruits were always lower at mass trapping plots, with significant differences due to treatment ($F_{1,3}$ = 16.64, p = 0.027) but not among trials ($F_{3,3}$ = 5.98, p = 0.088). The percentage reduction in damaged cherries using mass trapping in the Rozas, Cruz vieja, Cañadilla and Barrachina trials were 51%, 60%, 60% and 57%, respectively.

4. Discussion

In the trials comparing traps and attractants for *R. cerasi*, the best results were obtained with the folded yellow sticky trap combined with the attractant ammonium acetate. A good effectiveness of the device for capturing adults of the pest species is the first requirement for a mass trapping method to be useful. In addition, due to the high density of traps required, the cost of the trap-attractant combination is a key aspect for the feasibility of this control method on a large scale basis [28]. For this reason, in our field tests, we compared a trap as simple and cheap as possible with those commercial devices that have been recommended or have been shown to be effective for mass trapping of *R. cerasi* and other tephritid fruit flies, mainly for the Mediterranean fruit fly [*Ceratitis capitata* (Wiedemann)]. The "low cost" model of trap chosen is extremely simple: a plasticized yellow cardboard folded in the shape of a roof, displaying a glued sticky surface on its underside. The roof-shaped design protects that sticky surface and the bait from rain, sun exposition and contact with leaves, all three main factors that would shorten the life of the trap. At the same time, the active part of the trap remains oriented towards the ground, facilitating the attraction and capture of newly emerged *R. cerasi* adults. According to previous studies, the yellow color is a fundamental aspect for the attraction of *R. cerasi* adults [18,19,28]. On the other hand, ammonium acetate was chosen as the reference attractant for these tests since Katsoyannos et al. [20] found this food attractant to be the most effective for *R. cerasi*, on increasing the total number of flies of this species captured in the traps they used by 1.5-fold and the number of females by 1.8-fold. In addition to its high-power of attraction over adults of *R. cerasi*, ammonium acetate is cheap and easy to handle when used as bait in traps, since it works in a solid state.

Most of the traps tested in these trials are container-type devices, set with holes for the entry of flies and containing either some liquid or insecticide inside (Decis® Trap Cerasi, Cera Trap® bottle trap, Easy trap®, Tephri-trap ecological®, Olipe trap and Econex Bottle Trap). With most of these traps, catches were much lower than those obtained with the folded yellow sticky trap. Navarro-Llopis et al. [29] compared the behavior of different attract-and-kill devices against *C. capitata* and they found that panel traps, impregnated with glue or insecticide, were more effective than container-type devices, although the attraction capacity of both types of attract-and-kill devices was similar. Hence, these authors explain the difference in efficacy as due to a lower capacity of container-type traps to cause the death of the attracted flies, since these must overcome the added difficulty of entering through the holes to end up getting poisoned with the insecticide or drowned. In the 2016 trial, despite a clear trend of folded traps to catch more flies, no significant differences in accumulated catches of *R. cerasi* adults were found between the folded yellow sticky trap and the Easy trap® and Tephri-trap ecological®, when baited also with ammonium acetate. These traps have the disadvantage of their higher price to be used on a large scale, but they could be an interesting option to reduce the impact of this control method on non-target insect populations. Large numbers of non-target insects captured by non-selective devices can saturate the traps and reduce their effectiveness in a short period of time. On the other hand, the capture of beneficial arthropods (pollinators and natural enemies of pests) can lead to a reduction in their populations and their benefits on crops. Some studies have shown that captures of non-target arthropods by mass trapping devices designed for fruit flies, and particularly of some natural enemies, may not be a negligible effect [30–33]. Therefore, selectivity should be a factor to be considered together with the cost and effectiveness when choosing the most suitable mass trapping device. While panel-type traps are more effective by capturing fruit flies than container-type traps, they also capture a greater number of other insects and this effect should be valued too. Precisely, Tephri-trap ecological® is provided with a net on the entry holes, to prevent the capture of insects larger than fruit flies, and specifically that of lacewings. Larvae of lacewings are important predators of pests on many crops and, unfortunately, the adults of these beneficial insects are among the most captured arthropods by mass trapping devices for fruit flies [30–32].

Apart from the folded yellow sticky trap, Magnet® MED was the only other panel-type device used in these comparison tests. Magnet® MED is commercialized as an "attract-and-kill" device for *C. capitata*, against of which good efficacy has been shown [34], although no data has been found in the literature on the efficacy of this trap against *R. cerasi*. Our study seems to show that Magnet® MED is not a suitable trap for *R. cerasi*, as no adult fly was captured. However, it must be considered that this trap was only tested in the year reporting the lowest pest density.

Based on the results obtained at the tests comparing devices and attractants for *R. cerasi* and prioritizing the requirements of efficacy and low cost, the folded yellow sticky trap was chosen to evaluate, on a larger scale, the efficacy of the mass trapping strategy against this pest in commercial cherry orchards. Although there were important differences in the abundance and incidence of *R. cerasi* in the different trials, in general, mass trapping had a significant positive effect on the control of the pest. In addition, the application of mass trapping made it possible to reduce insecticide applications when the population levels of the pest were high.

The help that mass trapping can provide for the control of *R. cerasi* could be of great value, since the level of damage tolerance is very low (around 2% of fruits attacked) [1] and there are very few authorized insecticides for this use. In Spain, only acetamiprid, λ-cyhalothrin, deltamethrin and spinosad are authorized against *R. cerasi* [17] and the situation is very similar in the rest of European countries. Even by using the cheapest device, the cost of mass trapping is much higher than that of insecticide applications: 575 €/ha compared to, for example, 180 €/ha for each spinosad treatment (data provided by cherry growers who collaborated in the field trials). However, it should be noted that most orchards in the area are small in size (less than one ha) and growers can often handle mass trapping by themselves without additional labor costs. This makes mass trapping much more feasible on small family farms. Furthermore, insecticide applications against this pest are very restricted due to their undesirable effects. The risk of high levels of pesticide residues in cherries is very high, as cherries must be protected from *R. cerasi* females close to harvest time. In addition, insecticide applications reduce populations of predators and parasitoids that may lead to secondary pest outbreaks. The application of insecticides as bait treatments would reduce these negative effects as this method reduces the amount of pesticide applied and subsequently the impact on natural enemies and also the presence of pesticide residues in fruit [35].

Certainly, mass trapping can be an even more useful strategy in organic cherry orchards, where the availability of control tools against *R. cerasi* is very limited. Thus, non-chemical strategies such as covering nets and the application of entomopathogenic nematodes or fungi, which could be effective, are often not easy to implement due to economic constraints [1]. At least in Europe, spinosad is the only insecticide allowed against this pest in organic cherry production [36]. Spinosad sprays also stands as the only strategy of quick application when population thresholds are exceeded in organic orchards. However, although spinosad is a product of biological origin and its degradation in nature goes very fast, its negative effects on natural enemies, and especially on parasitoids, may not be negligible [37]. The risk of a decrease in susceptibility to spinosad in populations of *R. cerasi*, after its repeated use, must also be considered, as it has already been shown in studies carried out with other fruit flies [38–40]. For all these reasons, in organic cherry production, spinosad spraying is only recommended to save production at situations of extreme risk. In fact, the Spanish regulations limit spinosad use, in both organic and conventional cherry cultivation, to two applications per year. In our study, two applications of spinosad were no enough to keep the fruit damaged rate under the threshold (2%) in one of the trials with high pest pressure whereas, in similar circumstances, thanks to mass trapping, just a single application of spinosad was only needed.

Other capture devices have previously shown high efficacy in capturing *R. cerasi*, although due to their high cost, some of them such as Rebell® Amarillo with an ammonium acetate dispenser, have just been applied for monitoring only and not for mass trapping [1,19]. The cylinder-shaped trap "UFA-Samen Kirschenfliegenfalle", developed by Daniel et al. [20], in addition to being more economical than the Rebell® Amarillo one, showed also higher efficiency in capturing adults of *R. cerasi* in small-scale comparison trials, but farm-scale evaluation data have not yet been reported. Finally, in farm-scale trials, carried out under a high *R. cerasi* pressure, a drastic reduction both in population and damaged cherries was obtained with 100 traps/ha of Decis® Trap Cerasi, the container-type trap commercialized by Bayer CropScience and tested also in this study [21]. In our tests comparing different devices for capturing *R. cerasi*, the folded yellow sticky trap was even much more effective than Decis® Trap Cerasi, when baited either with Econex or homemade ammonium acetate dispensers. In addition, the lower cost of the folded yellow sticky trap adds up to its other advantages.

The low selectivity of all available devices may be a drawback of mass trapping against *R. cerasi*. For this reason, research to obtain much more selective attractants based on the male sexual pheromone that have shown promising results in field trials [26,27].

In conclusion, mass trapping can be a useful tool for controlling the European cherry fruit fly when the implemented devices, in addition to being highly effective in capturing adults of this species, are also cheap enough to be used on a large scale and in a high density. In our trials, a folded yellow sticky trap baited with a homemade ammonium acetate dispenser was the most effective trapping device as well as the most economical, when compared to various commercially available combinations of attractants and traps for fruit flies. Mass trapping may be sufficient by itself to obtain marketable fruit under low pest pressures or in combination with insecticide treatments, when pressure is higher. In the latter case, mass trapping can lead to a significant reduction in insecticide applications and their negative effects. However, it is necessary to improve the selectivity of this method to affect non-target arthropods to a lesser extent. In this regard, some traps such as Tephri-trap ecological®, which make it difficult to some not-target arthropods to enter, and especially the development of more specific baits, will improve this control method in the future, considering its ecological benefits and its effectiveness both together.

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