EFFICACY AND COST EFFICIENCY OF TRAPS FOR MASS CAPTURE OF *Rhynchophorus palmarum* L. IN A MEXICAN *Cocos nucifera* L. ORCHARD †

[EFICACIA Y COSTO EFICIENCIA DE TRAMPAS PARA LA CAPTURA MASIVA DE *Rhynchophorus palmarum* L. EN UNA HUERTA MEXICANA DE *Cocos nucifera* L.]

Jesús Germán De La Mora-Castañeda, Ingrid Yolotzin López-Mora, Wilberth Chan-Cupul* and José Manuel Palma-García

*Facultad de Ciencias Biológicas y Agropecuarias, Universidad de Colima. Km 40 Autopista Colima-Manzanillo, Tecomán, Colima, C. P. 28934, México. E-mail: * wchan@ucol.mx*
**Corresponding author*

SUMMARY

Background. *Rhynchophorus palmarum* is the main insect pest in *Cocos nucifera* orchards in the Pacific Centre of Mexico. The mass capture of adults is the strategy for control of this pest promoted by integrated pest management programs. It is essential to find an economic and efficient trap for farmers. **Objective.** The present study aimed to determine the efficacy and cost efficiency of five traps for capturing *R. palmarum* in a *C. nucifera* orchard and to correlate the capture with environmental parameters. **Methodology.** The bucket-trap (BT), trash-can trap (TCT), 20L-type trap (20LTT), bottle-type trap (BTT), and CSAT-type (Colegio Superior de Agricultura Tropical, a Spanish acronym) trap were evaluated. Total captured insects, number of males and females, cost of trapping, and cost-efficiency were measured. Total captured insects and environmental parameters were correlated using a Pearson model. **Results.** A total of 1065 insects were captured (60% females and 40% males). The TCT captured more (P=0.00001) insects than the BT, 20LTT and BTT. The CSAT ($540.5 USD) and TCT ($531.0 USD) were the most expensive traps during the period of the experiment (4.5 months), whereas the BTT was the cheapest ($515.5 USD). The cost of capture per insect in the TCT was $1.5 USD; therefore, this trap had the best cost efficiency overall of the studied traps (BT=2.6 USD, 20LTT=3.1 USD, CSAT=1.9 USD, and BTT=6.9 USD). The average (r=0.6115, P=0.0154) and maximum (r=0.6280, P=0.0122) wind speeds were correlated positively with the *R. palmarum* capture. **Implications.** This study demonstrates statistically that the TCT capture the same number of insects than the CSAT trap with lower cost. **Conclusion.** More females were caught than males, the TCT trap statistically captures the same amount of insects than the CSAT trap at a lower cost. Wind speed was positively correlated in the capture of *R. palmarum*.
Keywords: black palm weevil; coconut; mechanical control; integrated pest management; type traps.

RESUMEN

Antecedentes. *Rhynchophorus palmarum* es el principal insecto plaga en las plantaciones de *Cocos nucifera* en el pacífico centro de México. La captura masiva de adultos es la estrategia de control más impulsada por los programas de manejo integrado. Por lo tanto, es fundamental encontrar una trampa económica y eficaz para los agricultores. **Objetivo.** Determinar la eficacia y costo eficiencia de cinco trampas para la captura de *R. palmarum* en un huerto de *C. nucifera* y correlacionar la captura con parámetros ambientales. **Metodología.** Se evaluaron las trampas tipo: cubeta (TTC), bote de basura (TTB), 20L (TT20L), botella (TB) y CSAT (Colegio Superior de Agricultura Tropical). Se midió el total de insectos capturados, el número de machos y hembras, el costo de trampeo y el costo de captura por insecto. El total de insectos capturados y los parámetros ambientales se correlacionaron utilizando un modelo de Pearson. **Resultados.** Se capturaron un total de 1065 insectos (60% hembras y 40% machos). La TTB capturó más (P = 0.00001) insectos que la TTC, TT20L y TB. La CSAT ($ 540.5 USD) y TTB ($ 531.0 USD) fueron las trampas más caras durante el período del experimento (4.5 meses), mientras que el TB fue la más económica ($ 515.5 USD). El costo de captura por insecto en la TTB fue de $ 1.5 USD; por lo tanto, esta trampa obtuvo el mejor costo eficiencia en

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ORCID = **G. De la Mora Castañeda**: 0000-0001-5295-5579; **I. Y. López-Mora**: 0000-0003-4910-150X; **W. Chan-Cupul**: **0000-0001-8634-3618**; **J. M. Palma-García:** 0000-0001-6061-546X

comparación con las otras trampas estudiadas (TTC=2.6 USD, TT20L=3.1 USD, CSAT=1.9 USD y TB=6.9 USD). La velocidad media (r=0.6115, P=0.0154) y máxima (r=0.6280, P=0.0122) del viento se correlacionó positivamente con la captura de *R. palmarum*. **Implicaciones.** Este estudio demuestra estadísticamente que la TTB captura la misma cantidad de insectos que la trampa CSAT con menor costo. **Conclusión.** Se capturaron más hembras que machos, la trampa TTB captura estadísticamente la misma cantidad de insectos que la trampa CSAT a menor costo. La velocidad del viento se correlacionó positivamente en la captura de *R. palmarum*.
Palabras clave: picudo negro del cocotero; coco; control mecánico; manejo integrado de plagas; tipo trampas.

INTRODUCTION

The American palm weevil (APW), *Rhynchophorus palmarum* L. (Coleoptera: Curculionidae), is the main insect pest of coconut plantations (*Cocos nucifera* L.) in the Pacific Centre of Mexico, especially in the Colima, Michoacán, Jalisco and Guerrero States (Murguía-González *et al*., 2018). The APW also attacks oil and ornamental palms, sugarcane, and plantains (*Musa* x *paradisiaca*). Adult female weevils are attracted to damaged, stressed, flowering, or even healthy palms and oviposit 30 to 400 eggs per plant. Hatched larvae then bore into palms and, after nearly two months, some may develop into adults (Alpizard *et al*., 2002).

In addition, the APW is the main vector of *Bursaphelenchus cocophilus* and *Phytophthora palmivora*, which are the causal agents of red ring disease and bud rot disease, respectively, two important diseases widely affecting coconut palms (Grueso and Betancourt, 2009). When palms are infected by one of these pathogens, disease can spread rapidly among surrounding palms because of the feeding behavior of *R. palmarum*, which transmits the pathogen from one palm to another (Murguía-González *et al*., 2018). According to Moscoso-Ramírez *et al*. (2002), in tropical environments, the incidence of both coconut palm diseases is approximately 35%.

The plant health committee of Colima state (CESAVECOL, 2019) has established the APW as the main phytosanitary problem in coconut production, due to the fact that it is widely distributed throughout the country, including in the American continent, where it causes considerable losses to the coconut farmers, since the damage is manifested in the five years after the transplant, when flowering begins. At this stage, severe damage has been observed in plantations of up to 90%; however, this loss ranges between 40 and 50% after the five years post-transplant. Therefore, coconut farmers can lose up to 60% of their investment in a five-year period.

Chemical control of APW with carbaryl, carbofuran, imidacloprid, abamectin, deltamethrin, fipronil, spinosad and phenylpyrazole often is not fruitful (Al-Dosary *et al*., 2013; Dos Santos *et al*., 2018; Martinez *et al*., 2019). The application of entomopathogenic fungi, such as *Metarhizium anisopliae* (Metschn.) Sorokin 1883 and *Beauveria bassiana* (Bals. - Criv.) Vuill. 1912, has been demonstrated more effective under laboratory (Shawir and Al-Jabr, 2010) than in field conditions (Ricaño *et al*., 2013). The use of natural enemies is possible, a recent study demonstrated the parasitism of *Billaea claripalpis* (Diptera: Tachinidae) in APW larvae (Gaviria and Lohr, 2020) under laboratory observations.

By other hand, cultural control consists in the removal of the infested trees by cutting with a chainsaw and subsequent application of insecticides (Murguía-González *et al*., 2018). However, mass trapping of APW adults is the main control method; it is carried out by distributing traps, which generally consist of plastic containers, around the edges of production lots (Chinchilla and Oehlschlager, 1992; Costa-Miguens *et al*., 2011; Murguía-González *et al*., 2018). The most common and recommended trap in Mexico is the CSAT trap (CSAT=High College of Tropical Agriculture by its acronym in Spanish), which utilizes a synthetic aggregation pheromone (Rhynchophorol®) and a vegetable bait (kairomone) based on the fermentation of sugarcane and molasses (Montes and Ruiz, 2014).

For the mass trapping of APW, several additional traps have been designed. Oehlschlager *et al*. (1993) suggested that a plastic bucket (20-L capacity) with holes in the top lid and sides, which allow insects to enter, could be an effective trap. Moya-Murillo *et al*. (2015) found that *R. palmarum* could be captured in a gallon bucket (20-L capacity) with lateral windows in the upper portion covered with a mesh net (to enable insects to scale). Costa-Miguens *et al*. (2011) described two *R. palmarum* traps: The first was a white 10-L bucket with a 2.5-cm opening containing 4 kg of sugarcane. The second was a transparent 6-L bucket with 4 kg of sugarcane. Recently, Landero-Torres *et al*. (2015a) designed a trap using a cylindrical plastic column (33 cm high, 23-cm diameter, and 20-L volume) with two lateral windows (8 cm × 12 cm) situated at 15 cm from the base of palms. Traps were covered with a mesh net to enable insect entrance and filled with 500 g of fruits (pineapple, sugarcane, coconut, plantain, or palm fruit) as attractants. Notably, traps filled with coconut palm slices trapped more APW adults than traps with other attractants (Landero-Torres *et al*., 2015a).

The evaluation of the cost-effectiveness of traps for capturing *R. palmarum* adults in coconut plantations is important for the integrated management of this pest. Handmade traps are more accessible to farmers and highly efficient in the capture of *R. palmarum*; therefore, it represents an effective tool for monitoring populations of APW (Murguía-González *et al*., 2018). However, weather conditions can influence the success of APW capture. Several reports on the APW mass trapping indicate that solar radiation, precipitation, temperature, and wind speed influence the capture of APW (Ferreira *et al*., 2003; Cysne *et al*., 2013; Landero-Torres *et al*., 2015b). Therefore, it is necessary to understand the role of environmental parameters in the capture of APW in a specific study area in order to determine which environmental conditions are best for insect capture. Therefore, the present study aimed to determine the efficacy and cost efficiency of five types of traps to capture *R. palmarum* adults in a *Cocos nucifera* var. "Alto Pacifico" orchard and to correlate the mass capture with environmental parameters.

MATERIALS AND METHODS

Experimental site

The study was carried out in a coconut var. "Alto Pacifico" orchard in Armeria, Colima, Mexico (location: 18°54'59.2" N 103°59'39.3" W) at 10 masl. The climate type is warm sub-humid (86%) with an average temperature of 26.4 °C (maximum of 30 °C and minimum of 18 °C) and average rainfall of 790 mm. Sampling was carried out from August 2018 to December 2018. The coconut orchard has 30 years old and a dimension of 56 hectares. Forty percent of palms are less than five years old. The orchard in a monoculture of coconut palms, however, the surrounding vegetation is low deciduous forest.

Trap design

Five traps were constructed for *R. palmarum* capture according to the scientific literature. First, a bucket trap (BT) was designed according to Murguía-González *et al*. (2018). This trap consisted of a 19-L bucket with a 30-cm diameter and four holes (5-cm Ø) along both the upper rim and on the lid (Figure 1A) and six holes (0.5-1.0-cm Ø) in the base to avoid rainwater accumulation. Second, a trash-can trap (TCT) was made from a trash can (29 × 30 cm) with a hole (6-cm Ø) perforated in the center of the lid (Figure 1B), six holes of 6 mm perforated near the lower part of the base, two central holes perforated in the can, and several holes perforated at the edge of the base to avoid rainwater accumulation (Ramos *et al*., 2017). Third, a 20 L-type trap (20LTT) was made using a 20-L bottle. Two windows were placed on the front and back (Figure 1C) at a 45° angle (perpendicular to the horizontal axis of the trap). Near the base, a mesh cloth was attached to facilitate the entry of weevils into the trap (Moya-Murillo *et al*., 2015; Rodríguez-Currea *et al*., 2017). Fourth, a bottle-type trap (BTT) was built using a 3-L polyethylene bottle. Two windows (4 × 4 cm) were made at an approximate distance of 10 cm and a 45° angle to prevent rainwater entry; the base of bottle was also perforated (Figure 1D, Murguía-González *et al*., 2018). Finally, the fifth, a CSAT-type trap (Camino *et al*., 2000) recommended by the State Coconut Council of Colima, Mexico (COECOCO A.C., for its acronym in Spanish) and the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP, for its acronym in Spanish) for APW capture was used. The trap consists of a yellow plastic bucket without a bottom placed atop a basin, leaving space for insect entry, fitted with a white plastic container without a cover (Figure 1E). Coconut growers in various states of the country commonly use the CSAT trap; therefore, it was used as reference trap.

In each trap, 250 g of sugarcane slices (10 cm long) and 100 mL of molasses were added as bait in each trap. The bait was replaced every week. Likewise, 5 mL of Rhynchophorol® (6-Methyl-2E-hepten-4-ol) as aggregation pheromone was placed in each trap. The pheromone was replaced at each 10 weeks. The traps were randomly distributed along the periphery of the experimental site at a distance of 100 m from one another (Costa-Miguens *et al*., 2011). According to the references, the CSAT (Camino *et al*., 2000) and bottle traps (Murguía-González *et al*., 2018) were placed at a height of 1.7 m on palms. The other traps were deposited on the floor, avoiding full solar radiation. Traps were monitored every seven days during four and half months. Figure 2 illustrates the features of the traps evaluated at the experimental site. Six traps were established for each trap type, one trap was considered as an experimental unit (repetition).

Response variables

Capture of male and female insects

Total insects captured were recorded. Number of males and females were registered, the genders were differentiated morphologically according to their sexual dimorphism. Adult males have a tuft of hair on the dorsal part of the rostrum, while adult females have a smooth rostrum (Löhr, Vásquez-Ordoñez, and Lopez-Lavalle, 2015).

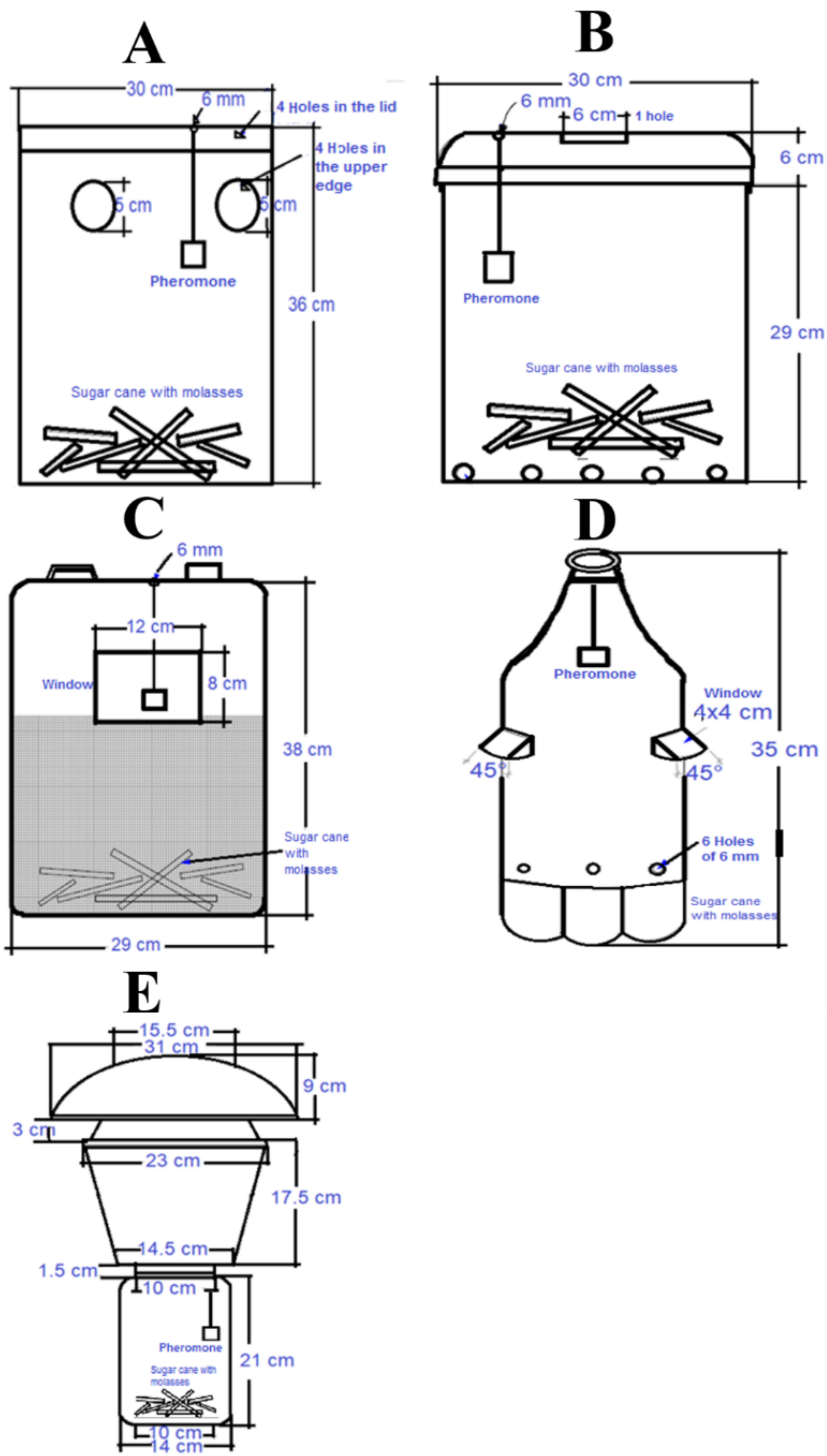

Figure 1. Design and sizes of the traps evaluated for the capture of *Rhynchophorus palmarum*.

Figure 2. Installation of studied tramps in the experimental site. Bucket trap (BT), trap can type (TCT), 20 L trap type (20LTT), CSAT trap (CSAT), and bottle trap type (BTT).

Cost of trapping (CT)

For each trap type, the cost of APW trapping (CT) was determined over four and a half months of sampling according to the following equation proposed by Murguía-González *et al*. (2018), which was adapted from Caudell *et al*. (2010):

$$CT = [Cm + (Cb)(Rf) + (Cp)(Fp) + (Cl)(Lc)](Ap) \quad \text{Equation 1}$$

Where:
CT = Quarterly (4.5 months) cost of APW trapping,
Cm = Cost of the materials used in the elaboration of the traps. The cost differs according to the type of trap,
Cb = Cost of sugarcane and/or molasses used as food bait,
Rf = Frequency of bait replacement over four and a half months of sampling,
Cp = Cost of aggregation pheromone according to the Plant Health Commission of Colima state (CESAVECOL),
Fp = Frequency of aggregation pheromone replacement,
Cl = Monetary cost of work required, including hiring day laborers for bait changes, according to the National Commission of Minimum Wages in Mexico,
Lc = Number of samples required in the study period (4.5 months), and
Ap = Number of established traps (six of each evaluated trap).

Supplies were purchased in a local supermarket. The cost APW trapping was calculated in Mexican pesos (MP) and United States dollars (USD).

Capture cost per insect

The capture cost per insects in each trap was calculated using equation 2:

$$CaC = \frac{CT}{TCA} \quad \text{equation 2}$$

where:
CaC = Capture cost per insect ($/captured insect)
CT = Cost of trapping, and
TCA = Total captured adults.

Environmental data

Data on temperature (mean, maximum, and minimum), relative humidity (mean, maximum, and minimum), radiation, precipitation, and wind speed (daily average) were obtained from a climatological station in Armeria, Colima, Mexico (location: 18°91'46.6" N 103°96'42.2" W) near the experimental site (less than 3 km away). The climatological station is the property of the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP). The environmental data were monitored in real time at the following link: http://clima.inifap.gob.mx/LNMySR/Estaciones/ConsultaDiarios15Min?Estado=6andEstacion=36754.

Experimental design and data analysis

A completely randomized experimental design with five treatments (type of traps) was used, each type trap was considered as a treatment. Six repetitions (number of traps) were established per treatment. The response variables: 1) the total number of captured insects and 2) number of captured male and female insects were analyzed by a Generalized Lineal Model (GLM) using a Poisson distribution (α=0.05). The effect of the traps and time capture (sampling) were analyzed in the GLM. A Tukey test (α=0.05) was used for mean comparison. Pearson correlations were calculated between the response variables (number male, female and total captured insects) and environmental variables (temperature [mean, maximum, and minimum], relative humidity [mean, maximum, and minimum]), radiation, precipitation, and wind speed). All analyses were performed in Statgraphics version 8.0 for Windows®.

RESULTS

Capture of male and female insects

A total of 1065 adult insects were captured during the experiment (4.5 months). Sixty percent of captured adults were female (639 insects), and 40% were male (426 insects; Table 1). According to the GLM model (df=21, F=4.76, P=0.0001, R^2=59.51), for captured males, there were significant differences for the type trap (df=4, F=7.11, P=0.0001) and sampling period (df=17, F=4.21, P=0.00001). The TCT (6.7 males) and CSAT (6.7 males) captured more males in comparison to 20LTT (3.5 males) and BTT (2.3 males) (Table 2). For the sampling period, the weeks 5th (8.4 males), 7th (9.0 males) and 18th (8.8 males) achieved the highest male's capture than the weeks 10th (1.2 males) and 17th (1.2 males, Table 2).

For captured adult females, the GLM analyses (df=21, F=5.17, P=0.00001, R^2=61.48) suggested significant differences for the type of trap (df=4, F=12.26, P=0.0001) and sampling period (df=17, F=3.50, P=0.00001). The TCT (12.7 females) and CSAT (8.8 females) captured the same number of females (Table 2); however, the TCT (12.7 females) capture more females than BT (6.3 females), 20LTT (5.7 females) and BTT (1.7 females). For the sampling period, in the week 3th was captured the highest numbers on females than in the week 17th (Table 2).

With respect to the total capture, the GLM (df=21, F=5.85, P=0.00001, R^2=64.37) indicated that the total insect capture was influenced by the type trap (df=4, F=12.62, P=0.00001) and sampling period (df=17, F=4.26, P=0.00001). The TCT (19.4 insects) captured the highest number of APW adults than the BT (10.7 insects), 20LTT (9.3 insects) and BTT (4.1 insects); however, the TCT captured statistically the same number of APW adults than the CSAT trap (15.5 insects, Table 2). For the sampling period, the highest

Table 1. Total captured insect.

Type trap	Captured adults		Ratio female: male	Total capture	Capture %
	Males	Females			
Bucket trap	78	115	1.47:1	193	18.1
Trash can trap	121	229	1.89:1	350	32.9
20 L type trap	64	104	1.63:1	168	15.8
CSAT	121	159	1.31:1	280	26.3
Bottle type trap	42	32	0.76:1	74	6.9
Total capture	426	639	-	1065	100

number of APW adults was found in the sampling at week 18th (22.0 insects), this value was superior statistically that the captured adults in the 10th (3.4 insects), 11th (5.0 insects), 16th (5.8 insects) and 17th (3.2 insects) weeks (Table 2).

Capture fluctuation

Figure 3 describes the fluctuation in APW capture in the studied traps over time. The TCT captured more insects than the BT (Figure 3A, Table 2), 20LTT (Figure 3B, Table 2), and BTT (Figure 3D, Table 2) during the study period. However, the TCT and CSAT traps captured the same number of APW adults (Figure 3C, Table 2). At two and half months of sampling, a decrease in captured insects was noted; this effect was due to the decreasing effect of the pheromone (Rhynchophorol®) in the traps. However, after the pheromone was replaced, insect capture increased again (after week 10).

Cost of trapping (CT) and cost efficiency

The number of captured insects per trap explained the cost efficiency (Figure 4). The CSAT [$10356.72 MP = $540.5 USD) and TCT ($10173.72 MP = $531.0 USD) traps were the most expensive in the studied period (4.5 months) according to equation 1. On the other hand, the BTT was the cheapest ($9876.72 MP = $515.2 USD, Table 3). The cost of capture per insect (cost efficiency) was calculated by equation 2, which indicated that the TCT achieved the lowest cost efficiency (Figure 4), with a value of $29.1 MP ($1.5 USD) per insect. However, the BTT had the highest cost efficiency with $133.5 MP ($6.9 USD; Figure 4) per insect. The trap recommended by the Mexican government (CSAT) had a cost efficiency of $37.0 MP ($1.9 USD), which was $7.9 MP ($0.41 USD) more than the TCT (Figure 4).

Correlation between environmental variables and APW capture

The Pearson correlation coefficients indicated that maximum wind speed (Pearson r=0.6280, P=0.0122; Figure 5A) and average wind speed (Pearson r=0.6115, P=0.0154, Figure 5B) were positively and significantly correlated with insect capture. The other environmental variables did not have significant correlations (Table 4).

DISCUSSION

The mass trapping of APW in bait-pheromone traps is one important strategy for the integrated management of this pest. This strategy was effective for trapping APW in the present study, as similarly found by Camino *et al*. (2000). The sex ratio, or the number of captured females and males, is also relevant and influenced by the use of pheromones as reported by Peña-Rojas and Reyes-cuesta (1997) and Moya-Murillo *et al*. (2015). In this regard, the capture of large amounts of females is highly beneficial for reducing the insect population, as pheromones attract females that would lay eggs that would hatch into damage-inflicting grubs (Faleiro, 2006). Previously, Kalleshwaraswamy *et al*. (2005) demonstrated that the

Table 2. Average of the capture of *Rhynchophorus palmarum* adults in the studied traps.

Source	Captures		
Traps	**Males**	**Females**	**Total**
Bucket trap	4.3 ab	6.3 b	10.7 b
Trash can trap	6.7 a	12.7 a	19.4 a
20 L type trap	3.5 b	5.7 bc	9.3 bc
CSAT	6.7 a	8.8 ab	15.5 ab
Bottle type trap	2.3 b	1.7 c	4.1 c
Samples			
Week 1 (August 31th)	3.4 ab	5.4 ab	8.8 abcd
Week 2 (September 7th)	2.0 ab	4.0 ab	6.0 abcd
Week 3 (September 14th)	7.8 ab	13.4 a	21.2 ab
Week 4 (September 21th)	2.6 ab	5.6 ab	8.2 abcd
Week 5 (September 28th)	8.4 a	11.8 ab	20.2 abc
Week 6 (October 5th)	2.6 ab	7.4 ab	10.0 abcd
Week 7 (October 12th)	9.0 a	12.8 ab	21.8 ab
Week 8 (October 19th)	3.6 ab	5.8 ab	9.4 abcd
Week 9 (October 26th)	5.6 ab	7.4 ab	13.0 abcd
Week 10 (November 2nd)	1.2 b	2.2 ab	3.4 d
Week 11 (November 9th)	2.6 ab	2.4 ab	5.0 cd
Week 12 (November 16th)	8.2 ab	3.6 ab	11.8 abcd
Week 13 (November 23th)	4.6 ab	13.0 ab	17.6 abcd
Week 14 (November 30th)	3.0 ab	6.2 ab	9.2 abcd
Week 15 (December 7th)	8.0 ab	8.4 ab	16.4 abcd
Week 16 (December 14th)	2.6 ab	3.2 ab	5.8 bcd
Week 17 (December 21th)	1.2 b	2.0 b	3.2 d
Week 18 (December 28th)	8.8 a	13.2 ab	22.0 a

Mean values in the same column with different literals are statistically different according to the Tukey test (P≤0.05).

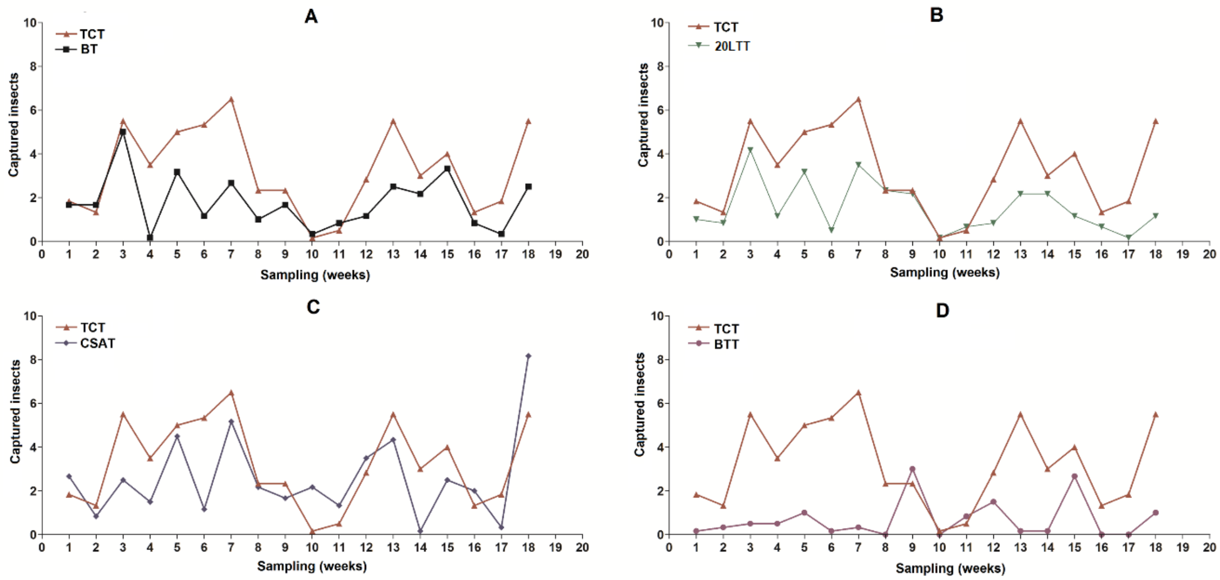

Figure 3. Comparison of the capture fluctuation of *R. palmarum* in the trash can trap against the other studied traps in a *Cocos nucifera* Var. "Alto Pacifico" orchard. A) TCT vs BT, B) TCT 20LTT, C) TCT vs CSAT, D) TCT vs BTT. BT=Bucket Trap, TCT=Trap Can Type, 20LTT=20 L Trap Type, CSAT=CSAT Trap and BTT=Bottle trap type.

Rhynchophorus ferrugineus females captured in bait-pheromone traps were young, fertile, or gravid. Moya-Murillo *et al*. (2015) captured an overall sex ratio of 1.5:1.0 females: males, which was more equitable than the ratios captured by the TCT (1.89:1.0) and 20LTT (1.63:1.0) in the present study. However, this is not a general rule, as Montes and Ruiz (2014) and Murguía-González *et al*. (2018) reported a greater capture of males when pheromones were used for APW capture. Therefore, the captured males were alive inside the trap and likely released more aggregation pheromones, leading to an increase in the number of female insects trapped (Rodríguez-Currea *et al*., 2017).

In regard to the baits used herein, the use of sugarcane and molasses was also effective for capturing APW adults. The baits were changed every two weeks, which increased APW capture. Bait and the synthetic pheromone act in synergy favoring the attraction of insects to the traps (Rochat, 1990; Chinchilla and Oehlschlager, 1992).

In regard to the effectiveness of the traps, the TCT captured 6.6% more insects that the CSAT trap, which is recommended by the CESAVECOL as the most effective trap for APW capture. The TCT was $183.0 MP ($9.5 USD) cheaper than CSAT trap over the four-and-a-half-month sampling period. In contrast, Sumano-López *et al*. (2012) evaluated the CSAT trap as a control for APW capture yet found that the BTT captured a larger number of insects. Murguía-González *et al*. (2018) also reported that a colorless PET (polyethylene terephthalate) trap and green PET trap (same design as the BTT evaluated herein) using banana + pineapple as bait were the trap and bait combinations with the lowest annual cost per hectare ($804.0 USD each) for APW capture in an ornamental palm orchard. In the present case, the BTT (similar design as the PET trap) was the cheapest but also the

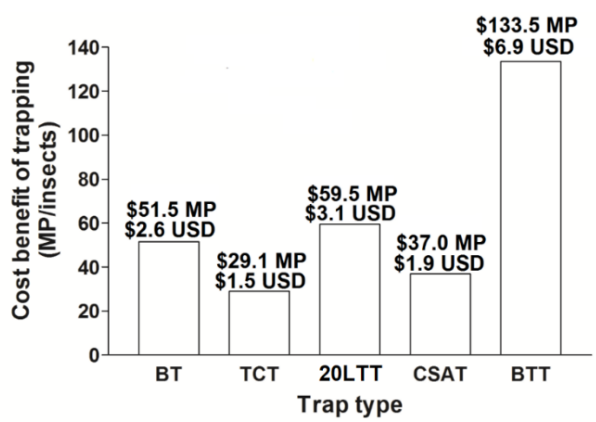

Figure 4. Cost efficiency of the *Rhynchophorus palmarum* capture. BT=Bucket Trap, TCT=Trap Can Type, 20LTT=20 L Trap Type, CSAT=CSAT Trap and BTT=Bottle trap type. One USD (US-Dollar)=19.16 MP, average for January 2019. MP=Mexican pesos.

Table 3. Cost of *Rhynchophorus palmarum* trapping in five type traps for four and half months of sampling.

Type trap	Cm	Cp	Cb		Rf	Fp	Cl	Lc	Ap	CT	
			Molasses	Sugar cane						($MP)	($US-Dollar)
Bucket trap	12	55	1.5	0.2	9	2	84.49	18	6	9948.72	519.2
Trash can trap	49.5	55	1.5	0.2	9	2	84.49	18	6	10173.72	531.0
20 L type trap	20	55	1.5	0.2	9	2	84.49	18	6	9996.72	521.7
CSAT	80	55	1.5	0.2	9	2	84.49	18	6	10356.72	540.5
Bottle type trap	0	55	1.5	0.2	9	2	84.49	18	6	9876.72	515.5

Cm = Cost of the materials used in the elaboration of the traps, Cp = cost of aggregation pheromone, Cb = cost of sugarcane and/or molasses used as bait, Rf = frequency of bait replacement over four and a half months of sampling, Fp = frequency of aggregation pheromone replacement, Cl = monetary cost of work required, including hiring day laborers for bait changes, according to the National Commission of Minimum Wages in Mexico, Lc = Number of samples required in the study period, Ap = number of established traps (six of each evaluated trap) and CT = Quarterly (4.5 months) cost of APW trapping. $MP=Mexican pesos and $US-Dollar, United States-Dollar, 1 US-Dollar = 19.16 MP, average for January 2019.

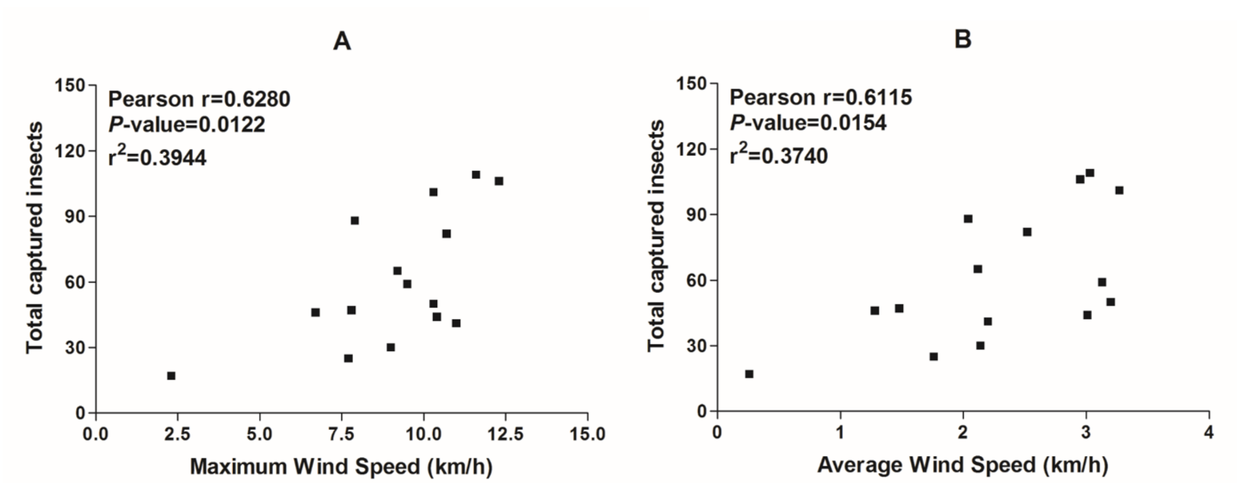

Figure 5. Pearson correlation of captured insects and maximum (A) and average wind speed (B).

most ineffective for *R. palmarum* capture under the experimental conditions of the coconut orchard. This trap had the highest cost efficacy but only captured 7% of total insects. Its inefficiency might be attributed to its design or the height at which it was placed (1.7 m). Oehlschlager *et al*. (1993) used traps placed at 1.7 m because they observed that insects fly in zigzag patterns between palms during light hours; however, they also concluded in their experiment that more insects are captured with traps placed at ground level than at a height of 1.7 m. By other side, Hoddle *et al*. (2020) reported that the average distance flown by males and females of APW was 41 and 53 km, respectively. A little percentage of females (10%) and males (4%) were able to fly > 100 km, and the major flown activity in APW was diurnal. These findings need to be considered in during field experiments for mass capturing of APW.

The trap with the lowest cost-efficiency was TCT, followed by the CSAT trap, although the BTT had the highest cost-efficiency. These findings contrast with those of Murguía-González *et al*. (2018), who found the BTT to be the most economical and effective (efficacy) trap. However, our findings coincide with the Murguía-González *et al*. (2018) study in that the CSAT-type trap was the most expensive. By other side, in Mexico, particularly in the Colima state, it has been introduced the Picusan® trap (a black pyramidal trap design) by Coco Colima Company, this trap has been used broadly in Europe to capture *Rhynchophorus ferrugineus.* According to Vacas *et al*. (2013) the Picusan® trap capture more total weevils (66.6%) than the standard bucket trap, and specifically more males, although the number of females captured was not significantly different.

Table 4. Pearson correlation coefficient (r) between environmental variables and the total capture of *Rhynchophorus palmarum* in a coconut orchard.

Environmental variable	Statistical parameter	
	r	*P*-value
Rainfall (mm)	-0.0510	0.8566
Maximum Temperature (°C)	0.4169	0.1221
Minimum Temperature (°C)	-0.2150	0.4417
Mean Temperature (°C)	0.0676	0.8108
Maximum Wind Speed (km/h).	0.6280	***0.0122***
Average Wind Speed (Km/h)	0.6115	***0.0154***
Global Radiation (W/m^2)	0.4803	0.0700
Relative Humidity (%)	-0.2499	0.3690

Significant values are in bold italics.

Recently, Milosavljević *et al*. (2020) used video camera data to know the behavior and capture efficacy of the APW in two traps types, the Picusan® and the bucket trap. The bucket traps attracted 30% more weevils than Picusan®; however, the bucket trap was not efficient, because the videos showed how the weevils scape from the traps, only the 18% of entered weevils was retained in the bucket traps. By contrast, Picusan® traps captured and retained 89% of weevils that entered the trap. Milosavljević *et al*. (2020) demonstrated that the bucket trap was efficient; their results highlight the importance of the sampling of the traps one or two times per week. In this study, the traps were sampled every week, thus preventing that the captured insects run away from the trap. Likewise, the use of food bait is important to ensure that the insects do not need to get out of the trap due to lack of food.

Environmental parameters have been found to affect insect behavior and *Rhynchophorus* spp. capture (Aldryhim and Ayedh, 2015). In the present study, the wind speed (average and maximum) favored *R. palmarum* capture in traps, probably because *R. palmarum* adults prefer to move when the wind speed is higher due to the ease of flying under this condition. In addition, higher wind speeds help to spread the synthetic pheromone in the traps longer distances, increasing the number of *R. palmarum* adults attracted to the traps. Wind speed was previously positively correlated with *R. ferrugineus* capture by Aldryhim and Ayedh (2015). However, for *R. palmarum* a longer sampling time is needed to clarify these findings.

In addition, low precipitation affects negatively the *R. palmarum* capture (Murguía-González *et al*., 2018) and *R. ferrugineus* (Afzan-Azmi *et al*., 2014) during the drier months of the year. Several other studies have confirmed that *R. palmarum* capture is highest during rainy periods (Chinchilla and Oehlschlager, 1992; Ramírez *et al*., 2000; Afzan-Azmi *et al*., 2014; Haris *et al*., 2014). Similarly, Cabrera-Mireles (1982) reported that the greatest capture of insects occurred in the months of greatest rainfall. In the present study, precipitation did not affect APW capture. However, a longer sampling period (>12 months) would be necessary to more clearly understand the effect of environmental variables on *R. palmarum* capture, because the results indicated that at the end of the experiment (December) an increase in insect capture was recorded, this could be due to the environmental conditions (temperature, relative humidity, wind speed, precipitation among others). The experiment began in autumn and ended at the beginning of winter, where the rainfall was low. It could be that *R. palmarum* adults have a preference to fly in times of low rainfall and thus favor their capture in the bait-traps, as occurred at the end of the experiment. At least, with *R. ferrugineus*, greater capture has been found in dates with less rainfall (Afzan-Azmi *et al*., 2014). Likewise, there is the possibility that at the end of autumn the temperature is lower and with this it is preferable for the flight and population fluctuation of *R. palmarum*, compared to spring and summer, where temperatures are higher. In this sense, Ovando-Cruz *et al*. (2019) reported an increase in the capture of *R. palmarum* in the month of December (3.67 adults/trap/week), when temperatures could be lower compared to the months of July (1.80 adults/trap/week) and august (2.03 adults/trap/week), where temperatures could be higher. It is clear that more studies are required to clarify these scenarios, if we want to know the behavior of *R. palmarum* and use this information for its integrated management in coconut orchards.

CONCLUSIONS

All of the studied traps were efficient in capturing *R. palmarum* adults with the exception of the bottle-type trap (BTT). This latter trap was the cheapest but also captured the lowest insects and had the lowest cost efficiency; therefore, it is not suitable for use in the integrated management of the American palm weevil. In contrast, the trash-can trap (TCT) demonstrated the highest cost-benefit because it captured the highest number of insects and had the lowest price per captured insect despite not being the cheapest overall. Accordingly, this trap is suitable and effective for *R. palmarum* capture in *Cocos nucifera* orchards. Finally, the wind speed was positively correlated with the capture of adults; this means that a greater capture of insects was obtained when a higher wind speed was recorded.

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Compliance with ethical standards. The authors declare that this research did not use or experiment with higher animals or humans.

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