Neotrop Entomol (2018) 47:302–310
DOI 10.1007/s13744-017-0545-8

PEST MANAGEMENT

Efficacy and Cost of Trap–Bait Combinations for Capturing *Rhynchophorus palmarum* L. (Coleoptera: Curculionidae) in Ornamental Palm Polycultures

J Murguía-González[1], I Landero-Torres[1], OR Leyva-Ovalle[1], ME Galindo-Tovar[1], RC Llarena-Hernández[1], E Presa-Parra[2], MA García-Martínez[1]

[1]Univ Veracruzana, Facultad de Ciencias Biológicas y Agropecuarias Zona Orizaba-Córdoba, Amatlán de los Reyes, Veracruz, Mexico
[2]Instituto de Ecología A.C., Xalapa, Veracruz, Mexico

Keywords

Tropical horticulture, black palm weevil, inexpensive traps, agroecosystems

Correspondence
MA García-Martínez, Univ Veracruzana, Facultad de Ciencias Biológicas y Agropecuarias Zona Orizaba-Córdoba, Josefa Ortiz de Domínguez S/N, Centro Peñuela, 94945 Amatlán de los Reyes, Veracruz, Mexico; magarciamartinez@hotmail.com; miguelgarcia05@uv.mx

Edited by Rafael M Pitta – Embrapa

Received 19 January 2017 and accepted 11 July 2017
Published online: 28 July 2017

© Sociedade Entomológica do Brasil 2017

Abstract

Ornamental palms are an economically important component of international trade yet have recently experienced yield losses in Mexico due to red ring and bud rot diseases, which are spread by *Rhynchophorus palmarum* L. Considering that massive capture is a common strategy to control this pest and the cost of commercial traps and baits could be inaccessible for small farmers, an inexpensive trap–bait combination is desired. In this study, 16 trap–bait combinations for capturing *R. palmarum* were assessed in ornamental palm polycultures over the course of 1 year. An expensive yellow bucket trap combined with aggregation pheromone + insecticide + banana was compared with inexpensive, handmade trap–bait combinations. A total of 4712 weevils were collected in all traps, of which 52.7% were male and 47.3% female. The efficacy of the handmade trap made from a colorless polyethylene bottle and baited with banana + pineapple + sugarcane + sugarcane molasses was similar to that of the yellow bucket trap baited with aggregation pheromone + insecticide + banana. These two trap–bait combinations remained effective even when the *R. palmarum* population significantly decreased during the dry, warm season. The affordable handmade trap baited with food attractants and without insecticides was highly efficient in capturing *R. palmarum* and therefore represents an effective tool for monitoring weevil populations. As ornamental crops have recently gained greater economic importance in the studied region, the use of a novel and cheap trap–bait combination could offer great benefits to producers and form part of the integrated management of *R. palmarum*.

Introduction

Palms (Arecales: Arecaceae) form a group of highly diverse monocots in tropical and subtropical regions of the world (Tregear *et al* 2011). Their economic importance in international trade is due to their high ornamental value and potential use in food products (Baker *et al* 2009). The cultivation of ornamental palms has recently become an important source of income for producers entering the market (Ramírez-Rojas *et al* 2011), and the pests that threaten palm yield, quality, and marketing must be monitored in order to effectively sustain production (MacLeod & Hussein 2017). Currently, the palm agribusinesses of central Veracruz and other Neotropical regions of Mexico have reported yield losses mainly caused by *Rhynchophorus palmarum* L. (García-Hernández *et al* 2003, Osorio-Osorio *et al* 2003, Sumano *et al* 2012, Landero-Torres *et al* 2015a, b).

The South American palm weevil (*R. palmarum*) has severely impacted the yield of ornamental palm agroecosystems in central Veracruz. Particularly, in the Tuxpango Valley prior to 2009, the palm species *Washingtonia robusta* Wendl. had the highest consumer demand. However, in this same year, the first cases of *R. palmarum* infestation in ornamental palms were reported. This pest directly and indirectly damaged palm crops of *W. robusta* and caused economic losses in the study region of approximately $6000.00 USD/ha. Since 2011, the infestation of palms with *R. palmarum* larvae in addition to the effects of red ring and bud rot diseases has led to a decreased demand for *W. robusta* in the national market (Landero-Torres *et al* 2015a).

In general, the South American palm weevil is a primary pest of palms cultivated for food or for ornamental purposes in the Americas (Esparza-Díaz *et al* 2013, Mazza *et al* 2014, Soto-Hernández *et al* 2016). This insect directly damages palms because females lay their eggs in palm crowns, and the hatched larvae then feed on meristematic tissue, preventing palms from producing new fronds (Plata-Rueda *et al* 2016). The larval phase of this weevil is the most destructive since larvae can tunnel palm stems and often destroy the growth point or damage the lower stem and rhizomes, eventually causing palm death (Alpizar *et al* 2002). *Rhynchophorus palmarum* also causes indirect damage as a vector of the oomycete *Phytophthora palmivora* Butler (Peronosporales: Pythiaceae), which is the causal agent of bud rot disease (Sarria *et al* 2008), and of the nematode *Bursaphelenchus cocophilus* (Cobb) (Tylenchida: Aphelenchoididae), which is the causal agent of the red ring disease (Moya-Murillo *et al* 2015, Plata-Rueda *et al* 2016). When a palm is infected by one of these pathogens, the associated disease may then rapidly spread among surrounding palms as a result of the foraging activity of *R. palmarum* through transmission by feeding (Moya-Murillo *et al* 2015). For this reason, the population monitoring of this pest in palm crops is a necessary tool for the implementation of any control strategy involving an integrated pest management approach (Moura *et al* 2006, Carreño-Correa *et al* 2013).

Among the methods for controlling *R. palmarum*, the most common one is the removal of diseased palms (inoculum) to reduce breeding sites (Oehlschlager *et al* 2002, Griffith *et al* 2005). However, various trap types and food attractants combined with synthetic aggregation pheromone have been widely used in the Americas to capture this weevil (Osorio-Osorio *et al* 2003, Quintero 2010, Carreño-Correa *et al* 2013, Moya-Murillo *et al* 2015, Rodríguez *et al* 2016). The prior studies differ significantly in trapping methods and suggest that the trapping effectiveness of *R. palmarum* could vary as a function of the trap–bait attractivity, season, and type of palm (i.e., for food or ornamental purposes).

In Mexico, one of the most common trap–bait combinations is a yellow bucket trap made from expensive materials that requires the use of chemical insecticides formulated with deltamethrin or methomyl and synthetic aggregation pheromone (Osorio-Osorio *et al* 2003, Sumano *et al* 2012). However, the insecticides used in these traps often cause the death of some beneficial insects and vertebrates that are also attracted to the utilized food attractants. Environmental contamination with insecticides may also occur during bait renewal when baits contaminated with insecticide are discarded. In addition, rainwater may enter into traps, leach insecticides from baits, and then drain to the soil surface (Sumano *et al* 2012). For this reason, it is important to provide an affordable, environmentally friendly management option for low-income growers that would significantly reduce insecticide applications.

In order to avoid further damages to ornamental palm crops that would threaten their quality and marketing as well as the income of producers (MacLeod & Hussein 2017), innovative strategies to monitor or control *R. palmarum* are necessary. This study explores the cost and efficacy of using expensive and inexpensive trap–bait combinations for capturing this weevil. In particular, the efficacy of 16 trap–bait combinations for capturing *R. palmarum* in four ornamental palm polycultures during three climatic seasons was compared.

Material and Methods

Study area

This study was performed in Tuxpango Valley, located near the localities of Campo Grande, Campo Chico and Capoluca in Ixtaczoquitlan, Veracruz, Mexico (Table 1). The climate is warm and humid with a mean annual temperature of 20°C and precipitation of 2199 mm. There are three distinct seasons in the area: a dry, warm season (March to June); a wet, warm season (July to October); and a relatively dry, cool season (November to February) (Landero-Torres *et al* 2014a, b). The landscape is a mosaic of small remnants of semi-evergreen forest, human settlements, ornamental crops, and vegetable crops (Landero-Torres *et al* 2014a, b).

Sampling design

In the study area, four commercial polycultures, each with an extension of 4 ha, were selected. Different ornamental palm species are cultivated on these sites (Table 1). These plots were selected based on the accessibility granted by owners and were located from 1 to 3 km apart, with an elevation varying from 793 to 803 m (Table 1). All palm plants had been established for 2 years.

A balanced sampling design was used, consisting of a total of 16 trap–bait combinations (4 trap × 4 bait types) that were

Table 1 Polyculture characteristics (P1–P4) and species composition of planted ornamental palms where *Rhynchophorus palmarum* adults were monitored.

Characteristics\polycultures	P1	P2	P3	P4
Elevation (m)	803	797	793	794
Latitude N	18°49′27″	18°49′36″	18°48′14″	18°48′25″
Longitude W	97°01′08″	97°00′32″	96°59′48″	97°00′29″
Area (ha)	4.1	4.05	4.08	4.13
Planting pattern[a]	3 × 4	3 × 3	4 × 4	2 × 3
Harvesting time (years)	1–3	1–3	1–4	1–2
Planted palm species[b]				
Archontophoenix alexandrae (Muell.)	370	490	50	70
Bismarckia nobilis Hildebrandt	15	45	0	0
Chamaedorea elegans Mart.	900	1500	600	1400
Dypsis decaryi (Jum.)	60	80	90	170
Dypsis lutescens (Wendl.)	900	150	70	1000
Howea forsteriana Becc.	70	95	40	75
Hyophorbe lagenicaulis (Bailey)	20	46	76	50
Livistona australis Mart.	120	290	70	95
Phoenix canariensis Hort.	0	0	90	0
Phoenix roebelenii O'Brien	0	600	760	890
Rhapis excelsa (Thunb.)	260	570	0	1940
Roystonea regia (Kunth)	80	90	140	160
Syagrus romanzoffiana (Cham.)	340	260	470	400
Washingtonia robusta Wendl.	17	45	15	81

[a] Distance between plants and rows.

[b] Number of individual palms in each polyculture.

assessed during a 16-week period in each of the three climatic seasons. Each polyculture was divided into four blocks of 1 ha containing 600 to 1600 palms. In each block, four palms were selected for installing a different trap–bait combination. In total, 16 trap–bait combinations per polyculture were installed. To avoid any effect from the spatial distribution of traps and baits, the trap–bait combinations were rotated clockwise on a weekly basis among the blocks of each polyculture.

Assessment of trap types

Four different types of traps were used to capture *R. palmarum* individuals (Fig 1). The first trap, made from a white bucket, was previously used by Sumano *et al* (2012) and Landero-Torres *et al* (2015a) (Fig 1a). The second and third traps were handmade from discarded polyethylene (PET) bottles (plastic soda bottles) (Fig 1b, c). The fourth trap type was a common yellow bucket trap that is currently recommended by the Plant Health Committee of the State of Tabasco (CESVETAB 2016) (Fig 1d).

The first trap was constructed from a cylindrical white bucket (19-L capacity) with a base diameter of 30.5 cm and a height of 36 cm (NOVATEC PAGANI® S.A. de C.V, Mexico City, Mexico) (Fig 1a). For adult weevil access, four equidistant holes of 5 cm in diameter were perforated on the sides of the bucket near the top rim in addition to four holes of the same diameter on the lid of the bucket. To drain water in case of rain, five holes of 6 mm in diameter were perforated on the bottom of the bucket. One of these holes was positioned in the center, and the other holes were positioned between the center hole and the bottom rim of the bucket. This trap followed the proposed design of Sumano *et al* (2012).

The second colorless PET-bottle trap was made from colorless polyethylene bottles (PET) of 3-L capacity (PepsiCo® Inc., New York City, New York) (Fig 1b). For adult weevil access, two square holes of 4 × 4 cm were cut into the sides of the bottle at a height of 20 cm from the base. Only three sides of the square opening were cut, as the upper side of the square was left uncut to avoid entry of excess rainwater. These trap openings simulated a ramp of 45° perpendicular to the axis of the bottle. In addition, five 6-mm-diameter holes were cut around the perimeter of the bottle at a height of 5 cm from the base to prevent potential accumulation of rainwater.

The third green PET-bottle trap (PepsiCo® Inc., New York City, New York) had the same features as colorless PET-bottle trap, with one notable modification aside from the difference in color (Fig 1c). The bottom sides of the square openings, rather than the upper side, were left uncut to form ramps.

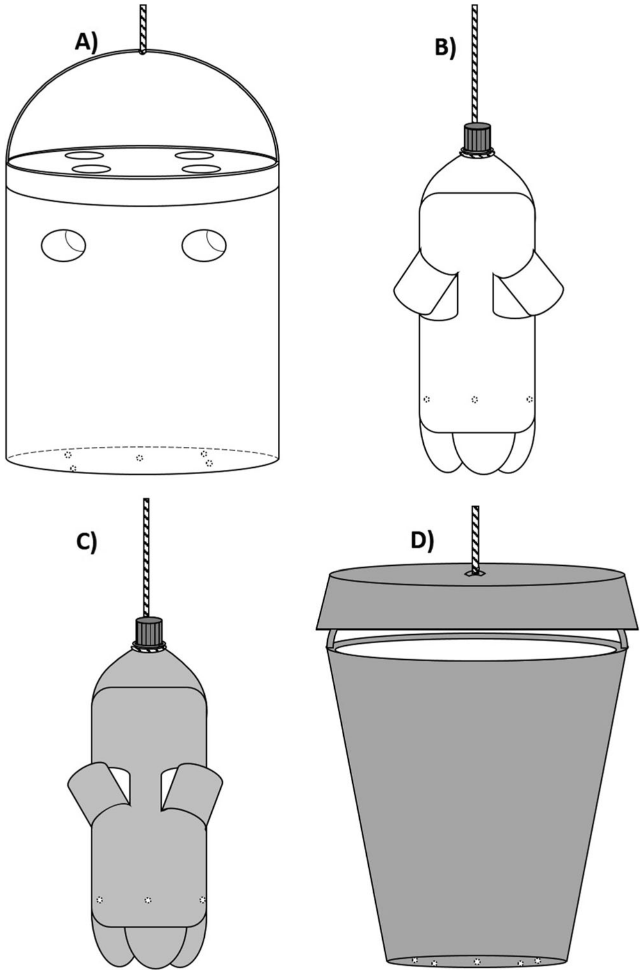

Fig 1 Frontal view of the evaluated trap types for capturing *Rhynchophorus palmarum*. **A** White bucket trap. **B** Colorless PET-bottle trap. **C** Green PET-bottle trap. **D** Yellow bucket trap.

The fourth yellow bucket-type trap was made from a yellow plastic container with a base diameter of 30 cm, a top diameter of 37 cm, and a length of 29 cm (Cuplasa® Mexico City, Mexico) (Fig 1d). A circular yellow tray with a diameter of 40 cm and a depth of 10 cm (Cuplasa®, Mexico City, Mexico) was inversely fastened at 5 cm from the top rim of the bucket to allow for adult weevil access.

Each trap was set in the field and hung from a palm frond by a rope tied to the handle of the bucket or the neck of the bottle. In each polyculture, 16 traps were set. Four traps of each trap type were assessed: one per selected palm in each block. To ensure that weevils would enter the traps after perching on palm stems, the hanged traps were carefully adjusted to be in direct contact with the stem of the selected palm at a height of 1.5 m above ground level (Chinchilla & Oehlschlager 1992).

Assessment of baits

Three different bait combinations previously used by Landero-Torres *et al* (2015b) and the bait–lure combination currently recommended by CESVETAB (2016) were compared. The four bait combinations were (1) a 1:1 mixture of banana (*Musa paradisiaca* L.; Zingiberales: Musaceae) and pineapple (*Ananas comosus* Merr.; Poales: Bromeliaceae), (2) a 1:1 mixture of sugarcane (*Saccharum officinarum* L.; Poales: Poaceae) and sugarcane molasses, (3) a 1:1 mixture of bait 1 and bait 2, and (4) a 1:1 combination of the synthetic aggregation pheromone rhynchophorol (RHYNKO-LURE® ASD, Costa Rica) and banana. This latter bait-lure combination also included the commercial insecticide LANNATE®, which has methomyl as the active ingredient (E.I. du Pont de Nemours and Company, Wilmington, DE).

The baits were placed in the traps in similar amounts (200 g) in addition to 200 mL of water. These amounts were adequate for guaranteeing that the bait would ferment and attract weevils for 7 days until its replacement. To disperse the aggregation pheromone, a commercially available polyethylene diffuser was installed in the middle of the trap. This device has a diffusion rate of 1.6 mg/day and a duration of 45 days, so it was replaced every 4 weeks (Moya-Murillo *et al* 2015).

Cost estimates for each trap–bait combination

The cost-effectiveness (C_E) of each of the 16 evaluated trap–bait combinations (4 baits × 4 traps) was evaluated during 1 year of sampling according to the following equation (Caudell *et al* 2010):

$$C_E = [Cm + (Cb)(Rf) + (Cl)(Lf)](Ap)$$

where C_E represents the annual estimated cost per trap for capturing adult weevils, considering the necessary materials and supplies for manufacturing the traps and the labor required for the preparation, placement, and maintenance of traps. *Cm* is the monetary cost of the materials required to make the traps by hand according to the suppliers' price list. *Cb* is the average market cost of the exact quantity of evaluated bait according to the price per kilogram of product at Wal-Mart Stores, Inc.®. *Rf* is the replacement frequency of the baits for each trap–bait combination during 1 year of sampling. *Cl* is the monetary cost of the required labor, including the hiring of laborers to change baits, as per the minimum salary established by the National Commission of Minimum Wages in Mexico (CONASAMI 2016). *Lf* is the number of times that manpower was required for collecting weevils in each trap–bait combination during 1 year of sampling. *Ap* is the number of traps set per polyculture. All monetary costs and C_E are expressed in US dollars, considering the average exchange rate from January to December 2016.

Sample processing

All captured specimens were sorted and counted. Of the total captured weevils, 1% were dry mounted to create a reference collection. The remaining 99% of specimens were preserved in 70% alcohol. All representative vouchers were deposited in the Entomological Collection of the Instituto de Ecología A.C. in Xalapa, Veracruz, Mexico (IEXA; Reg. SEMARNAT: Ver. IN.048.0198).

Statistical analysis

From the number of weevils recorded weekly, the number of weevils per trap per day (WTD) was determined. To calculate this index, the number of males, females, and total weevils captured weekly per trap was divided by the number of days in the week (7 days) in order to provide a relative estimate of the average size of the adult population in a given space and time (Aparicio-Del Moral *et al* 2015). In order to detect the possible effects of trap type, bait mixture, sampling season, sex, and polyculture on the number of weevil captures per trap per day, a generalized linear model was used, assuming a Gaussian error distribution and an identity link function. The analysis was based on a balanced repeated measures design with four fixed factors (trap type, bait mixture, sampling season, and sex). The analyses were performed using the function "glmer" of the R package "lme4" (Bates *et al* 2014). The models were evaluated according to the Akaike's Information Criterion (AIC) (Akaike 1987), comparing the ΔAIC of the null model with respect to the aforementioned model. Models with ΔAIC ≤2 were considered equivalent. In order to test for differences among the different levels of the fixed factors, a Tukey's post-hoc test was performed using the "glht" function of the R package "multcomp" (Hothorn *et al* 2008). All analyses were performed in the statistical software R 3.2.3 (R Development Core Team 2014).

Results

A total of 4712 *R. palmarum* adults were captured using 16 trap–bait combinations in four ornamental palm polycultures during 1 year of sampling that comprised three climatic seasons (Table 2). Of the captured weevils, 47.3% were female and 52.7% were male. The colorless PET trap and the yellow bucket trap combined with banana + pineapple + sugarcane + sugarcane molasses and with pheromone + banana + insecticide captured the highest number of adult weevils (~10% each). The remaining 12 trap–bait combinations captured less than 7% of total weevils. Most weevils were captured in the wet, warm season (46%), followed by the dry, cool season (28%) and the dry, warm season (26%). All trap–bait combinations captured at least one weevil per trap per week in the wet, warm season. The total number of zero captures was 19, of which 21% occurred in the dry, cool season and the remaining 79% in the dry, warm season (Table 2).

The factors of trap type (F = 254.67, df = 3, P = 0.001), bait mixture (F = 128.97, df = 3, P = 0.001), sampling season (F = 366.97 df = 2, P = 0.001), and sex (F = 28.57, df = 1, P = 0.001) significantly affected the number of captured weevils per trap per day (WTD). However, only the interaction among trap type, bait mixture, and sex led to a significant variation (F = 11.91; df = 9; P = 0.001; Fig 2) in the number of captured WTD. Pairwise tests indicated that both the yellow bucket trap and the colorless PET trap captured a significantly higher number of WTD than the white bucket trap (t = 13.39; P = 0.001) and the green PET trap (t = 17.95; P = 0.001). The bait mixtures of pheromone + banana + insecticide and of banana + pineapple + sugarcane + sugarcane molasses captured a significantly higher number of WTD than the bait mixtures of banana + pineapple and sugarcane + sugarcane molasses (F = 86.02; df = 3; P = 0.001) (Fig 2). When WTD was divided by sex, the observed mean number of males (0.46) was significantly higher than that of females (0.41) over the course of 1 year of sampling (F = 28.57; df = 1; P = 0.001) (Fig 2).

The sampling season factor independently affected variation in captured WTD; a significantly higher number of weevils were captured in the wet, warm season than in the dry, cool season and the dry, warm season (F = 244.77; df = 2; P = 0.001) (Fig 3). Additionally, the interaction among the factors of sampling season, trap type, and sex (F = 2.16; df = 6; P = 0.04) significantly affected the number of captured WTD.

The combined cost of each trap and bait type affected the cost-effectiveness of the 16 trap–bait combinations for capturing *R. palmarum* (Table 3). The banana + pineapple bait combined with the colorless PET or the green PET trap were the combinations with the lowest annual cost per hectare ($804 USD each), followed by the latter bait combined with the white bucket trap ($831 USD) and the yellow bucket trap ($846 USD). Meanwhile, the mixture of pheromone + banana + insecticide bait combined with the white bucket, the colorless PET, or the green PET trap had an annual cost per hectare of $1636 USD, mainly attributable to the high cost of the pheromone and insecticide. The highest annual cost per hectare ($1678 USD) resulted from the combination of this bait mixture with the yellow bucket trap. Among the trap–bait combinations that captured the highest number of adult weevils (~10% each, Table 2), the mixture of banana + pineapple + sugarcane + sugarcane molasses bait combined with colorless PET trap was the cheapest and the mixture of pheromone + banana + insecticide bait combined with yellow bucket trap was the most expensive.

Discussion

Based on the results of the weevil sampling in the present study, some effective and affordable trap types that may be used with food attractant and without insecticide are

Table 2 Number of *Rhynchophorus palmarum* adults captured by 16 trap–bait combinations in four polycultures of ornamental palms during three climatic seasons in Veracruz, Mexico.

Trap–bait combinations	Trapped weevils			No. zero captures[a]
	Total	Females	Males	
Yellow bucket trap—banana + pineapple bait	302	126	176	0
Yellow bucket trap—sugarcane + sugarcane molasses bait	271	137	134	2
Yellow bucket trap—banana + pineapple + sugarcane + sugarcane molasses bait	470	217	253	0
Yellow bucket trap—pheromone + banana + insecticide bait	483	223	260	0
White bucket trap—banana + pineapple bait	218	117	101	3
White bucket trap—sugarcane + sugarcane molasses bait	215	93	122	2
White bucket trap—banana + pineapple + sugarcane + sugarcane molasses bait	265	137	128	1
White bucket trap—pheromone + banana + insecticide bait	226	117	109	2
Colorless PET trap—banana + pineapple bait	261	147	114	0
Colorless PET trap—sugarcane + sugarcane molasses bait	291	98	193	0
Colorless PET trap—banana + pineapple + sugarcane + sugarcane molasses bait	464	191	273	0
Colorless PET trap—pheromone + banana + insecticide bait	472	239	233	0
Green PET trap—banana + pineapple bait	166	79	87	3
Green PET trap—sugarcane + sugarcane molasses bait	158	86	72	4
Green PET trap—banana + pineapple + sugarcane + sugarcane molasses bait	233	113	120	2
Green PET trap—pheromone + banana + insecticide bait	217	107	110	0

[a] Number of traps that did not capture *Rhynchophorus palmarum* adults (considering all traps during the entire sampling period).

proposed. In comparing the efficacy of the studied traps, the colorless PET and the yellow bucket traps captured a similar number of weevils per trap per day (Fig 2). One of the characteristics that may have contributed to the efficacy of the colorless PET-bottle trap was design of the trap openings (4 cm × 4 cm) (Fig 1). The trap openings may have facilitated volatile emission (e.g., ethyl acetate) from the fermented baits and the entry of weevils into the trap, as demonstrated by Osorio-Osorio *et al* (2003) and Landero *et al* (2015b). In

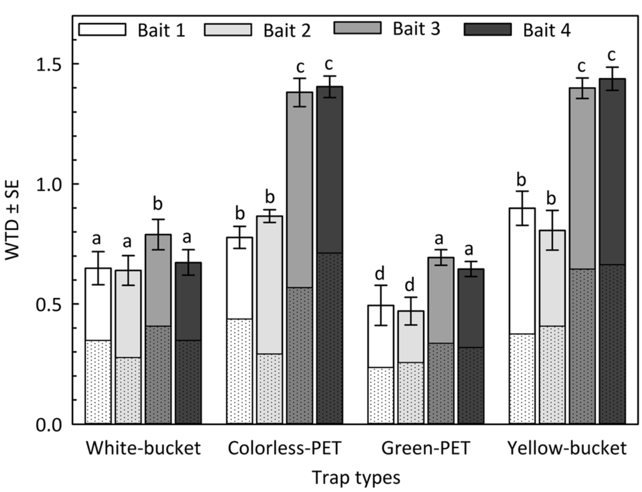

Fig 2 Variation or interaction in the number of adult weevils captured per trap per day (WTD) ± standard error (SE) among the different traps and baits evaluated for capturing *Rhynchophorus palmarum*. The *dotted sections* of each bar indicate female WTD, and the *solid sections* indicate male WTD. *Bars labeled with the same letter* are not significantly different (Tukey's test, *P* > 0.05). Baits corresponds with (*1*) a mixture of banana + pineapple, (*2*) a mixture of sugarcane + sugarcane molasses, (*3*) a mixture of banana + pineapple + sugarcane + sugarcane molasses, and (*4*) a combination of rhynchophorol + banana + insecticide. The ingredients of each bait were of equal ratio.

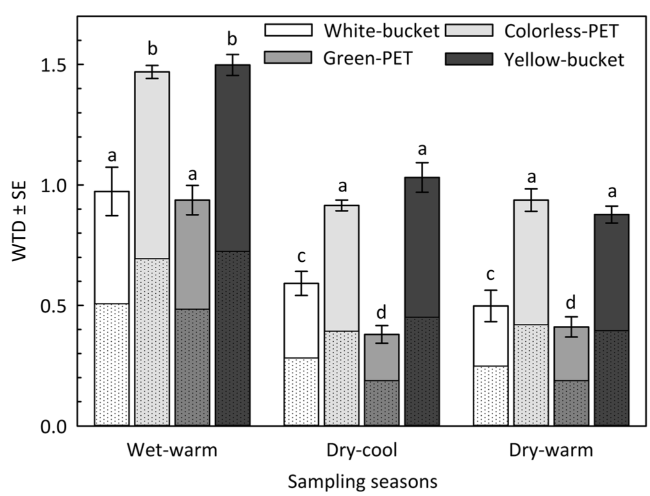

Fig 3 Variation or interaction in the total number of *Rhynchophorus palmarum* adults per trap per day (WTD) ± standard error (SE) captured by four different trap types during the three sampling seasons. The *dotted sections* of each bar indicate female WTD, and the *solid sections* indicate male WTD. *Bars labeled with the same letter* are not significantly different (Tukey's test, *P* > 0.05).

Table 3 Cost estimates of each trap–bait combinations for capturing *Rhynchophorus palmarum* in ornamental palm polycultures in Veracruz, Mexico.

Trap–bait combinations	*Cm*[a]	*Cb*[a]	*Rf*[b]	*Cl*[a]	*Lf*[b]	*Ap*[c]	Cost-effectiveness (C_E)
Yellow bucket trap—banana + pineapple bait	10.50	1.11	52	2.76	52	4	846.98
Yellow bucket trap—sugarcane + sugarcane molasses bait	10.50	1.99	52	2.76	52	4	1030.97
Yellow bucket trap—banana + pineapple + sugarcane + sugarcane molasses bait	10.50	3.10	52	2.76	52	4	1260.96
Yellow bucket trap—pheromone + banana + insecticide bait	10.50	22.11	12	2.76	52	4	1678.49
White bucket trap—banana + pineapple bait	6.63	1.11	52	2.76	52	4	831.50
White bucket trap—sugarcane + sugarcane molasses bait	6.63	1.99	52	2.76	52	4	1015.49
White bucket trap—banana + pineapple + sugarcane + sugarcane molasses bait	6.63	3.10	52	2.76	52	4	1245.48
White bucket trap—pheromone + banana + insecticide bait	6.63	22.11	12	2.76	52	4	1663.01
Colorless PET trap—banana + pineapple bait	0.00	1.11	52	2.76	52	4	804.97
Colorless PET trap—sugarcane + sugarcane molasses bait	0.00	1.99	52	2.76	52	4	988.96
Colorless PET trap—banana + pineapple + sugarcane + sugarcane molasses bait	0.00	2.76	52	2.76	52	4	1149.95
Colorless PET trap—pheromone + banana + insecticide bait	0.00	22.11	12	2.76	52	4	1636.47
Green PET trap—banana + pineapple bait	0.00	1.11	52	2.76	52	4	804.97
Green PET trap—sugarcane + sugarcane molasses bait	0.00	1.99	52	2.76	52	4	988.96
Green PET trap—banana + pineapple + sugarcane + sugarcane molasses bait	0.00	3.10	52	2.76	52	4	1218.95
Green PET trap—pheromone + banana + insecticide bait	0.00	22.11	12	2.76	52	4	1636.47

[a] Monetary costs of the materials (*Cm*), baits (*Cb*), and labor (*Cl*) required for making, preparing, and maintaining each trap–bait combination. All monetary costs and CE are expressed in US dollars, considering the average exchange rate from January to December 2016.

[b] Frequency of bait replacement (*Rf*) and labor for collecting captured weevils (*Lf*) for each trap–bait combination.

[c] Number of traps set per polyculture (1 trap/ha).

fact, the flaps left uncut on the upper side of the square openings at an angle of 45° with respect to the central axis of the trap (Fig 1) might retain weevils in the trap after their capture. Similar results were demonstrated in a previous study carried out in a palm oil plantation in Colombia (Moya-Murillo *et al* 2015).

The attraction of weevils to the colorless PET-bottle trap baited with a mixture of banana + pineapple + sugar cane + sugarcane molasses was similar to their attraction to the yellow bucket trap baited with pheromone + banana + insecticide that is normally used by producers (Fig 2). The difference between these trap–bait combinations is that the first does not require insecticides to kill weevils in order to prevent their escape from the trap. In fact, during the experimental period, the captured insects were observed to remain alive at the interior of the colorless PET-bottle trap since food was present. Similar results were demonstrated by Osorio-Osorio *et al* (2003), Sumano *et al* (2012), and Landero *et al* (2015b) for distinct trap types. These authors also suggest that the captured males could remain alive inside traps by feeding on the fermenting bait and could emit aggregation pheromone, attracting other *R. palmarum* weevils to the trap.

The olfaction of weevils plays an important role in their attraction toward baited traps (Saïd *et al* 2003). The bait mixtures of banana + pineapple + sugar cane + sugarcane molasses and of pheromone + banana + insecticide captured the highest numbers, which were similar to one another, of weevils per trap per day (Fig 2). Previous studies in the study area and in other palm-producing regions indicate that banana, pineapple, and sugarcane produce ethanol, pentane, and ethyl acetate during fermentation (Oehlschlager *et al* 2002, Plata-Rueda *et al* 2016). These compounds are crucial for attracting adults of *R. palmarum* in field conditions and across short distances (Saïd *et al* 2003, Moya-Murillo *et al* 2015, Plata-Rueda *et al* 2016).

The abundance of *R. palmarum* significantly increased in the wet, warm season and decreased during the driest season of the year (Fig 3). Similar results have been found in other studies in which higher levels of rainfall and humidity were associated with greater numbers of captured weevils (Ferreira *et al* 2003, Correia *et al* 2015, Pinho *et al* 2016). During the rainy season, the plant fibers used by larvae to pupate are soft and easily opened by insects upon their emergence. However, in the dry season, plant structures are more rigid; insects may have more difficulty emerging or may become trapped and die (Correia *et al* 2015). This factor should be considered when planning campaigns to monitor this pest. For instance, the number of traps could be increased during the wet, warm season when weevil abundance is higher and could be decreased during drier seasons when weevil abundance is lower.

With regards to the annual cost estimates for each trap–bait combination, the cost of the yellow bucket trap baited with pheromone + banana + insecticide was the highest due to the prices of the LANNATE® insecticide and the rhynchophorol aggregation pheromone (Table 3). The annual investment in materials and maintenance of colorless PET-bottle traps with the bait mixture of banana + pineapple + sugar cane + sugarcane molasses was lower in comparison to of the annual cost of yellow bucket traps baited with the mixture of pheromone + banana + insecticide (a saving of $528 USD). Otherwise, both bait–trap combinations did not significantly differ in terms of weevil attraction or capture. Therefore, the cheaper trap–bait combination may replace the traditional yellow bucket trap that has been widely used by palm producers in Mexico for capturing *R. palmarum* (CESVETAB 2016).

The use of PET bottles for capturing *R. palmarum* could have significant advantages for growers. Palm growers with limited economic resources can easily use and construct this highly efficient, cheap, and simple trap, as colorless PET bottles (Figs 1 and 2) are available worldwide. In addition, these traps can last several years (Lasa *et al* 2014). Thus, the use of these traps could represent significant savings for growers using traps as strategy for capturing *R. palmarum*. Although the durability of these PET traps was not evaluated, these traps were re-used during the entire experimental period and remained in good enough condition to use for a second year. In contrast, the yellow and the white bucket traps were discarded after the experimental period because the plastic structure of the buckets, lids, and trays had begun to break from use and exposure to climatic conditions (rain and sun). Thus, the overall advantage of using PET traps is that they reduce trap costs without significantly influencing trapping efficacy (Table 3). However, additional tests should be conducted to evaluate the durability of these traps as well as the stability and sensitivity of the utilized baits, whose modification could potentially further improve costs.

From our cost estimate results, additional trap–bait combinations that are cheaper but less attractive can be highlighted for capturing *R. palmarum* in ornamental palm polycultures (Tables 2 and 3). Palm producers of the studied region often capture adult weevils by hand, collecting them during their times of greatest activity and also killing them by hand, which represents a common cultural control practice (Landero-Torres *et al* 2015a, b). In other areas of the country, palm producers commonly use the expensive trap made from the yellow bucket and baited with banana + synthetic aggregation pheromone + insecticide for capturing palm weevils (Osorio-Osorio *et al* 2003, Sumano *et al* 2012). However, in other municipalities of the state of Veracruz such as Villa Unión, Cuatlapan, Zapoapan, and Zapoapita insecticides are systematically applied to planted palms to protect them from this pest (Landero-Torres *et al* 2015a). This is considered an ineffective practice since *R. palmarum* adults do not remain for long periods of time on healthy palm fronds. Adult weevils are only attracted to wounded or diseased palms where they stop and reproduce (Osorio-Osorio *et al* 2003, Plata-Rueda *et al* 2016).

In conclusion, the implementation of affordable traps and baits for capturing *R. palmarum* represents an effective tool for monitoring weevil populations. In particular, the colorless PET-bottle trap baited with a mixture of banana + pineapple + sugar cane + sugarcane molasses may be useful for palm producers. Due to the recent economic importance of ornamental crops in the studied region (Murguía-González *et al* 2007, Ramírez-Rojas *et al* 2011, SIAP 2016), the use of a novel and cheap trap–bait combination may provide great benefits to producers in the integrated management of *R. palmarum*.

Acknowledgements Funding was provided by the Cuerpo Académico de Horticultura Tropical (UV-CA-32) of the Facultad de Ciencias Biológicas y Agropecuarias at Orizaba-Córdoba region of the Universidad Veracruzana. We thank Delfino Hernández Lagunes and Eder F. Mora Aguilar for their technical assistance in the Entomological Collection IEXA-INECOL. We are grateful to the owners of the ornamental palm polycultures in Ixtaczoquitlán, Veracruz, Mexico. Finally, we thank the two anonymous reviewers, the section editor and the editor in chief for their valuable comments and suggestions to improve the manuscript. The English version of the manuscript was reviewed by Allison Marie Jermain.

References

Akaike H (1987) Factor analysis and AIC. Psychometrika 52:333–342

Alpizar D, Fallas M, Oehlschlager AC, Gonzalez LM, Chinchilla CM, Bulgarelli J (2002) Pheromone mass trapping of the West Indian sugarcane weevil and the American palm weevil (Coleoptera: Curculionidae) in palmito palm. Fla Entomol 85:426–430

Aparicio-Del Moral YM, Huerta-de la Peña A, Dzul-Cauich JF, Hernández-Ortiz V (2015) Fluctuación poblacional de adultos de *Rhagoletis zoqui* en nogal de Castilla (*Juglans regia* L.) en Puebla, México. Southwest Entomol 40:409–418

Baker WJ, Savolainen V, Asmussen-Lange CB, Chase MW, Dransfield J, Forest F, Wilkinson M (2009) Complete generic-level phylogenetic analyses of palms (Arecaceae) with comparisons of supertree and supermatrix approaches. Syst Biol 58:240–256

Bates D, Maechler M, Bolker B, Walker S (2014) lme4: linear mixed-effects models using *Eigen* and *S4* – R package version 1.0–6. http://CRAN.R-project.org/package=lme4 Accessed 25 Nov 2016

Carreño-Correa RD, Salazar-Mercado SA, Espinel-Rodríguez M (2013) Evaluación de cebos para el control de *Rhynchophorus palmarum* L. (Coleoptera: Curculionidae) en el cultivo de *Elaeis guineensis* Jacq (Arecales: Arecaceae). Rev Agron 21:65–72

Caudell JN, Shwiff SA, Slater MT (2010) Using a cost-effectiveness model to determine the applicability of OvoControl G to manage nuisance Canada geese. J Wildl Manage 74:843–848

CESVETAB (2016) Comité estatal de sanidad vegetal de Tabasco, México – secretaría de agricultura, ganadería, desarrollo rural, pesca y alimentación (SAGARPA) http://www.cesvetab.com Accessed 5 Aug 2016

Chinchilla CM, Oehlschlager CA (1992) Comparación de trampas para capturar adultos de *Rhynchophorus palmarum* utilizando la feromona de agregación producida por el macho. ASD Oil Palm Pap 5:9–14

CONASAMI (2016) Comisión nacional de los salarios mínimos, México – secretaría del trabajo y previsión social (STPS) http://www.gob.mx/conasami Accessed 5 August 2016

Correia RG, Lima ACS, Cordeiro ACC, Maciel FCS, Martins WBR, Dionísio LFS (2015) Flutuação populacional de *Rhynchophorus palmarum* L.(Coleoptera: Curculionidae) em plantios de palma de óleo em Roraima. EntomoBrasilis 8:130–134

Esparza-Díaz G, Olguin A, Carta LK, Skantar AM, Villanueva RT (2013) Detection of *Rhynchophorus palmarum* (Coleoptera: Curculionidae) and identification of associated nematodes in south Texas. Fla Entomol 96:1513–1521

Ferreira JM, Leal MLS, Sarro FB, Araujo RP, Moura JIL (2003) Avaliação de diferentes fontes atrativas e suas prováveis interações na captura de *Rhynchophorus palmarum*. Man Int Plag Agroecol 67:23–29

García-Hernández JL, Beltrán-Morales F, Loya-Ramírez JG, Morales-Cota JR, Troyo-Diéguez E, Beltrán-Morales FA (2003) First record of *Rhynchophorus palmarum* (Coleoptera: Dryophthoridae) in Baja California Sur. Folia Entomol Mex 42:415–417

Griffith R, Giblin-Davis RM, Koshy PK, Sosamma VK (2005) Nematode parasites of coconut and other palms. In: Luc M, Sikora RA, Bridge J (eds) Plant parasitic nematodes in subtropical and tropical agriculture. CAB International Publishing, Egham, pp 493–528

Landero-Torres I, García-Martínez MA, Galindo-Tovar ME, Leyva-Ovalle OR, Lee-Espinosa HE, Murguía-González J, Negrín-Ruiz J (2014a) Diversidad alfa de la mirmecofauna del área natural protegida Metlac de Fortín, Veracruz, México. Southwest Entomol 39:541–553

Landero-Torres I, García-Martínez MA, Galindo-Tovar ME, Leyva-Ovalle OR, Lee-Espinosa HE, Murguía-González J, Negrín-Ruiz J (2014b) Un cultivo ornamental de heliconias como reservorio de la mirmecofauna nativa: un caso de horticultura tropical en el centro de Veracruz, México. Southwest Entomol 39:135–146

Landero-Torres I, Presa-Parra E, Galindo-Tovar ME, Leyva-Ovalle OR, Murguía-González J, Valenzuela-González JE, García-Martínez MA (2015a) Variación temporal y espacial de la abundancia del picudo negro (*Rynchophorus palmarum* L., Coleoptera: Curculionidae) en cultivos de palmas ornamentales del centro de Veracruz, México. Southwest Entomol 40:179–188

Landero-Torres I, Galindo-Tovar ME, Leyva-Ovalle OR, Murguía-González J, Presa-Parra E, García-Martínez MA (2015b) Evaluación de cebos para el control de *Rhynchophorus palmarum* (Coleoptera: Curculionidae) en cultivos de palmas ornamentales. Entomol Mex 2: 112–118

Lasa R, Toxtega Y, Herrera F, Cruz A, Navarrete MA, Antonio S (2014) Inexpensive traps for use in mass trapping *Anastrepha ludens* (Diptera: Tephritidae). Fla Entomol 97:1123–1130

MacLeod A, Hussein M (2017) Economic and social impacts of *Rhynchophorus ferrugineus* and *Paysandisia archon* on palms. In: Soroker V, Colazza S (eds) Handbook of major palm pests: biology and management. John Wiley & Sons Ltd, Chichester, pp 54–68

Mazza G, Francardi V, Simoni S, Benvenuti C, Cervo R, Faleiro JR, Llácer E, Longo S, Nannelli R, Tarasco E, Roversi PF (2014) An overview on the natural enemies of *Rhynchophorus* palm weevils, with focus on *R. ferrugineus*. Biol Control 77:83–92

Moura JIL, Toma R, Sgrillo RB, Delabie JHC (2006) Natural efficiency of parasitism by *Billaea rhynchophorae* (Blanchard) (Diptera: Tachinidae) for the control of *Rhynchophorus palmarum* (L.) (Coleoptera: Curculionidae). Neotrop Entomol 35:273–274

Moya-Murillo OM, Aldana-De La Torre RC, Bustillo-Pardey AE (2015) Eficacia de trampas para capturar *Rhynchophorus palmarum* (Coleoptera: Dryophthori-dae) en plantaciones de palma de aceite. Rev Colomb Entomol 41:18–23

Murguía-González J, Lee-Espinosa HE, Landero-Torres I (2007) La horticultura ornamental en el estado de Veracruz, México. Act Hort 48:485–488

Oehlschlager AC, Chinchilla C, Castillo G, Gonzalez L (2002) Control of red ring disease by mass trapping of *Rhynchophorus palmarum* (Coleoptera: Curculionidae). Fla Entomol 85:507–513

Osorio-Osorio R, Cibrián-Tovar J, López-Collado J, Cortez-Madrigal H, Cibrián-Tovar D (2003) Exploración de factores para incrementar la eficiencia de captura de *Rhynchophorus palmarum* (Coleoptera: Dryophthoridae). Folia Entomol Mex 42:27–36

Pinho RC, Farias PRS, Rodrigues KCV, Tinôco RS, dos Santos AVF, Marssena RTP (2016) Spatial distribution of *Rhynchophorus palmarum* in oil palm on the Pará State, Amazon. Rev Cienc Agrar 59:22–31

Plata-Rueda A, Martínez LC, Fernandes FL, Ramalho FS, Zanuncio JC, Serrão JE (2016) Interactions between the bud rot disease of oil palm and *Rhynchophorus palmarum* (Coleoptera: Curculionidae). J Econ Entomol 109:962–965

Quintero JL (2010) Dinámica de captura de adultos de *Rhynchophorus palmarum* L. (Coleoptera: Curculionidae) en la red de monitoreo de la Zona Occidental. Palmas 31:17–27

R Development Core Team (2014) R: a language and environment for statistical computing—R foundation for statistical computing, Vienna, Austria. http://www.R-project.org Accessed 25 Nov 2016

Ramírez-Rojas JL, Sandoval-Vega CA, Ramírez-Vázquez Y (2011) Diagnóstico de las condiciones de operación y manejo administrativo de la producción de palmas ornamentales en las unidades productoras de los municipios de Actopan, Emiliano Zapata, Paso de Ovejas y Puente Nacional. Cienc Admin 11:56–63

Rodríguez C, Oehlschlager AC, Chinchilla CM (2016) Examination of critical components of *Rhynchophorus palmarum* pheromone traps. ASD Oil Palm Pap 46:15–19

Saïd I, Tauban D, Renou M, Mori K, Rochat D (2003) Structure and function of the antennal sensilla of the palm weevil *Rhynchophorus palmarum* (Coleoptera, Curculionidae). J Insect Physiol 49:857–872

Sarria GA, Torres GA, Aya HA, Ariza JG, Rodríguez J, Martínez G (2008) *Phytophthora* sp. es el responsable de las lesiones iniciales de la pudrición del cogollo (PC) de la palma de aceite en Colombia. Palmas 29:31–41

SIAP (2016) Servicio de información agroalimentaria y pesquera – secretaría de agricultura, ganadería, desarrollo rural, pesca y alimentación (SAGARPA). http://www.siap.gob.mx/ Accessed 5 August 2016

Soto-Hernández M, Reyes-Castillo P, García-Martínez O, Ordaz-Silva S (2016) Curculiónidos de diversas localidades de la República Mexicana (Coleoptera: Curculionoidea). Acta Zool Mex 32:62–70

Sumano D, Sánchez S, Romero J, Sol Á (2012) Eficacia de captura de *Rhynchophorus palmarum* L. (Coleoptera: Dryophthoridae) con diferentes diseños de trampas en Tabasco, México. Fitosanidad 16:43–48

Tregear JW, Rival A, Pintaud JC (2011) A family portrait: unravelling the complexities of palms. Ann Bot 108:1387–1389