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RESEARCH

The influence of temperature and precipitation on the abundance of *Anastrepha ludens* and *A. obliqua* (Diptera: Tephritidae), in "Barranqueño" mango (*Mangifera indica*) in Jalisco, Mexico

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Abstract The objective of this research was to evaluate the influence of agroclimatic factors on the abundance of *Anastrepha ludens* (Loew) and *A. obliqua* (Macquart), in orchards of creole "Barranqueño" mango (*Mangifera indica* L.) in the municipalities of Amatitán, San Cristóbal de la Barranca, and Tequila (Jalisco, Mexico). Eighty-four Multilure traps were established to catch specimens from May to September 2021.The most abundant species was *A. ludens* (98.7%). The greatest abundance of *A. ludens* occurred during the postharvest (June) and at new vegetative growth of the mango -with and abundant presence of newly fallen fruit on the ground- (July) in all the municipalities, while *A. obliqua* was in June. The index of flies captured per trap per day (FTD) had values greater than 0.010, which showed that the study area has a high prevalence of pests. There was a significant correlation (*P*-value = 0.001) between the abundance of *A. ludens* with precipitation (19.30-260.60 mm) and minimum temperature (16.7–22.20 °C). The abundance of *A. obliqua* was very low (504 individuals in total) and did not correlate with any variable. The altitude range (842-1151.75 m asl) could influence the mango phenology and explain the differences in the abundance of these species. These results are evidence that precipitation and the survival of adults of these species, do not have a cause-effect relationship, and that population fluctuations between both *Anastrepha* species may be correlated with mango phenology and altitude.

Keywords Fruit flies · Pest · *Anastrepha* · Jalisco · México

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Introduction

The Tephritidae (Diptera) is widely distributed throughout the world and includes about 4,800 species and 500 genera. These flies are known as "true fruit flies" because their larval stages develop inside the fruits of many plants, both cultivated and wild, potentially causing large economic losses. Three species of this family are considered the most important pests for fruit growing worldwide: *Ceratitis capitata* (Wiedemann), *Bactrocera dorsalis* (Hendel), and *Zeugodacus cucurbitae* (Coquillett) (Chen & Ye, 2007; Hernández-Ortiz et al., 2010; Savaris et al., 2016; Shikano et al., 2022).

In the American neotropical region, 916 species of fruit flies have been described in 71 genera. The genus *Anastrepha* (Diptera: Tephritidae) is the most diverse native genus (> 300 species) in the region, and is distributed from the southern USA to northern Argentina, with seven species being considered quarantine pests in many countries in the northern hemisphere, and has a wide range of hosts, including fruit crops such as mango and citrus (Hernández-Ortiz, 2007; Hernández-Ortiz et al., 2010; Savaris et al., 2016; CIFP, 2016).

Five species of *Anastrepha* are considered pests in Mexico: *A. striata* Schiner, *A. obliqua* (Macquart), *A. ludens* (Loew), and *A. serpentina* (Wiedemann), due to their polyphagous habits. Two of these fruit fly species (*A. obliqua* and *A. ludens*) are pests associated with mango, limiting production and commercialization (DOF, 1995; Tucuch et al., 2005; Hernández-Ortiz, 2007; Isiordia-Aquino et al., 2017).

The Mango (*Mangifera indica* L.) (Family: Anacardiaceae) is native to northeastern India, but it has been distributed to many tropical and subtropical regions of the world, where it has become a fruit of great importance (Chávez et al., 2001). Mexico is the sixth largest world producer of this fruit with an annual production of 2,156,039.86 tons, 94% coming from the states of Sinaloa, Guerrero, Nayarit, Chiapas, Oaxaca, Michoacán, Jalisco, and Veracruz (Chávez et al., 2001; SIAP, 2021). In Jalisco, 110,916.50 tons of mango were produced in 2020, mostly from improved varieties; 7.64% of 'criollo' mango production is concentrated mainly in San Cristóbal de la Barranca, Amatitán, and Tequila, where it is known as "Barranqueño" mango. This mango is more fibrous than the commercial varieties but has a sweeter flavor and a more pleasant smell. In these regions, the plantations of this crop date back more than 90 years and have been developed with little or no agronomic management, so the trees are large, making harvesting difficult (Carrillo, 1997; SIAP, 2021).

The abundance of the fruit fly has been related to the phenology of the crop and climatic factors (Montoya et al., 2008). Knowledge of the relationship between agroclimatic variables and the abundance of the fruit fly in mango orchards is an essential tool to choose appropriate techniques for its control, reduction of economic damage in fruit production, and preventing the colonization, establishment, and dispersion of the pest (Hernández-Ortiz et al., 2010). Therefore, the objective of this research was to evaluate the influence of agroclimatic factors on the abundance of *A. ludens* and *A. obliqua* from May to September 2021, in "Barranqueño" criollo mango (*M. indica*) crops in the municipalities of Amatitán, San Cristóbal de la Barranca, and Tequila, Jalisco, Mexico.

Materials and methods

Study area

The study area is located west of the Mexican Volcanic Belt, in Amatitán, San Cristóbal de la Barranca, and Tequila, municipalities of the state of Jalisco, Mexico. Tequila and Amatitán area in the Valles's region, while San Cristóbal de la Barranca is in the Centro region (Fig. 1a-c). Images of the study area were taken using Google Earth (www.google.com/earth) allowing us to view close-ups of the mango crops. Climate data by municipalities were taken from the IIEG (Instituto de Información Estadística y Geográfica de Jalisco) (2019, 2021a, b) (Table 1). This study took place in mango orchards (Fig. 1d and o), located in the Santiago River canyon. The topography of the place varies from small, stepped plateaus and large slopes to ravines with slopes ranging from 4 to 40%; outside the cultivated areas, natural tropical deciduous and oak forests develop (Carrillo, 1997). The mango orchards are made up of large trees and randomly sown. In some plots, other fruit trees are established such as mamey sapote (*Pouteria sapota* (Jacq.) H.E. Moore & Stearn), chirimoya (*Annona longiflora* S.Watson), white sapote (*Casimiroa*

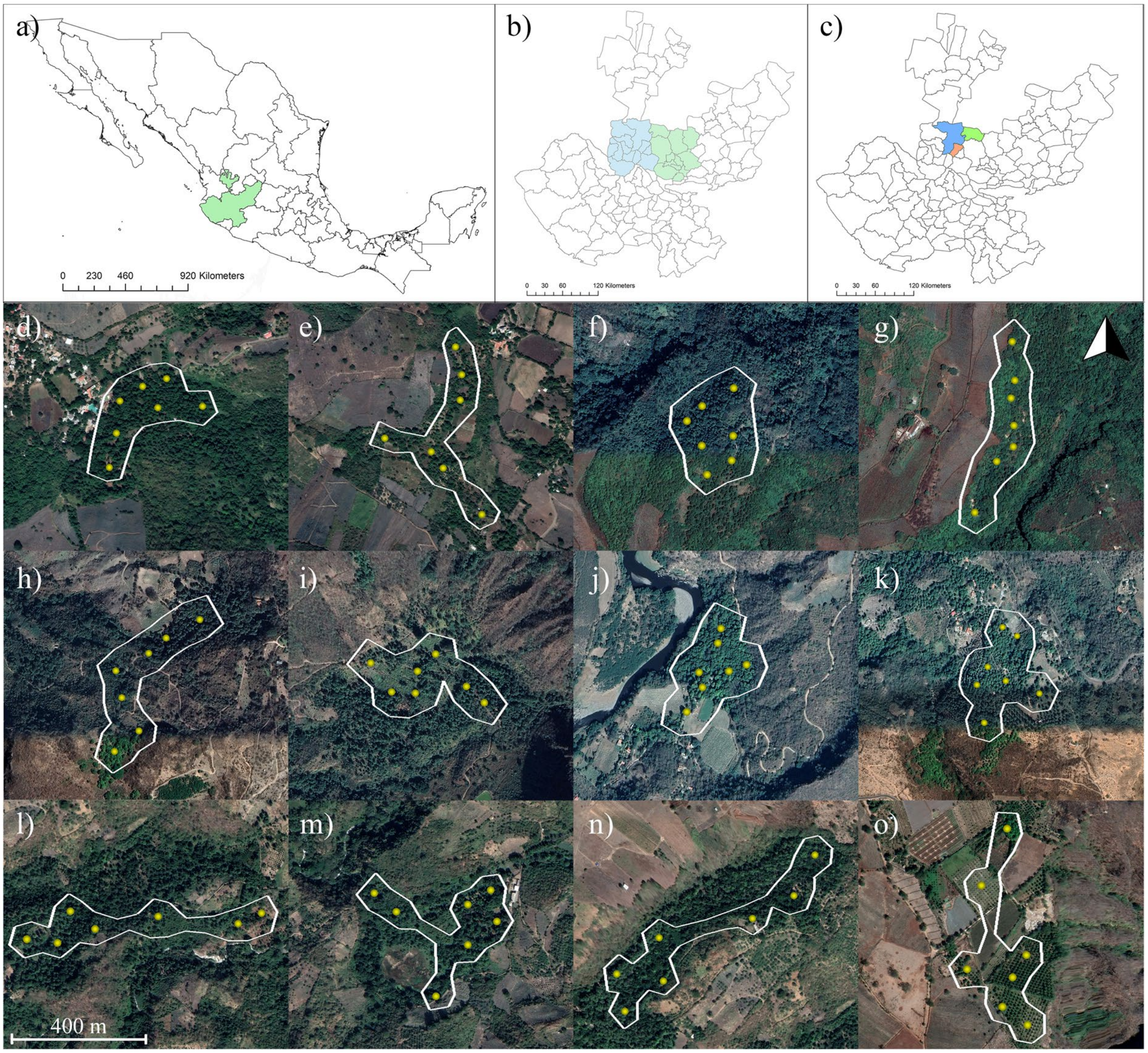

Fig. 1 Location of **a** Jalisco state, Mexico; **b** Regions. Blue color: Valles's Green color: Centro; **c** Municipalities. Blue color: Tequila, Red color: Amatitán, Green color: San Cristóbal de la Barranca; **d–o.** Distribution of traps in mango farms in different localities of the municipalities of Amatitán: **d** La Chome; **e** La Mata; **f** Tecuane uno; **g** Tecuane dos. San Cristóbal de la Barranca: **h** El potero; **i** El Ahuate; **j** Sosocola; **k** El Escalón. Tequila: **l** La Toma; **m** San Antonio del Potrero; **n** El Paraíso; **o** San Martín de las Cañas. (Google Earth, 2022; IIEG, 2018)

watsonii Engl., Engl. & Prant), and banana (*Musa paradisiaca* L.), and irrigation is done by gravity. In the region, the mango presents its flowering stage from September to October, the ripening of the fruits begins at the beginning of March, the harvest begins around March and the beginning of May, and the commercialization extends until May and June. The mango grows well between 24 and 27 °C, and it tolerates up to 50 °C for a short time, but with low humidity and wind, it suffers water stress. The lower limit of 4.4 °C causes damage to leaves and tender shoots of mature trees (SADER, 2014).

Information on agronomic management was collected through surveys of producers in the area, complementing and verifying the data by field visits. In most of the plots, the producers used Malathion as the insecticide and other practices, such as weeding, pruning, and the use of killer traps (The traps are open plastic

Table 1 Description of physical characteristics of the study areas in each municipality (Own elaboration with data from García 2004; IIEG, 2019, 2021a, b)

Municipality	Latitude N (range)	Longitude W (range)	Altitude (m asl)	Climate	Temperature °C (range)	Precipitation (mm)
Amatitán	20°45’- 20°56’	103°37’-103°48’	620- 2,866	Aw: Warm sub-humid with summer rain	9.4–34.2	800-1,100
San Cristóbal de la Barranca	20°56’-21°10’	103°20’-103°41’	740-2,240	Aw: Warm sub-humid with summer rain	8.9–33.6	700-1,000
Tequila	20°47’ -21°27’	103°30’ -104°04’	420-2,940	(A)Cw: Semi-warm sub-humid with summer rains	9.1–33.6	700-1,100

containers with insecticide and sugar mixtures. These traps are abandoned in the field, they are not checked or changed periodically), were less used. No post-harvest waste management is done on any plots (Table 2).

Sampling

Sampling with Multilure traps was conducted weekly in twelve preselected farms (four per municipality) from May to September 2021 (Fig. 1). In each plot (seven hectares each), seven Multilure traps (Better World MFG Inc., Fresno, CA) were established giving a total of 84 Multilure traps baited with the food attractant Torula yeast (Pelmos, Promotora Agropecuaria Universal, SA CV, CDMX), which was used in doses of five tablets dissolved in 250 ml of tap water per trap. All traps were established in the lower branches of mango trees, between two and three meters from the ground, and were checked weekly (SENASICA, 2017).

For examination of the traps, they were removed from the branches of the trees with the help of an extension with a hook. The trap was subsequently disassembled, and the collected insects were placed in a plastic container. An inspection of the captured material was done and *Anastrepha* spp. flies were placed in plastic bottles with 70% alcohol and labeled. The flies were taxonomically determined in the laboratory.

Taxonomic work

The specimens were determined using the taxonomic keys of Hernández-Ortiz et al. (2010). The captured fruit flies were preserved in 70% ethanol and some of

Table 2 Description of agronomical management of the study areas in each municipality and locality

Municipality	Locality	Irrigation	Weeding	Fumigation	Pruning	Killer traps
Amatitán	La Chome	MJS	MJ	MJ	S	-
	La Mata	MJS	MJ	MJ	S	-
	Tecuane 2	MJS	-	J	S	-
	Tecuane 1	MJS	M	MJ	S	-
San Cristóbal de la Barranca	El Ahuate	MJ	S	MJ	-	-
	El Escalón	MJXA	MJXA	MJX	MJ	-
	El Potrero	MJXA	MJXAS	MJX	-	-
	Sosocola	MJ	-	MJ	-	-
Tequila	El Paraíso	MJXAS		MJXA	-	MJXA
	La Toma	MJXA		MJXAS	M	MJXAS
	San Antonio del Potrero	MJXAS		MJXAS	-	MJXAS
	San Martín de las Cañas	MJXAS		MJXAS	MJXS	MJXAS

Abbreviations: M: May, J: June, X: Jul, A: August, S: September 2021. The absence of a letter means that the activity is not carried out during that month them were pinned in a species series represented by each sex and deposited in the Entomological Collection of the Center for Zoological Research, University of Guadalajara (Guadalajara, Mexico). Additional specimens, preserved in ethanol, were housed in the same collection. Voucher will also be deposited at the Colección de Insectos de Interés Agrícola, ASICA (Agencia de Sanidad, Inocuidad y Calidad Agroalimentaria de Jalisco).

Meteorological data

Dataloggers (Extech RHT10 Humidity and Temperature USB Datalogger, FLIR Systems, Inc., Nashua, NH, U.S.A.) registered the temperature at each site, while the precipitation information was received from Weather Spark (https://es.weatherspark.com/). For each municipality, we collected the historical data of the atmospheric variables from 2006 to 2019 at Servicio Meteorológico Nacional (n.d) to reduce potential variations in environmental variables during the sampling period.

Data analysis

The permutational multivariate analysis of variance (PERMANOVA) (Anderson, 2001; McArdle & Anderson, 2001) was used to compare the abundance of each species of fruit fly by locality of each municipality and months. The multivariate response was fruit fly species abundance across the study area. A principal component analysis was used to reduce the dimensionality of the historical abiotic data through time. The canonical principal coordinate analysis (CCA) proposed by Anderson and Willis (2003), based on the Bray-Curtis distance matrix, and including a 10,000 permutations test, was carried out to explore the relationships between the atmospheric variables (precipitation and temperature), altitude and agronomical variables (agronomical management), and the fly abundance in each municipality over time and the phenology stages of the mango. This analysis was performed with the Vegan 2.2-1 package (Oksanen et al., 2019). The relative risk was calculated as the ratio of two bivariate kernel distributions, i.e., the temperature-precipitation distribution when catches were positive. The values of this index are positive, and the interpretation is that the higher its value, the greater the conditions for the risk situation to occur, in this case, the capture of fruit flies. All statistical analyses were performed with the R v. 4.1.1 program (R Core Team, 2021).

The calculation of the fruit flies per trap per day index (FTD) was carried out, which determines the level of infestation of the pest in a determinate area and period. It is obtained with the formula FTD = F/TD where F = number of flies captured; T = number of traps inspected; D = an average number of days of exposure of the traps (DOF, 1995).

Results

During the five months, 41,141 fruit fly individuals were captured, 98.78% were *A. ludens* and 1.22% *A. obliqua*. The highest abundance of *A. ludens* in all municipalities occurred during the months of June and July in the phenological stages of postharvest and vegetative growth – with an abundant presence of newly fallen fruit on the ground-, while for *A. obliqua* it was in June in the postharvest. The greatest abundance of *A. ludens* and *A. obliqua* was found in the localities of Amatitán municipality. The lowest abundance of the two species of fly in all the municipalities was in September in the phenological stage of pre-flowering (Table 3).

The FTD index of *A. ludens* in the three municipalities remained above 0.010, which is why they are areas of a high prevalence of this pest according to the NOM-023-FITO-1995 (DOF, 1995). In July, the highest level of the index was presented in Amatitán (15.0635), followed by Tequila (6.0172), and San Cristóbal de la Barranca (1.0423). September had the lowest index for the three municipalities (Tequila: 0.0886, San Cristóbal de la Barranca: 0.0569, and Amatitán: 0.0331) (Fig. 2a). Regarding the FTD index of *A. obliqua*, the highest values (> 0.0100) occurred in June in Amatitán (0.0536) and Tequila (0.1450), and in May in San Cristóbal de la Barranca (0.0161). September presented the lowest index for all three municipalities: 0.0410, 0.0079, and 0.0000, respectively (Fig. 2b).

Differences between the abundance of *A. ludens* in each municipality over time and the phenology stages of the mango were highly significant (Table 4; *P*-value = 0.0004). In Amatitán, from June to July, 60.37% of the total (24,534 individuals) of

Table 3 Percentage of the abundance of *Anastrepha ludens* and *A. obliqua* per month (phenological stage) and per municipality

	May Harvest			June Postharvest			July VGF			August VGD			September Pre-flowering		
Species	A	S	T	A	S	T	A	S	T	A	S	T	A	S	T
A. ludens	5.57	1.12	1.53	32.35	2.20	11.32	28.02	1.94	11.19	1.40	0.24	2.77	0.06	0.11	0.16
A. obliqua	3.57	1.79	2.98	10.12	2.38	27.38	7.14	1.19	15.67	3.37	0.99	16.07	1.19	0.00	6.15

VGF: Vegetative growth -with an abundant presence of newly fallen fruit on the ground-, VGD: Vegetative growth – with the presence of fallen fruit on the ground completely decomposed and dry - (Original data)

A: Amatitán. S: San Cristóbal de la Barranca. T: Tequila

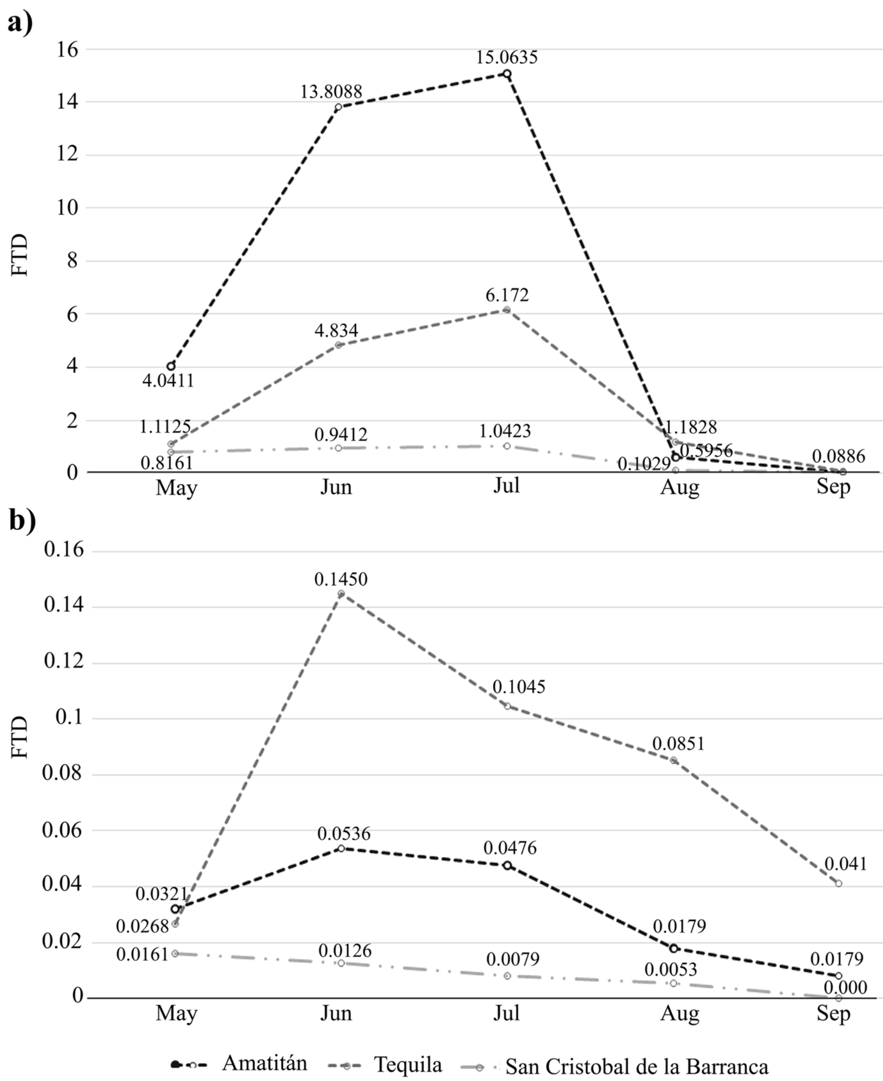

Fig. 2 Index of flies captured per trap per day (FTD) of **a** *Anastrepha ludens* and **b** *A. obliqua* in Amatitán, San Cristóbal de la Barranca and Tequila

A. ludens were captured; while in Tequila, 26.99% (10,966 individuals) were captured during the five months, and in San Cristóbal de la Barranca, 5.62% (2,282 individuals) of *A. ludens* were captured. In the case of *A. obliqua*, significant differences in abundance occurred between municipalities (Table 4;

Table 4 PERMANOVA

Source of variation	df	SS	MS	pseudo-f	*P*-value
Abundance *A. ludens*					
Municipality	2	1.4355	0.71774	6.8660	0.0002 ***
Locality	3	0.4415	0.14717	1.4079	0.1902
Months	4	6.4458	1.61144	15.4153	0.0001 ***
Municipality:Locality	6	0.8820	0.14701	1.4063	0.1487
Municipality:Months	8	2.3258	0.29072	2.7811	0.0004 ***
Locality:Months	12	2.0335	0.16946	1.6211	0.0379 *
Residuals	24	2.5089	0.10454		
Total	59	16.073			
Abundance *A. obliqua*					
Municipality	2	2.4552	1.22760	13.3883	0.0001***
Locality	3	0.4220	0.14067	1.5342	0.1978
Months	4	1.7458	0.43644	4.7599	0.0008***
Municipality:Locality	6	0.9781	0.16301	1.7779	0.0912
Municipality:Months	8	1.1286	0.14108	1.5386	0.1354
Locality:Months	12	1.7626	0.14688	1.6019	0.0944
Residuals	24	2.2006	0.09169		
Total	59	10.6929			

Analysis of the abundance of *Anastrepha ludens* and *A. obliqua* captured in traps in the state of Jalisco, Mexico

95% of confidence level

a = 0.0001) as well as between months (Table 4; *P*-value = 0.0008); however, no significant differences occurred between the interaction of these factors (Table 4; *P*-value = 0.1354). For *A. obliqua*, the largest capture occurred after five months in Tequila, with 344 individuals (68.25% of the total), with June in the same municipality being the month with the highest concentration of individuals captured (138). In Amatitán, 128 individuals of *A. obliqua* were captured and 32 in San Cristóbal de la Barranca.

In the study area, the highest incidence of the fruit fly occurred at a temperature between 20.1 and 34.8 ºC and rainfall between 150.8 and 182.45 mm. (Fig. 3).

The model is highly significant (*P*-value = 0.001) for the analysis of the data obtained. The CCA shows a high correlation between the minimum temperature (*P*-value = 0.001) and precipitation (*P*-value = 0.001), with the abundance of *A. ludens* was recorded during the months of June (Postharvest) and July (Vegetative growth - with an abundant presence of newly fallen fruit on the ground-) in the localities of Amatitán (24,534) and Tequila (9,151), which corresponds to the months with the highest capture of the species. The agronomic management, the average temperature, and the maximum temperature, show a certain trend in the abundance of the pest in June and July in the localities of the municipality of San Cristóbal de la Barranca, but the correlations are not significant (*P*-value = 0.397; 0.089; 0.168) (Fig. 4).

Discussion

Altitude

Hernández-Ortiz (2007) reported that *A. obliqua* has a marked preference for native plant species of Anacardiacea (the same family as the mango), while *A. ludens* is mainly found infesting species of the Rutacea or citrus family; however, the abundance of *A. ludens* (40,637 individuals) in this research is considerably higher that presented by *A. obliqua* (504); 98.77% and 1.23% of the total, respectively;

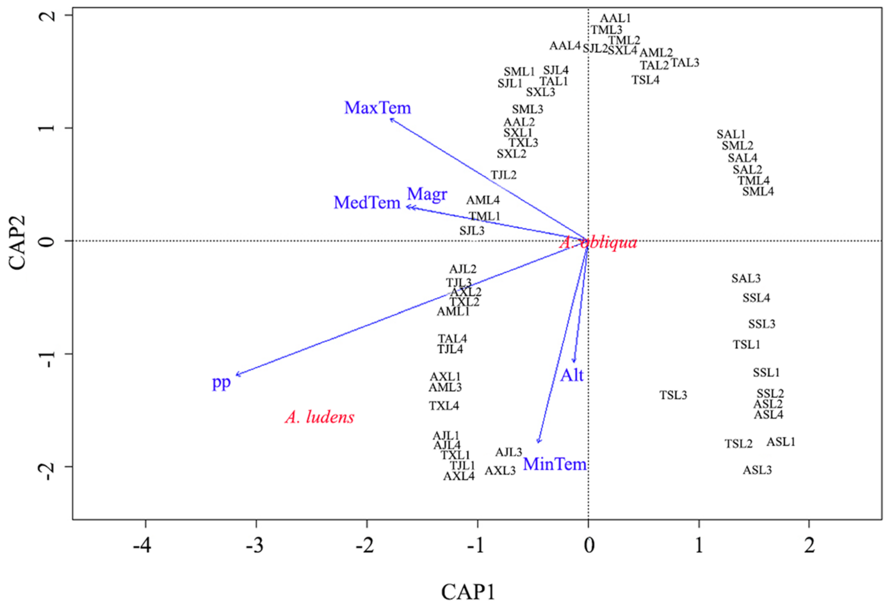

Fig. 3 Composite bivariate kernel distributions of temperature and precipitation of *Anastrepha ludens* in the study area. The intensity of color indicates the catch density. (Own elaboration with data from Servicio Meteorológico Nacional, n.d; and original data)

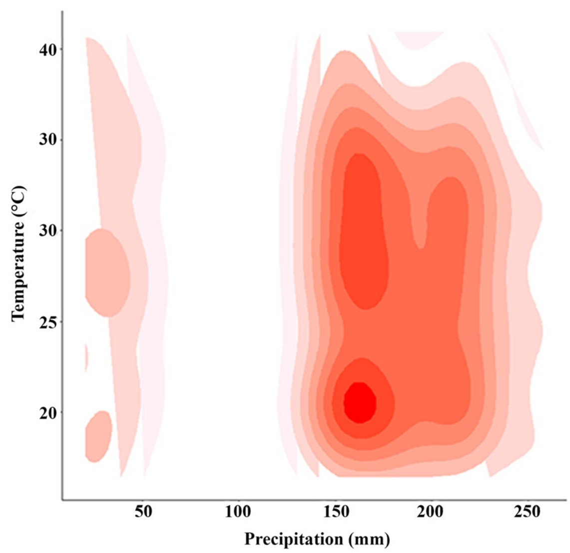

Fig. 4 Graph of the coordinate analysis of the abundance of *Anastrepha ludens* and *A. obliqua*. The first letter indicates the initial of the municipality: A, Amatitán; S, San Cristóbal de la Barranca Municipality; T, Tequila. The second letter indicates the month and phenological stage: M: May (Harvest); J: Jun (Postharvest); X: Jul (Vegetative growth -with an abundant presence of newly fallen fruit on the ground-); A: Aug (Vegetative growth -with the presence of fallen fruit on the ground completely decomposed and dry-); S: Sep (Pre-flowering). 95% of confidence level. (Own elaboration with original data)

and differs from other studies in Mexico; Aluja et al. (1996), in the Soconusco region (0-250 m above sea level (asl)), (Chiapas, Mexico) captured 66.14% of *A. obliqua* and 30.41% of *A. ludens*. Martínez et al. (2004), in mamey sapote orchards, at Jalpa de Méndez (Tabasco, Mex.), at 10 m asl, found higher populations of *A. obliqua*, capturing 1,049 specimens in contrast to only 58 specimens of *A. ludens*. Rodríguez (2017) in Atoyac de Álvarez (Guerrero, Mex.), located at 40 m asl captured only 4 individuals of *A. ludens* compared to 418 of *A. obliqua*. This may be because *A. ludens* is mostly polyphagous and can present in other host fruits of the study area (*P. sapota*, *A. longiflora* and *C. watsonii*) and because the higher altitudes of the sampled localities (834-1,166 m asl) were more favorable to this species, while the reduced abundance of *A. obliqua* is due to its distribution being associated with lower altitudes (< 500 m asl) (Rodríguez-Rodríguez et al., 2018).The abundance of *A. ludens* has also been associated at high altitudes (> 500 m asl) in the states of Chiapas and Oaxaca (Aluja et al., 1996; Hernández-Ortiz, 2007; Antonio-Hernández, 2019). This coincides with the report of Aluja et al. (1990) in Mazapa de Madero (1,040 m asl), (Chiapas), who found a capture percentage of 65.2% for *A. ludens* and 30.1% for *A. obliqua*. Montoya et al. (2014), found a higher proportion of *A. ludens* to *A. obliqua* in mango in Hoyo del Aire, Taretan, (Michoacán, Mex.), located at an altitude of 900 m asl, and Rodríguez (2017) in Tetipac, (Guerrero), at an altitude of 1,660 m asl reported an abundance of 448 *A. ludens* and 326 *A. obliqua.*

Fruit flies per trap per day

The FTD index remained above 0.0100, so the category to which the three municipalities belong is one of high prevalence for the pest, the values obtained herein being above even the maximum FTD reported in other research: 0.250 in June in mango (Tucuch et al., 2008), 0.5–1.6 between April and June in mango (Montoya et al., 2014), 0.6726 in March in citrus (Vanoye-Eligio et al., 2015). In the case of *A. obliqua*, in Amatitán (0.079; September) and in San Cristóbal de la Barranca (0.0079 July; 0.0053 August; 0.0000 September) values corresponding to a low (<0.0100) and even zero prevalence. However, even if the numbers of captured flies decrease, or even if the pest is not detected when the fruit is not available, it should not be assumed that the control actions have been effective because the pest tends to enter and leave the orchards in search of alternative food hosts (Celedonio-Hurtado et al., 1995; Aluja et al., 1996).

Climatic factors

The correlation between precipitation (*P*-value = 0.001) and the abundance of *A. ludens* is positive, representing an increase in the capture of *A. ludens*, while the rainy season is established in the area. This agrees with Tucuch et al. (2008) in Campeche (Mex.) in mango crops, who found a highly positive correlation between precipitation and *A. ludens* populations, since its high populations coincided with the period of greatest precipitation in the region. Aluja et al. (2012), in Martínez de la Torre and Apazapan, (Veracruz, Mex.) reported that precipitation has a delayed effect on the population rates of *A. ludens*, concluding that when the seasonal difference in precipitation is maximal, the rate of population change should diminish. Likewise, Conde-Blanco et al. (2018), found that precipitation is the main covariate that influences the population fluctuation of *Anastrepha* spp. in Caranavi (Bolivia), showing a positive correlation, while Vanoye-Eligio et al. (2019) reported in Santa Engracia, (Tamaulipas, Mex.) that precipitation influences the population dynamics of *A. ludens* females in the field by benefiting their survival at high ambient temperatures.

The minimum temperature presented a significant correlation (*P*-value = 0.001) with the abundance of *A. ludens*, coinciding with that reported by Vanoye-Eligio et al. (2017) in Miquihuana and Bustamante (Tamaulipas, Mex.), who found a positive, weak but significant correlation between the minimum temperature and the capture of *Anastrepha* spp.; moreover, they mention that, in practical terms, it did not represent a functional relationship, and the lack of captures in the coldest months is related to the absence of food, as it is also presented in our results, in which the lowest abundance occurs in the pre-flowering phenological stage (In September) where there are no fruits (mango). It is known that there is a direct relationship between mango maturity, and it is sensitivity to cold temperatures, which could also indirectly influence the development of fruit flies (CONASPROMANGO, 2012; SADER, 2014).

However, it must be understood that even if a correlation is found, it does not necessarily represent a cause-effect relationship (Celedonio-Hurtado et al., 1995) and that it should be interpreted according to the biology of the flies and the field conditions; a lack of rain can cause pupal dehydration in the soil or the adults die due to lack of food, in contrast, extreme rainfall can affect the quality of food for the adult fruit flies, decreasing their fecundity and longevity (Aluja, 1994), or affect pupal survival by drowning (McPhail & Bliss 1933; Baker et al., 1944 as; Montoya et al., 2008). The results obtained contrast with those previously reported, as the sampling of this research was carried out during the harvest periods, postharvest and vegetative growth (with the presence of fallen fruits) periods – in which the food was abundant – giving even more relevance to the inferred relationships between the climatic variables (precipitation and low temperatures) with fruit fly abundance.

The present results also differ from those obtained by Celedonio-Hurtado et al. (1995) and Aluja et al. (1996) in the Soconusco region (Chiapas); Martínez et al. (2004) in Jalpa de Méndez (Tabasco); and those of Altafin et al. (2019) in Pindorama, São Paulo (Brazil), who mentioned that they did not find a significant correlation between the climatic variables and the collected fruit fly individuals.

Agronomic management

The agronomic management had no significant correlation with the abundance of *Anastrepha* (*P*-value = 0.397); pest control could therefore be ineffective and promote resistance to insecticides. Another reason is that any reduction of the *A. ludens* population by insecticide applications is quickly counteracted by the immigration of individuals from neighboring orchards or those from native hosts (Aluja et al., 2012). Consequently, efforts to control this pest should still be directed toward comprehensive pest management in all mango plots. When the FTD index is higher than 0.0100 the orchards must be considered highly prevalent according to NOM-023-FITO-1995 so integrated management should be practiced at this time (DOF, 1995).

It is also important to mention the existing relationship between the abundance of *Anastrepha* spp. and the phenology of the crop, it was observed that the highest captures of the insect coincided with the mango fruiting stage (postharvest), a fact that had already been reported by other authors (Celedonio-Hurtado et al., 1995; Tucuch et al., 2008; Vanoye-Eligio et al., 2017).

The results of this research can be used as a reference for future studies in Mexico. Also, considering the dates of the highest incidence of the pest, the climatic conditions, the altitude, and the phenology of the mango are important to understand the behavior of the fruit flies, these results can be used as a basis for decision-making in the integrated management of the fruit fly in "Barranqueño" mango plantations, in the state of Jalisco.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

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