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ECOLOGY, BEHAVIOR AND BIONOMICS

# Population Dynamics of *Anastrepha ludens* (Loew) (Diptera: Tephritidae) on Citrus Areas in Southern Tamaulipas, Mexico

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**Keywords**

Climatic factors, host availability, Mexican fruit fly, population fluctuation

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**Abstract**

An analysis of adult population fluctuation of *Anastrepha ludens* (Loew) was performed in southern Tamaulipas, Mexico from 2008 to 2011. The aim was to analyze population dynamics of *A. ludens* and its relationships with climatic factors in the citrus region of Llera, Tamaulipas, Mexico. Population densities were weekly examined to identify variation through the year and study period. Four periods were identified according to population size, amplitude, host availability and season of the year. The correlation between population density vs. rainfall and temperature (average, minimum and maximum) was determined by linear and multiple regression analyses. Simple linear regression analysis showed that population density with minimum temperature and rainfall was the most consistent correlation, whereas in multiple regression analysis, rainfall and maximum temperature showed more consistency. A seasonal association between the availability of commercial host, climatic variation, and population peaks of *A. ludens* was determined. This study may have practical implications for the design of specific control strategies, monitoring, and infestation prevention based on different phases of the pest through the year. This strategy, along with the area-wide approach implemented by the Plant Protection Service may lead to an optimization of material, financial and human resources.

## Introduction

The Mexican fruit fly, *Anastrepha ludens* (Loew), is one of the most important pests of citrus in Mexico, Belize, Guatemala, and the lower Rio Grande Valley in Texas (Aluja *et al* 1996, Thomas & Loera-Gallardo 1998). Major damage is caused when the larvae feed on the pulp of the ripe fruit, leading to deterioration in quality and premature fruit drop, accounting for great economic losses to producers. About 37% of fruit injuries provoked by infestations of *A. ludens* can occur in Mexico (Lopéz-Arroyo & Loera-Gallardo 2009), although higher damages have been observed in Tamaulipas, especially in grapefruit.

In the southern region of the state, in contrast to municipalities located in the central portion, control activities of the National Campaign Against Fruit Flies (NCAFF) are generally carried out at local scale (orchard). Ground bait sprays are basically the control method used, which have little impact on pest populations because of the continuous reinfestation of neighboring groves (Aluja *et al* 2012). This situation is particularly so in the case of Llera, Tamaulipas, aggravated by the geographic location of this citrus area between the foothills of the Sierra Madre Oriental (SMO) and Sierra de Tamaulipas.

An additional characteristic of the region is the scarce presence of the wild host "yellow chapote," *Casimiroa greggi* (Plummer *et al* 1941, Thomas 2003) at the foothills of the SMO or close to groves as occurs at the central region. This could suggest a population flow toward the orchards or vice versa (Quintero *et al* 2009). The tropical condition of the region promotes common presence of host in backyards such as mango (*Mangifera indica*) and sour orange (*Citrus aurantium*).

The fluctuation of adult populations of *Anastrepha* spp. has been documented in several studies in tropical areas of Mexico (Celedonio-Hurtado *et al* 1995, Aluja *et al* 1996, Martínez-Morales *et al* 2003, Tucuch-Cahuich *et al* 2008, Aluja *et al* 2012, Ordano *et al* 2013) and elsewhere in the American continent (Houston 1981, Nguyen *et al* 1992, Hedström 1993, Ronchi-Teles & Da Silva 2005, Montes *et al* 2012). However, in general, these studies have reported discrepant results on the association between population dynamics and climatic factors. This suggests local behavior because of different host availability, along with different environmental and ecological conditions on each study area.

In northeastern Mexico, *A. ludens* is considered a native pest (Plummer *et al* 1941, Thomas 2003, Quintero *et al* 2009) exhibiting high citrus infestations during the ripening period. Fruit damage is detected on sweet citrus such as Valencia orange, grapefruit, and mandarins, probably associated with seasonality and climatic factors. Tephritidae populations of *Ceratitis capitata* Wiedemann and *Bactrocera dorsalis* (Hendel) have been linked to climatic variables, ripening and host availability (Chen & Ye 2007, Appiah *et al* 2009).

At local scale (orchard), dispersion studies on sterile flies of *A. ludens* have reported weak correlations between catches with the maximum temperature and rainfall in northern Tamaulipas (Thomas & Loera-Gallardo 1998). In the state of Nuevo León, Mexico, Thomas (2003, 2012) studied population fluctuation of *A. ludens* associated with its wild host *Casimiroa greggi* in the Sierra Madre Oriental, and a significant correlation with rainfall was determined.

This work aimed to analyze the population dynamics of *A. ludens* from 2008 to 2011 and to evaluate its relationship with climatic variables in the citrus area of Llera, Tamaulipas, Mexico.

## Material and Methods

### *Study area*

The citrus area at the municipality of Llera is located in southern Tamaulipas between 23°18′ and 23°07′N and 99°03′ and 98°44′W at km 65 southern Victoria city, Tamaulipas capital, and 120 km away from the citrus area in the central portion of the state. This region has about 4300 ha of citrus groves; the main citrus variety is Valencia orange, followed by grapefruits and mandarins (SAGARPA 2013). The altitude varies from 150 to 300 m above sea level and the west side of the region borders with the Sierra Madre Oriental. The geographic orientation of the study area is from north to south along Guayalejo riverbed (Fig 1).

### *Sampling*

Data obtained from 137 McPhail traps deployed by NCAFF during the period 2008 to 2011 were used to determine adult population fluctuation of *A. ludens*. These data were provided by the Comité Estatal de Sanidad Vegetal de Tamaulipas (CESAVETAM). McPhail traps were baited with four tablets (20 g) of torula yeast (Trampol 300®, Grupo PAUSA S.A. de C.V) diluted in 250–300 mL of water and hung in a tree between 3 and 4 m above the ground. Traps were serviced every 7 days and distributed at a distance of 120 to 150 m between them, trying to achieve a uniform network. Host availability was the main criterion for placing the traps, although in large citrus areas different sweet varieties are observed in an intercalate way inside the orchards or near them.

Weekly trap captures were transformed to flies per trap per day (FTD) values by using the formula total number of flies/(number of traps×days of trap exposure). This parameter is expressed with four digits after zero (IAEA 2013). Thus, variability in trap number or capture periods was standardized (Aluja *et al* 2012).

### *Weather data*

Records of four climatic variables from 2008 to 2011 were used as follows: weekly average of mean, minimum, maximum temperature (Celsius), and rainfall (millimeters). Data were obtained from a weather station operated by the Comisión Nacional del Agua (CNA) at Ejido Emilio Carranza (23°15′18″N, 99°49′60″W) in the central part of the citrus area.

### *Data analysis*

A descriptive statistical analysis of the weekly FTD per year was performed. The citrus variety, climatic oscillations, and weekly FTD were taken into account to determine infestation periods. This is because of the importance of population variations in short periods of time and its implications in control activities and monitoring.

Following Aluja *et al* (2012), monthly FTD data were considered to work (i.e., averaged over 4 weeks) coupled with data of climatic variables that were calculated as monthly averages, as well. Because of high variability of monthly FTD data, these values were transformed to $\log_{10}$ that enabled to stabilize the variance and use the data for further analysis.

By using FTD transformed data and a statistical significance of $p \leq 0.05$, FTD was considered as a response variable

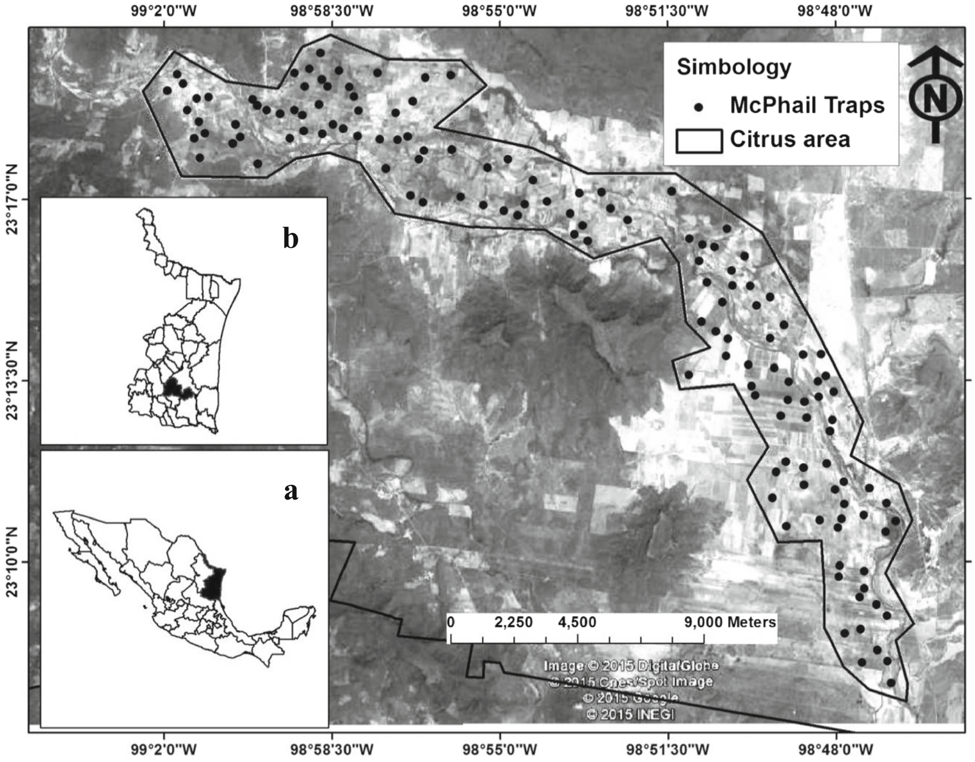

Fig 1 Geographic location of the citrus area of Llera, Tamaulipas, México, and McPhail traps spatial distribution. **a** Tamaulipas State; **b** Llera municipality.

and climatic variables data as explanatory potential factors in a simple linear regression. Coefficient of determination ($r^2$) was utilized to judge the best fit of the data. Also, the contribution of an explanatory variables combination was determined by using a multiple regression model. The forward stepwise method was used to individually add or delete the independent variables from the model at each step of the regression, until the best fit model was obtained. These analyses were carried out with STATISTICA 6.1 program (StatSoft 2004).

## Results and Discussion

### *Population fluctuation*

Weekly FTD values pointed higher values of the mean over the median and positive skewness as well (Table 1). This suggests heterogeneity of FTD values (captures) and non-normally distributed data, which is very common in insect population (García 2006). Population peaks were consistently observed in certain periods with a variation in the FTD level. Therefore, the population dynamics of *A. ludens* was classified into fourth periods through the year based on FTD level, production season, and climatic variations (Fig 2 and Table 2).

The highest population densities were observed in the period January–April, particularly in March to early spring, which is related to the higher citrus production (Valencia orange). The Valencia orange represents about 78% of the citrus crops in Tamaulipas (SAGARPA 2013); thus, agroecosystem complexity gives advantages to the reproductive potential of *A. ludens*, as well as other Tephritidae such as *Ceratitis capitata*, due to the wide access to host availability, shelter, and food (Aluja 1994, Appiah *et al* 2009, Aluja & Rull 2009).

According to SAGARPA (2013), about 60% of citrus growing in Tamaulipas belongs to the ejido system. This is an important socioeconomic factor, because there are generally economic necessities of the growers in the first 2 months of the year, so they sell their product at that time. In this way, fruit availability in March–April is likely to be lower than in January and February. However, FTD showed the lowest value at the beginning of the year, whereas the highest in March, respectively (Fig 2 and Table 2). This latter occurred when the Valencia orange had almost achieved the optimum level of ripeness.

In an integrated pest management, large captures of insect pest in traps usually have been associated with a high population density (Bearup *et al* 2015), but it could also be related to a greater search for food, fly physiological condition, age, population structure, and environmental conditions (Hendrichs *et al* 1991, Baker & Chan 1991, Thomas *et al* 2001, Díaz-Fleischer *et al* 2009). There are many aspects in *A. ludens* biology, which are not taken into account in the control strategies of the NCAFF in Tamaulipas. In Llera, for example, suppression activities are focused on the

Table 1 *Anastrepha ludens* populations, Llera, Tamaulipas, Mexico, descriptive statistic of weekly FTD, 2008–2011.

| Year | Valid *N* | Mean | Median | Minimum | Maximum | Variance | Standard deviation | Skewness |
|---|---|---|---|---|---|---|---|---|
| 2008 | 53 | 0.1529 | 0.1006 | 0.0010 | 0.6726 | 0.0250 | 0.1581 | 1.6446 |
| 2009 | 52 | 0.1000 | 0.0282 | 0.0000 | 0.4015 | 0.0127 | 0.1126 | 0.9243 |
| 2010 | 52 | 0.0478 | 0.0314 | 0.0000 | 0.2065 | 0.0024 | 0.0491 | 1.3357 |
| 2011 | 52 | 0.0503 | 0.0355 | 0.0021 | 0.1606 | 0.0021 | 0.0460 | 0.7865 |

*FTD* flies per trap per day.

population peaks by applying ground bait sprays, which have little impact on the pest populations. We assumed that several generations are involved in the infestation on Valencia orange; thus, demographic parameters as age structure would be determinants for a strategic planning (Carey 1982).

Another condition is the presence of ripe grapefruit of the previous year, which represents a continuous focus of infestation. The commercialization of grapefruit in the last months of the year is very important to suppress the population increase and damage of *A. ludens* next year, because of its preference for this citrus (Baker *et al* 1944, Robacker & Fraser 2002, Thomas 2003, Birke *et al* 2006). Although the grapefruit area is smaller than the Valencia orange, grapefruit trees are commonly found throughout the citrus area in the orchards or backyards.

A second period was considered from May to mid-August and is characterized by a drastic reduction of the Valencia orange production, along with an increase of temperature by the advent of the summer season. By this time, the harvest is almost over, and only some growers from the private sector maintain the fruit in the tree (Valencia orange) trying to obtain better prices. Although several phytosanitary measures are performed in these orchards in order to preserve the fruit, harvest residues represent a source of local infestations.

A wide range in the FTD values was detected, from 0.0000 in 2010 to 0.5251 in 2008 (Table 2). It is noteworthy that the size of the population peaks in this period was determined by the level of pest populations in January–April (Fig 2), but these populations declined over a short period of time due to the scarcity of commercial hosts. Pest outbreaks after maximum host availability have been reported for *Anastrepha* spp. by Aluja (1994) and Celedonio-Hurtado *et al* (1995). Population growth after the main harvest may be attributed to the search of food for flies, which promotes greater catches in traps (Baker & Chan 1991).

On the other hand, at this time, the ripeness of yellow chapote (Table 3) could explain the high captures in traps. However, the scarcity of the wild host in southern Tamaulipas is an advantage with respect to the citrus areas located at central Tamaulipas, which are in many cases bordered by yellow chapote populations. Therefore, in the citrus region of Llera, there is less probability of movement of fruit flies from the wild to the nearest citrus areas. Southernmost distribution of yellow chapote in Tamaulipas has not been established; it has been observed growing some 70 km south of Ciudad Victoria (Plummer *et al* 1941).

A third period based on the relative absence of citrus production and the presence of high temperatures (up to 47°C) was determined and comprises only 5 weeks (Au-

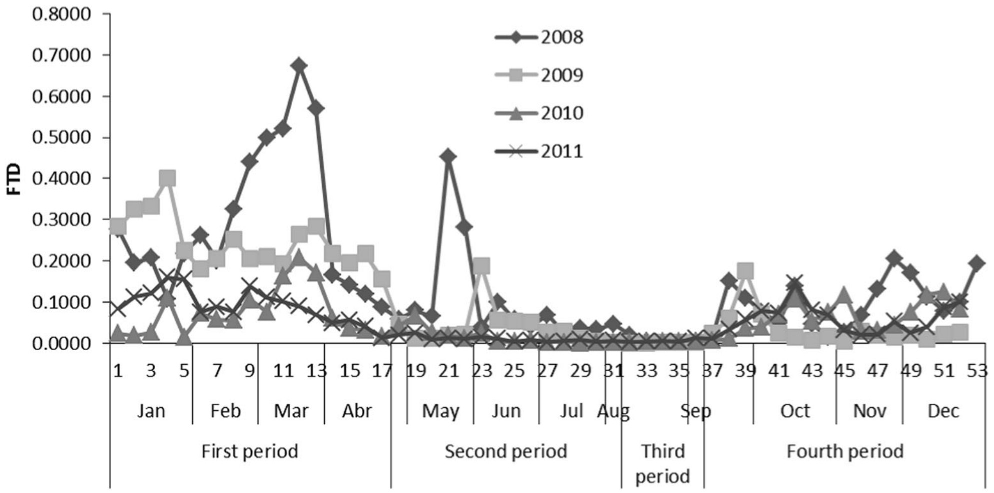

Fig 2 *Anastrepha ludens* adult population fluctuation, 2008–2011, based on weekly FTD and delimitation of four periods taking into account FTD level and months of the year. Llera, Tamaulipas, citrus area.

Table 2 Main characteristics of the four identified periods, 2008–2011, based on weekly FTD *Anastrepha ludens* populations, Llera, Tamaulipas, Mexico (citrus area).

| Period | Months | Main citrus variety | Season of the year | FTD range 2008 | FTD range 2009 | FTD range 2010 | FTD range 2011 |
|---|---|---|---|---|---|---|---|
| I | Jan–Apr | Valencia orange, grapefruits[a] | Winter–Spring | 0.0864–0.6726 | 0.1554–0.4015 | 0.0146–0.2065 | 0.0125–0.1606 |
| II | May–Aug | Valencia orange [b] | Spring–Summer | 0.0261–0.4531 | 0.1887–0.5251 | 0.0000–0.0657 | 0.0021–0.0240 |
| III | Aug–Sep | No citrus production | Summer | 0.0010–0.0198 | 0.0000–0.0021 | 0.0010–0.0052 | 0.0021–0.0115 |
| IV | Sep–Dec | Early oranges, grapefruits, and mandarins | Autumn–Winter | 0.0146–0.2044 | 0.0042–0.1746 | 0.0063–0.1251 | 0.0104–0.1460 |

*FTD* flies per trap per day.

[a] Generally, for commercial reasons, grapefruit is a citrus present after December.

[b] Low production of Valencia orange and scarce availability of commercial hosts.

gust–September). This phase preceded the initiation of ripening of early varieties, mainly grapefruits. Zero values were observed in several cases that suggest null prevalence (NOM-023-FITO-1995) of *A. ludens* populations in the orchards. High temperatures along with the host availability play an important role in the population size of *B. dorsalis* and *Ceratitis capitata* elsewhere in the world (Chen & Ye 2007, Appiah *et al* 2009).

The scarcity of captures may be because of the distances among the traps (120–150 m), and not because of effective control actions (Celedonio-Hurtado *et al* 1995). In studies at local scale (orchard) on adult populations of *Anastrepha suspensa* (Loew) and *Ceratitis capitata*, it was determined that effective trapping ranges were between 30 and 40 m by using different attractants (Epsky *et al* 2010, Kendra *et al* 2010).

Another aspect is the role of alternating host that serves as shelter and breeding sites in the absence of high availability of commercial hosts (Aluja 1994, Aluja & Rull 2009). For multivoltine fruit flies, the absence of fructification of its main host may be solved by exploiting alternative hosts (Aluja & Mangan 2008), as is the case with sour orange or "cucha" present all year in backyards (Table 3). Likewise, *A. ludens* seems to have developed physiological and behavioral strategies at different scenarios of host availability (Aluja *et al* (2011). Nonetheless, other factors such as lack of marketing of the product and harvest residues in the orchards may also contribute to the sustainability of local populations of the pest.

Lastly, a fourth period from September to December was considered and included the ripening phase of grapefruit, mandarin, and early oranges (Table 3). FTD range was lower than the first and the second peaks and fluctuated between 0.0042 and 0.2044 (Table 2). This outbreak was consistent and extended from the end of September until December, where the highest FTD level may continue until early next year. In addition, a temperature decline caused by the arrival of winter was observed (Fig 3). It is suggested that this is the most important second peak after January–April, because of the beginning of the citrus commercial season, where the grapefruit is a representative variety in the period. It occupies about 80 ha in Llera (SAGARPA 2013) and has intercalated presence with Valencia orange in mixed orchards (Aluja 1994), or backyards, which provides food and host for *A. ludens* in the entire region at this time of year.

The adult population of *A. ludens* was lower than in the other periods; however, in tropical areas, the number of flies detected in grapefruit orchards can be almost equal to the number of flies captured in orange orchards (Houston 1981). A high population of larvae was detected in the area throughout the study, mainly in October–November. About 60% of fruit damage in a grapefruit orchard caused by

Table 3 Fruiting period of main commercial, native, and backyard hosts of *Anastrepha ludens.* The citrus region is Llera, Tamaulipas, Mexico.

| Host | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Valencia orange | ■ | ■ | ■ | ■ | ■ | | | | | | | ■ |
| Grapefruit | ■ | ■ | ■ | | | | | | | ■ | ■ | ■ |
| Early orange | | | | | | | | | ■ | ■ | ■ | |
| Mandarin | ■ | ■ | ■ | | | | | | | ■ | ■ | ■ |
| Sour orange | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Yellow chapote | | | | | ■ | ■ | ■ | ■ | | | | |

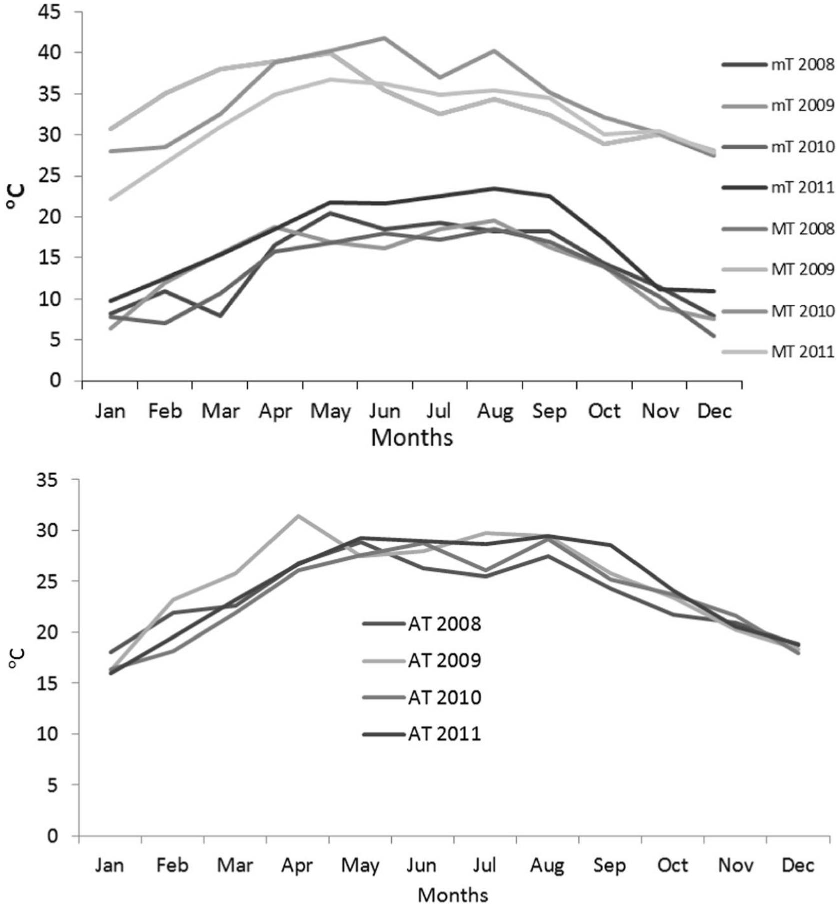

Fig 3 Monthly records of minimum (mT), maximum (MT), and average (AT) temperature from 2008 to 2011 at the weather station Emilio Carranza (CNA). Llera, Tamaulipas, Mexico, citrus region.

*A. ludens* has been documented by the NCAFF in the centre of Tamaulipas. The above coincides with Thomas (2003) that pointed out the importance of oviposition on grapefruit in October and November, which leads to the emergence of adults in January–February. In this case, an earlier emergence of adults occurred since November–December and had a tendency to continue until the end of the Valencia orange season as seen in 2008–2009 (Fig 2).

It should be noted that larvae and egg stages of *A. ludens* comprises about 68% of a total population (Liedo *et al* 1993). Therefore, pest population dynamics in this period seems to be an important basis for designing specific regional strategies in an area-wide approach aimed at preventing high populations in Valencia orange, with a low potential impact on non-target insect population (Thomas 2012, Ordano *et al* 2013).

### *FTD and climatic variables*

The presence of commercial hosts (oranges, grapefruits, and mandarins) modulates *A. ludens* population density in the citrus areas of Llera. Additionally, changes in climatic conditions, especially changes in temperature and rainfall, came along with the FTD variation during the study.

Annual accumulated rainfall ranged from 72 mm in 2011 to 151 mm in 2008. The average temperature showed values from 11°C in winter to 32°C in summer. Regarding maximum temperatures, these data fluctuated between 16 and 47°C (Fig 3). Thus, differences were observed between average (5°C) and maximum temperature (15°C) in winter and summer, respectively. Thomas (2012) reported for the Sierra Madre Oriental in the state of Nuevo León, Mexico, lower ranks between average and maximum temperature (5–8°C), as well as higher cumulative annual rainfall (129–481 mm).

The FTD of 2009 did not show any significant correlation with any climatic variable. FTD variations during the study period may be the factor that influences correlations with the independent variables. This is most evident in the FTD of 2011, which showed values of dispersion measures (variance and standard deviation) lower than those in other years (Table 1) of the study. Consequently, less variation in the FTD could have contributed to the higher coefficients of determination ($r^2$) in 2011. Similarly, the scatterplots did not reveal any pattern involving non-parametric tests.

A significant relationship ($p<0.05$) of the FTD transformed data with rainfall and temperature per year (except 2009) was obtained. Minimum temperature and rainfall were the most consistent correlations with the FTD throughout the

Table 4 Results of the simple linear regressions ($p$<0.05) between FTD transformed data and climatic variables from 2008 to 2011.

| Variable | Year | $r^2$ | $r$ | $p$ value |
|---|---|---|---|---|
| Rainfall | 2008 | 0.56 | −0.59 | 0.005 |
| Minimum temperature | | 0.37 | −0.61 | 0.036 |
| Rainfall | 2010 | 0.62 | −0.78 | 0.002 |
| Average temperature | | 0.42 | −0.64 | 0.023 |
| Minimum temperature | | 0.52 | −0.72 | 0.008 |
| Maximum temperature | | 0.39 | −0.63 | 0.027 |
| Rainfall | 2011 | 0.61 | −0.78 | 0.003 |
| Average temperature | | 0.64 | −0.80 | 0.001 |
| Minimum temperature | | 0.62 | −0.79 | 0.002 |
| Maximum temperature | | 0.63 | −0.79 | 0.002 |

The citrus region is Llera, Tamaulipas, Mexico.

study. The most representative correlations for each variable and FTD were observed in 2011 ($r^2$>0.60), in which FTD with average temperature was the highest value ($r^2$=0.64, Table 4).

At local level (orchard), weak relationships between captures of *A. ludens* sterile adults, maximum temperature, and rainfall (Thomas & Loera-Gallardo 1998) have been reported in northern Tamaulipas. In tropical areas, high temperatures, rainfall, and abundance of host have been associated significantly with high populations of *Anastrepha* spp. (Celedonio-Hurtado *et al* 1995, Montes *et al* 2012). Contrary, to the north of Mexico, tropical areas show an average temperature relatively constant through the year (Celedonio-Hurtado *et al* 1995, Ronchi-Teles & Da Silva 2005).

Minimum temperature recorded in winter, as low as 0°C, did not affect *A. ludens* populations drastically. The lowest populations at freezing temperatures were observed in 2010 (Fig 2), but these temperatures were not maintained for a long time. Survival of Tephritidae populations at low temperatures has been reported for *Ceratitis capitata* and *A. ludens* on citrus areas and at upper sites in the Sierra Madre Oriental, respectively (Israely *et al* 1997, Martínez-Ferrer *et al* 2010, Thomas 2012). On average, December and January were the coldest months (Fig 3); it seems to be a critical point for *A. ludens*, but grapefruit and early orange infestations played an important role to maintain pest populations (Table 2). In addition, the formation of large compact mosaics of citrus growing provides diverse habitats at different spatial scales (Aluja & Rull 2009), which include backyard alternative hosts as *Citrus aurantium* (sour orange) in urban areas.

Temperature influence has been discarded as an important factor on the population dynamics of *Anastrepha* spp., in southern areas (Celedonio-Hurtado *et al* 1995, Ronchi-Teles & Da Silva 2005). However, in northern Mexico, the role of temperature seems to be more important on the number of generations of *A. ludens* on its native host in the Sierra Madre Oriental by accumulation of degree-days (Leyva-Vázquez 1988, Thomas 2003, 2012). Likewise, in the citrus areas, a seasonal association between the host availability and temperature changes was determined.

The highest rainfall occurred from the end of April through September, so there is no match between the main population peaks of the insect and wide host availability (January–March and October–December, Fig 4). This has been reported also for *Anastrepha* spp., from tropical areas of the American continent (Hedström 1993, Ronchi-Teles & Da Silva 2005, Montes *et al* 2012). However, in nature, rainfall is closely related to the fruiting stage of yellow chapote, the wild host of *A. ludens* in the Sierra Madre Oriental (Plummer *et al* 1941, Thomas 2003, 2012).

The highest correlation value of rainfall with FTD was obtained in 2010 ($r^2$=0.62). This contribution may be considered significant taking into account that the host availability is the regulatory factor in population size (Hedström 1993,

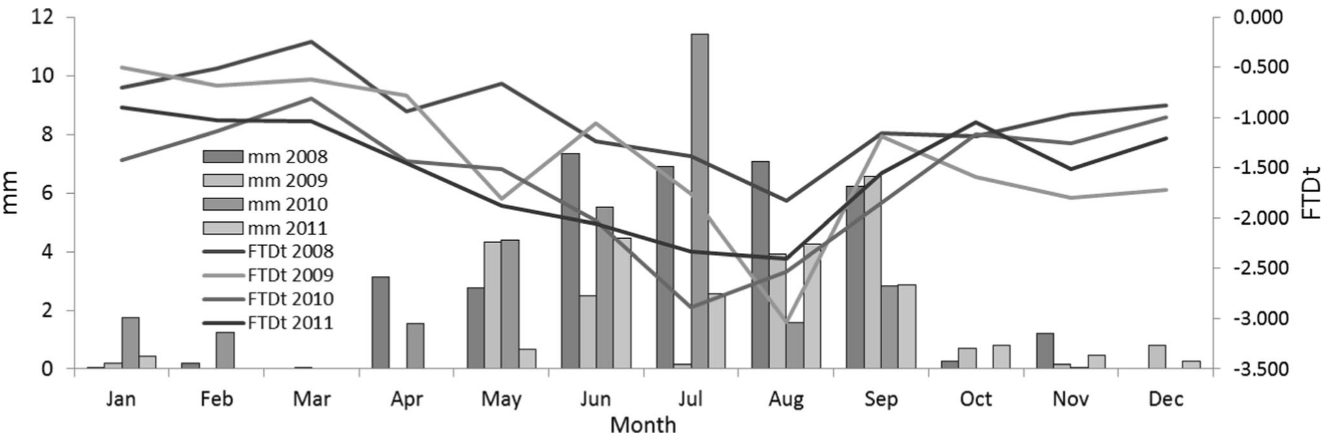

Fig 4 Monthly rainfall and monthly FTD transformed (FTDt) from 2008 to 2011, region of Llera, Tamaulipas, Mexico. It is observed that high levels of FTDt do not coincide with highest rainfall but with the lowest rainfall in the year.

Table 5 Multiple regression analysis ($p<0.05$) between FTD transformed data and climatic variables, 2008–2011.

| Variable | Year | Regression coefficient | Standard error | *t*-value | *p* value | $r^2$ adjusted |
|---|---|---|---|---|---|---|
| Rainfall | 2008 | −0.85 | 0.16 | −5.231 | 0.000 | 0.72 |
| Maximum temperature | | 0.47 | 0.16 | 2.887 | 0.017 | |
| Rainfall | 2010 | −0.78 | 0.19 | −4.06 | 0.002 | 0.58 |
| Rainfall | 2011 | −0.49 | 0.18 | −2.624 | 0.027 | 0.74 |
| Maximum temperature | | −0.51 | 0.18 | −2.729 | 0.023 | |

The citrus region is Llera, Tamaulipas, Mexico.

Aluja 1994, Celedonio-Hurtado *et al* 1995, Ronchi-Teles & Da Silva 2005). In this study, high rainfall probably has an important role in sustaining *A. ludens* low populations during the scarcity of commercial hosts in the period May–August.

Moreover, correlation values may be low compared with those obtained by Thomas (2012) between precipitation and adult captures ($r^2=0.926$) in the Sierra Madre Oriental. However, irrigation activities represent a variable in the citrus areas that may replace the effect of precipitation at local scale. This moisture can vary from a wilting point to field capacity during certain periods, exposing pupae of *A. ludens* to different ranges of soil moisture. The immature stages of *A. ludens* have shown a high adaptive capacity to these conditions (Montoya *et al* 2008).

The correlation of rainfall and maximum temperature with FTD in the multiple regression models was the best fit of the data (Table 5). As in the simple linear regression, relationships of FTD with any climatic variable were not determined in 2009. Correlation of FTD with rainfall was the most consistent in the 3 years. Rainfall has been associated with *A. ludens* populations in a delayed way influenced by the global climate phenomena in a citrus area (Aluja *et al* 2012).

The summer season has two characteristics, high temperature and rainfall, which are not linked to high infestations of *A. ludens*, but rather related to low populations in the citrus areas. This finding and the lack of host availability provide agro-ecological conditions to suppress pest populations, in contrast to wild population in the Sierra Madre Oriental, where two or three generations are reported (Thomas 2003, 2012).

Our results show that, the size and amplitude of the peak populations of *A. ludens* were modulated by the availability of the commercial host throughout the year. Fruit fly population affecting the main commercial season was concentrated in a period of 7 months (October–April). Furthermore, FTD relationships with temperature and rainfall were determined by host availability, along with seasonal changes. Considering that control actions of the NCAFF are usually more reactive rather than preventive, this study may contribute to a more appropriate management of this pest considering its population dynamics and the related factors. This would have important implications for control and monitoring activities at regional level, and an optimization of financial and human resources.

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