Factors Affecting Thrips (Thysanoptera: Thripidae) Population Densities in Watermelon Crops

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Research

Factors affecting thrips (Thysanoptera: Thripidae) population densities in watermelon crops

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Abstract

Watermelon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai (Cucurbitales: Cucurbitaceae), is one the 5 most-consumed fresh fruits in the world. The thrips *Frankliniella schultzei* (Trybom) (Thysanoptera: Thripidae) is an important pest of watermelon crops in tropical regions. Among the principal factors that regulate pest populations in crops are phenological stage of the host plant, weather and climate, and natural enemies. Thus, knowledge of such factors may allow the prediction of the risk of pest damage to such crops. The objective of this study was to identify factors that drive *F. schultzei* population densities in watermelon crops. During 2014 and 2015, we evaluated the effect of abiotic (weather) and biotic (phenological stage of leaves, and occurrence of natural enemies) factors on *F. schultzei* population densities on watermelon commercial crops. *Frankliniella schultzei* densities were higher in dry periods with more intense winds. Insect pest density was higher on younger leaves of plants in the vegetative stage. *Frankliniella schultzei* preferred to attack younger leaves of the plant located at the apex of the branches. The results obtained in this work suggest that the population growth of *F. schultzei* in watermelon crops is higher in periods of low rainfall. The population densities of *F. schultzei* depend on the phenological stage of plants, weather, and populations of natural enemies. Farmers should seek to preserve the populations of *Chrysoperla* sp. (Neuroptera: Chrysopidae), which are an important natural enemy of *F. schultzei*.

Key Words: *Citrullus lanatus*; *Frankliniella schultzei*; plant stage; rainfall

Resumo

A melancia, *Citrullus lanatus* (Thunb.) Matsum. & Nakai (Cucurbitales: Cucurbitaceae), é uma das cinco frutas frescas mais consumidas do mundo. O tripes *Frankliniella schultzei* (Trybom) (Thysanoptera: Thripidae) é uma das pragas mais importante da cultura em regiões tropicais. Entre os principais fatores que regulam as populações de pragas estão o estágio fenológico da planta hospedeira, elementos climáticos e populações de inimigos naturais. Assim, o conhecimento de tais fatores possibilitam o entendimento da bioecologia destes organismos e servem de base para o planejamento do uso de métodos de controle. O objetivo deste estudo foi determinar os fatores que regulam a intensidade de ataque de *F. schultzei* à cultura da melancia. Durante 2014 e 2015, avaliamos o efeito dos fatores abióticos (fatores climáticos) e bióticos (fase fenológica das folhas e ocorrência de inimigos naturais) nas densidades populacionais de *F. schultzei* em lavouras comerciais de melancia. A densidade de *F. schultzei* foi maior no período seco com ventos mais intensos. A densidade da praga foi maior em plantas no estágio vegetativo. *Frankliniella schultzei* prefere atacar as folhas mais jovens da planta localizadas no ápice dos ramos. Os resultados obtidos neste trabalho sugerem que o crescimento populacional de *F. schultzei* é maior em períodos de baixa precipitação e dependem do estágio fenológico das plantas, dos elementos climáticos e das populações de inimigos naturais. Os agricultores devem procurar preservar as populações de *Chrysoperla* sp. (Neuroptera: Chrysopidae), que são um importante inimigo natural de *F. schultzei.*

Palavras Chave: *Citrullus lanatus*; *Frankliniella schultzei*; estágio da planta; chuva

Watermelon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai (Cucurbitales: Cucurbitaceae), is the most widely cultivated plant in the family Cucurbitaceae in the world, occupying 6.8% of the total area cultivated with vegetables. It is among the 5 most consumed fresh fruits in the world, comprising a worldwide production of 186 million metric tonnes (FAO 2014). Brazil is the fourth-largest producer of watermelon in the world, producing 2,163,501 metric tonnes of this crop in the 2013/2014 growing season. The State of Tocantins is responsible for approximately 10% of Brazilian watermelon production, and is the fourth largest producer of this fruit in the country (FAO 2014). In Brazil, watermelon plants are grown in multiple seasons, where the weather varies throughout the year, though generally with a dry winter and a

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rainy summer. Therefore, pest densities are expected to differ in each season (Pereira et al. 2017).

Thrips are among the primary pests of the watermelon crop in tropical regions, especially *Frankliniella schultzei* (Trybom) (Thysanoptera: Thripidae) (Morais et al. 2007; Pereira et al. 2017). *Frankliella schultzei* is widely distributed, occurring in 136 countries, and attacking 83 plant species belonging to 35 different plant families (Palmer 1990). Thrips adults and nymphs cause damage to plants by sucking out their cell contents, injecting enzymes into the plant that are in their saliva, and acting as vectors of viruses (Mound 1995; Monteiro et al. 2001; Morsello et al. 2008; Riley et al. 2011; Cavalleri & Mound 2012; Costa et al. 2015; Shrestha et al. 2015).

The identification of factors that regulate the intensity of pest attacks on crops is important for pest sampling and control (Picanço et al. 2000, 2002; Rosado et al. 2015). Such studies also permit the establishment of predictive models of pest attacks on crops, so that the farmers can determine the correct time to start pest control (Herms 2004; Rosado et al. 2015; Silva et al. 2016).

Among the principal factors that regulate pest populations on crops are the characteristics of the host plant, weather and climate, and populations of natural enemies (Price et al. 1980). Among the characteristics of the host plant that affect populations of herbivorous insects are phenological stage (Herms 2004), and the age of the plant tissue on which these organisms feed (Joost & Riley 2008; Rosado et al. 2015). The age and phenological stage of the plant on which the insects feed also may affect the nutritional content, as well as the chemical and morphological defenses against arthropod herbivores (Moreira et al. 2016).

The principal elements of weather and climate that affect populations of pests on crops are air temperature, rainfall, wind, and photoperiod (Wellington 1957; Morsello et al. 2008; Rosado et al. 2015). Weather and climate affect the survival, development, reproduction, and dispersal of insects (Wellington 1957; Morsello et al. 2008; Rosado et al. 2015). In tropical regions, the weather and climate features that vary most over the year consist of rainfall intensity and wind speed, whereas air temperature and photoperiod display less variation (Alvares et al. 2013).

The principal natural enemies of insect pests in watermelon crops are predators, with *Geocoris* sp. (Hemiptera: Geocoridae), *Eriopis connexa* (Coleoptera: Coccinellidae), and *Orius* sp. (Hemiptera: Anthocoridae) most frequently observed (Picanço et al. 2007; Lima et al. 2014).

Despite the importance of *F. schultzei* as a pest of watermelon, and the need to shed light on the factors that determine its damage potential, there has been a lack of research on this subject, especially in tropical regions. The purpose of this study was to determine the factors regulating the population growth of *F. schultzei* in watermelon plantations in tropical regions. To this end, we evaluated the effect of abiotic (weather and climate) and biotic (phenological stage of leaves and occurrence of natural enemies) factors on *F. schultzei* population densities on commercial watermelon crops in a tropical region over a period of 2 yr.

Materials and Methods

EXPERIMENTAL CONDITIONS

This study was conducted during 2014 and 2015 in commercial watermelon fields in Formoso do Araguaia (11.902106°S, 49.561603°W, with an altitude of 240 masl, and a tropical climate with a dry winter and rainy summer) in Tocantins State, Brazil. The study covered 2 seasons of watermelon cultivation in these yr, which runs from May to Aug (the dry season) and from Jan to Apr (the rainy season) for each yr. The fields were established according to Santos & Zambolim (2011), and the chosen spacing was 2.80 m between rows and 1.45 m between plants. The fields had an area of approximately 15 ha. Specimens of thrips were collected at each evaluation time, and taken to the laboratory for later identification using taxonomic keys and morphological characterization according to Palmer et al. (1990) and Monteiro et al. (2001). Weather data were monitored daily by the central weather station of the National Institute of Meteorology in Formoso do Araguaia, located at the same elevation as the experimental field. The air temperature (°C), wind velocity (m per s), photoperiod (h), and rain (mm per day) were recorded hourly.

This research was divided into 2 parts. In the first part, we evaluated the variation in the abundance of *F. schultzei* in relation to leaf position, as well as the phenological stage of the plants. In the second part, we evaluated the abundance of *F. schultzei* in relation to the occurrence of natural enemies in 2 seasons of watermelon cultivation.

Abundance of *Frankliniella schultzei* Relative to Leaf Position and Phenological Stage of Plants

This study was carried out in 5 commercial watermelon fields (cultivar Manchester, Isla Superpak). In each field, 100 plants were evaluated for each plant growth stage, totalling 300 plants. Plants were randomly selected and 1 vine of each plant was selected. Subsequently, the density of the larvae and adults of *F. schultzei* were recorded on each leaf of the vine to verify the choice of the thrips in relation to the position of the leaf, and in relation to the phenological stage of the plants. The most apical leaf on the vine was labelled number 1, the second most apical leaf was labelled number 2, and so on, until the base of the plant was reached. Three assessments were carried out as follows: the first was undertaken on plants at the vegetative stage (40 days after planting, before the appearance of the first flower); the second on flowering plants (between the appearance of the first flower and the development of first fruit); and the third on fruiting plants (after the formation of the first fruit). *Frankliniella schultzei* densities were evaluated by visual examination and direct count, because this is the best technique for determining the abundance of this pest in watermelon crops (Pinto et al. 2017). During the evaluations, the leaves were carefully handled to prevent escape of thrips.

The data on *F. schultzei* densities in relation to leaf position and phenological stage were subjected to regression analysis. The selection of the regression curve was based on its significance ($P < 0.05$), the coefficient of regression (R^2), and the simplicity of the equation (Johnson & Omland 2004). All analyses were performed using SAS Version 8.1 (2002) (SAS Institute, Cary, North Carolina).

Densities of *Frankliniella schultzei* and Natural Enemies in Relation to Season

This work was carried out in 8 watermelon commercial fields cultivated in the dry and rainy seasons during 2014 and 2015, as previously described. These 2 seasons (periods) were chosen because they are the normal watermelon cultivation periods in tropical regions such as Brazil (Santos & Zambolim 2011), and they experience the highest variation in weather (Alvares et al. 2013). The densities of *F. schultzei* and natural enemies were assessed in 50 samples per field. Each sample consisted of 5 watermelon plants. To eliminate possible directional trends, the plants assessed were located equidistantly in each row and between rows; therefore reflecting systematic sampling points (Bacci et al. 2008).

Natural enemies were sampled using the visual examination and direct count techniques, as used for thrips. Specimens collected were classified into morphospecies and stored in glass bottles (10 mL) containing 70% ethanol, for later identification. These morphospecies were identified using taxonomic keys (Picanço et al. 2007), and compared to the Regional Museum of Entomology collection at the Federal University of Viçosa, Minas Gerais State, Brazil.

Frankliniella schultzei and natural enemy densities data as a function of the cropping season were analyzed by ANOVA at $P < 0.05$. Daily averages and standard errors of the weather data (air temperature [°C], wind speed [m per s], photoperiod [hours], and rainfall [mm per day]) were determined. Stepwise multiple regression analyses were performed to identify the most important weather, natural enemy, and plant phenological stage variables that influence the abundance of *F. schultzei* in watermelon. Each yr was considered a replicate. The independent variables for the analysis were the climatic elements, densities of natural enemies, and plant phenological stages data, and the dependent variable of interest was the *F. schultzei* density per leaf. In this model, the plant stages were represented by the following numbers: 1 (vegetation), 2 (flowering), and 3 (fruiting). Natural enemies (spiders, *Chrysoperla* sp. and *Geocoris* sp.) and 2 of the weather and climate variables (mean rainfall and wind speeds) were used in this regression model because they were different between the 2 growing seasons. All analyses were performed using SAS Version 8.1 (SAS Institute, Cary, North Carolina).

Results

The abundance of *F. schultzei* was affected by the phenological stages of the plant and the position of the leaf on the vine. The highest densities of thrips were observed during the vegetative stage, while the densities were intermediate during flowering, and lowest in the fruiting plants (Fig. 1).

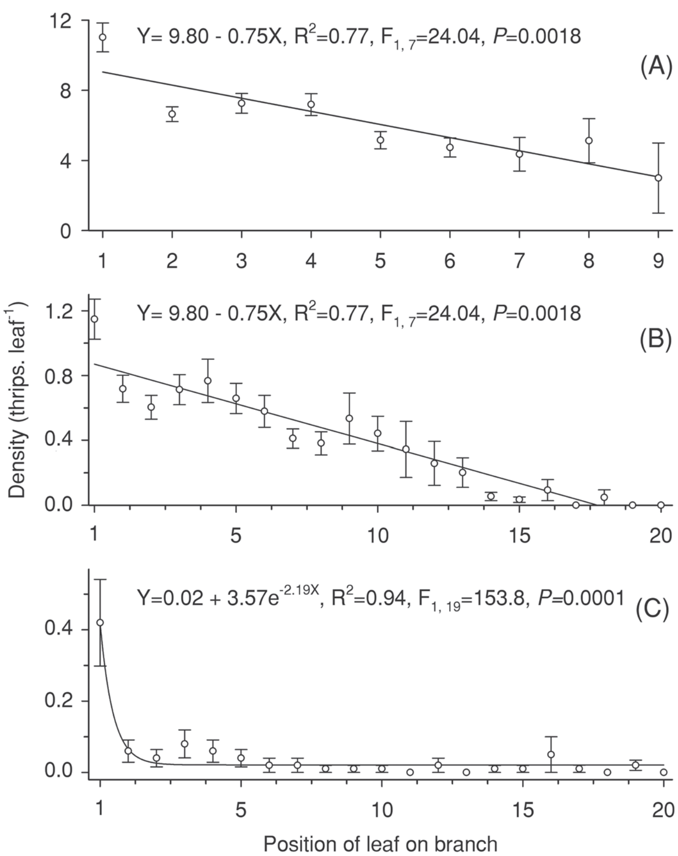

Fig. 1. *Frankliniella schultzei* density depending on the position of the leaf on the branch in watermelon plants in vegetative (A), flowering (B), and (C) fruiting stages. The more apical leaf branch was considered number 1, the second number 2, and so on.

In the vegetative and flowering stages the density of thrips decreased from the apex to the base of the vines (F = 24.04; df = 1,7; P = 0.0018) (Figs. 1A, B). During the fruiting stage, the density of the pest was higher on apical leaves than on the other leaves (F = 158.80; df = 1,19; P = 0.0001) (Fig. 1C).

The densities of adults observed were higher than that of nymphs of *F. schultzei* in all plant growth stages (ratio of 10:1 adults:nymphs). The natural enemies found in watermelon fields consisted only of predators: various spiders, *Eriopis connexa* (German) (Coleoptera: Coccinellidae), *Chrysoperla* sp. (Neuroptera: Chrysopidae), *Geocoris* sp. (Hemiptera: Geocoridae), and *Orius* sp. (Hemiptera: Anthocoridae). The descending order of predator densities observed in watermelon crops were: *Geocoris* sp. > *Chrysoperla* sp. > spiders > *E. connexa* > *Orius* sp. (Table 1).

Frankliniella schultzei and predator densities varied according to the planting season. During the 2 planting seasons, *F. schultzei* densities were higher than the predator densities. The densities of *Chrysoperla* sp. ($F_{1,398}$ = 9.26; P = 0.0025) and *Geocoris* sp. ($F_{1,398}$ = 15.19; P < 0.001) were higher in the dry season, whereas the spider density was higher in the rainy season than in the dry season ($F_{1,398}$ = 4.83; P = 0.028), and the densities of *Orius* sp. ($F_{1,398}$ = 1.00; P = 0.317) and *E. connexa* ($F_{1,398}$ = 2.79; P = 0.095) were similar in the 2 growing seasons. The densities of *F. schultzei* and total predators to watermelon plants was higher in the dry season than in the rainy season (*F. schultzei* [$F_{1,398}$ = 29.6; P < 0.0001]; total predators [$F_{1,398}$ = 13.95; P < 0.0001]) (Fig. 2).

Mean temperatures remained high and similar for both cropping seasons. Similarly, the photoperiod did not vary between the 2 growing seasons. The rainfall was higher in the rainy season, and the wind speeds were higher in the dry season (Fig. 3).

The multiple linear regression model of the density of *F. schultzei* in watermelon culture varied in relation to the phenological stage of plants, rainfall (mm per day), wind speed (m per s), and density of the predators *Chrysoperla* sp., spiders, and *Geocoris* sp. was significant (P = 0.032). This model explained 69% of the variation in the density on *F. schultzei* in the watermelon fields studied. In this model, the angular coefficients of the effects of phenological stage of plants and rainfall on *F. schultzei* densities were negative. On the other hand, the angular coefficients from the effects of wind speed and density of the predator *Chrysoperla* sp. on *F. schultzei* densities were positive. The angular coefficient of the effects of spiders and *Geocoris* sp. densities on *F. schultzei* density were not significant (P > 0.05) (Table 2).

Discussion

We observed the highest densities of *F. schultzei* on watermelon leaves in the vegetative stage. In this stage, plants provide large num-

Table 1. Densities of thrips pests and predators in watermelon crops.

Taxon	Densities* (individuals per sample^{-1})
Frankliniella schultzei	
Nymphs	0.33 ± 0.04
Adults	4.87 ± 0.26
Total	5.20 ± 0.27
Predators	
Spiders	0.10 ± 0.014
Eriopis connexa	0.03 ± 0.008
Chrysoperla sp.	0.11 ± 0.022
Geocoris sp.	0.17 ± 0.023
Orius sp.	0.006 ± 0.004
Predators total	0.41 ± 0.04

*The samples were made up of 5 leaves.

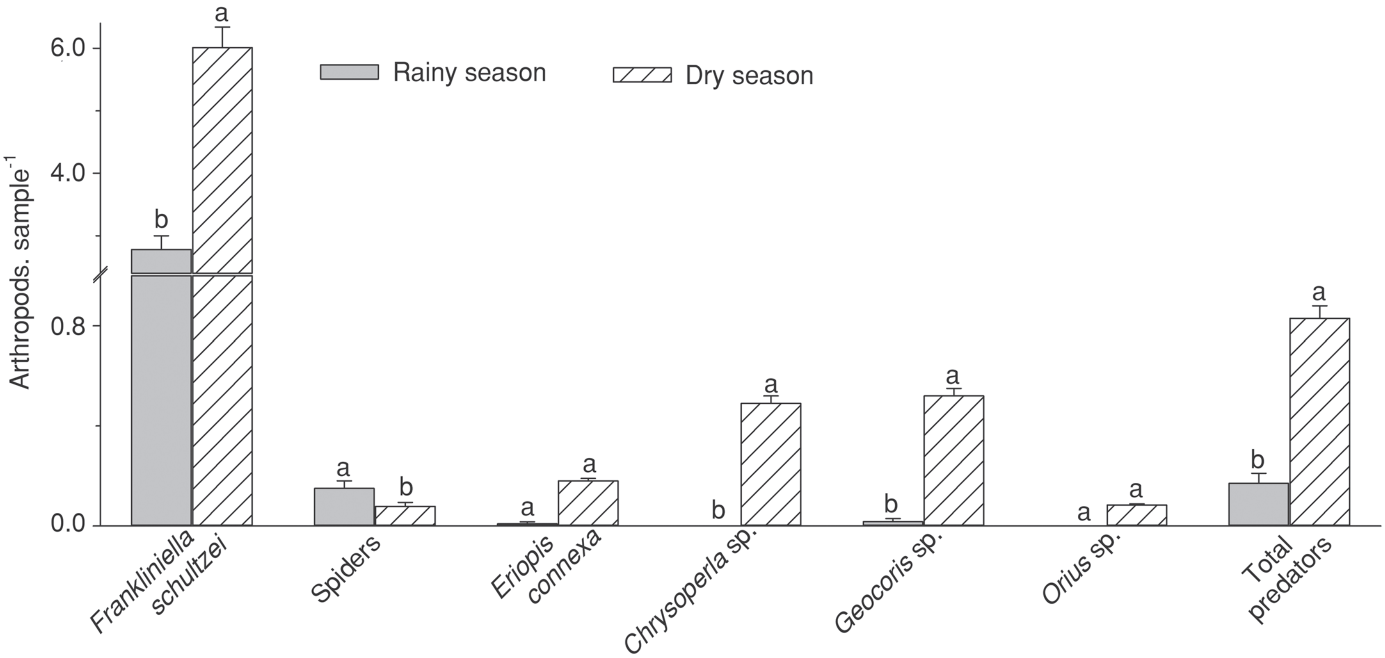

Fig. 2. *Frankliniella schultzei* and predator densities (mean ± standard error) in 2 seasons of watermelon cultivation. *When a pair of histograms is topped by the same letter, the average densities of this arthropod did not differ in the 2 seasons of cultivation according to the *F* test and $P < 0.05$.

bers of new leaves (Braga et al. 2011). Another fact that reinforces this statement was the presence of higher densities of *F. schultzei* on younger leaves, which were located on the most apical parts of the vine. This was observed in watermelon plants at all 3 phenological stages (vegetative, flowering, and fruiting).

The preference of *F. schultzei* for younger leaves might be related to the higher nutritional quality of these leaves; for example, the presence of high concentrations of protein, carbohydrates, and vitamins (Bernays & Chapman 1994; Gurevitch et al. 2006; Newton et al. 2009). Higher nutrient concentrations in young leaves compared to older leaves is due to the nutrient translocation (especially nitrogen) from older to younger leaves (Mattson 1980; Joost & Riley 2008; Barker & Pilbeam 2015; Mengel 2015). In addition, older leaves often have a tough epidermis, as well as larger trichomes (Leite et al. 2004), which may prevent insects from feeding on them (Scott Brown & Simmonds 2006). Such plant defenses reduce the ability of thrips to penetrate the leaf and remove the sap (Milne & Walter 2000). This could explain the preference of the thrips for younger leaves.

An important factor regulating pest populations in crops is weather and climate (Wellington 1957; Semeão et al. 2012). In this context, we observed higher populations of *F. schultzei* in watermelon crops in the dry season than in the rainy season. In the multiple regression analysis, we observed a negative impact of rainfall on *F. schultzei* populations. Rainfall may affect pest populations in direct and indirect ways (Pereira et al. 2007; Morsello et al. 2008; Semeão et al. 2012). In a direct way, rainfall causes insect death due to the mechanical impact of droplets which wash small insects down onto the soil (Semeão et al. 2012). Indirectly, rainfall may have both negative and positive effects on insect herbivorous population. The indirect negative effect is due to the increase in humidity, which increases insect mortality by entomopathogenic fungi (Augustyniuk-Kram & Kram 2012). The indirect positive effect of rainfall is due to the increase in water available to the plants, which become a food resource to herbivorous insects; this is probably what happened to *F. schultzei* in our experiments (Floater 1997).

In the multiple regression model, we observed that winds showed a positive correlation with *F. schultzei* populations in watermelon crops. It is known that thrips do not have the ability to fly long distances (Gatehouse 1997); however, they can be dispersed rapidly by winds (Pelikan 1989), and thus may move long distances (Mound 1983). This was observed by Pearsall and Myers (2001), who verified that another

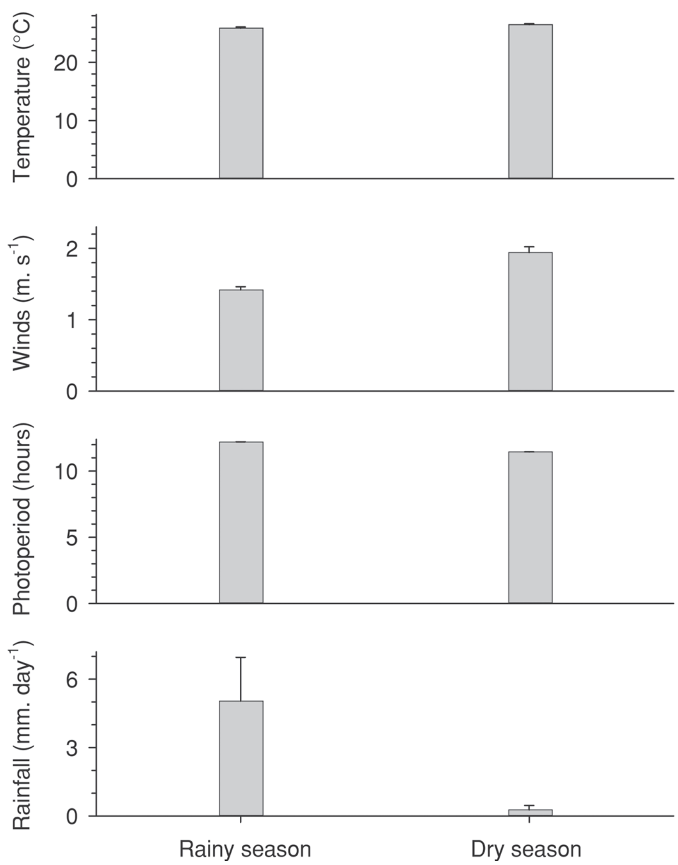

Fig. 3. Daily average (mean ± standard error) of air temperature, wind speed, photoperiod, and rain during 2 seasons of watermelon cultivation.

Table 2. Angular coefficients of multiple linear regression of *Frankliniella schultzei* density according to the phenological stage of watermelon plants, weather elements, and densities of predators.

Independent variable	Angular coefficients of multiple linear regression
Phenological stage of plants	−0.35*
Climatic elements	
Rainfall (mm per day^{-1})	−0.33*
Average speed of the winds (m per s^{-1})	0.66*
Predators	
Spiders per sample^{-1}	0.21
Chrysoperla sp. sample^{-1}	0.50*
Geocoris sp. sample^{-1}	−0.05
Characteristics of model	
R^2	0.69
F	5.58
P	0.032

*Significant coefficients by *F* test and *P* < 0.05.

thrips species (*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) disperses in the wind direction in nectarine orchards.

In the multiple regression model of the factors that affected *F. schultzei* density on watermelon plants, we found a positive correlation between pest density and occurrence of the predator *Chrysoperla* sp. Therefore, we favor the hypothesis that the high densities of thrips found in our study might explain the increased populations of *Chrysoperla* sp. on watermelon plants. This higher availability of food results in the increased reproduction rate and survival of natural enemies, as well as the migration of such insects to the surrounding areas of crops.

In conclusion, the study presented here contributes to an understanding of the factors regulating the attack of thrips *F. schultzei* in watermelon crops. The intensity of *F. schultzei* attack depends on the phenological stage of plants, weather and climate, and natural enemy populations. *Frankliniella schultzei* are more abundant during dry periods when winds are relatively higher. *Frankliniella schultzei* populations also are higher in the vegetative stage, and on young leaves of watermelon plants. *Chrysoperla* sp. may be an important natural enemy of *F. schultzei* in watermelon fields.

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