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Modelling the Impact of Key Pests of Watermelon on its Performance Using Linear Regression Models

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Abstract

Despite the economic, health, and nutritional values of watermelon, insect pests remain a key limitation to its production globally. However, there has, hardly been any research that has statistically modeled the impact of insect pests on its performance. Therefore, this study aims to determine the relationship between the performance of watermelon and the density of its key pests with the aid of correlation and linear regression models, thereby presenting models for forecasting crop performance vis-à-vis pest density for optimum pest management. Data were collected from 40 m^2 plots grouped into 4 replicates (10 plots/replicate) in field experiments (arranged in a randomized complete block design) in the early- and late-sown crops of 2016 and 2017 in the Research Farm of Federal University, Wukari, Nigeria. Plant survival rate (%) negatively and significantly ($P \leq 0.05$) correlated with each of mean number leaf-feeding beetles ($r = -0.80$, $R^2 = 63.5$ %, $Y = 92.023 - 3.145x$; $r = -0.79$, $R^2 = 62.1$ %, $Y = 95.986 - 5.975x$), *A. gossypii* density ($r = -0.67$, $R^2 = 44.9$ %, $Y = 184.048 - 50.444x$; $r = -0.65$, $R^2 = 42.4$ %, $Y = 131.852 - 14.618x$), and *B tabaci* density ($r = -0.67$, $R^2 = 45.2$ %, $Y = 188.832 - 11.138x$; $r = -0.66$, $R^2 = 43.3$ %, $Y = 178.738 - 3.701x$) in both the early- and late-sown crop of 2016, respectively, with a similar trend in those of 2017. All parameters significantly ($P \leq 0.05$) fitted the linear regression model. Densities of all major pests consistently correlated negatively and significantly with fruit yield. Student's t-test detected significant differences between the early- and late-sown crops of both years. We therefore conclude that watermelon experiences multiple pest infestations whose compositions and intensities vary between seasons, and that their influence on agronomic performance, as shown by the coefficient of determination (R^2) values (which were indicative of the reliability of the models with respect to the effect of pests on crop performance), were largely close or > 50 %.

Keywords: Flower sex ratio, Generalized linear regression, Leaf-feeding beetles, Leaf injury, Plant survival rate

Introduction

Across the tropics and Mediterranean regions of the world, watermelon [*Citrullus lanatus* Thunb. (Cucurbitaceae)] remains a key fruit vegetable, as it is cultivated on about 6.8 % of earth field used for the production of vegetables [1]. Regardless of the high economic, health, and nutritional values of the crop, arthropod pests, particularly insects, remain a major limitation to its production [2] and crop performance has been shown to be suppressed by pest infestations [3,4]. Around the world, insect species that are sap sucking, fruit feeding, and leaf eating are widespread, and have been reported to infest watermelon throughout its growth stages [5,6]. The most abundant insect pest species for watermelon in the study site (Wukari, Nigeria) are *Aulacophora africana* Weise, *Asbecesta nigripennis* Weise, *Asbecesta transversa* Allard, *Monolepta nigeriae* Bryant, *Epilachna chrysomelina* Fab. (leaf-feeding beetles); *Aphis gossypii* L., *Bemisia tabaci* Genn. (sap-sucking insects); *Bactrocera cucurbitae* Coq., *Helicoverpa armigera* Hub. (fruit-boring insects) [7].

Evaluating the influence of pests on crop agronomic performance has been found to be very useful in pest modeling and forecasting [8,9]. However, despite the fact that yield losses of up to 100 % due to insect pest infestations have been documented in watermelon [2], there has hardly been any study that has presented a model which could be used for predicting injury, survival, and eventual yield, vis-à-vis key pest pressure. Since crop pests are inherently part of every agroecosystem, estimating their contributions to crop performance is very important [10], and this area of investigation is currently receiving high attention in the field of pest management. The use of generalized linear regression has been shown to be proper and is widely acceptable in detecting the relationships between factors [11].

Therefore, the aim of this study is to determine the relationship between the agronomic performance of watermelon and the density of its major insect pests using correlation and linear regression models. This will aid forecasting of crop performance in relation to pest density for optimum pest management, as well as provide base-line information for further studies.

Materials and methods

Study site

The field experiments were conducted in the Research Farm of Federal University Wukari, Nigeria, in the 2016 and 2017 early- and late-cropping seasons. Wukari, which is located at N7°50’37”, E9°46’31”, has an altitude of 187 m above sea level, an average annual temperature of 26.8 °C, and an average annual rainfall of 1,205 mm. The study area experiences a warm tropical climate characterized by wet and dry seasons. The wet season starts in April and ends in October, with peaks in June and September [12].

The data

The data used for this study is available in the research published in [7]. The experimental design and treatments applied are also detailed in [7], in which forty 5 m long × 8 m wide plots (40 m^2) were demarcated on a 0.21 hectare of field during the 2016 and 2017 early- and late-cropping seasons. The plots were grouped into 4 replications of 10 treatments, arranged in a Randomized Complete Block Design (RCBD).

The treatments were applications of 0.5 % Cypermethrin 30g/L + Dimethoate 250g/L EC (Cyper-diforce®) [produced by Jubaili Agrotec Ltd.] at 200 L/ha spray output at: seedling stage (S); mid-vegetative stage (V); mid-flowering stage (F); and mid-fruiting stage (FR), and at the following combinations of stages: − S + V + F; S + V + FR; S + F + FR; V + F + FR; and S + V + F + FR. An unsprayed plot, which served as the control (CT), was also included.

Mancozeb 80 % WP. (Zeb-care®), a preventive contact fungicide, was applied at the rate of 2 kg/ha at the vegetative, flowering, and fruiting stages. The field was left for natural infestation, while manual weeding was done when due.

Data collected

Assessment of insect population

Sampling of insect species commenced at the 2nd week after planting (WAP), and thereafter at weekly intervals until maturity of fruit (collections were made between 1,600 and 1,800 h), as described in [7]. Leaf feeding beetles and *Helicoverpa armigera* larvae were sampled using a shoulder-mounted suction sampler having a 10 cm diameter inlet cone (Burkard Scientific Ltd., Uxbridge, UK.) which was swept through a 5 m length of the middle row of each plot at an approximate walking speed of 1 m/s, as also shown in [7].

Whiteflies (*Bemisia tabaci* Genn.) were sampled using a 15×15 cm^2 yellow sticky board waved across a 5 m length of the middle row of each plot on shaking the plants, as described by [6,7]. Estimates of population densities of aphids (*Aphis gossypii* Glove) was made by assessing the colony size on 12 randomly selected leaves/plot using a scale from 0 - 9 [where **0** = no aphids; **1** = 1 - 4 aphids; **2** = 5 - 20 aphids; **3** = 21 - 100 aphids; **4** = 101 - 500 aphids, and **5** ≥ 500 aphids]. Fruits infested by fruit fly were isolated and counted in each plot. Infested fruits were split open and the number of fruit fly larvae therein counted and expressed as number of fruit fly larvae/fruit.

Samples of dominant insects collected were killed in ethyl acetate in a killing jar, preserved in 70 % ethanol, and then identified at the Insect Museum of Ahamadu Bello University, Zaria, Nigeria. Immature stages were reared to adult in the laboratory before identification, as shown in [7].

Assessment of leaf injury and plant survival

At 3, 6, and 9 WAP, a random sample of 15 leaves/plot were taken, and the proportion damaged was recorded following the method described by [13], and as adopted in [7]. Fifteen randomly selected leaves/plot were similarly scored for severity of injury on a scale of 0 - 4, where;

0 = 0 % leaf area injured
1 = 1 - 25 % leaf area injured
2 = 26 - 50 % leaf area injured
3 = 51 - 75 % leaf area injured
4 = 76 - 100 % leaf area injured [13].

The individual scores obtained per plot were then converted to attack severity (%) using the equation described by [7]. The plant survival rate (%) was computed by dividing the final number of individual plants/plot by the number of individual plants/plot at 10 days after planting and multiplying the outcome by 100.

Assessment of marketable fruit yield

Fruits in a plot were harvested twice at 10 day intervals, counted, weighed, and sorted into marketable and unmarketable categories. The latter comprised fruits that were discolored, misshapen, cracked, insect damaged, and infected with blossom end rot. The proportion of the marketable fruits was then computed as described in [7].

Modelling

The relationships between leaf-feeding beetles and leaf injury indices, between dominant insect pests and plant survival, and between dominant insect pests and marketable fruit yield were determined by Pearson's correlation and linear regression ($Y = c + mx$, where y is the dependent variable, c is the intercept for a given line, m is slope, and x is the independent variable) analyses. Two-tailed paired-samples Student's t-test was then used for comparing the parameters between the early- and late-sown crops. This was done using the means of the 4 replicates for each treatment and data set collected. The analyses were done using IBM® SPSS® version 23.0 (SPSS Inc., Chicago, Illinois) which was licensed in 2015. However, before running the aforementioned parametric tests, numerical data were transformed to $\sqrt{x} + 0.5$, while data in percentages were transformed to arcsine. This was done to normalize them and to meet the assumptions of the parametric tests. However, the raw data were further subjected to Shapiro and Wilk's test to confirm their normality at $P > 0.05$ [7,14].

Results and discussion

After appropriate transformations, data collected were found to be approximately normally distributed ($P > 0.05$) using the Shapiro and Wilk's test [7,14]. In 2016, the results showed positive and significant correlation of leaf-feeding beetle density with proportion of damaged leaves ($r = 0.94$, $Y = 1.202 + 4.169x$ for early- and $r = 0.91$, $Y = 5.015 + 2.545x$ for late-sown crop), and severity of leaf injury ($r = 0.96$, $Y = -6.200 + 3.082x$ and $r = 0.93$, $Y = 0.973 + 1.839x$, respectively) (**Table 1**). Leaf-beetles influenced a high proportion of the variation in both parameters, as shown by the R^2 values (which were indicative of the reliability of the models with respect to the effect of pests on crop performance) of 88.4 and 92.1 %, respectively. Plant survival rate (%) negatively and significantly ($P \leq 0.05$) correlated with each of mean number leaf-feeding beetles (r = −0.80, Y = 92.023 – 3.145*x* and r = −0.79, *Y* = 95.986 – 5.975*x*), *A. gossypii* density (r = −0.67, *Y* = 184.048 – 50.444*x* and r = −0.65, *Y* = 131.852 – 14.618*x*), and *B tabaci* density (r = −0.67, *Y* = 188.832 – 11.138*x* and r = −0.66, *Y* = 178.738 – 3.701*x*) in both the early- and late-sown crops, respectively. The R^2 values were 63.5, 44.9 and 45.2% in the early-sown, and 62.1, 42.4 and 43.3 % in the late-sown crops, respectively. Plant survival was less influenced by density of *H. armigera* larvae (r = −0.64, R^2 = 40.9 %, *Y* = 114.096 – 6.341*x*) in the late-sown crop. All parameters analyzed significantly ($P \leq 0.05$) fit the linear regression model (**Table 1**). In 2017, the results presented in **Table 2** largely followed a trend similar to that of the preceding year.

Table 1 Linear regression and correlation analysis between leaf injury indices, plant survival, and major watermelon pests on the early- and late-sown crop in 2016.

Variables	Correlation coefficient (r)	Regression equation[e] ($Y = c + mx$)	Coefficient of determination (R^2)	F-value	*p*-value for R^2
2016 early					
PLI[a]×LFB[b]	0.94	$Y = 1.202 + 4.169x$	0.884	60.85	0.000***
SLI[c]×LFB[b]	0.96	$Y = -6.200 + 3.082x$	0.921	93.21	0.000***
PS[d]×LFB[b]	−0.80	$Y = 92.023 – 3.145x$	0.635	13.89	0.006**
PS×*A. gossypii*	−0.67	$Y = 184.048 – 50.444x$	0.449	6.52	0.034*
PS×*B. tabaci*	−0.67	$Y = 188.832 – 11.138x$	0.452	6.61	0.033*
2016 late					
PLI×LFB	0.91	$Y = 5.015 + 2.545x$	0.831	38.99	0.000***
SLI×LFB	0.93	$Y = 0.973 + 1.839x$	0.866	51.33	0.000***
PS×LFB	−0.79	$Y = 95.986 – 5.975x$	0.621	13.32	0.007**
PS×*A. gossypii*	−0.65	$Y = 131.852 – 14.618x$	0.424	5.90	0.041*
PS×*B. tabaci*	−0.66	$Y = 178.738 – 3.701x$	0.433	6.10	0.039*
PS×*H.armigera* larvae	−0.64	$Y = 114.096 – 6.341x$	0.409	5.53	0.047*

[a]PLI - Proportion of leaves injured (%)
[b]LFB - Leaf-feeding beetles (mean of *Asbecesta nigripennis, Asbecesta transversa, Aulacophora africana, Monolepta nigeriae*, and *Epilachna chrysomelina*)
[c]SLI - Severity of leaf injury (%)
[d]PS - Plant survival rate (%)
[e]$Y = c + mx$. Where *Y* is the dependent variable, *c* is the intercept for a given line, *m* is slope, and *x* is the independent variable
df (degree of freedom): Regression = 1, Residual = 8, Total = 9
* = significantly different ($P \leq 0.05$)
** = significantly different ($P \leq 0.01$)
*** = significantly different ($P \leq 0.001$)
[ns] = not significantly different ($P > 0.05$)

Densities of all major pests were negatively and significantly correlated with fruit yield in both the early- and late-sown crops of 2016 and 2017 (**Tables 3** and **4**). The coefficient of determination (R^2) for leaf-feeding beetles, *A. gossypii*, *B. tabaci,* and *B. cucurbitae* larvae were 78.6, 77.2, 73.5 and 81.9 %, respectively, in the early-sown crop, and 81.2, 80.9, 78.9 and 86.6 % in the late-sown crop. *H. armigera* was negatively (r = −0.86) and significantly (P = 0.001) correlated with marketable fruit yield with an R^2 value of 73.7 % (**Table 3**). The R^2 values for the 2017 cropping season ranged from 0.720 to 0.831 in the early-sown crop and from 0.600 to 0.846 in the late-sown crop. *H. armigera* (in the late-sown crop) was also negatively (−0.850) and significantly (P = 0.002) correlated with marketable fruit yield, with R^2 values of 0.723 (**Table 4**).

Student's t-test detected significant differences between the early- and late-sown crops in both 2016 and 2017. Leaf-feeding beetle density, proportions of leaves injured, severity of leaf injury, *B. cucurbitae* larvae/fruit, and flower sex ratio were significantly ($t\alpha \leq 0.05$) higher in the early-sown crops, while *A. gossypii*, *B. tabaci* density, main vine length (cm) at 9 WAP, number of leaves at 9 WAP, number of fruits/ha, and fruit yield/ha were significantly ($t\alpha \leq 0.05$) higher in the late-sown crops in both 2016 and 2017 (**Tables 5** and **6**).

Table 2 Linear regression and correlation analysis between leaf injury indices, plant survival, and major watermelon pests on the early- and late-sown crop in 2017.

Variables	Correlation coefficient (r)	Regression equation[e] ($Y = c + mx$)	Coefficient of determination (R^2)	F-value	*p*-value for R^2
2017 early					
PLI[a]×LFB[b]	0.94	$Y = 5.161 + 4.118x$	0.883	60.69	0.000***
SLI[c]×LFB[b]	0.96	$Y = -6.925 + 3.373x$	0.922	94.74	0.000***
PS[d]×LFB[b]	−0.78	$Y = 89.346 - 3.029x$	0.612	12.61	0.008**
PS×*A. gossypii*	−0.66	$Y = 130.731 - 15.662x$	0.433	6.13	0.039*
PS×*B. tabaci*	−0.72	$Y = 252.059 - 11.475x$	0.511	8.34	0.020*
2017 late					
PLI×LFB	0.90	$Y = 9.774 + 2.363x$	0.817	36.51	0.000***
SLI×LFB	0.93	$Y = 1.073 + 2.005x$	0.864	50.64	0.000***
	−0.84	$Y = 95.845 - 6.263x$	0.703	18.80	0.002**
PS×LFB					
PS×*A. gossypii*	−0.57	$Y = 316.092 - 41.351x$	0.320	3.77	0.088[ns]
PS×*B. tabaci*	−0.70	$Y = 188.724 - 4.014x$	0.492	7.74	0.024*
PS×*H. armigera* larvae	−0.73	$Y = 133.196 - 7.303x$	0.531	9.07	0.017*

[a]PLI - Proportion of leaves injured (%)
[b]LFB - Leaf-feeding beetles (mean of *Asbecesta nigripennis, Asbecesta transversa, Aulacophora africana, Monolepta nigeriae*, and *Epilachna chrysomelina*)
[c]SLI - Severity of leaf injury (%)
[d]PS - Plant survival rate (%)
[e]$Y = c + mx$. Where Y is the dependent variable, c is the intercept for a given line, m is slope, and x is the independent variable
df (degree of freedom): Regression = 1, Residual = 8, Total = 9
* = significantly different ($P \leq 0.05$)
** = significantly different ($P \leq 0.01$)
*** = significantly different ($P \leq 0.001$)
[ns] = not significantly different ($P > 0.05$)

Table 3 Linear regression and correlation analysis between marketable fruit yield and major watermelon pests on the early- and late-sown crop in 2016.

Variables	Correlation coefficient (r)	Regression equation[c] ($Y = c + mx$)	Coefficient of determination (R^2)	F-value	*p*-value for R^2
2016 early					
MFY[a]×LFB[b]	−0.89	$Y = 36.220 - 2.316x$	0.786	30.18	0.001**
MFY×*A. gossypii*	−0.88	$Y = 120.039 - 43.786x$	0.772	27.73	0.001**
MFY×*B. tabaci*	−0.86	$Y = 121.079 - 9.394x$	0.735	22.68	0.002**
MFY×*B. cucurbitae* larvae	−0.91	$Y = 43.062 - 2.539x$	0.819	40.67	0.000***
2016 late					
MFY×LFB	−0.90	$Y = 46.324 - 5.879x$	0.812	35.91	0.000***
MFY×*A. gossypii*	−0.90	$Y = 94.662 - 17.357x$	0.809	34.32	0.000***
MFY×*B. tabaci*	−0.89	$Y = 147.458 - 4.299x$	0.789	30.32	0.001**
MFY×*B. cucurbitae* larvae	−0.93	$Y = 48.115 - 8.642x$	0.866	52.92	0.000***
MFY×*H. armigera* larvae	−0.86	$Y = 72.076 - 7.323x$	0.737	22.77	0.001**

[a]MFY - Marketable fruit yield
[b]LFB - Leaf-feeding beetles (mean of *Asbecesta nigripennis, Asbecesta transversa, Aulacophora africana, Monolepta nigeriae*, and *Epilachna chrysomelina*)
[c]$Y = c + mx$. Where; Y is the dependent variable, c is the intercept for a given line, m is slope, and x is the independent variable
df (degree of freedom): Regression = 1, Residual = 8, Total = 9
* = significantly different ($P \leq 0.05$)
** = significantly different ($P \leq 0.01$)
*** = significantly different ($P \leq 0.001$)
[ns] = not significantly different ($P > 0.05$)

Table 4 Linear regression and correlation analysis between marketable fruit yield and major watermelon pests on the early- and late-sown crop in 2017.

Variables	Correlation coefficient (r)	Regression equation[c] ($Y = c + mx$)	Coefficient of determination (R^2)	F-value	*p*-value for R^2
2017 early					
MFY[a]×LFB[b]	−0.88	$Y = 36.121 - 2.267x$	0.782	28.74	0.001**
MFY×*A. gossypii*	−0.88	$Y = 76.670 - 13.841x$	0.772	27.04	0.001**
MFY×*B. tabaci*	−0.85	$Y = 165.042 - 9.015x$	0.720	20.54	0.002**
MFY×*B.cucurbitae* larvae	−0.91	$Y = 38.624 - 2.535x$	0.831	39.46	0.000***
2017 late					
MFY×LFB	−0.90	$Y = 46.464 - 5.796x$	0.813	34.71	0.000***
MFY×*A. gossypii*	−0.78	$Y = 313.380 - 48.685x$	0.600	12.01	0.009**
MFY×*B. tabaci*	−0.90	$Y = 153.636 - 4.407x$	0.801	32.25	0.000***
MFY× *B. cucurbitae* larvae	−0.92	$Y = 69.967 - 8.022x$	0.846	53.02	0.000***
MFY×*H. armigera* larvae	−0.85	$Y = 86.293 - 7.328x$	0.723	20.90	0.002**

[a]MFY - Marketable fruit yield
[b]LFB - Leaf-feeding beetles (mean of *Asbecesta nigripennis, Asbecesta transversa, Aulacophora africana, Monolepta nigeriae*, and *Epilachna chrysomelina*)
[c]$Y = c + mx$. Where Y is the dependent variable, c is the intercept for a given line, m is slope, and x is the independent variable
df (degree of freedom): Regression = 1, Residual = 8, Total = 9
* = significantly different ($P \leq 0.05$)
** = significantly different ($P \leq 0.01$)
*** = significantly different ($P \leq 0.001$)
[ns] = not significantly different ($P > 0.05$)

Details of the injuries caused by pests of crops leading to damage, and eventually yield losses, are available in the literature [8]. Relationships between yield losses and damages caused by pests can be well expressed using regression statistics [8,9]. Generalized linear regression models have been shown to be effective and reliable for detecting relationships between parameters [11] and are widely acceptable. The linear regression models generated by this study are highly reliable, as their coefficients of determination (R^2) were mostly significant ($P \leq 0.05$) and largely close or > 50 %. Hence, preliminary models are here presented for forecasting agronomic performance in the study area in the face of each of the key pest densities. This is especially important for determining the critical pest densities at which management strategies can be employed, with documented outrageous pesticide application, with its attendant health and environmental consequences, in the study area [7,15].

Table 5 Comparisons between early- and late-sown crop at Wukari in 2016.

Variables	Means for early-sown	Means for late-sown	Mean difference[1]	t-value	df	*p*-value
Leaf-feeding beetles[2]	9.52±1.79	4.73±0.86	4.79±0.93	5.131	9	0.001**
Proportion of leaves injured (%)	40.91±7.94	17.06±2.40	23.85±5.61	4.251	9	0.002**
Severity of leaf injury (%)	23.15±5.75	9.68±1.69	13.47±4.08	3.303	9	0.009**
A. gossypii	2.42±0.94	4.39±0.29	−1.97±0.20	−10.011	9	0.000***
B. tabaci density	11.38±0.43	29.99±1.16	−18.62±0.73	−25.402	9	0.000***
B. cucurbitae larvae/fruit	11.27±1.61	3.43±0.60	7.84±1.01	7.76	9	0.000***
Main vine length (cm) at 9 WAP	201.73±24.57	223.58±25.72	−21.85±1.27	−17.262	9	0.000***
Number of leaves/plant at 9 WAP	137.10±31.33	166.59±33.47	−29.49±2.17	−13.605	9	0.000***
Plant Survival Rate (%)	62.07±7.07	67.71±6.52	−5.64±0.88	−6.387	9	0.000***
Flower sex ratio	5.81±0.28	5.41±0.27	0.40±0.02	20.25	9	0.000***
Total number of fruits/ha	8871.3±1838.6	10492.4±1964.6	−1621.1±176.5	−9.186	9	0.000***
Fruit yield (tha^{-1})	17.67±4.92	23.04±5.77	−5.37±0.92	−5.827	9	0.000***

[1] - Values indicates means (±SE) for early-sown minus means (±SE) for late-sown
[2] = Mean of *Asbecesta nigripennis, Asbecesta transversa, Aulacophora africana, Monolepta nigeriae*, and *Epilachna chrysomelina*
* = significantly different ($P \leq 0.05$)
** = significantly different ($P \leq 0.01$)
*** = significantly different ($P \leq 0.001$)
^{ns} = not significantly different ($P > 0.05$)
WAP - Weeks after planting

Throughout the 2-year intensive study, prevalence of *H. armigera* (a key fruit boring insect) in the early-season crop was low. The early-season crop was marked by high frequency and intensity of rainfall, which might not have been amenable for *H. armigera* colonization and population growth. Non-stationary climate has been reported to change the behavior of insects and their host plants [16]. These changes may be due to seasonal parameters or changes in physiological attributes. These alterations have given rise to inconsistent insect/weather parameter relationships [17]. There is, therefore, the need for extensive study of the influence of weather on population dynamics of the major pests of watermelon in order to aid pest forecasting.

Table 6 Comparisons between early- and late-sown crop at Wukari in 2017.

Variables	**Means for early-sown**	**Means for late-sown**	**Mean difference[1]**	**t-value**	**df**	***p*-value**
Leaf-feeding beetles[2]	9.69±1.83	4.83±0.87	4.86±0.96	5.090	9	0.001**
Proportion of leaves injured (%)	45.05±8.00	21.18±2.28	23.88±5.79	4.122	9	0.003**
Severity of leaf injury (%)	25.75±6.41	10.75±1.88	15.00±4.56	3.290	9	0.009**
A. gossypii	4.52±0.30	6.06±0.89	−1.54±0.22	−7.164	9	0.000***
B. tabaci density	16.74±0.44	30.66±1.14	−13.93±0.75	−18.649	9	0.000***
B. cucurbitae larvae/fruit	9.65±1.68	6.50±0.62	3.16±1.07	2.95	9	0.016*
Main vine length (cm) at 9 WAP	189.38±22.30	210.15±23.36	−20.77±3.20	−6.488	9	0.000***
Number of leaves/plant at 9 WAP	128.91±29.42	147.84±31.45	−18.93±2.24	−8.445	9	0.000***
Plant Survival Rate (%)	60.00±7.07	65.63±6.52	−5.63±1.07	−5.219	9	0.001**
Flower sex ratio	5.88±0.29	5.48±0.27	0.41±0.02	20.41	9	0.000***
Total number of fruits/ha	8494.5±1790.6	10079.6±1911.1	−1585.2±171.1	−9.265	9	0.00***
Fruit yield (tha^{-1})	16.98±4.77	22.20±5.60	−5.22±0.89	−5.872	9	0.000***

[1] - Values indicates means (±SE) for early-sown minus means (±SE) for late-sown
[2] = Mean of *Asbecesta nigripennis, Asbecesta transversa, Aulacophora africana, Monolepta nigeriae*, and *Epilachna chrysomelina*
* = significantly different ($P \leq 0.05$)
** = significantly different ($P \leq 0.01$)
*** = significantly different ($P \leq 0.001$)
^{ns} = not significantly different ($P > 0.05$)
WAP - Weeks after planting

It has been shown that leaf injury has serious implications for fruit quality and quantity, as the leaves play a key role in synthesizing sugar and in accumulating water in the fruit [18]. That herbivory suppresses reproductive performance of plants has been reported by [8,19]. They showed that defoliation of plant tissue by defoliators and allocation of resources for plant defense lowers the amount of resources which would have been allocated for reproduction and, eventually, yield. [20] found out that, even though leaf feeding beetles are all-season pests, they are most attractive to cucurbits during the seedling and vegetative stages of growth. The ability of leaf-eating beetles to compromise seedlings and/or bring about loss of plant stands and, eventually, yield has been reported by [21]. Our statistical analyses showed that, of the key pests of watermelon in the study area, the leaf-feeding beetle had the most suppressive influence on survival and, ultimately, yield. However, since the pattern of injury of the 5 major leaf beetle species (*A. nigripennis, A. transversa, A. africana, M. nigeriae*, and *E. chrysomelina*) are similar, it was difficult to isolate the most important leaf-eating beetle species, even though they were all found to be significantly higher in density on the early- than on the late-sown crop, with *A. nigripennis* and *M. nigeriae* being more predominant.

Conclusions

The present study showed that watermelon experiences multiple pest infestations and their compositions and intensities vary between seasons, variably influencing agronomic performance, as indicated by the R^2 values. Lower pest infestation (frequency and intensity) was also empirically shown to give rise to better growth indices, higher numbers of staminate and pistillate flowers with lower floral sex ratio, signifying higher numbers of female flowers and, consequently, higher yields. Preliminary models for predicting the crop performance in relation to the individual key pest densities are here also formulated.

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