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Statistical Modeling of the Impact of Major Insect Pests of Watermelon on its Agronomic Performance: Linear Regression Perspective

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***Abstract* -** Studies on the impact of major pests of watermelon on its agronomic performance are hard to find. This paper presents the relationship between the agronomic performance of watermelon and density of its major insect pests with the aid of correlation and linear regression models using data collected from forty (40 m^2) plots grouped into 4 replicates (10 plots/replicate) in field experiments in the early- and late-sown crop of 2016 and 2017 in the Research Farm of Federal University, Wukari, Nigeria. Plant survival rate (%) negatively and significantly ($P < 0.05$) correlated with each of mean number leaf-feeding beetles, *A. gossypii* density and *B tabaci* density in both the early- and late-sown crops of 2016, respectively; with a similar trend in 2017. All parameters significantly ($P < 0.05$) 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 pest and agronomic characters of 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 effect of pests on crop performance) were largely > 50 %. Lower pest infestation (frequency and intensity) was also empirically shown to give rise to better growth indices and higher yields.

***Keywords* -** Flower sex ratio, leaf-feeding beetles, leaf injury, plant survival rate, total fruit yield

I. INTRODUCTION

Regardless of the high economic, health and nutritional values of watermelon [*Citrullus lanatus* Thunb. (Cucurbitaceae)], arthropod pests, particularly insects; remain a major limitation to its production [1]. Sap sucking, fruit feeding insects and leaf feeding beetle species are widespread and have been reported to be infesting the crop throughout it growth stages [2,3]. Even though yield losses of up to 100% due to insect pest infestations have been documented on watermelon [1], hardly any study had presented a model which could be used for predicting injury, survival and eventually yield vis-à-vis key pest pressure. Since crop pests are inherently part of every agroecosystem, estimating their contributions on crop performance is vital [4]. This paper models the relationship between the agronomic performance of watermelon and density of its major insect pest complex using correlation and linear regression models hence; providing a base line information for further studies.

II. MATERIALS AND METHODS

Study site and field layout

The field experiments were conducted in the Research farm of Federal University Wukari, Nigeria in 2016 and 2017 early- and late-cropping seasons. Wukari has an altitude of 187 m above sea level, an average annual temperature of 26.8 ^oC and an average annual rainfall of 1205 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 [5]. Forty 5 m long x 8 m wide plots were demarcated on a 0.21 hectare of field. The plots were grouped into four replications of 10 plots in each replicate and each plot was 40 m^2.

Data collection

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 1600 and 1800 h). 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 the 5 m length of the middle row of each plot at an approximate walking speed of 1 m/second.

Whiteflies (*Bemisia tabaci* Genn.) were sampled using a 15 x 15 cm yellow sticky board waved across the 5 m length of the middle row of each plot on shaking the plants as described by [3]. Estimates of population density 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 Ahmadu Bello University, Zaria, Nigeria. However, immature stages were reared to adult in the laboratory before identification.

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 [6]. Fifteen randomly selected leaves/plot were similarly scored for severity of injury on a scale of 0 – 4;

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 [6].

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 days interval, counted, weighed, and sorted into marketable and unmarketable categories. The latter comprised of fruits that were discoloured, misshapen, cracked, insect damaged, and infected with blossom end rot. The proportion of the marketable fruits was then computed.

Data analysis

The relationship 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 Student's t-test was then used for comparing the parameters between the early- and late-sown crops. The analyses were done using IBM SPSS version 23.0 (SPSS Inc., Chicago, Illinois).

III. RESULTS AND DISCUSSION

In 2016, the results shows positive and significant correlation of leaf-feeding beetle density with proportion of damaged leaves ($r = 0.94$ for early- and $r = 0.91$ for late-sown crop) and severity of leaf injury ($r = 0.96$ and $r = 0.93$, respectively) (Table 1a). Leaf-beetles influenced a high proportion of the variation in both parameters as shown by the R^2 values (which were indicative of the effect of pests on crop performance) of 88.4 % and 92.1 %, respectively. Plant survival rate (%) negatively and significantly ($P < 0.05$) correlated with each of mean number of leaf-feeding beetles ($r = -0.80$ and $r = -0.79$), *A. gossypii* density ($r = -0.67$ and $r = -0.65$) and *B tabaci* density ($r = -0.67$ and $r = -0.66$) 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 crop, respectively. Plant survival was less influenced by density of *H. armigera* larvae ($r = -0.64$, $R^2 = 40.9$ %) in the late-sown crop. All parameters analysed significantly ($P < 0.05$) fit the linear regression model (Table 1a). In 2017, the results presented in Table 1b largely followed a trend largely similar to that of the preceding year.

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 2a and b). 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 73.7 % (Table 2a). The R^2 values for 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 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 2b).

Student's t-test detected significant differences between the measured parameters of 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 ($t\alpha < 0.05$) higher in the early-sown crop 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 ($t\alpha < 0.05$) higher in the late-sown crop in both 2016 and 2017 (Table 3a and b).

Table 1a: 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)	P-value for R^2
2016 early				
PLI[a] x LFB[b]	0.94***	Y = 1.202 + 4.169x	0.884	<0.001***
SLI[c] x LFB[b]	0.96***	Y = -6.200 + 3.082x	0.921	<0.001***
PS[d] x LFB[b]	-0.80**	Y = 92.023 – 3.145x	0.635	0.006**
PS x *A. gossypii*	-0.67*	Y = 184.048 – 50.444x	0.449	0.034*
PS x *B. tabaci*	-0.67*	Y = 188.832 – 11.138x	0.452	0.033*
2016 late				
PLI x LFB	0.91***	Y = 5.015 + 2.545x	0.831	<0.001***
SLI x LFB	0.93***	Y = 0.973 + 1.839x	0.866	<0.001***
PS x LFB	-0.79**	Y = 95.986 – 5.975x	0.621	0.007**
PS x *A. gossypii*	-0.65*	Y = 131.852 – 14.618x	0.424	0.041*
PS x *B. tabaci*	-0.66*	Y = 178.738 – 3.701x	0.433	0.039*
PS x *H. armigera* larvae	-0.64*	Y = 114.096 – 6.341x	0.409	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
* = 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 1b: 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)	P-value for R^2
2017 early				
PLI[a] x LFB[b]	0.94***	Y = 5.161 + 4.118x	0.883	<0.001***
SLI[c] x LFB[b]	0.96***	Y = -6.925 + 3.373x	0.922	<0.001***
PS[d] x LFB[b]	-0.78**	Y = 89.346 – 3.029x	0.612	0.008**
PS x *A. gossypii*	-0.66*	Y = 130.731 – 15.662x	0.433	0.039*
PS x *B. tabaci*	-0.72*	Y = 252.059 – 11.475x	0.511	0.020*
2017 late				
PLI x LFB	0.90***	Y = 9.774 + 2.363x	0.817	<0.001***
SLI x LFB	0.93***	Y = 1.073 + 2.005x	0.864	<0.001***
PS x LFB	-0.84**	Y = 95.845 – 6.263x	0.703	0.002**
PS x *A. gossypii*	-0.57[ns]	Y = 316.092 – 41.351x	0.320	0.088[ns]
PS x *B. tabaci*	-0.70*	Y = 188.724 – 4.014x	0.492	0.024*
PS x *H. armigera* larvae	-0.73*	Y = 133.196 – 7.303x	0.531	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
* = 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 2a: 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)	P-value for R^2
2016 early				
MFY[a] x LFB[b]	-0.89**	Y = 36.220 – 2.316x	0.786	0.001**
MFY x *A. gossypii*	-0.88**	Y = 120.039 – 43.786x	0.772	0.001**
MFY x *B. tabaci*	-0.86**	Y = 121.079 – 9.394x	0.735	0.002**
MFY x *B. cucurbitae* larvae	-0.91***	Y = 43.062 – 2.539x	0.819	<0.001***
2016 late				
MFY x LFB	-0.90***	Y = 46.324 – 5.879x	0.812	<0.001***
MFY x *A. gossypii*	-0.90***	Y = 94.662 – 17.357x	0.809	<0.001***
MFY x *B. tabaci*	-0.89**	Y = 147.458 – 4.299x	0.789	0.001**
MFY x *B. cucurbitae* larvae	-0.93***	Y = 48.115 – 8.642x	0.866	<0.001***
MFY x *H. armigera* larvae	-0.86**	Y = 72.076 – 7.323x	0.737	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
* = 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 2b: 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)	P-value for R^2
2017 early				
MFY[a] x LFB[b]	-0.88**	Y = 36.121 – 2.267x	0.782	0.001**
MFY x *A. gossypii*	-0.88**	Y = 76.670 – 13.841x	0.772	0.001**
MFY x *B. tabaci*	-0.85**	Y = 165.042 – 9.015x	0.720	0.002**
MFY x *B. cucurbitae* larvae	-0.91***	Y = 38.624 – 2.535x	0.831	<0.001***
2017 late				
MFY x LFB	-0.90***	Y = 46.464 – 5.796x	0.813	<0.001***
MFY x *A. gossypii*	-0.78**	Y = 313.380 – 48.685x	0.600	0.009**
MFY x *B. tabaci*	-0.90***	Y = 153.636 – 4.407x	0.801	<0.001***
MFY x *B. cucurbitae* larvae	-0.92***	Y = 69.967 – 8.022x	0.846	<0.001***
MFY x *H. armigera* larvae	-0.85**	Y = 86.293 – 7.328x	0.723	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
* = 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 3a: Comparisons between early- and late-sown watermelon at wukari in 2016

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

[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

Table 3b: Comparisons between early- and late-sown watermelon at Wukari in 2017

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

[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

That injuries caused by pests of crops lead to damage, and eventually yield losses have been well documented [8]. However, the level of this relationship can be well expressed by regressing data from well designed empirical studies [8,9]. It has been shown that leaf injury has serious implication on fruit quality and quantity of watermelon as the leaves play a key role in synthesizing sugar and in accumulating water in the fruit [10]. That herbivory has suppresses reproductive performance of plants have been reported by [8,11]. They found out that, defoliation of plant tissue by pests and allocation of resources for plant defense lowers the amount of resources which would have been allocated for reproduction and eventually, yield. Zehnder [12] showed that though leaf feeding beetles are all season pests and that, 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 substantial loss of plant stands and yield loss has been reported by [13]. Our statistical analyses showed that of the major insect pest of watermelon, the leaf-feeding beetles, had the most suppressive influence on survival and ultimately yield.

Throughout the 2 years intensive study, prevalence of *H. armigera* in the early-season crop was low. The early-season crop was characterized by high frequency and intensity of rainfall which might not have been amenable for *H. armigera* proliferation. Nonstationary climate has been reported to change the behavior of insects and their host plants [14]. These changes may be due to seasonal parameters or changes in physiological attributes. These alterations have given rise to inconsistent insect/weather parameter relationships [15]. 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.

IV. CONCLUSION

The present study showed that watermelon experiences multiple pest infestations and that, 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 number of staminate and pistillate flowers with lower floral sex ratio signifying higher number of female flowers and consequently higher yields.

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