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Interactive Effects of Major Insect Pest of Watermelon on its Yield in Wukari, Nigeria

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Abstract:

Watermelon is known to be infested by multiple insect pests both simultaneously and in sequence. Interactions by pests have been shown to have positive or negative, additive or non additive, compensatory or over compensatory effects on yields. Hardly has this sort of relationship been defined for watermelon vis-à-vis insect herbivores. A 2-year, 2-season (4 trials) field experiments were laid in the Research Farm of Federal University Wukari, to investigate the interactive effects of key insect pests of watermelon on fruit yield of Watermelon in 2016 and 2017 using natural infestations. The relationship between the dominant insect pests and fruit yield were determined by correlation (r) and linear regression (simple and multiple) analyses. Multimodel inference was used to define the predictor that impacted on fruit yield the most. Results indicated that, each pest had highly negative and significant ($p < 0.05$) impact on yield (range of $r = -0.78$ to -0.92), and that the coefficient of determination (R^2) values (which were indicative of the effect of pests or their complexes on yield) did not rise on addition of interaction terms. This reveals a non additive negative impact of insect interactions on the fruit yield of watermelon. This may be due to among others; competition by the pest, phenology, plant defenses or changes in nutritional content of the plant. The need to therefore employ discriminate analysis to ascertain the contribution of each pest to yield loss when multiple pest infest a crop is thus highlighted.

Keywords: Fruit yield, Interactions by pests, Leaf-feeding beetles, Regression, Watermelon.

Introduction:

Crop plants [Watermelon, *Citrullus lanatus* Thunb. (Cucurbitaceae), inclusive] are often infested by complexes of pests with their attendant impact on yield¹. Infestations are known to suppress the totality of crop agronomic performance^{2, 3}. The pest complex may occur jointly or in succession differing among localities and seasons. However, many scientists and publications dwell on one or two insect pests vis-à-vis yield while ignoring the complex and their cumulative effect on yield thereby disregarding a valid principle which holds that no single pest can be responsible for all the yield loss in an agro-ecosystem. That concurrent infestation by multiple insect pests does not

automatically have additive negative effects on yield have been shown by evolutionary researches on wild plants¹. Nonetheless, whether this principle applies to all cultivated plants remains a subject for continuous studies. Aside additive negative effects^{4, 5}, research findings have also shown compensatory or over compensatory effects on yield¹. Studies aimed at investigating the interactive effects of insect pest complexes on fruit yield of watermelon had hardly been conducted.

Watermelon is an important vegetable fruit crop produced throughout the tropics and the Mediterranean region of the world. It accounts for 6.8% of the world area devoted to vegetable

production⁶. Despite its huge nutritional, health and economic values, insect pests remain a critical constraint to its production^{7, 8}. Aside sap sucking and fruit feeding insects; leaf feeding beetle species are widespread and very critical to its production as they are found infesting the crop throughout its growth stages and their intensities varying among seasons^{2, 10}. While yield losses of up to 100% due to specific insect pest infestation have been reported on watermelon⁷, hardly any study had presented a statistical model which could be used as a basis for predicting yield vis-à-vis key insect pest pressure. Additionally, since crop pests are inherently part of every agro-ecosystem, quantifying their impact on crop performance is now an important field of study^{11, 12}. We therefore present here an investigation on the interactive impacts of major leaf feeding beetles (cumulatively), sap-sucking and fruit feeding insects on watermelon fruit yield.

Materials and Methods:

Study Site, Field Layout and Management

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 187m above sea level, an average annual temperature of 26.8°C, and an average annual rainfall of 1205mm. 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 September¹³. A 2 year by 2 seasons field research conducted by Okrikata et al.⁹ showed that leaf feeding beetles predominated by *Aulacophora africana* (Weise), *Asbecesta nigripennis* (Weise), *A. transversa* (Allard), *Epilachna chrysolina* (Fab.), *Monolepta nigeriae* (Bryant); sap-sucking insects, mainly; *Aphis gossypii* (Glove), *Bemisia tabaci* (Genn.), and fruit feeding insects [*Bactrocera cucurbitae* (Coq.), *Heliothis armigera* (Hub.)] are the major insect pest of watermelon in the study site. In this study however, the leaf feeding beetle species were treated as a single taxon since the injury they cause were indistinguishable. Data on natural enemy populations were also disregarded as the focus was on pest populations.

Forty 5 m long x 8 m wide plots were demarcated on a 0.21 hectare of field in four replications and treatments applied as reported by Okrikata and Ogunwolu¹⁴ in which aside application of insecticide (0.5 % Cypermethrin 30g/L + Dimethoate 250g/L EC [Cyper-diforce[®]]) at the recommended rate at various growth stages and their combinations; insecticide untreated plots were regarded as the control. Additionally, to

suppress the impact of pathogen and weed pests; a broad spectrum preventive fungicide; Mancozeb 80% WP. (Zeb-care[®]) which has a contact mode of action was applied at the rate of 2 kg ha⁻¹ at the vegetative, flowering and fruiting stages and, when necessary, weeding was done manually following the method described by Okrikata and Ogunwolu¹⁴.

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. Leaf feeding beetles and *Heliothis armigera* larvae were sampled using a motorized shoulder-mounted suction machine having a 10 cm diameter inlet cone (Burkard Scientific Ltd., Uxbridge, UK.). Sampling was done by sweeping the machine through the 5 m length of the middle row of each plot at an approximate walking speed of 1m/second.

Whiteflies (*Bemisia tabaci* Genn.) were sampled using a 15 x 15cm yellow sticky board waved across the 5 m length of the middle row of each plot on shaking the plants as described by Okrikata and Ogunwolu¹⁴. Estimates of population density of aphids (*Aphis gossypii* Glove) were made by assessing the colony size on 12 randomly selected leaves/plot using a scale from 0 – 9 as described by Okrikata and Ogunwolu¹⁴. Similarly, 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 as also described by Okrikata and Ogunwolu¹⁴.

Samples of dominant insects collected were 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 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 cracked, discoloured, infected with blossom end rot, misshapen and insect damaged. The proportion of the marketable fruits was then computed.

Data Analysis

The relationship between dominant insect pests and marketable fruit yield were determined by Pearson's product-moment correlation, and linear regression (simple and multiple) analyses. Multimodel inference was used to determine the independent variable that impacted on yield the

most hence forming the basis for comparing different combinations of independent variables. All analyses were done using IBM SPSS version 23.0 (SPSS Inc., Chicago, Illinois).

Results:

Relationships between Marketable Fruit Yield and Individual or Combined Insect Pests of Watermelon

Results presented in Table 1 indicates that all the major insect pests across years and seasons; either individually or combined showed highly negative and significant (range: 0.79 to 0.92; $p < 0.05$) impact on marketable fruit yield of watermelon. However, correlation coefficients were generally higher and more significant on fruits predisposed to individual than for combination of insect pests indicating that losses caused by combinations of pests were not additive.

Relationship between Marketable Fruit Yield and Major Watermelon Pests without or with Interactions

The coefficient of determination (R^2) values presented in Tables 2a and b indicates the interactive and non interactive effects of pests on fruit yield of watermelon. Across years and seasons; the results revealed that addition of interactive terms did not increase the R^2 values. The generally comparatively lower R^2 values observed in the interactions, showed that the effect of pest complexes did not explain all the losses in fruit yield. All the regression analyses consistently and significantly ($p < 0.05$) followed the linear model, and their R^2 values ranged from 62.4 – 85.2% for interactive insects; and from 73.5 – 86.6% for non interactive insects in 2016 cropping season. Corresponding values for 2017 were 63.2 – 85.2% and 60.0 – 84.6%, respectively.

Table 1. Correlation coefficients (r) for fruit yield (tha^{-1}) of watermelon in relation to individual or combined insect pest infestations on early and late-sown crop of 2016 and 2017

Variables	Marketable fruit yield (tha^{-1}) [MY] ^a	
	2016 Early-Sown Crop	2017 Early-Sown Crop
Leaf feeding beetles (LB) ^b	-0.89**	-0.88**
<i>Aphis gossypii</i> (Ag)	-0.88**	-0.88**
<i>Bemisia tabaci</i> (Bt)	-0.86**	-0.85**
<i>Bactrocera cucurbitae</i> (Bc)	-0.91***	-0.91***
Ag*Bt	-0.87**	-0.88**
LB*Ag*Bt*Bc	-0.83**	-0.82**
	2016 Late-Sown Crop	2017 Late-Sown Crop
LB	-0.90***	-0.90***
Ag	-0.90***	-0.78**
Bt	-0.89**	-0.90***
Bc	-0.93***	-0.92***
<i>Heliothis armigera</i> (Ha)	-0.86**	-0.85**
Ag*Bt	-0.89**	-0.87**
Bc*Ha	-0.90**	-0.90**
LB*Ag*Bt*Bc*Ha	-0.79**	-0.83**

^aMY – Marketable fruit yield

^bLB – Leaf-feeding beetles (*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 ($P > 0.05$)

Table 2a. Multiple regression functions to estimate variations in watermelon fruit yield (tha⁻¹) due to interactive and non interactive infestation by major insect pests in early and late-sown crop of 2016

Regressed Variables	Regression Equation	Coefficient of Determination (R ²)	P-value for R ²
2016 early			
MY ^a x LB ^b	MY = 36.220 - 2.316LB	0.786	0.001
MY x Ag	MY = 120.039 - 43.786Ag	0.772	0.001
MY x Bt	MY = 121.079 - 9.394Bt	0.735	0.002
MY x Bc	MY = 43.062 - 2.539Bc	0.819	<0.001
MY x Ag*Bt	MY = 69.377 - 1.958Ag*Bt	0.748	0.001
MY x LB, Ag*Bt, Bc	MY = 57.876 + 2.422LB - 0.388Ag*Bt - 4.910Bc	0.852	0.007
MY x LB*Ag*Bt*Bc	MY = 27.492 - 0.003LB*Ag*Bt*Bc	0.690	0.003
2016 late			
MY x LB	MY = 46.324 - 5.879LB	0.812	<0.001
MY x Ag	MY = 94.662 - 17.357Ag	0.809	<0.001
MY x Bt	MY = 147.458 - 4.299Bt	0.789	0.001
MY x Bc	MY = 48.115 - 8.642Bc	0.866	<0.001
MY x Ha	MY = 72.076 - 7.323Ha	0.737	0.001
MY x Ag*Bt	MY = 68.625 - 0.366Ag*Bt	0.787	0.001
MY x Bc*Ha	MY = 41.403 - 0.773Bc*Ha	0.813	<0.001
MY x Ag*Bt, Bc*Ha	MY = 48.170 - 0.088Ag*Bt - 0.596Bc*Ha	0.815	0.003
MY x LB, Ag*Bt, Bc*Ha	MY = 80.986 - 9.726LB - 0.364Ag*Bt + 1.175Bc*Ha	0.846	0.008
MY x LB*Ag*Bt*Bc*Ha	MY = 31.458 + 0.001LB*Ag*Bt*Bc*Ha	0.624	0.007

^aMY - Marketable fruit yield^bLB - Leaf-feeding beetles (*Asbecesta nigripennis*, *Asbecesta transversa*, *Aulacophora africana*, *Monolepta nigeriae* and *Epilachna chrysolina*)Ag - *Aphis gossypii*Bt - *Bemisia tabaci*Bc - *Bactrocera cucurbitae** = significantly different (P ≤ 0.05); ** = significantly different (P ≤ 0.01); *** = significantly different (P ≤ 0.001); ^{ns} = not significantly different (P > 0.05)**Table 2b. Multiple regression functions to estimate variations in watermelon fruit yield (tha⁻¹) due to interactive and non interactive infestation by major insect pests in early and late-sown crop of 2017**

Regressed Variables	Regression Equation	Coefficient of Determination (R ²)	P-value for R ²
2017 early			
MY ^a x LB ^b	MY = 36.121 - 2.267LB	0.782	0.001
MY x Ag	MY = 76.670 - 13.841Ag	0.772	0.001
MY x Bt	MY = 165.042 - 9.015Bt	0.720	0.002
MY x Bc	MY = 38.624 - 2.535Bc	0.831	<0.001
MY x Ag*Bt	MY = 59/736 - 0.594Ag*Bt	0.770	0.001
MY x LB, Ag*Bt, Bc	MY = 47.550 + 2.298LB - 0.188Ag*Bt - 4.274Bc	0.852	0.007
MY x LB*Ag*Bt*Bc	MY = 25.730 - 0.001LB*Ag*Bt*Bc	0.632	0.004
2017 late			
MY x LB	MY = 46.464 - 5.796LB	0.813	<0.001
MY x Ag	MY = 313.380 - 48.685Ag	0.600	0.009
MY x Bt	MY = 153.636 - 4.407Bt	0.801	<0.001
MY x Bc	MY = 69.967 - 8.022Bc	0.846	<0.001
MY x Ha	MY = 86.293 - 7.328Ha	0.723	0.002
MY x Ag*Bt	MY = 112.550 - 0.524Ag*Bt	0.750	0.001
MY x Bc*Ha	MY = 50.512 - 0.504Bc*Ha	0.803	<0.001
MY x Ag*Bt, Bc*Ha	MY = 68.119 - 0.136Ag*Bt - 0.381Bc*Ha	0.810	0.003
MY x LB, Ag*Bt, Bc*Ha	MY = 70.816 - 4.888LB - 0.181Ag*Bt + 0.081Bc*Ha	0.827	0.011
MY x LB*Ag*Bt*Bc*Ha	MY = 33.011 + 0.001LB*Ag*Bt*Bc*Ha	0.682	0.003

^aMY - Marketable fruit yield^bLB - Leaf-feeding beetles (*Asbecesta nigripennis*, *Asbecesta transversa*, *Aulacophora africana*, *Monolepta nigeriae* and *Epilachna chrysolina*)Ag - *Aphis gossypii*Bt - *Bemisia tabaci*Bc - *Bactrocera cucurbitae** = significantly different (P ≤ 0.05); ** = significantly different (P ≤ 0.01); *** = significantly different (P ≤ 0.001); ^{ns} = not significantly different (P > 0.05)

Discussion:

It is known that injuries caused by crop pests lead to damage, and that damage leads to yield losses^{12, 15}. However, the extent of these

relationships can be better expressed by linear regression analyses. Assessing the impacts of pests on crop performance has been shown to be very important in modelling^{15, 16}.

Kirmse and Chaboo¹⁷ reported that though chrysomelid beetles are season-long pests of cucurbits, they are most attractive during the 1st 2 to 3 weeks post emergence. The ability of leaf-eating beetles to weaken seedlings and/or bring about loss of plant stands resulting to yield loss has been demonstrated by Konstantinov¹⁸. Our multimodel inference analyses showed that of the major pest of watermelon, the leaf-eating beetles, had the highest impact on fruit yield. It has been shown that leaf injury has serious implication on the quantity and quality of fruits produced by watermelon as the leaves play a major role in manufacturing sugar and gathering water in the fruit^{19,20}.

Throughout the 2 years study, presence of *H. armigera* (a key fruit boring insect) in the early-season crop was sporadic. The early-season crop growth period was characterized by higher intensity and frequency of rain which might not augur well with *H. armigera* colonization, and population rise. Alternating dry and wet spells have been shown to favour its outbreak²¹. Another predominant, fruit boring insect was *B. cucurbitae*. The damage caused by fruit borers is very obvious. Yield losses of 30 – 100% have been attributed to fruit feeding insects alone²².

The sap sucking insects predominated by *A. gossypii* and *B. tabaci* have direct and indirect effect on yield. Though, assessing their impact on yield was difficult as it was largely physiological, they are known to, aside sucking sap; leading to stunted growth and curly leaves, vector pathogens, and excrete honey dews which attracts fruit flies²³.

It is therefore obvious that each of the 3 pest groups (leaf feeding, sap sucking and fruit boring) affects yield negatively, and that the individual species attack watermelon crop either simultaneously or sequentially⁹. But are their interactions additive? As evidenced by results of correlation and regression analyses, the current finding showed non additive negative interactions by the component pests. That the correlation coefficients were slightly higher and significant in plants not predisposed to multiple pests, and that R² values largely did not improve under interactive pest infestations, so indicate. However, of interest is that the multimodel inference analyses identified the leaf feeding beetles as the most determinants of the negative yield.

While a finding similar to the current was reported by Jörg²⁴ when investigating the interactions of foliar pathogens on Wheat growth indices; the current finding is at variance with that of Vesna et al.¹ who reported that, two stem and seed weevils known to individually suppress yield on Winter oil seed rape²⁵; jointly increases

(positive impact) yield by > 2 folds. Hence, their findings showed non additive positive impact on yield. Arguably, as reported by Stephens et al.⁵; the interactive effects of multiple insect attacks have been hinged on competition by insect pest components for resources, seasonal variations, plant defensive response and nutritional quality change.

Conclusion:

The current finding shows that the impact of the component insect pests on fruit yield reduction in watermelon was not additive. This may be attributed to competition among pest species, influence of natural enemy species, seasonal variations, plant defenses and changes in nutritional quality of the plant. Hence, no single insect pest is completely responsible for the totality of yield loss even though the leaf beetles had more impact. The need to recruit discriminate analyses when multiple pest infest a crop should be a focus.

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Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Besides, the Figures and images, which are not ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in Federal University Wukari.

Authors' contributions statement:

O Emmanuel conceived and designed the research as part of his PhD research project. He also drafted the manuscript. OE Oludele was the major supervisor of the research. He contributed in the conception and design of the work. OJ Itohan revised and proofread the manuscript. OA Oyewole analysed and interpreted the data. All authors read carefully and approved the final version of the manuscript. However, Prof. OE Oludele passed away after the research was completed and the research project (thesis) defended.

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التأثيرات التفاعلية للآفات الحشرية الرئيسية على محصول الرقي في ووكاري ، نيجيريا

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الخلاصة:

من المعروف أن الرقي يصاب بآفات حشرية متعددة في نفس الوقت وبالتسلسل. وقد تبين أن تفاعلات الآفات لها آثار إيجابية أو سلبية أو مضافة أو غير مضافة أو تعويضية أو زائدة التأثير على الغلة. بالكاد تم تحديد هذا النوع من العلاقة للبطيخ مقابل أكالات الحشرات العاشبة. تم إجراء تجارب ميدانية لمدة عامين وموسمين (4 تجارب) في مزرعة الأبحاث التابعة لجامعة ووكاري الفيدرالية ، للتحقيق في التأثيرات التفاعلية للآفات الحشرية الرئيسية للرقي على محصول ثمار الرقي في عامي 2016 و 2017 باستخدام الإصابات الطبيعية. تم تحديد العلاقة بين الآفات الحشرية السائدة وحاصل الثمار من خلال تحليل الارتباط (r) والانحدار الخطي (البسيط والمتعدد). تم استخدام الاستدلال المتعدد النماذج لتحديد المتنبئ الذي يؤثر على إنتاج الفاكهة أكثر. أوضحت النتائج أن كل آفة لها تأثير سلبي معنوي ($p < 0.05$) على الغلة) نطاق $r = -0.78$ إلى 0.92 (وأن معامل التحديد (R^2) قيم (والتي كانت تدل على تأثير الآفات أو مجتمعاتهم على العائد) عند إضافة شروط التفاعل. هذا يكشف عن تأثير سلبي غير مضاف لتفاعلات الحشرات على محصول ثمار الرقي. قد يكون هذا بسبب من بين أمور أخرى ؛ منافسة الآفات أو الظواهر أو الدفاعات النباتية أو التغيرات في المحتوى الغذائي للنبات. وبالتالي ، فإن الحاجة إلى استخدام تحليل تمييزي للتأكد من مساهمة كل آفة في تحقيق الخسارة عند تسليط الضوء على الآفات المتعددة التي تصيب المحصول.

الكلمات المفتاحية: غلة الفاكهة ، تفاعلات الآفات ، خنافس تغذية الأوراق ، الانحدار ، الرقي