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Determination of the Critical Period of Cyper-diforce® Treatment against Arthropod fauna and Productivity of Watermelon

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Abstract

Watermelon has been reported to be vulnerable to insect pest pressure throughout its growth stages with a resultant indiscriminate calendar-based insecticide application (of up to 25 sprays/season in the study area), with its attendant consequences. In order to recommend the crop growth period(s) to effect chemical control measures that will give better return on investment, field trials were set-up in the early- and late-cropping seasons of 2016 and 2017. Forty, 5m long x 8m wide plots were demarcated in randomized complete block design in 4 replications. Treatments were applications of 0.5% Cyper-diforce® (Cypermethrin 30g/L + Dimethoate 250g/L) at seedling, mid-vegetative, mid-flowering, mid-fruiting stages and their combinations. Unsprayed plots served as control. Pest and beneficial arthropod density, leaf injury, crop growth and yield data were collected and subjected to variance analysis and significantly different means were separated by SNK at 5% level of probability. Cost:benefit ratios of the various treatments was also computed. Findings indicate that, leaf-eating beetles had the highest impact on stand survival and yield. Insect pest density and damage generally decreased with increase in frequency of insecticide application and treatment differences were significant ($p < 0.05$) except in the case of *A. gossypii* in the late-sown crop of 2017. Plot sprayed at seedling + vegetative + fruiting stages gave the highest fruit yield and return on investment. It is therefore suggested that, for economic production of watermelon, the crop should not be sprayed during the flowering period.

Keywords: Cost:benefit ratio, Critical Treatment Period, Crop growth stages, Cyper-diforce®, Watermelon

Introduction

It has been shown that no growth stage of watermelon in the study area is spared of insect pest pressure as such growers in Nigeria and more specifically within the study area depends almost solely on outrageous calendar-based insecticide application of up to 25 applications per growing season [1]. Asides increasing the cost of production, this indiscriminate insecticide application has serious detrimental effect on beneficial arthropods such as the natural enemy species and the pollinators – most prominent of which is the honey bees (*Apis mellifera* L.) which a sizable proportion of watermelon farmers in the study area erroneously view as pest and spray them with insecticides on their farms [1, 2].

Good fruits set and development for Watermelon (*Citrullus lanatus* Thunb.) is highly dependent on insect pollinators, especially the honey bees which pollinate the female flowers. It has been estimated that eight or more visits of honey bees per blossom are necessary for optimum fruit set in Watermelon [3]. The roles of predators and parasitoids as natural enemies of insect pests and the relevance of pollinators are well documented; however, application of insecticides often result in significant

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outbreaks of the insect pests via development of pesticide resistance and/or suppression of natural enemies and also negative impact on pollinators as a result of their broad-spectrum of activity [2].

An important strategy for efficient pest management is to ascertain the critical treatment period which is the crop growing period/stage at which pest suppression must take place to prevent significant yield losses [4]. Available literature reveals that, there is hardly any documented information on the impact of recommended insecticides on the arthropod fauna associated with Watermelon in Nigeria and more specifically in the Southern Guinea Savanna Zone nor has the critical treatment period(s) for optimal yield been determined. Therefore, the present study is an assessment of the impact of a recommended insecticide (Cyper-diforce® - Cypermethrin 30g/L + Dimethoate 250g/L) applied at different crop growth stage(s) on the arthropod fauna associated with watermelon and the resultant yield and return on investment.

Materials and Methods

Description of the study area

The Research was carried out in a ploughed and harrowed land at the Teaching and Research Farm of Federal University Wukari within the Southern Guinea Savanna Zone of Nigeria (N7^{o}50'37", E9^{o}46'31" and 187 m altitude) in 2016 and 2017 early- and late-cropping seasons. Wukari has an altitude of 187 m above sea level, a warm tropical climate, an average annual temperature of 26.8^{o}C and a distinct rainy season with annual rainfall of 1205 mm which commences in April and terminates in October with maximums in June and September [5].

Field layout and experimental design

Watermelon (var. Kaolack) was sown on forty (5 m long x 8 m wide) plots during the 2016 and 2017 early- and late-cropping seasons (2016 sowing dates; May 14th and August 23rd and 2017 sowing dates; May 10th and August 15th; early and late sowing, respectively). The plots were grouped into four 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®) at 200 litres/ha spray output with the aid of 15 Litre Knapsack sprayer at the following stages of growth:

i. Seedling stage **(S)** – From 50 % emergence to 50 % vine creeping stage/about 30 cm main vine length stage,
ii. Mid-vegetative stage **(V)** – Starting at 50 % vine creeping to 50 % flowering stage,
iii. Mid-flowering stage **(F)** – Starting at 50 % flowering to 50 % fruiting stage,
iv. Mid-fruiting stage **(FR)** – Starting at 50 % fruiting stage to 2 weeks to harvest,
v. S+V+F,
vi. S+V+FR,
vii. S+F+FR,
viii. V+F+FR, and
ix. S+V+F+FR.

An unsprayed plot was included as the control **(CT)**.

Aside following the recommended crop cultural procedures, application of a preventive, contact fungicide [Mancozeb 80% WP. (Zeb-care®)] at the rate of 2 kg/ha was done at the vegetative, flowering and fruiting stages.

Arthropod sampling and identification

The sampling of arthropod species commenced at 70 % emergence stage (2 weeks after planting) and proceeded weekly up to the time of fruit maturity. Collections were made 1600 and 1800 h but it was made between 0700 and 0900 h at the flowering stage for an effective sampling of pollinating insects - as watermelon flowers open early in the morning and close by afternoon [6, 7]. The collections were done with a motorized suction sampler (Burkard Scientific Ltd., Uxbridge, UK.) with a 10 cm diameter inlet cone which was swept through the 5 m middle row at an approximate walking speed of 1m/second. The dominant sap-sucking insects were *Bemisia tabaci* Genn and *Aphis gossypii* Glover. *B. tabaci* was sampled using 15 x 15 cm yellow sticky board waved across the 5 m middle row on shaking the plants [2] while, estimates of density of *A. gossypii* was assessed using 12 randomly selected leaves/plot on a scale of 0 – 9 [where **0** = no aphids; **1** = 1 – 4 aphids; **3** = 5 – 20 aphids; **5** = 21 – 100 aphids; **7** = 101 – 500 aphids and **9** = > 500 aphids] [8].

Samples of dominant insects collected were identified using morphological techniques at the Insect Museum of Ahmadu Bello University, Zaria, Nigeria. Immature stages collected were however reared to adults in the laboratory before identification.

Assessment of leaf injury and growth parameters

At 3, 6 and 9 weeks after planting (WAP), the percentage of leaves injured was computed and presented as mean leaf injury (%). Similarly, the severity of leaf injury was computed on a scale of 0 – 4 as described by [9] 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

The individual scores thus obtained were converted and presented as mean attack severity (%) using the equation described by [10]:

Attack severity (%) = $\sum n \times 100/N \times 4$

Where;
$\sum n$ = summation of individual injury scores/plot,
N = number of scores taken/plot (= 15), and
4 = highest score on the scale.

The growth parameters [number of leaves and main vine length (cm)] were assessed at 9 WAP from 3 randomly selected plants per plot.

Economic analysis

The economic viability of the treatments was assessed by determining their cost: benefit ratios. All values were computed on per hectare basis using the average United States Dollar (US$) to Naira (₦) exchange rate during the study period (US$279.64 to ₦1). The procedure for economic analysis was as described by [11].

Data analysis

Count data were transformed to $\sqrt{x} + 0.5$ while data in percentages were transformed to arcsine before subjection to one-way variance analysis. Significantly different treatment means were separated by Students Newman Keul's (SNK) test at 5 % level of probability using SAS statistical software, version 9.2.

Results

Effect of 0.5 % cyper-diforce® applications at various stages of growth of watermelon on abundance of major pest and beneficial arthropods

Across years and on the early- and late-sown crops, the most abundant pest species were *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) while the most abundant beneficial arthropods were *Apis mellifera* L., predatory ants and spiders (Tables-1 – 4, Figures-1 – 3). Control plots consistently had the highest density of leaf feeding beetles and it differed significantly ($p < 0.05$) from insecticide treated plots. Densities generally decreased with an increase in frequency of spray and were higher on early-than on late-sown crop (Tables-1a, b).

The response of the major sap-sucking insects to the various treatments follows a somewhat similar trend to that of the leaf eating beetles except that, observed differences in *A. gossypii* density among the treatments in the late-sown crop of 2017 were not significant ($p = 0.1631$) and densities were consistently higher on the late-sown crops. Additionally, throughout the two years research period, densities of the sap sucking insects on the control plots were observed to be statistically comparable with those on plots sprayed at S and/or V (Table-2).

Density of *B. cucurbitae* larvae (a fruit borer) per fruit was significantly ($p < 0.0001$) lower across years and seasons on plots sprayed throughout the crop growth period and highest on the control plots. Though there was higher infestation on the early-sown crop, density generally decreases with an increase in spray frequency (Table-3). *Helicoverpa armigera*, another fruit borer, was rarely seen in the early- but was prominent on the late-sown. Results show that, treatment with 0.5% cyper-diforce®

at the various growth stages of watermelon significantly ($p < 0.0001$) suppressed their population (Table-3).

Tables 4a and b show that the insecticide treatments significantly ($p < 0.0001$) suppressed populations of beneficial arthropods. Across years and seasons, spraying throughout the crop growth period was numerically most suppressive of *A. mellifera* (the major pollinator) density but, statistically comparable with spraying at S+V+F, S+F+FR and V+F+FR. Significant differences in *A. mellifera* density were not detected in unsprayed plots and those sprayed at S, V, F, FR and S+V+FR. Except on the early-sown crop with respect to spiders and late-sown with respect to predatory ants in 2017 cropping year, spraying throughout the crop growth period was significantly ($p < 0.0001$) the most suppressive.

Effect of 0.5 % cyper-diforce® applications at various stages of growth on leaf injury and growth of watermelon

Table-5 shows that the proportion and severity of leaf injury were higher in the early- than on the late-sown crop and highest on unsprayed plots when compared with the sprayed plots. Except, on the late-sown crop of 2016 and 2017 cropping seasons with respect to proportion of leaf injury, the unsprayed plots were statistically at par with plots sprayed at S, V, F and FR in both proportion and severity of leaf injury. Overall, plots sprayed throughout the crop growth period was most suppressive of proportion and severity of leaf injury but was statistically comparable with plots sprayed at S+V+F, S+V+FR, S+F+FR and V+F+FR.

Table-6 shows that controls plots had significantly ($p < 0.0001$) the shortest main vine length while plots sprayed throughout the crop growth period had the longest which was statistically at par with those on plots spayed at S+V+F and S+V+FR on the early-sown crop of 2016 and 2017. Similarly, the number of leaves per plant was significantly increased by insecticide application with plots sprayed throughout the crop growth period producing consistently and significantly ($p < 0.0001$) the highest which was statistically at par with those produced by plots sprayed at S+V+FR and comparable with those produced by plots sprayed at S+V+F on the late-sown crop of 2016 and 2017 cropping seasons.

Economic analysis of 0.5 % cyper-diforce® applications on watermelon production

Investment in insecticidal control of pests of watermelon returned profit across seasons and years. Consistently, plots sprayed at the seedling stage returned the lowest net profit while those sprayed at S+V+FR returned the highest profit. In the early-sown crop of 2016, net profit ranged from US\$130.26ha^{-1} in plots sprayed at seedling stage to US\$4581.80ha^{-1} in plots sprayed at S+V+FR. In decreasing order of magnitude, cost:benefit ratio was S+V+FR > S+V+F+FR > S+V+F > S+F+FR > V+F+FR > F > FR > V > S (Table-7a). In 2017, net profit ranged from US\$96.10ha^{-1} - US\$4766.87ha^{-1} for the early-sown crop and from US\$245.32ha^{-1} – US\$5847.62ha^{-1} for the late-sown crop (Table-7b)

Table 1a-Effect of 0.5 % cyper-diforce® applications at various stages of growth on the abundance of major leaf-feeding beetles of watermelon at Wukari in 2016

Plant growth stage[1]	**Mean (±SE) number of insects collected/5m length of row[2]**				
	Aulacophora africana	***Asbecesta nigripennis***	***Asbecesta transversa***	***Monolepta Nigeriae***	***Epilachna chrysomelina***
Early-sown					
S	11.95±0.28^{b}	22.48±0.42^{b}	14.38±0.26^{bc}	20.45±0.19^{b}	3.40±0.09^{b}
V	9.76±0.27^{c}	16.67±0.30^{c}	13.35±0.28^{bc}	19.23±0.22^{c}	3.06±0.04^{b}
F	9.80±0.55^{c}	16.92±0.64^{c}	12.58±0.37^{c}	19.11±0.41^{c}	3.04±0.03^{b}
FR	11.47±0.22^{b}	22.12±0.91^{b}	15.02±0.34^{b}	20.51±0.22^{b}	3.42±0.07^{b}
S+V+F	6.75±0.53^{e}	7.98±0.27^{d}	4.77±0.16^{d}	5.02±0.09^{d}	0.50±0.05^{c}
S+V+FR	6.70±0.34^{e}	8.03±0.59^{d}	4.93±0.24^{d}	5.07±0.03^{d}	0.54±0.09^{c}
S+F+FR	8.01±0.45^{d}	7.54±0.49^{d}	4.69±0.03^{d}	5.15±0.22^{d}	0.52±0.05^{c}
V+F+FR	6.12±0.30^{e}	8.29±0.35^{d}	4.92±0.65^{d}	5.32±0.14^{d}	0.55±0.01^{c}
S+V+F+FR	1.95±0.22^{f}	4.67±0.37^{e}	2.00±0.35^{e}	2.04±0.07^{e}	0.40±0.06^{c}
CT	15.19±0.33^{a}	30.28±0.39^{a}	22.05±0.71^{a}	23.60±0.16^{a}	3.93±0.27^{a}
F (9, 27)	11.61	23.63	20.21	18.08	25.04
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Late-sown					
S	5.75±0.10^{b}	7.66±0.13^{b}	7.65±0.18^{b}	12.37±0.23^{b}	1.50±0.04^{b}
V	5.81±0.33^{b}	7.58±0.16^{b}	6.25±0.18^{c}	9.17±0.16^{c}	1.35±0.01^{b}
F	5.70±0.31^{b}	7.50±0.02^{b}	6.28±0.35^{c}	9.31±0.35^{c}	1.33±0.01^{b}
FR	6.27±0.29^{b}	7.62±0.18^{b}	7.35±0.14^{b}	12.17±0.50^{b}	1.51±0.03^{b}
S+V+F	1.91±0.06^{c}	2.42±0.06^{c}	4.32±0.34^{e}	4.39±0.15^{d}	0.22±0.02^{c}
S+V+FR	1.97±0.09^{c}	2.45±0.02^{c}	4.29±0.22^{e}	4.42±0.32^{d}	0.20±0.02^{c}
S+F+FR	1.88±0.01^{c}	2.50±0.15^{c}	5.13±0.29^{d}	4.15±0.27^{d}	0.73±0.02^{c}
V+F+FR	1.97±0.26^{c}	2.62±0.09^{c}	3.92±0.19^{e}	4.56±0.19^{d}	0.24±0.00^{c}
S+V+F+FR	0.80±0.14^{d}	0.39±0.05^{d}	1.26±0.13^{f}	2.57±0.20^{e}	0.18±0.03^{c}
CT	8.82±0.28^{a}	10.54±0.22^{a}	9.72±0.21^{a}	16.65±0.22^{a}	1.73±0.12^{a}
F (9, 27)	15.88	11.67	11.85	23.50	11.67
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[1]**S** = Seedling stage; **V** = Mid-vegetative stage; **F** = Mid-flowering stage; **FR** = Mid-fruiting stage; **CT** = Control; [2]Means are values of 4 replications; Means (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman Keul's (SNK) test (P ≤0.05).

Table 1b-Effect of 0.5 % cyper-diforce® applications at various stages of growth on the abundance of major leaf-feeding beetles of watermelon at Wukari in 2017

Plant growth stage[1]	**Mean (±SE) number of insects collected/5m length of row[2]**				
	Aulacophora africana	***Asbecesta nigripennis***	***Asbecesta transversa***	***Monolepta Nigeriae***	***Epilachna chrysomelina***
Early-sown					
S	14.64±0.27^{bc}	20.67±0.18^{b}	12.16±0.29^{b}	22.72±0.43^{b}	3.50±0.09^{b}
V	13.59±0.30^{bc}	19.43±0.22^{c}	9.91±0.27^{c}	16.86±0.29^{c}	3.15±0.05^{b}
F	12.82±0.40^{c}	19.32±0.40^{c}	9.97±0.58^{c}	17.11±0.65^{c}	3.14±0.05^{b}
FR	15.30±0.33^{b}	20.74±0.21^{b}	11.67±0.22^{b}	22.36±0.94^{b}	3.52±0.07^{b}
S+V+F	4.88±0.18^{d}	5.09±0.07^{d}	6.87±0.55^{e}	8.08±0.25^{d}	0.52±0.07^{c}
S+V+FR	5.03±0.24^{d}	5.14±0.04^{d}	6.82±0.34^{e}	8.13±0.58^{d}	0.57±0.08^{c}
S+F+FR	4.79±0.03^{d}	5.22±0.21^{d}	8.15±0.45^{d}	7.63±0.51^{d}	0.56±0.05^{c}
V+F+FR	5.03±0.65^{d}	5.40±0.15^{d}	6.22±0.30^{e}	8.39±0.36^{d}	0.57±0.01^{c}
S+V+F+FR	2.05±0.37^{e}	2.08±0.06^{e}	2.00±0.22^{f}	4.73±0.36^{e}	0.42±0.06^{c}
CT	22.44±0.73^{a}	23.84±0.16^{a}	15.43±0.34^{a}	30.60±0.38^{a}	5.04±0.26^{a}
F (9, 27)	19.01	20.44	11.04	23.80	26.89
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Late-sown					
S	7.84±0.19^{b}	12.59±0.22^{b}	5.77±0.09^{b}	7.81±0.14^{b}	1.56±0.06^{b}
V	6.40±0.17^{c}	9.34±0.18^{c}	5.83±0.31^{b}	7.73±0.17^{b}	1.40±0.03^{b}
F	6.44±0.35^{c}	9.49±0.35^{c}	5.72±0.30^{b}	7.64±0.03^{b}	1.39±0.03^{b}
FR	7.53±0.14^{b}	12.40±0.51^{b}	6.29±0.29^{b}	7.77±0.18^{b}	1.57±0.05^{b}
S+V+F	4.44±0.33^{e}	4.49±0.13^{d}	1.93±0.07^{c}	2.47±0.07^{c}	0.25±0.03^{c}
S+V+FR	4.41±0.24^{e}	4.51±0.34^{d}	1.99±0.10^{c}	2.51±0.03^{c}	0.23±0.04^{c}
S+F+FR	5.26±0.29^{d}	4.24±0.29^{d}	1.90±0.03^{c}	2.56±0.05^{c}	0.26±0.02^{c}
V+F+FR	4.02±0.21^{e}	4.66±0.18^{d}	1.99±0.26^{c}	2.69±0.09^{c}	0.27±0.01^{c}
S+V+F+FR	1.31±0.11^{f}	2.63±0.21^{e}	0.82±0.16^{d}	0.41±0.06^{d}	0.20±0.04^{c}
CT	9.96±0.22^{a}	16.95±0.24^{a}	8.84±0.30^{a}	10.74±0.23^{a}	1.80±0.13^{a}
F (9, 27)	11.71	23.73	15.36	10.85	20.71
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[1]**S** = Seedling stage; **V** = Mid-vegetative stage; **F** = Mid-flowering stage; **FR** = Mid-fruiting stage; **CT** = Control; [2]Means are values of 4 replications; Means (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman Keul's (SNK) test ($p \leq 0.05$).

Table 2-Effect of 0.5 % cyper-diforce® applications at various stages of growth on abundance (mean±SE) of major sap-sucking insects of watermelon

Plant growth stage[1]	*Aphis gossypii*[3]		*Bemisia tabaci*[4]	
	Early-sown[2]	**Late-sown[2]**	**Early-sown[2]**	**Late-sown[2]**
2016 cropping season				
S	2.81 ± 0.01^{a}	5.58 ± 0.01^{a}	12.81 ± 0.25^{a}	34.18 ± 0.46^{a}
V	2.75 ± 0.01^{b}	5.41 ± 0.02^{b}	12.98 ± 0.25^{a}	34.17 ± 0.03^{a}
F	2.54 ± 0.07^{c}	4.76 ± 0.02^{c}	11.91 ± 0.20^{b}	31.14 ± 0.61^{b}
FR	2.51 ± 0.01^{d}	4.67 ± 0.02^{d}	11.83 ± 0.25^{b}	31.32 ± 0.37^{b}
S+V+F	2.22 ± 0.01^{e}	3.77 ± 0.02^{e}	10.37 ± 0.16^{c}	27.28 ± 0.52^{c}
S+V+FR	2.12 ± 0.01^{f}	3.46 ± 0.02^{f}	10.22 ± 0.14^{c}	26.72 ± 0.26^{c}
S+F+FR	2.21 ± 0.00^{e}	3.76 ± 0.04^{e}	10.09 ± 0.23^{c}	26.73 ± 0.34^{c}
V+F+FR	2.11 ± 0.00^{f}	3.43 ± 0.01^{f}	10.14 ± 0.16^{c}	26.68 ± 0.14^{c}
S+V+F+FR	2.11 ± 0.00^{f}	3.44 ± 0.01^{f}	10.07 ± 0.09^{c}	26.32 ± 0.11^{c}
CT	2.80 ± 0.05^{a}	5.60 ± 0.06^{a}	13.39 ± 0.28^{a}	35.44 ± 0.44^{a}
F (9, 27)	29.08	29.70	43.17	88.79
p-value	<0.0001	<0.0001	<0.0001	<0.0001
2017 cropping season				
S	5.74 ± 0.02^{a}	6.45 ± 0.18^{a}	17.28 ± 0.27^{b}	35.05 ± 0.46^{a}
V	5.56 ± 0.02^{b}	6.40 ± 0.18^{a}	18.39 ± 0.26^{a}	35.04 ± 0.49^{a}
F	4.89 ± 0.01^{c}	6.16 ± 0.36^{a}	18.22 ± 0.21^{a}	31.93 ± 0.62^{b}
FR	4.81 ± 0.03^{d}	5.89 ± 0.25^{a}	17.20 ± 0.26^{b}	32.12 ± 0.38^{b}
S+V+F	3.88 ± 0.04^{e}	5.85 ± 0.24^{a}	15.69 ± 0.17^{c}	27.98 ± 0.53^{c}
S+V+FR	3.57 ± 0.01^{f}	5.84 ± 0.25^{a}	15.54 ± 0.16^{c}	27.40 ± 0.28^{c}
S+F+FR	3.87 ± 0.01^{e}	5.84 ± 0.24^{a}	15.41 ± 0.23^{c}	27.41 ± 0.44^{c}
V+F+FR	3.54 ± 0.01^{f}	5.85 ± 0.23^{a}	15.46 ± 0.18^{c}	27.36 ± 0.13^{c}
S+V+F+FR	3.55 ± 0.02^{f}	5.82 ± 0.26^{a}	15.38 ± 0.09^{c}	27.00 ± 0.12^{c}
CT	5.75 ± 0.02^{a}	6.47 ± 0.13^{a}	18.80 ± 0.28^{a}	35.35 ± 0.45^{a}
F (9, 27)	21.88	1.61	42.21	91.34
p-value	<0.0001	0.1631^{ns}	<0.0001	<0.0001

[1]**S** = Seedling stage, **V** = Mid-vegetative stage, **F** = Mid-flowering stage, **FR** = Mid-fruiting stage, **CT** = Control; [2]Means are values of four replications,Means (±SE) followed by the same superscript(s) letter within a column are not significantly different using Student-Newman Keul's (SNK) test ($p \leq 0.05$), [ns] Not significantly different ($p > 0.05$).

Table 3-Effect of 0.5 % cyper-diforce® applications at various stages of growth on abundance (mean±SE) of major fruit-feeding insects of Watermelon

Plant growth stage[1]	**Early-sown[2]**	**Late-sown[2]**	
	B. cucurbitae **larvae/fruit[z]**	***B. cucurbitae*** **larvae/fruit[3]**	***H. armigera*** **larvae/5m length of row**
2016 cropping season			
S	16.37 ± 0.11^{b}	5.32 ± 0.04^{b}	9.91 ± 0.02^{b}
V	14.35 ± 0.22^{c}	4.66 ± 0.08^{c}	9.10 ± 0.03^{c}
F	14.59 ± 0.22^{c}	4.57 ± 0.08^{c}	8.18 ± 0.08^{d}
FR	16.26 ± 0.09^{b}	5.32 ± 0.03^{b}	8.08 ± 0.01^{d}
S+V+F	7.08 ± 0.02^{d}	1.88 ± 0.01^{d}	5.90 ± 0.02^{e}
S+V+FR	7.28 ± 0.18^{d}	1.96 ± 0.07^{d}	5.94 ± 0.02^{e}
S+F+FR	7.31 ± 0.26^{d}	1.97 ± 0.14^{d}	5.18 ± 0.06^{f}

V+F+FR	7.22±0.28^{d}		1.93±0.13^{d}	5.25±0.07^{f}
S+V+F+FR	4.14±0.34^{e}		0.69±0.08^{e}	5.12±0.05^{f}
CT	18.12±0.29^{a}		5.97±0.11^{a}	10.50±0.16^{a}
F (9, 27)	31.16		46.87	11.18
p-value	<0.0001		<0.0001	<0.0001
2017 cropping season				
S	14.94±0.12^{b}		8.43±0.04^{b}	11.82±0.04^{b}
V	12.85±0.23^{c}		7.66±0.18^{c}	10.11±0.05^{d}
F	13.09±0.33^{c}		7.75±0.09^{c}	11.02±0.10^{c}
FR	14.94±0.10^{b}		8.42±0.04^{b}	10.01±0.03^{d}
S+V+F	5.28±0.02^{d}		4.92±0.01^{d}	7.85±0.02^{e}
S+V+FR	5.49±0.19^{d}		4.97±0.07^{d}	7.89±0.03^{e}
S+F+FR	5.52±0.27^{d}		5.01±0.10^{d}	7.13±0.07^{f}
V+F+FR	5.42±0.29^{d}		5.00±0.10^{d}	7.21±0.08^{f}
S+V+F+FR	2.22±0.36^{e}		3.71±0.09^{e}	7.08±0.06^{f}
CT	16.76±0.32^{a}		9.09±0.01^{a}	12.40±0.14^{a}
F (9, 27)	31.44		46.16	91.87
p-value	<0.0001		<0.0001	<0.0001

[1]**S** = Seedling stage; **V** = Mid-vegetative stage; **F** = Mid-flowering stage; **FR** = Mid-fruiting stage; **CT** = Control; Means (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman Keul's (SNK) test ($p \leq 0.05$); [3]Number of fruit fly (*B. cucurbitae*) larvae per fruit = Number of infested fruits x Number of larvae per infested fruit ÷ Number of fruits per plot.

Table 4a-Effect of 0.5 % cyper-diforce® applications at various stages of growth on abundance (mean±SE) of major beneficial arthropods in 2016

Plant growth stage[1]	***Apis mellifera***	**Predatory ants[2]**	**Spiders[3]**
Early-sown			
S	3.52±0.16^{a}	2.43±0.03^{b}	1.20±0.04^{b}
V	2.89±0.07^{a}	2.41±0.03^{b}	1.19±0.03^{b}
F	2.89±0.06^{a}	2.42±0.02^{b}	1.20±0.03^{b}
FR	3.58±0.19^{a}	2.40±0.05^{b}	1.11±0.05^{b}
S+V+F	1.20±0.03^{b}	1.56±0.02^{c}	0.56±0.02^{c}
S+V+FR	3.00±0.05^{a}	1.58±0.02^{c}	0.57±0.02^{c}
S+F+FR	1.10±0.01^{b}	1.56±0.01^{c}	0.58±0.03^{c}
V+F+FR	1.33±0.06^{b}	1.57±0.01^{c}	0.61±0.04^{c}
S+V+F+FR	1.27±0.10^{b}	1.05±0.06^{d}	0.35±0.02^{d}
CT	3.23±0.45^{a}	3.28±0.04^{a}	1.71±0.02^{a}
F (9, 27)	43.44	37.88	19.85
p-value	<0.0001	<0.0001	<0.0001
Late-sown			
S	4.15±0.19^{a}	2.64±0.04^{b}	1.19±0.04^{b}
V	3.41±0.09^{a}	2.61±0.04^{b}	1.18±0.03^{b}
F	3.42±0.07^{a}	2.63±0.02^{b}	1.19±0.03^{b}
FR	4.23±0.22^{a}	2.60±0.06^{b}	1.07±0.05^{b}

S+V+F	1.42±0.04^{b}	1.69±0.03^{c}	0.55±0.02^{c}
S+V+FR	3.55±0.06^{a}	1.70±0.02^{c}	0.56±0.02^{c}
S+F+FR	1.31±0.01^{b}	1.69±0.01^{c}	0.58±0.03^{c}
V+F+FR	1.57±0.07^{b}	1.70±0.01^{c}	0.60±0.04^{c}
S+V+F+FR	1.51±0.12^{b}	1.14±0.06^{d}	0.35±0.02^{d}
CT	3.80±0.54^{a}	3.55±0.04^{a}	1.69±0.02^{a}
F (9, 27)	43.05	37.61	18.90
p-value	<0.0001	<0.0001	<0.0001

[1]**S** = Seedling stage; **V** = Mid-vegetative stage; **F** = Mid-flowering stage; **FR** = Mid-fruiting stage; **CT** = Control; Means are values of four replications;Means (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman Keul's (SNK) test ($p \leq 0.05$); [2]*Camponotus* sp., *Crematogaster* sp., *Pheidole* sp.; [3]Spider species were treated as a single population/taxon.

Table 4b-Effect of 0.5 % cyper-diforce® applications at various stages of growth on abundance (mean±SE) of major beneficial arthropods in 2017

Plant growth stage[1]	*Apis mellifera*	Predatory ants[2]	Spiders[3]
Early-sown			
S	4.22±0.18^{a}	1.82±0.02^{b}	1.21±0.03^{b}
V	3.48±0.11^{a}	1.74±0.01^{c}	1.11±0.04^{b}
F	3.47±0.08^{a}	1.74±0.01^{c}	1.20±0.01^{b}
FR	4.31±0.20^{a}	1.80±0.04^{bc}	1.17±0.01^{b}
S+V+F	1.45±0.05^{b}	0.89±0.01^{e}	0.42±0.03^{c}
S+V+FR	3.61±0.06^{a}	1.06±0.01^{d}	0.33±0.04^{c}
S+F+FR	1.34±0.02^{b}	0.87±0.02^{e}	0.29±0.03^{c}
V+F+FR	1.61±0.06^{b}	0.89±0.01^{e}	0.28±0.03^{c}
S+V+F+FR	1.54±0.12^{b}	0.66±0.02^{f}	0.29±0.03^{c}
CT	3.89±0.52^{a}	2.39±0.03^{a}	1.68±0.20^{a}
F (9, 27)	46.19	12.18	80.16
p-value	<0.0001	<0.0001	<0.0001
Late-sown			
S	4.54±0.22^{a}	2.71±0.04^{b}	1.48±0.01^{b}
V	3.74±0.11^{a}	2.69±0.04^{b}	1.55±0.05^{b}
F	3.74±0.07^{a}	2.71±0.02^{b}	1.52±0.04^{b}
FR	4.63±0.25^{a}	2.67±0.06^{b}	1.53±0.03^{b}
S+V+F	1.56±0.04^{b}	1.74±0.02^{c}	0.54±0.02^{c}
S+V+FR	3.88±0.07^{a}	1.76±0.01^{c}	0.51±0.02^{c}
S+F+FR	1.50±0.03^{b}	1.75±0.01^{c}	0.55±0.03^{c}
V+F+FR	1.73±0.09^{b}	1.76±0.01^{c}	0.53±0.03^{c}
S+V+F+FR	1.66±0.15^{b}	1.19±0.07^{c}	0.39±0.02^{d}
CT	4.16±0.59^{a}	3.64±0.03^{a}	2.27±0.09^{a}
F (9, 27)	40.00	40.78	32.21
p-value	<0.0001	<0.0001	<0.0001

[1]**S** = Seedling stage; **V** = Mid-vegetative stage; **F** = Mid-flowering stage; **FR** = Mid-fruiting stage; **CT** = Control; Means are values of four replications;Means (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman Keul's (SNK) test ($p \leq 0.05$); [2]*Camponotus* sp., *Crematogaster* sp., *Pheidole* sp.; [3]Spider species were treated as a single population/taxon.

Table 5-Effect of 0.5 % cyper-diforce® applications at various stages of growth on leaf injury of watermelon

Plant growth stage[1]	Mean proportion of leaves injured (%)			Mean severity of leaf injury (%)	
	Early-sown[2]	Late-sown[2]		Early-sown[2]	Late-sown[2]
2016 cropping season					
S	$54.17±7.20^{a}$	$18.07±4.57^{ab}$		$37.55±3.12^{a}$	$12.36±0.49^{a}$
V	$57.99±4.44^{a}$	$22.92±4.86^{ab}$		$37.98±4.95^{a}$	$14.06±0.52^{a}$
F	$68.40±3.32^{a}$	$24.31±5.93^{ab}$		$38.06±3.57^{a}$	$15.54±2.46^{a}$
FR	$68.75±5.70^{a}$	$25.69±2.08^{a}$		$43.07±2.71^{a}$	$15.64±0.61^{a}$
S+V+F	$13.20±5.68^{b}$	$8.35±2.95^{b}$		$4.29±1.31^{b}$	$4.13±1.56^{b}$
S+V+FR	$15.29±4.91^{b}$	$10.44±2.70^{ab}$		$4.79±1.77^{b}$	$4.68±0.86^{b}$
S+F+FR	$21.53±3.23^{b}$	$10.78±2.80^{ab}$		$6.32±0.86^{b}$	$5.26±0.61^{b}$
V+F+FR	$28.14±9.69^{b}$	$15.66±1.05^{ab}$		$10.95±2.86^{b}$	$5.63±0.48^{b}$
S+V+F+FR	$11.48±3.13^{b}$	$7.30±3.13^{b}$		$4.18±1.68^{b}$	$3.73±1.55^{b}$
CT	$70.12±5.25^{a}$	$27.08±4.59^{a}$		$44.31±1.00^{a}$	$15.73±1.38^{a}$
F (9, 27)	16.15	3.95		43.56	15.81
p-value	<0.0001	0.0027		<0.0001	<0.0001
2017 cropping season					
S	$57.78±6.85^{a}$	$22.22±3.51^{abc}$		$41.58±3.50^{a}$	$13.69±0.55^{a}$
V	$62.77±3.88^{a}$	$26.10±2.78^{ab}$		$42.12±5.51^{a}$	$15.65±0.58^{a}$
F	$72.22±2.94^{a}$	$28.33±4.39^{a}$		$42.25±3.96^{a}$	$17.26±2.70^{a}$
FR	$73.33±4.80^{a}$	$28.88±0.08^{a}$		$47.76±3.00^{a}$	$17.37±0.63^{a}$
S+V+F	$17.22±6.87^{b}$	$12.78±2.78^{c}$		$4.74±1.44^{b}$	$4.59±1.74^{b}$
S+V+FR	$19.44±3.44^{b}$	$15.00±1.90^{bc}$		$5.30±1.96^{b}$	$5.22±0.95^{b}$
S+F+FR	$25.00±1.40^{b}$	$15.00±1.90^{bc}$		$7.00±0.95^{b}$	$5.86±0.67^{b}$
V+F+FR	$31.66±8.18^{b}$	$20.56±0.55^{abc}$		$12.18±3.18^{b}$	$6.30±0.54^{b}$
S+V+F+FR	$16.11±2.99^{b}$	$11.67±3.19^{c}$		$4.62±1.86^{b}$	$4.14±1.73^{b}$
CT	$75.00±4.10^{a}$	$30.55±3.19^{a}$		$49.94±1.11^{a}$	$17.40±1.46^{a}$
F (9, 27)	21.12	6.69		43.44	16.10
p-value	<0.0001	<0.0001		<0.0001	<0.0001

[1]**S** = Seedling stage; **V** = Mid-vegetative stage; **F** = Mid-flowering stage; **FR** = Mid-fruiting stage; **CT** = Control; [2]Means are values of four replications; Means (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman Keul's (SNK) test ($p \leq 0.05$).

Table 6-Effect of application of 0.5 % cyper-diforce® at different stages of growth on vine length and leaf production of watermelon

Plant growth stage[1]	Main vine length (cm) at 9WAP			Number of leaves/plant at 9WAP	
	Early-sown[2]	Late-sown[2]		Early-sown[2]	Late-sown[2]
2016 cropping season					
S	$126.45±0.45^{e}$	$145.21±0.99^{e}$		$42.98±0.18^{e}$	$65.99±0.37^{d}$
V	$147.40±0.59^{d}$	$167.91±1.18^{d}$		$49.58±0.39^{d}$	$73.05±0.42^{c}$
F	$126.45±0.61^{e}$	$144.35±0.50^{e}$		$42.93±0.14^{e}$	$63.55±0.24^{d}$
FR	$121.93±0.39^{f}$	$139.58±1.54^{f}$		$40.70±0.25^{e}$	$66.03±0.42^{d}$
S+V+F	$276.75±0.54^{a}$	$301.85±1.22^{b}$		$231.40±2.47^{b}$	$267.04±3.34^{ab}$
S+V+FR	$277.45±0.30^{a}$	$300.59±1.21^{b}$		$234.08±0.52^{a}$	$270.46±0.47^{a}$
S+F+FR	$270.60±0.98^{c}$	$297.05±0.56^{c}$		$227.43±1.31^{c}$	$263.33±1.03^{b}$
V+F+FR	$272.23±0.40^{b}$	$294.87±0.79^{c}$		$227.30±0.26^{c}$	$262.80±0.82^{b}$
S+V+F+FR	$278.35±0.36^{a}$	$307.11±0.95^{a}$		$234.88±0.08^{a}$	$270.98±1.29^{a}$

CT	119.68±0.66^{g}	137.30±8.21^{f}		39.68±0.25^{e}	62.65±0.38^{d}
F (9, 27)	21.30	70.19		12.00	71.72
p-value	<0.0001	<0.0001		<0.0001	<0.0001
2017 cropping season					
S	140.16±0.47^{c}	138.95±0.90^{e}		46.80±0.20^{d}	53.52±0.45^{d}
V	120.98±0.65^{d}	159.91±1.07^{d}		40.50±0.39^{e}	59.87±0.45^{c}
F	121.02±0.53^{d}	138.10±0.46^{e}		40.43±0.20^{e}	53.32±0.20^{d}
FR	116.87±0.35^{e}	133.76±1.40^{f}		38.48±0.31^{e}	51.00±0.42^{d}
S+V+F	257.55±0.44^{a}	281.22±1.11^{b}		217.20±2.24^{b}	242.39±3.16^{ab}
S+V+FR	258.19±0.23^{a}	280.08±1.10^{b}		220.70±0.59^{a}	245.43±0.41^{a}
S+F+FR	251.96±0.81^{b}	274.88±0.51^{c}		213.83±1.31^{c}	238.29±1.08^{b}
V+F+FR	253.22±0.39^{b}	276.86±0.72^{c}		213.79±0.43^{c}	238.55±0.79^{b}
S+V+F+FR	258.85±0.30^{a}	286.01±0.86^{a}		220.03±0.12^{a}	246.00±1.24^{a}
CT	115.01±0.49^{f}	131.68±0.67^{f}		37.33±0.26^{e}	50.05±0.28^{d}
F (9, 27)	21.8	70.32		11.20	70.23
p-value	<0.0001	<0.0001		<0.0001	<0.0001

[1]**S** = Seedling stage; **V** = Mid-vegetative stage; **F** = Mid-flowering stage; **FR** = Mid-fruiting stage; **CT** = Control; [2]Means are values of four replications; Means (±SE) followed by the same superscript letter(s) within a column are not significantly different using Student-Newman Keul's (SNK) test ($p \leq 0.05$); WAP = Weeks after planting.

Table 7a-Economic analysis of application of 0.5 % cyper-diforce® at different growth stages of watermelon in 2016

Plant growth stage[1]	**Marketable yield (kgha^{-1})**	**Cost of application of insecticide (US\$ha^{-1})[2]**	**Gross income (US\$ha^{-1})[3]**	**Profit (US\$ha^{-1})**	**Cost:benefit ratio**
Early-sown					
S	1401.40^{d}	37.91	168.17	130.26	1:2.55
V	1639.13^{d}	37.91	196.70	158.79	1:3.31
F	3213.03^{d}	56.86	385.56	328.70	1:5.19
FR	2481.76^{d}	56.86	297.81	240.95	1:3.65
S+V+F	24574.89^{b}	132.67	2948.99	2816.32	1:20.98
S+V+FR	39287.28^{a}	132.67	4714.47	4581.80	1:34.28
S+F+FR	19846.28^{bc}	151.62	2381.55	2229.93	1:14.49
V+F+FR	17824.50^{c}	151.62	2138.94	1987.32	1:12.89
S+V+F+FR	37384.50^{a}	189.53	4486.14	4296.61	1:22.49
CT	278.57^{d}	0.00	33.43	33.43	
F (9, 27)	65.32				
p-value	<0.0001				
Late-sown					
S	2630.04^{c}	37.91	315.60	277.69	1:5.15
V	3547.43^{c}	37.91	425.69	387.78	1:8.06
F	6428.96^{c}	56.86	771.48	714.62	1:11.12
FR	4004.74^{c}	56.86	480.57	423.71	1:6.00
S+V+F	30747.09^{b}	132.67	3689.65	3556.98	1:26.19
S+V+FR	48166.70^{a}	132.67	5780.00	5647.33	1:41.95
S+F+FR	27148.33^{b}	151.62	3257.80	3106.18	1:19.94
V+F+FR	24683.91^{b}	151.62	2962.07	2810.45	1:17.99
S+V+F+FR	45808.14^{a}	189.53	5496.98	5307.45	1:27.57
CT	686.06^{c}	0.00	82.33	82.33	
F (9, 27)	75.01				
p-value	<0.0001				

Average United States Dollar (US$) to Naira (₦) exchange rate during the study period = US$279.64 to ₦1; [1]**S** = Seedling stage (2 sprays); **V** = Mid-vegetative stage (2 sprays); **F** = Mid-flowering stage (3 sprays); **FR** = Mid-fruiting stage (3 sprays); **CT** = Control (no spray); [2]Cost of labour for spraying (US$3.58/manday) and purchase of pesticide and water; [3]Analysis was based on US$0.12 per kg which was the prevailing selling price at farm gate in Wukari, Taraba State.

Table 7 b-Economic analysis of application of 0.5 % cyper-diforce® at different growth stages of watermelon in 2017

Plant growth stage[1]	Marketable yield (kgha^{-1})	Cost of application of insecticide (US$ha^{-1})[2]	Gross income (US$ha^{-1})[3]	Profit (US$ha^{-1})	Cost:benefit ratio
Early-sown					
S	1113.27[c]	48.63	144.73	96.10	1:1.37
V	1360.11[c]	48.63	176.81	128.18	1:2.03
F	2966.15[c]	72.95	385.60	312.65	1:3.88
FR	2241.32[c]	72.95	291.37	218.42	1:2.59
S+V+F	23564.15[b]	170.22	3063.34	2893.12	1:16.82
S+V+FR	37977.64[a]	170.22	4937.09	4766.87	1:27.83
S+F+FR	18984.46[b]	194.54	2467.98	2273.44	1:11.53
V+F+FR	16917.19[b]	194.54	2199.24	2004.70	1:10.15
S+V+F+FR	36279.25[a]	243.17	4716.30	4473.13	1:18.27
CT	227.96[c]	0.00	29.63	29.63	
F (9, 27)	54.95				
p-value	<0.0001				
Late-sown					
S	2261.19[c]	48.63	293.95	245.32	1:3.35
V	3040.97[c]	48.63	395.33	346.70	1:5.44
F	5989.33[c]	72.95	778.61	705.66	1:8.55
FR	3691.70[c]	72.95	479.92	406.97	1:4.45
S+V+F	29456.54[b]	170.22	3829.35	3659.13	1:21.01
S+V+FR	46291.09[a]	170.22	6017.84	5847.62	1:33.87
S+F+FR	25916.70[b]	194.54	3369.17	3174.63	1:15.90
V+F+FR	23463.22[b]	194.54	3050.22	2855.68	1:14.25
S+V+F+FR	44236.20[a]	243.17	5750.71	5507.54	1:22.31
CT	632.69[c]	0.00	82.25	82.25	
F (9, 27)	65.38				
p-value	<0.0001				

Average United States Dollar (US$) to Naira (₦) exchange rate during the study period = US$279.64 to ₦1; [1]**S** = Seedling stage (2 sprays); **V** = Mid-vegetative stage (2 sprays); **F** = Mid-flowering stage (3 sprays); **FR** = Mid-fruiting stage (3 sprays); **CT** = Control (no spray); [2]Cost of labour for spraying (US$5.36/manday) and purchase of pesticide and water; [3]Analysis was based on US$0.13 per kg which was the prevailing selling price at farm gate in Wukari, Taraba State.

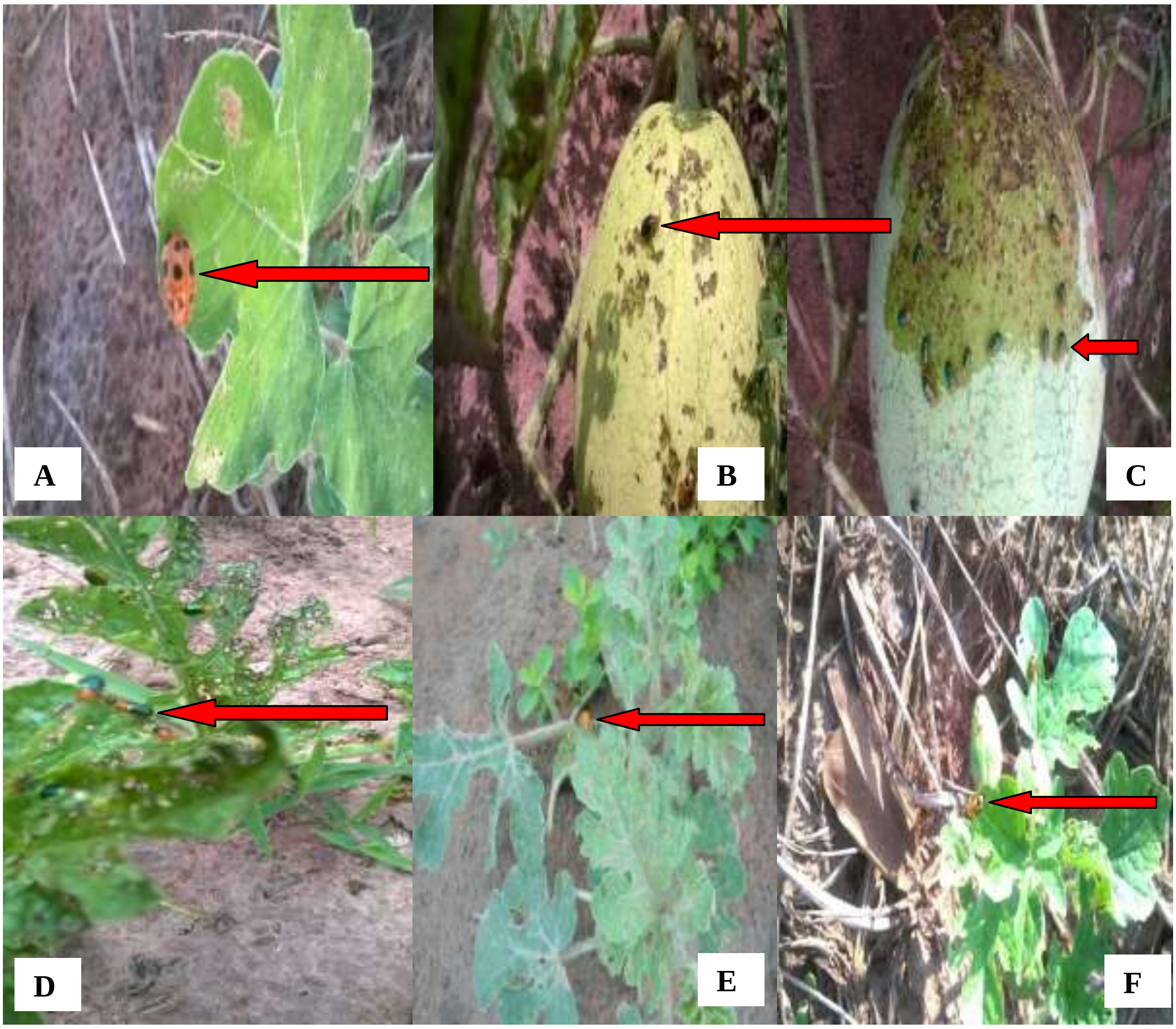

Figure 1-Leaf-feeding beetles infesting watermelon plant; **A.***Epilachna chrysomelina*; **B.***Asbecesta nigripennis*; **C, D.***Monolepta nigeriae;* **E.***Aulacophora africana*; **F.***Asbecesta transversa*

Figure 2-A.*Aphis gossypii* on abaxial surfce of watermelon leaf; **B.** Leaf curling caused by sap-sucking insects

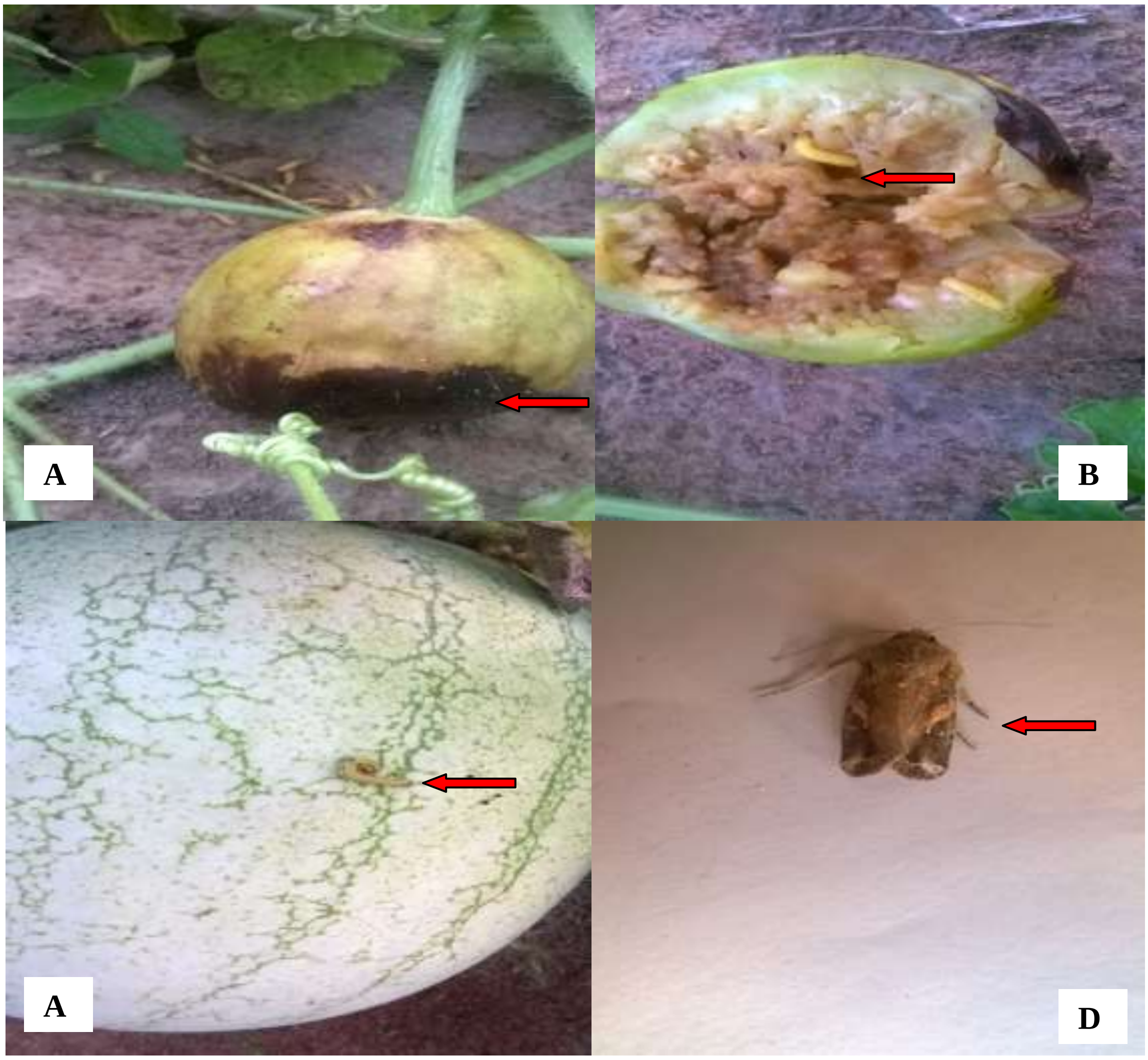

Figure 3-A. Young fruit infested by *B. cucurbitae*; **B.***Bactrocera cucurbitae* larvae within infested fruit; **C.** *Helicoverpa armigera* infested fruit; **D.***Helicoverpa armigera* adult (reared from larva)

Discussion

The results in this study indicate that effective protection against insect pests of watermelon is necessary. Leaf-eating beetles dominated by *A. africana, A. nigripennis, A. transversa, M. nigeriae* and *E. chrysomelina* were critical to watermelon production across its growth stages in the study area. This agrees with previous reports that listed leaf-eating beetles alongside aphids, whiteflies and fruit flies as key pests of watermelon in Nigeria [12, 13]. It has been shown that leaf injury has serious implication on the quantity and quality of fruits produced by watermelon plant as the leaves play a key role in synthesizing sugar and in accumulating water in the fruit [14].

The significant reduction in the population of leaf-eating beetles and consequently the proportion and severity of leaf injury due to insecticide treatments highlights the efficacy of the insecticide used. The significantly higher infestation of leaf-eating beetles on the early-sown crop vis-à-vis late-sown may be as a result of migration from alternative hosts (particularly, *Cucumeropsis mannii* Naudin which is largely early-sown in the study area) on nearby fields. That watermelon is a preferred host to leaf-eating beetles in comparison to *C. mannii* has been shown in field studies by [15]. The preference of the chrysomelid beetles to watermelon over and above the afore-mentioned crop is attributable to among other factors, higher amount of cucurbitacin [16].

It has been reported that chrysomelid beetles are most attractive to cucurbits during the 1st two to three weeks (corresponding with the seedling and vegetative stages of growth) after emergence [17]. The ability of leaf-eating beetles to weaken seedlings and/or bring about loss of plant stands resulting to yield loss has also been shown by [18]. The results obtained in this study corroborate these findings thus highlighting the need to commence protection early in the season to prevent loss. That herbivory directly affects the reproductive performance of plants was reported by [19]. They showed that removal of plant tissue by herbivory and consequently allocation of resources to plant defence reduces the number of resources which would have been allocated to reproduction.

Chemical control of *A. gossypii*, preferentially infesting abaxial leaf surface has been reported to be difficult [20]. The inability of the applied insecticide (cyper-diforce®) to effectively control the insect in all the trials conducted may be an indication of resistance development as had been earlier reported by [21]. A comparatively higher density of *A. gossypii* and *B. tabaci* in the late-sown crop may be attributed to favorable weather conditions most especially a relatively lower rainfall as reported by [22].

Bactrocera cucurbitae infestation was significantly suppressed by the applied insecticide and incidence was consistently higher in the early-sown crop as was reported by [13]. Throughout the 2 years research, the occurrence of *H. armigera* in the early-season crop was sporadic. The early-season crop growth period was marked by increasing frequency and intensity of rainfall which might not have been favourable for *H. armigera* colonization and population growth as alternating wet and dry spells have been reported to favour outbreak [23].

Hitherto, early- and late-cropping seasons were clearly defined and designated in the study area (Early-planting commenced from March to April, and late-planting commenced from August to early September). In recent times, however, climate change with its characteristic unpredictable onset of rainfall, unexpected dry spell following early rain, and early cessation of rain, has forced alteration in time of sowing. Therefore, there is need for an extensive study (that could span between 5 to 10 years) of the influence of weather on population dynamics of the major pests of watermelon in order to aid pest forecasting. This is because climate change has been reported to alter the behavior of insects and their hosts [24] giving rise to inconsistent insect – weather parameter relationships [25].

The number of insecticide sprays tested was from two to ten/season. Plots treated at F and FR had higher pest damage and lower survival. Among the treatments, plots treated at S+V+FR consistently had higher marketable fruit yield over those sprayed throughout the growth period (S+V+F+FR). This can be linked to a significantly reduced level of insect damage coupled with higher bee activity. This highlights the need to minimize and/or proper time insecticide application during flowering period to maximize bee activities as recommended by [26].

It has been shown that watermelon flowers are viable for only one day and that, each pistillate watermelon flower requires a minimum of between 6 – 8 bee (*A. mellifera*) visits to successfully set fruit as it needs 500 to 1000 pollen grains to be effectively fertilized [27]. Research has also shown that over 20 visits by honeybees may be needed for full set and full size. Fruits become misshapen and/or undersized when there is insufficient pollination [28].

That the insecticide (cyper-diforce®) provided good protection against pest infestation and damage is seen by a 3.6 X to 165.1 X increase in marketable fruit yield. It was observed that plots treated at S and V had higher fruit yield than those sprayed at F and FR. This may be attributed to better plant stand establishment and survival in the former. Farmers (especially, commercial farmers) are most likely to accept a profitable pest management recommendation. The economic analysis reveals a very high economic benefit (US\$4581.80ha^{-1} to US\$5847.62ha^{-1}) in spraying watermelon at S+V+FR (7 sprays). In the current trials, the maximum cost-benefit ratio recorded was 1:34.28. This high cost-benefit ratio buttresses previous reports that show that watermelon has a high return on investment [29].

Conclusion

Overall, plots with higher frequency of insecticide application had lower pest infestation (frequency and intensity) which resulted in higher yields. Spraying at seedling through to vegetative stage was critical as the leaf-eating beetles; if not checked at the aforementioned stages could cause severe crop loss. Spraying at S+V+FR gave the highest marketable yield. Addition of spray at flowering stage to the aforementioned regime did not enhance yield. The monetary benefit and subsequently, the cost:benefit ratio were highest in plots sprayed at S+V+FR stages.

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