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Research Article

Efficiency and economic viability of neem seed oil emulsion and cyper-diforce® insecticides in watermelon production within the Nigerian Southern Guinea Savanna zone

Okrikata Emmanuel[1*], Ogunwolu Emmanuel Oludele[2] and Ukwela Monday Unwabunne[2]

1. Department of Biological Sciences, Federal University Wukari, Taraba State, Nigeria.
2. Department of Crop and Environmental Protection, Federal University of Agriculture, Makurdi, Benue State, Nigeria.

Abstract: The efficiency of neem based insecticides have been assessed by many studies however, there is scanty information on the cost:benefit ratio of their use vis-a-viz synthetics, particularly, in watermelon production. In this study, thirty-six 5 m long x 8 m wide plots were arranged in Randomized Complete Block Design in 4 replications of weekly spray of; 0.5% Cyper-diforce® (CD); 1, 3 and 5% Neem Oil Emulsion (NOE); 0.25% CD + 1, 3 and 5% NOE; 1% soap solution and, Control (unsprayed plots). Arthropods were sampled on 5 m length of row using Suction Sampler and Yellow Sticky Board. Severity of leaf damage and aphid colony size was also assessed. At harvest, marketable fruits were weighed and used to compute cost-benefit ratio. The prevalent pests were five species of leaf-beetles, *Aphis gossypii* Glover, *Bemisia tabaci* (Gennadius), *Bactrocera cucurbitae* (Coquillett) and *Helicoverpa armigera* (Hubner). The beneficials included; *Apis mellifera* L., *Cardiochiles niger* Szépligeti and *Cheilomenes sulphurea* (Olivier). The 0.5% CD was ineffective against Aphids but 3 and 5% NOE were. Overall, insecticide treatments reduced infestation by 2.9-95.3%. Though, combination of 0.25% CD with NOE treatments suppressed pest infestation relative to sole neem oil treatments, leaf injury and yields were statistically comparable. Sole NOE treatments were observed not to significantly suppress populations of beneficials when compared to 0.25% CD or their combinations. 0.25% CD + 5% NOE consistently gave the highest yield/season (39192-44642 kgha^{-1}). Monetary benefits exceeded US$3724 ha^{-1}. The insignificant differences in yield among the insecticide treatments showcased neem's potential in managing watermelon pests. The ineffectiveness of Cyper-diforce® against *A. gossypii* suggests resistance development.

Keywords: Arthropods, Cost-benefit analysis, Cyper-diforce®, Neem oil emulsion

Introduction

Each year, about 130,000 metric tons of pesticides have been reported to be applied in Nigeria (Ikemefuna, 1998; Ndubuaku and Asogwa, 2006). It has also been observed that though the chemical industry is aware of the environmental effect of the misuse of pesticides, they are not giving due regards to promotion of ecologically sound practices that will enhance sustainability in agricultural production (Ndubuaku and Asogwa, 2006). The fact that the agrochemical business in Nigeria is

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* **Corresponding author**, e-mail: eokrikata@gmail.com
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not adequately coordinated has led to wrong use of pesticides, counterfeiting and faking, recycling of old stocks and lack of disposal facilities (Oduwole, 2001). Besides numerous environmental related issues, health problems associated with pesticide toxicity such as cancers, congenital malformations, neurological disorders, infertility, blood dyscrasias, impotence, immunological disorders, liver and kidney damage, skin alterations and worsening of existing health conditions have resulted to a shift from synthetic pesticides to non-synthetic pesticides all over the world (Jobling *et al.,* 1995; Ogah *et al.,* 2011). Pesticide residues in fruits and vegetables and, in watermelon in particular beyond the allowable limits due to improper/faulty use of synthetic pesticides have severally been reported in Nigeria (Akan *et al*., 2015; Mahmud *et al*., 2015; Okrikata and Ogunwolu, 2017; Omoyajowo *et al*., 2018). There is obviously a strong request for reduced synthetic insecticide use which is an important aspect of Integrated Pest Management (IPM).

The increasing demand for food safety has stimulated research on plant based pesticides, foremost of which is neem *Azadirachta indica* A. Juss. Neem has a long history of use as a biopesticide and has been reported to control over 500 pests which include insects, mites, ticks and nematodes (Vethanayagam and Rajendran, 2010; Lokanadhan *et al*., 2012). It is nearly non-toxic to birds, fishes, bees and wildlife. Studies have also shown that it has no cancer or other disease causing effects hence, safe for use when applied properly (Vethanayagam and Rajendran; 2010; Gahukar, 2014). Owing to its environmental friendliness, neem is now recognized as a natural product which has much to offer in solving global agricultural, environmental and public health concerns (Lokanadhan *et al.,* 2012).

Neem seed is reported to contain the bulk of the active ingredients in neem and the oil extracted from the seed is used as insecticides for different crops and works systemically in many plants (Abdelrahim Satti *et al.,* 2013). Diver, 2008 reported that a neem oil based formulation reduced cucumber beetle populations by 50-70% overnight. Neem oil is also reported to have antifeedant, growth inhibition and oviposition deterrent modes of action against a wide ray of insect pests (Ahmed *et al.,* 1995). Neem oil ranging from 1-5% has been recommended for the management of a broad spectrum of insect pests and diseases of vegetables including (Isman, 2008; Lokanadhan *et al*., 2012; TNAU, 2014). Neem oil has also been reported to be used in combination with synthetic pesticides for better performance and for both economic and environmental reasons (Anis *et al.,* 2010).

Watermelon, *Citrulus lanatus* Thunb., is highly vulnerable to insect pest pressure with 30-100% yield losses documented (Fomekong *et al.,* 2008; Shagufta, 2012). Producers in the study area largely rely on synthetic insecticide for protection with residues above allowable limits reported aside many other environmental and health challenges associated with their usage (Okrikata and Ogunwolu, 2017; Omoyajowo *et al*., 2018). Despite the enormous quantity of neem trees in Nigeria and more specifically, within the Southern Guinea Savanna Zone of Nigeria, available literature shows no documented information on the use of Neem Seed Oil solely or in combination with synthetic insecticides in the management of insect pests of watermelon in Nigeria neither are there information on their economic viability vis-à-vis synthetic insecticides. This study is therefore designed to compare the efficiency and compatibility of Neem Seed Oil and a recommended synthetic insecticide against the insect pests of watermelon and their natural enemies and to quantify the costs and benefits of the control measures used.

Materials and Methods

The Research was carried out in a 0.20 ha ploughed and harrowed land at the Research Farm of Federal University Wukari, Nigeria (N7°50’37”, E9°46’31” and 187m altitude) in 2016 and 2017 early- and late-cropping seasons (sowing dates: May 14th and August 23rd in 2016 and May 10th and August 15th in 2017).

The area is characterized by warm tropical climate with an average annual temperature of 26.8°C and has a well defined rainy season which commences in April and ends in October with peaks in June and September (Okrikata and Yusuf, 2016).

Watermelon (var. Kaolack) was sown on thirty-six 5 m long x 8 m wide plots. The 4 replicated treatments laid in randomized complete block design were 0.5% Cyper-diforce® (Jubaili Agrotec Ltd.), 1, 3, 5% Neem Oil Emulsion; 0.25% Cyper-diforce® + 1, 3 and 5% Neem Oil Emulsion (Olmacen Organic); 1% liquid soap solution (PZ Cussons Nig. Plc.) and control (untreated). The Neem Oil Emulsions were prepared following the method described by Ukeh *et al*. (2007). There were 10 sprays per season at weekly intervals following the farmers' synthetic insecticide application practice in the study area. A 15 litre, Knapsack sprayer calibrated at 200 L/ha spray output was used for insecticide application. Mancozeb 80% WP. (Zeb-care®), a preventive, contact fungicide was applied at the rate of 2kg/ha at the vegetative, flowering and fruiting stages. Recommended cultural management practices were adopted for crop management.

Arthropod sampling

Arthropod sampling commenced 2 weeks after planting (WAP) and proceeded at weekly intervals until fruit maturity. Collections were made between 1600 and 1800h using a motorized, shoulder mounted suction sampler (Burkard Scientific Ltd., Uxbridge, UK.) with a 10 cm diameter inlet cone which was swept through the middle row at an approximate walking speed of 1m/sec. However, *Bemisia tabaci* (Gennadius) was sampled using 15cm x 15cm yellow sticky board waved through the middle row on shaking the plants as described by Anaso, 1999 while, density of *Aphis gossypii* Glover was assessed on 12 randomly selected leaves using a visual scale of 0-9 as described by Asante *et al*. (2001) and Egbo (2011). To ensure effective sampling of pollinators (which are active in the mornings), collections were made between 0700 h and 0900 h during the flowering stage of the crop.

Assessment of leaf injury and growth parameters

At 3, 6 and 9 WAP, the proportion of leaves injured was computed and presented as mean leaf injury (%). Similarly, the severity of injury was computed on a scale of 0-4 as described by Trusca *et al.* (2013). The individual scores obtained were converted and presented as mean attack severity (%) using the equation:

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 (Okrikata and Anaso, 2008).

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

Data analysis

Count data were transformed to $\sqrt{x} + 0.5$ while data in percentages transformed to arcsine before variance analysis (one way). 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 (SAS Institute Inc., 2009).

Economic analysis

The economic viability of the treatments was assessed by determining their cost:benefit ratio. The total seasonal crop protection expenses were calculated by multiplying expenses per spray by the total number of sprays/season. 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). Depending on the treatment, the expenses/spray were computed by adding cost of the insecticide, water for spraying insecticide, liquid soap (which was used as the emulsifier for Neem Seed Oil) and labour for spraying insecticide. The labour cost for spraying insecticide per hectare was

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US$3.58/man day in 2016 and US$5.36/man day in 2017 which was the man-day rate for an unskilled labourer in the study area during the study period. For each spray, 2 man days was used. A litre of Cyper-diforce® was US$10.01 in 2016 while that of each of neem seed oil and liquid soap costs US$3.56. In 2017 however, the costs were US$11.80, US$4.11 and US$4.29, respectively. The cost of water for spraying a hectare of land (200 litres of water) was US$ 1.79 for both 2016 and 2017 cropping years.

At harvest, yield/plot were harvested and sorted into marketable and unmarketable categories. This was done twice at ten days interval. The unmarketable fruits were those that were discolored, misshapen, cracked and insect damaged. The income/ha was calculated by multiplying marketable yield/ha in kg by the prevailing farm gate selling price (US$0.12/kg in 2016 and US$0.13/kg in 2017). The benefit/ha was calculated by subtracting the crop protection expenses from the income/ha while, the cost:benefit ratio was calculated by subtracting the benefit of the control treatment from the benefit of each sprayed treatment and the difference divided by the total cost of crop protection for each treatment as described by Amoabeng *et al*. (2014).

Results

Effects of neem oil emulsion and cyper-diforce® on major pest and beneficial arthropods of watermelon

The dominant pests associated with Watermelon in both the early- and late-sown crops across years were *Aulacophora africana*, *Asbecesta nigripennis*, *Monolepta nigeriae*, *Epilachna chrysomelina* (leaf-feeding beetles); *Aphis gossypii*, *Bemisia tabaci* (sap-sucking insects), and *Bactrocera cucurbitae* (a fruit-feeding insect). However, throughout the two years study, occurrence of *Helicoverpa armigera* in the early-season was sporadic. The dominant beneficial arthropods were; *Apis mellifera* (pollinator), *Cardiochiles niger*, *Cheilomenes sulphurea*, Predatory ants (*Camponotus* sp., *Crematogaster* sp. and *Pheidole* sp.) and Spiders (natural enemies).

Data in Tables 1a and b consistently reveal that sprayed crops had significantly ($p < 0.0001$) lower leaf-feeding beetle density than the unsprayed or plots sprayed with 1% emulsifier. Application of 0.25% CD combined with either 1, 3 or 5% NOE resulted in statistically comparable levels of beetle density and were generally more effective than the individual treatments. In Table 2, the results indicate that whereas 0.5% CD and 1% NOE were ineffective against *A. gossypii*, 3 and 5% NOE, 0.25% CD + 1, 3 and 5% NOE were significantly ($p < 0.01$) effective. Results for *B. tabaci* density follows a pattern similar to that of leaf-feeding beetles. While 0.5% CD was largely comparable with 1, 3 and 5% NOE in checking *B. cucurbitae* infestation, combinations of CD with NOE and particularly, 0.25% CD + 5% NOE were most effective (Table 3). A similar trend was observed on *H. armigera* density. Tables 4a and b showed that combinations of CD with NOE largely reduced the suppressive effects of CD on beneficial arthropods.

Effects of neem oil emulsion and cyper-diforce® on leaf injury and growth

Table 5 shows a consistently significant ($p < 0.0001$) and statistically comparable higher proportions and severity of leaf injury in plants on unsprayed plots and those sprayed with 1% emulsifier. While those parameters were statistically at par on plants in all the insecticide treated plots, plots sprayed with the combination treatments recorded lower injury both in proportion and intensity. Table 6 also shows that, combination of 0.25% CD with 5% NOE had significantly ($p < 0.0001$) the longest main vine length and statistically comparable with 0.5% CD in number of leaves during the 2016 and late-sown crop of 2017.

Effects of neem oil emulsion and cyper-diforce® application on return on investment in watermelon production

Table 7a shows that marketable yield of insecticide treatments, though highest on 0.25%

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CD + 5% NOE treated plots were statistically at par on both the early- and late-sown crop of 2016. Also, even though the gross income was consistently highest on 0.25% CD + 5% NOE in the early-sown (US$4844.57ha^{-1}) and late-sown (US$5268.18ha^{-1}) crop, the monetary benefits and return on investment was on 0.5% CD treated plots. Economic analysis of 2017 cropping season follows a trend similar to that of 2016 (Table 7b).

Table 1a Individual and composite effect of Cyper-diforce® and neem oil emulsion on the abundance (Mean ± SE) of major leaf-feeding beetles in watermelon at Wukari in 2016.

Treatment	Number of insects collected/5m length of row[1]				
	Aulacophora africana	*Asbecesta nigripennis*	*Asbecesta transversa*	*Monolepta nigeriae*	*Epilachna chrysomelina*
Early-sown					
0.5% CD[2]	2.23 ± 0.06^{b}	5.02 ± 0.31^{d}	2.26 ± 0.08^{bc}	2.29 ± 0.24^{b}	1.05 ± 0.20^{bc}
1% NOE[3]	2.43 ± 0.08^{b}	8.64 ± 0.25^{b}	2.58 ± 0.15^{b}	2.46 ± 0.07^{b}	1.15 ± 0.03^{b}
3% NOE	2.21 ± 0.09^{b}	8.37 ± 0.41^{b}	2.13 ± 0.03^{c}	2.18 ± 0.16^{b}	0.95 ± 0.03^{bc}
5% NOE	1.56 ± 0.04^{c}	7.17 ± 0.11^{c}	1.72 ± 0.08^{d}	1.92 ± 0.14^{b}	0.77 ± 0.04^{bc}
0.25% CD + 1% NOE	1.04 ± 0.01^{d}	4.66 ± 0.40^{d}	1.05 ± 0.01^{e}	1.36 ± 0.12^{c}	0.77 ± 0.03^{bc}
0.25% CD + 3% NOE	1.04 ± 0.01^{d}	4.54 ± 0.33^{d}	1.04 ± 0.01^{e}	1.13 ± 0.01^{c}	0.65 ± 0.05^{bc}
0.25% CD + 5% NOE	1.05 ± 0.02^{d}	4.29 ± 0.45^{d}	1.06 ± 0.06^{e}	1.16 ± 0.02^{c}	0.54 ± 0.04^{c}
1% Soap solution	17.47 ± 0.10^{a}	30.32 ± 0.47^{a}	22.01 ± 0.63^{a}	24.60 ± 0.97^{a}	7.35 ± 0.51^{a}
Control	17.22 ± 0.67^{a}	30.87 ± 0.30^{a}	22.07 ± 0.71^{a}	24.60 ± 0.68^{a}	6.93 ± 0.68^{a}
F (8, 24)	16.43	47.38	11.46	79.22	16.49
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Late-sown					
0.5% CD[2]	1.01 ± 0.03^{b}	0.50 ± 0.05^{bc}	1.22 ± 0.04^{b}	2.75 ± 0.17^{d}	0.50 ± 0.09^{bc}
1% NOE[3]	1.16 ± 0.07^{b}	0.54 ± 0.02^{b}	1.34 ± 0.04^{b}	4.77 ± 0.12^{b}	0.55 ± 0.01^{b}
3% NOE	0.97 ± 0.01^{b}	0.48 ± 0.03^{bc}	1.21 ± 0.05^{b}	4.60 ± 0.19^{b}	0.45 ± 0.02^{bc}
5% NOE	0.77 ± 0.03^{c}	0.43 ± 0.04^{bcd}	0.85 ± 0.02^{c}	3.87 ± 0.06^{c}	0.37 ± 0.02^{bc}
0.25% CD + 1% NOE	0.48 ± 0.01^{d}	0.29 ± 0.03^{cd}	0.57 ± 0.00^{d}	2.55 ± 0.22^{d}	0.37 ± 0.02^{bc}
0.25% CD + 3% NOE	0.46 ± 0.00^{d}	0.25 ± 0.00^{d}	0.58 ± 0.01^{d}	2.49 ± 0.16^{d}	0.31 ± 0.02^{bc}
0.25% CD + 5% NOE	0.48 ± 0.03^{d}	0.25 ± 0.01^{d}	0.58 ± 0.01^{d}	2.35 ± 0.26^{d}	0.26 ± 0.03^{c}
1% Soap solution	9.80 ± 0.30^{a}	11.00 ± 0.40^{a}	9.57 ± 0.13^{a}	16.59 ± 0.23^{a}	3.06 ± 0.19^{a}
Control	9.97 ± 0.32^{a}	11.07 ± 0.31^{a}	9.51 ± 0.36^{a}	16.98 ± 0.28^{a}	2.89 ± 0.27^{a}
F (8, 24)	15.03	14.45	14.84	50.06	15.88
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[1] 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] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[3] NOE = Neem oil emulsion.

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Table 1b Individual and composite effect of Cyper-diforce® and neem oil emulsion on the abundance (Mean ± SE) of major leaf-feeding beetles in watermelon at Wukari in 2017.

Treatments	Number of insects collected/5m length of row[1]				
	Aulacophora africana	*Asbecesta nigripennis*	*Asbecesta transversa*	*Monolepta nigeriae*	*Epilachna chrysomelina*
Early-sown					
0.5% CD[2]	2.32 ± 0.07^{bc}	2.33 ± 0.26^{b}	2.28 ± 0.06^{b}	5.09 ± 0.33^{d}	1.09 ± 0.20^{bc}
1% NOE[3]	2.64 ± 0.17^{b}	2.50 ± 0.07^{b}	2.48 ± 0.08^{b}	8.75 ± 0.24^{b}	1.20 ± 0.02^{b}
3% NOE	2.19 ± 0.03^{c}	2.22 ± 0.16^{b}	2.25 ± 0.09^{b}	8.47 ± 0.41^{b}	0.99 ± 0.03^{bc}
5% NOE	1.76 ± 0.07^{d}	1.95 ± 0.14^{b}	1.59 ± 0.05^{c}	7.26 ± 0.11^{c}	0.81 ± 0.05^{bc}
0.25% CD + 1% NOE	1.08 ± 0.01^{e}	1.39 ± 0.11^{c}	1.07 ± 0.01^{d}	4.72 ± 0.39^{d}	0.81 ± 0.02^{bc}
0.25% CD + 3% NOE	1.07 ± 0.01^{e}	1.16 ± 0.01^{c}	1.07 ± 0.01^{d}	4.60 ± 0.34^{d}	0.68 ± 0.05^{bc}
0.25% CD + 5% NOE	1.10 ± 0.07^{e}	1.19 ± 0.04^{c}	1.08 ± 0.01^{d}	4.35 ± 0.46^{d}	0.57 ± 0.06^{c}
1% Soap solution	22.40 ± 0.65^{a}	24.85 ± 1.00^{a}	17.74 ± 0.11^{a}	30.64 ± 0.46^{a}	7.55 ± 0.53^{a}
Control	22.44 ± 0.72^{a}	24.86 ± 0.70^{a}	17.50 ± 0.68^{a}	31.19 ± 0.31^{a}	7.11 ± 0.69^{a}
F (8, 24)	16.27	77.23	16.21	47.02	15.89
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Late-sown					
0.5% CD[2]	1.25 ± 0.04^{b}	2.81 ± 0.18^{d}	1.05 ± 0.05^{b}	0.52 ± 0.04^{b}	0.53 ± 0.08^{bc}
1% NOE[3]	1.37 ± 0.04^{b}	4.87 ± 0.14^{b}	1.20 ± 0.06^{b}	0.57 ± 0.02^{b}	0.59 ± 0.03^{b}
3% NOE	1.24 ± 0.05^{b}	4.69 ± 0.21^{b}	1.01 ± 0.03^{b}	0.51 ± 0.02^{b}	0.48 ± 0.04^{bc}
5% NOE	0.87 ± 0.02^{c}	3.95 ± 0.08^{c}	0.81 ± 0.02^{c}	0.46 ± 0.05^{bc}	0.40 ± 0.03^{bc}
0.25% CD + 1% NOE	0.58 ± 0.00^{d}	2.61 ± 0.22^{d}	0.51 ± 0.03^{d}	0.31 ± 0.02^{c}	0.39 ± 0.03^{bc}
0.25% CD + 3% NOE	0.59 ± 0.01^{d}	2.56 ± 0.15^{d}	0.49 ± 0.01^{d}	0.27 ± 0.01^{c}	0.34 ± 0.03^{bc}
0.25% CD + 5% NOE	0.59 ± 0.01^{d}	2.41 ± 0.25^{d}	0.50 ± 0.02^{d}	0.27 ± 0.01^{c}	0.29 ± 0.02^{c}
1% Soap solution	9.78 ± 0.14^{a}	16.90 ± 0.23^{a}	10.01 ± 0.31^{a}	11.21 ± 0.40^{a}	3.17 ± 0.20^{a}
Control	9.72 ± 0.37^{a}	17.28 ± 0.29^{a}	10.19 ± 0.34^{a}	11.27 ± 0.31^{a}	3.00 ± 0.29^{a}
F (8, 24)	14.89	51.51	13.86	15.46	15.63
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[1] 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] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[3] NOE = Neem oil emulsion.

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Table 2 Individual and composite effect of Cyper-diforce® and neem oil emulsion on abundance (Mean ± SE) of major sap-sucking insects in early-and late-sown watermelon at Wukari.

Treatments	*Aphis gossypii*[3]		*Bemisia tabaci*[4]	
	Early-sown	Late-sown	Early-sown	Late-sown
2016 cropping season				
0.5% CD[1]	3.02 ± 0.27[ab]	4.07 ± 0.29[ab]	10.29 ± 0.12[b]	29.92 ± 0.21[b]
1% NOE[2]	2.86 ± 0.14[ab]	4.24 ± 0.16[ab]	9.84 ± 0.22[b]	29.33 ± 0.42[b]
3% NOE	2.54 ± 0.25[b]	3.72 ± 0.27[b]	9.58 ± 0.74[b]	28.24 ± 2.04[b]
5% NOE	2.49 ± 0.12[b]	3.67 ± 0.12[b]	8.90 ± 0.53[bc]	25.47 ± 1.23[bc]
0.25% CD + 1% NOE	2.36 ± 0.39[b]	3.29 ± 0.42[b]	9.63 ± 0.27[b]	28.49 ± 0.42[b]
0.25% CD + 3% NOE	2.15 ± 0.02[b]	3.30 ± 0.02[b]	8.53 ± 0.22[bc]	26.23 ± 0.83[bc]
0.25% CD + 5% NOE	2.14 ± 0.41[b]	3.53 ± 0.44[b]	7.51 ± 0.82[c]	22.60 ± 2.02[c]
1% Soap solution	3.58 ± 0.26[a]	4.85 ± 0.28[a]	13.42 ± 0.27[a]	38.53 ± 0.39[a]
Control	3.59 ± 0.13[a]	4.84 ± 0.14[a]	13.89 ± 0.38[a]	39.53 ± 0.69[a]
F (8, 24)	5.11	5.13	21.06	25.68
p-value	0.0009	0.0008	< 0.0001	< 0.0001
2017 cropping season				
0.5% CD[1]	3.34 ± 0.28[ab]	6.70 ± 0.32[a]	15.62 ± 1.11[b]	26.61 ± 0.42[b]
1% NOE[2]	3.16 ± 0.15[ab]	4.63 ± 0.09[b]	15.15 ± 0.21[b]	27.00 ± 0.44[b]
3% NOE	2.81 ± 0.26[b]	4.40 ± 0.17[b]	14.88 ± 0.76[b]	25.89 ± 2.11[b]
5% NOE	2.75 ± 0.33[b]	3.72 ± 0.17[bc]	14.18 ± 0.53[bc]	23.83 ± 1.26[bc]
0.25% CD + 1% NOE	2.61 ± 0.43[b]	3.70 ± 0.03[bc]	14.93 ± 0.26[b]	26.14 ± 1.44[b]
0.25% CD + 3% NOE	2.38 ± 0.22[b]	3.64 ± 0.16[bc]	13.80 ± 1.22[bc]	23.05 ± 0.85[bc]
0.25% CD + 5% NOE	2.36 ± 0.44[b]	3.25 ± 0.43[c]	12.76 ± 0.85[c]	20.11 ± 2.06[c]
1% Soap solution	3.96 ± 0.29[a]	6.86 ± 0.44[a]	18.84 ± 2.27[a]	36.44 ± 1.40[a]
Control	3.94 ± 0.74[a]	6.90 ± 0.44[a]	19.32 ± 0.39[a]	37.47 ± 0.60[a]
F (8, 24)	5.38	30.70	21.54	25.59
p-value	0.0006	< 0.0001	< 0.0001	< 0.0001

[1] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[2] NOE = Neem oil emulsion.
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 ($p \leq 0.05$).
[3] Estimates of population density was made by assessing the colony size on 12 randomly selected leaves using a 0-9 scale [where, 0 = no aphids; 1 = 1-4 aphids; 3 = 5-20 aphids; 5 = 21-100 aphids; 7 = 101-500 aphids and, 9 = >500 aphids (Asante *et al*., 2001; Egbo, 2011)].
[4] A 15cm x 15cm yellow sticky board was used to trap the insects by waving it across the 5m length of row on shaking the inner row plants.

[DOR: 20.1001.1.22519041.2019.8.1.9.9]

Table 3 Individual and composite effect of Cyper-diforce® and neem oil emulsion on abundance (Mean ± SE) of major fruit-feeding insects in early- and late-sown watermelon at Wukari in 2017.

Treatments	Early-sown[1]	Late-sown[1]	
	B. cucurbitae larvae/fruit[4]	*B. cucurbitae* larvae/fruit[4]	*H. armigera* larvae/5m length of row
2016 cropping season			
0.5% CD[2]	2.29 ± 0.14^{b}	2.57 ± 0.04^{bc}	5.35 ± 0.03^{bc}
1% NOE[3]	2.37 ± 0.03^{b}	2.60 ± 0.01^{b}	7.80 ± 1.17^{b}
3% NOE	2.25 ± 0.04^{b}	2.55 ± 0.02^{bc}	6.31 ± 1.50^{bc}
5% NOE	2.16 ± 0.02^{bc}	2.54 ± 0.01^{bc}	6.15 ± 0.40^{bc}
0.25% CD + 1% NOE	1.95 ± 0.02^{cd}	2.49 ± 0.01^{bc}	6.21 ± 0.81^{bc}
0.25% CD + 3% NOE	1.85 ± 0.02^{d}	2.46 ± 0.01^{cd}	5.44 ± 0.05^{bc}
0.25% CD + 5% NOE	1.55 ± 0.04^{e}	2.39 ± 0.01^{d}	3.81 ± 0.35^{c}
1% Soap solution	15.67 ± 0.37^{a}	8.71 ± 0.14^{a}	10.64 ± 0.29^{a}
Control	15.89 ± 0.30^{a}	8.54 ± 0.15^{a}	11.18 ± 0.23^{a}
F (8, 24)	17.12	24.00	10.74
p-value	< 0.0001	< 0.0001	< 0.0001
2017 cropping season			
0.5% CD[2]	5.38 ± 0.15^{bc}	0.58 ± 0.14^{bc}	7.31 ± 1.04^{bc}
1% NOE[3]	5.46 ± 0.13^{b}	0.61 ± 0.11^{b}	9.73 ± 1.16^{b}
3% NOE	5.34 ± 0.04^{bc}	0.56 ± 0.02^{bc}	8.26 ± 1.50^{bc}
5% NOE	5.25 ± 0.02^{bc}	0.55 ± 0.01^{bc}	8.10 ± 0.40^{bc}
0.25% CD + 1% NOE	5.03 ± 0.02^{cd}	0.50 ± 0.01^{bcd}	8.15 ± 0.79^{bc}
0.25% CD + 3% NOE	4.93 ± 0.02^{d}	0.47 ± 0.01^{cd}	7.39 ± 2.04^{bc}
0.25% CD + 5% NOE	4.61 ± 0.22^{e}	0.40 ± 0.01^{d}	5.78 ± 0.36^{c}
1% Soap solution	19.29 ± 0.39^{a}	6.67 ± 0.14^{a}	12.53 ± 0.29^{a}
Control	19.53 ± 1.31^{a}	6.85 ± 1.15^{a}	13.07 ± 2.24^{a}
F (8, 24)	17.05	24.24	10.67
p-value	< 0.0001	< 0.0001	< 0.0001

[1] 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] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[3] NOE = Neem oil emulsion.
[4] No. of fruit fly larvae per fruit = Number of infested fruits x Number of larvae per infested fruit.
Number of fruits per plot.

[DOR: 20.1001.1.22519041.2019.8.1.9.9]

Table 4a Individual and composite effect of Cyper-diforce® and neem oil emulsion on abundance (Mean ± SE) of major beneficial arthropods in early-sown watermelon at Wukari in 2016.

Treatments	*Apis mellifera*	*Cardiochiles niger*	*Cheilomenes sulphurea*	Predatory Ants[3]	Spiders[4]
Early-sown					
0.5% CD[1]	1.30 ± 0.09[c]	1.06 ± 0.30[c]	1.03 ± 0.28[b]	1.28 ± 0.12[c]	1.08 ± 0.24[b]
1% NOE[2]	3.53 ± 0.02[a]	3.04 ± 0.02[a]	2.42 ± 0.01[a]	3.78 ± 0.04[a]	2.65 ± 0.02[a]
3% NOE	3.44 ± 0.02[a]	2.94 ± 0.04[a]	2.41 ± 0.04[a]	3.78 ± 0.13[a]	2.75 ± 0.02[a]
5% NOE	3.34 ± 0.05[a]	2.91 ± 0.04[a]	2.33 ± 0.04[a]	3.82 ± 0.12[a]	2.76 ± 0.09[a]
0.25% CD + 1% NOE	1.75 ± 0.08[b]	1.64 ± 0.06[b]	1.44 ± 0.04[b]	2.01 ± 0.04[b]	1.56 ± 0.02[b]
0.25% CD + 3% NOE	1.65 ± 0.01[b]	1.54 ± 0.02[b]	1.55 ± 0.04[b]	1.99 ± 0.01[b]	1.56 ± 0.17[b]
0.25% CD + 5% NOE	1.56 ± 0.17[b]	1.44 ± 0.02[b]	1.55 ± 0.04[b]	2.07 ± 0.02[b]	1.34 ± 0.02[b]
1% Soap solution	3.53 ± 0.17[a]	3.16 ± 0.30[a]	2.41 ± 0.26[a]	3.81 ± 0.16[a]	2.84 ± 0.47[a]
Control	3.58 ± 0.17[a]	3.21 ± 0.27[a]	2.26 ± 0.35[a]	3.81 ± 0.27[a]	2.92 ± 0.51[a]
F (8, 24)	95.14	24.90	10.47	94.33	11.85
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Late-sown					
0.5% CD[1]	1.51 ± 0.08[b]	1.38 ± 0.50[b]	1.24 ± 0.26[b]	1.28 ± 0.11[c]	0.74 ± 0.20[b]
1% NOE[2]	4.24 ± 0.15[a]	3.61 ± 0.04[a]	3.18 ± 0.12[a]	3.80 ± 0.04[a]	1.75 ± 0.01[a]
3% NOE	4.13 ± 0.16[a]	3.79 ± 0.03[a]	3.29 ± 0.11[a]	3.80 ± 0.13[a]	1.74 ± 0.04[a]
5% NOE	4.09 ± 0.15[a]	3.39 ± 0.04[a]	3.30 ± 0.12[a]	3.84 ± 0.12[a]	1.67 ± 0.03[a]
0.25% CD + 1% NOE	2.05 ± 0.09[b]	2.63 ± 0.01[a]	1.87 ± 0.08[b]	1.98 ± 0.03[b]	1.03 ± 0.04[b]
0.25% CD + 3% NOE	1.98 ± 0.06[b]	2.68 ± 0.03[a]	1.83 ± 0.27[b]	2.01 ± 0.01[b]	1.11 ± 0.04[b]
0.25% CD + 5% NOE	1.90 ± 0.18[b]	3.21 ± 0.03[a]	1.68 ± 0.06[b]	2.09 ± 0.02[b]	1.12 ± 0.04[b]
1% Soap solution	4.16 ± 0.36[a]	3.68 ± 1.13[a]	3.30 ± 0.62[a]	3.83 ± 0.27[a]	1.63 ± 0.26[a]
Control	4.30 ± 0.29[a]	3.87 ± 0.72[a]	3.53 ± 0.69[a]	3.85 ± 0.16[a]	1.74 ± 0.19[a]
F (8, 24)	49.40	3.56	9.50	93.28	10.32
p-value	< 0.0001	0.007	< 0.0001	< 0.0001	< 0.0001

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 ($p \leq 0.05$).
[1] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[2] NOE = Neem oil emulsion.
[3] *Camponotus* sp., *Crematogaster* sp., *Pheidole* sp.
[4] Spider species were treated as a single population/taxon.

[DOR: 20.1001.1.22519041.2019.8.1.9.9]

Table 4b Individual and composite effect of Cyper-diforce® and neem oil emulsion on abundance (Mean ± SE) of major beneficial arthropods in early-sown watermelon at Wukari in 2017.

Treatments	*Apis mellifera*	*Cardiochiles niger*	*Cheilomenes sulphurea*	Predatory Ants[3]	Spiders[4]
Early-sown					
0.5% CD[1]	1.31 ± 0.09[c]	0.73 ± 0.25[b]	1.10 ± 0.24[b]	1.32 ± 0.13[c]	1.05 ± 0.27[c]
1% NOE[2]	3.54 ± 0.02[a]	1.91 ± 0.03[a]	2.69 ± 0.03[a]	3.85 ± 0.04[a]	2.45 ± 0.01[a]
3% NOE	3.45 ± 0.02[a]	1.99 ± 0.03[a]	2.79 ± 0.03[a]	3.86 ± 0.13[a]	2.45 ± 0.04[a]
5% NOE	3.35 ± 0.03[a]	1.79 ± 0.03[a]	2.81 ± 0.09[a]	3.90 ± 0.13[a]	2.37 ± 0.04[a]
0.25% CD + 1% NOE	1.76 ± 0.07[b]	1.42 ± 0.03[ab]	1.59 ± 0.01[b]	2.06 ± 0.04[b]	1.47 ± 0.04[b]
0.25% CD + 3% NOE	1.67 ± 0.01[b]	1.38 ± 0.00[ab]	1.60 ± 0.16[b]	2.05 ± 0.02[b]	1.58 ± 0.04[b]
0.25% CD + 5% NOE	1.57 ± 0.16[b]	1.70 ± 0.03[a]	1.37 ± 0.01[b]	2.13 ± 0.02[b]	1.59 ± 0.04[b]
1% Soap solution	3.54 ± 0.16[a]	2.04 ± 0.39[a]	2.89 ± 0.49[a]	3.89 ± 0.16[a]	2.45 ± 0.25[a]
Control	3.59 ± 0.17[a]	1.94 ± 0.60[a]	2.97 ± 0.53[a]	3.89 ± 0.28[a]	2.29 ± 0.35[a]
F (8, 24)	10.45	3.36	11.53	87.10	11.55
p-value	< 0.0001	0.0101	< 0.0001	< 0.0001	< 0.0001
Late-sown					
0.5% CD[1]	1.51 ± 0.07[b]	1.12 ± 0.30[c]	0.77 ± 0.21[b]	1.33 ± 0.12[c]	1.29 ± 0.27[b]
1% NOE[2]	4.23 ± 0.14[a]	3.19 ± 0.02[a]	1.79 ± 0.00[a]	3.90 ± 0.06[a]	3.29 ± 0.11[a]
3% NOE	4.08 ± 0.16[a]	3.08 ± 0.02[a]	1.78 ± 0.04[a]	3.90 ± 0.13[a]	3.41 ± 0.10[a]
5% NOE	4.07 ± 0.16[a]	3.04 ± 0.02[a]	1.72 ± 0.02[a]	3.95 ± 0.11[a]	3.42 ± 0.14[a]
0.25% CD + 1% NOE	2.07 ± 0.11[b]	1.72 ± 0.04[b]	1.07 ± 0.04[b]	2.05 ± 0.03[b]	1.95 ± 0.06[b]
0.25% CD + 3% NOE	1.99 ± 0.08[b]	1.53 ± 0.12[bc]	1.15 ± 0.04[b]	2.07 ± 0.01[b]	1.90 ± 0.28[b]
0.25% CD + 5% NOE	1.90 ± 0.18[b]	1.52 ± 0.03[bc]	1.16 ± 0.05[b]	2.15 ± 0.03[b]	1.75 ± 0.05[b]
1% Soap solution	4.12 ± 0.36[a]	3.31 ± 0.32[a]	1.78 ± 0.22[a]	3.94 ± 0.16[a]	3.42 ± 0.65[a]
Control	4.27 ± 0.28[a]	3.36 ± 0.30[a]	1.68 ± 0.28[a]	3.93 ± 0.29[a]	3.65 ± 0.72[a]
F (8, 24)	46.61	24.82	9.05	89.71	9.50
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

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 ($p \leq 0.05$).

[1] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.

[2] NOE = Neem oil emulsion.

[3] *Camponotus* sp., *Crematogaster* sp., *Pheidole* sp.

[4] Spider species were treated as a single population/taxon.

[DOR: 20.1001.1.22519041.2019.8.1.9.9]

Table 5 Individual and composite effect of Cyper-diforce® and neem oil emulsion on leaf injury in early-and late-sown watermelon at Wukari.

Treatments	Mean proportion of leaves injured (%)[1]		Mean severity of leaf injury (%)[1]	
	Early-sown	Late-sown	Early-sown	Late-sown
2016 cropping season				
0.5% CD[2]	9.39 ± 3.13^b	9.07 ± 3.01^b	4.26 ± 1.45^b	4.08 ± 1.61^b
1% NOE[3]	15.66 ± 1.05^b	15.01 ± 1.11^b	6.79 ± 0.99^b	6.55 ± 0.95^b
3% NOE	12.52 ± 2.95^b	11.98 ± 2.82^b	5.26 ± 1.33^b	5.08 ± 1.28^b
5% NOE	9.39 ± 3.13^b	9.17 ± 3.07^b	4.23 ± 1.45^b	4.11 ± 1.40^b
0.25% CD + 1% NOE	11.48 ± 2.63^b	11.08 ± 2.53^b	4.74 ± 0.98^b	4.58 ± 0.95^b
0.25% CD + 3% NOE	9.39 ± 2.00^b	9.06 ± 1.93^b	4.24 ± 1.87^b	4.08 ± 1.80^b
0.25% CD + 5% NOE	7.30 ± 3.13^b	6.02 ± 2.02^b	2.69 ± 0.98^b	2.60 ± 0.95^b
1% Soap solution	65.97 ± 2.79^a	33.13 ± 2.90^a	42.58 ± 1.05^a	15.82 ± 0.43^a
Control	64.57 ± 4.41^a	33.79 ± 1.70^a	42.71 ± 1.34^a	15.87 ± 0.62^a
F (8, 24)	35.55	11.15	34.60	6.68
p-value	< 0.0001	< 0.0001	< 0.0001	0.0001
2017 cropping season				
0.5% CD[2]	12.78 ± 2.78^b	13.89 ± 2.78^b	4.71 ± 1.60^b	4.53 ± 1.79^b
1% NOE[3]	19.44 ± 1.40^b	18.33 ± 1.67^b	7.61 ± 1.12^b	7.28 ± 1.05^b
3% NOE	17.22 ± 1.67^b	17.22 ± 1.67^b	5.85 ± 1.48^b	5.64 ± 1.42^b
5% NOE	13.89 ± 2.78^b	13.89 ± 2.78^b	4.73 ± 1.61^b	4.56 ± 1.55^b
0.25% CD + 1% NOE	16.11 ± 1.40^b	16.11 ± 1.40^b	5.26 ± 1.10^b	5.08 ± 1.06^b
0.25% CD + 3% NOE	12.78 ± 2.10^b	13.89 ± 1.06^b	4.71 ± 2.09^b	4.53 ± 2.01^b
0.25% CD + 5% NOE	10.56 ± 2.29^b	10.56 ± 2.29^b	2.98 ± 1.08^b	2.88 ± 1.05^b
1% Soap solution	70.00 ± 2.13^a	37.22 ± 2.46^a	47.40 ± 1.19^a	17.56 ± 0.49^a
Control	68.33 ± 2.75^a	38.33 ± 1.67^a	47.66 ± 1.47^a	17.84 ± 0.69^a
F (8, 24)	57.84	16.50	36.06	6.83
p-value	< 0.0001	< 0.0001	< 0.0001	0.0001

[1] 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] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[3] NOE = Neem oil emulsion.

Table 6 Individual and composite effect of Cyper-diforce® and neem oil emulsion on growth of early-and late-sown watermelon at Wukari.

Treatments	Main vine length (cm) at 9WAP[1]		Number of leaves/plant at 9WAP[1]	
	Early-sown[2]	Late-sown[2]	Early-sown[2]	Late-sown[2]
2016 cropping season				
0.5% CD[3]	276.88 ± 0.50[b]	303.94 ± 0.66[b]	233.80 ± 0.36[ab]	270.75 ± 0.47[ab]
1% NOE[4]	269.22 ± 0.38[c]	296.05 ± 0.56[c]	224.16 ± 0.49[e]	259.35 ± 0.16[d]
3% NOE	273.31 ± 0.29[b]	300.39 ± 0.18[b]	227.11 ± 0.59[d]	261.25 ± 0.79[d]
5% NOE	276.63 ± 0.51[b]	302.07 ± 0.62[b]	231.50 ± 1.68[bc]	265.30 ± 1.91[c]
0.25% CD + 1% NOE	274.89 ± 0.70[b]	303.74 ± 0.87[b]	229.80 ± 1.29[c]	267.71 ± 0.99[bc]
0.25% CD + 3% NOE	276.69 ± 0.29[b]	303.99 ± 0.48[b]	233.20 ± 0.55[ab]	269.50 ± 0.50[b]
0.25% CD + 5% NOE	281.22 ± 2.12[a]	308.56 ± 2.27[a]	236.04 ± 1.25[a]	273.15 ± 1.47[a]
1% Soap solution	118.83 ± 0.34[d]	136.29 ± 0.30[d]	39.73 ± 0.74[f]	62.61 ± 0.79[e]
Control	119.08 ± 0.86[d]	136.52 ± 0.94[d]	39.15 ± 0.09[f]	60.99 ± 0.09[e]
F (8, 24)	60.70	53.61	96.51	10.39
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
2017 cropping season				
0.5% CD[3]	257.40 ± 0.45[b]	283.17 ± 1.60[b]	222.44 ± 0.36[b]	248.74 ± 1.38[ab]
1% NOE[4]	250.45 ± 2.35[c]	275.95 ± 2.51[c]	213.31 ± 1.31[e]	239.55 ± 0.03[d]
3% NOE	254.16 ± 0.26[b]	279.90 ± 0.16[b]	216.30 ± 0.63[d]	237.93 ± 0.78[d]
5% NOE	257.18 ± 0.47[b]	282.94 ± 0.56[b]	220.15 ± 1.62[bc]	246.05 ± 1.93[b]
0.25% CD + 1% NOE	255.60 ± 1.63[b]	281.43 ± 0.89[b]	218.57 ± 1.13[cd]	243.34 ± 0.89[c]
0.25% CD + 3% NOE	257.24 ± 0.26[b]	283.13 ± 0.44[b]	221.93 ± 2.58[b]	247.39 ± 1.49[b]
0.25% CD + 5% NOE	261.35 ± 1.92[a]	287.32 ± 2.06[a]	224.89 ± 1.07[a]	251.04 ± 1.31[a]
1% Soap solution	113.89 ± 0.31[d]	130.77 ± 0.57[d]	38.05 ± 0.82[f]	50.76 ± 0.70[e]
Control	114.12 ± 0.88[d]	130.98 ± 0.86[d]	37.52 ± 0.35[f]	50.34 ± 1.01[e]
F (8, 24)	60.69	53.61	94.66	99.05
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[1] WAP-Weeks after planting.
[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 ($p \leq 0.05$).
[3] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[4] NOE = Neem oil emulsion.

Table 7a Economic analysis of watermelon production by spraying Cyper-diforce® and neem oil emulsion individually and in combination in 2016.

Treatments	Marketable yield (kgha^{-1})	Cost of application of insecticide (US\$ha^{-1})[3]	Gross income (US\$ha^{-1})	Monetary benefit (US\$ha^{-1})	Cost:benefit ratio[4]
Early-sown					
0.5% CD[1]	39473.26[a]	189.53	4658.19	4468.67	1:23.35
1% NOE[2]	35907.35[a]	303.96	4237.39	3933.42	1:12.80
3% NOE	37394.63[a]	590.04	4412.90	3822.85	1:6.41
5% NOE	38850.63[a]	860.03	4584.72	3724.68	1:4.28
0.25% CD + 1% NOE	37005.07[a]	354.03	4366.93	4012.90	1:11.21
0.25% CD + 3% NOE	39349.04[a]	640.11	4643.54	4003.43	1:6.19
0.25% CD + 5% NOE	41052.58[a]	926.19	4844.57	3918.38	1:4.18
1% Soap solution	391.83[b]	160.92	46.24	-114.68	1:0.98
Control	360.28[b]	0.00	42.52	42.52	
F (8, 24)	17.56				
p-value	<0.0001				
Late-sown					
0.5% CD[1]	42401.21[a]	189.53	5003.72	4814.19	1:25.09
1% NOE[2]	39686.31[a]	303.96	4683.34	4379.37	1:14.21
3% NOE	42844.10[a]	590.04	5055.98	4465.94	1:7.47
5% NOE	42219.12[a]	860.03	4982.23	4122.20	1:4.72
0.25% CD + 1% NOE	41384.01[a]	354.03	4883.68	4529.65	1:12.63
0.25% CD + 3% NOE	43465.80[a]	640.11	5129.35	4489.24	1:6.92
0.25% CD + 5% NOE	44642.28[a]	926.19	5268.18	4341.99	1:4.62
1% Soap solution	504.40[b]	160.92	59.52	-101.40	1:-1.00
Control	499.51[b]	0.00	58.95	58.95	
F (8, 24)	66.96				
p-value	< 0.0001				

[1] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[2] NOE = Neem oil emulsion.
[3] Cost of insecticide, neem seed oil, liquid soap, water and insecticide application as applicable.
[4] A ratio of (1)-indicates neither profit nor loss, (< 1)-indicates loss, (>1)-indicates profit (Shabozoi *et al.,* 2011).

Table 7b economic analysis of watermelon production by spraying Cyper-diforce® and neem oil emulsion individually and in combination in 2017.

Treatments	Marketable yield ($kgha^{-1}$)	Cost of application of insecticide ($US\$ha^{-1}$)[3]	Gross income ($US\$ha^{-1}$)	Monetary benefit ($US\$ha^{-1}$)	Cost:benefit ratio[4]
Early-sown					
0.5% CD[1]	37149.82[a]	243.17	4848.98	4605.81	1:18.78
1% NOE[2]	34541.18[a]	375.48	4508.49	4133.00	1:10.91
3% NOE	36750.37[a]	704.48	4796.84	4092.36	1:5.76
5% NOE	37467.13[a]	1033.47	4890.40	3856.92	1:3.70
0.25% CD + 1% NOE	35625.20[a]	434.49	4649.98	4215.49	1:9.62
0.25% CD + 3% NOE	37178.55[a]	763.48	4852.73	4089.25	1:5.31
0.25% CD + 5% NOE	39192.12[a]	1092.48	5115.55	4023.07	1:3.65
1% Soap solution	311.97[b]	210.99	40.72	-170.27	1:-0.99
Control	290.30[b]	0.00	37.89	37.89	
F (8, 24)	67.60				
p-value	< 0.0001				
Late-sown					
0.5% CD[1]	41059.32[a]	243.17	5359.27	5116.10	1:20.81
1% NOE[2]	38232.30[a]	375.48	4990.27	4614.79	1:12.14
3% NOE	40814.93[a]	704.48	5327.37	4622.89	1:6.48
5% NOE	41491.53[a]	1033.47	5415.68	4382.21	1:4.19
0.25% CD + 1% NOE	39366.85[a]	434.49	5138.36	4703.87	1:10.70
0.25% CD + 3% NOE	41221.07[a]	763.48	5380.38	4616.90	1:5.98
0.25% CD + 5% NOE	43202.25[a]	1092.48	5638.97	4546.50	1:4.11
1% Soap solution	424.96[b]	210.99	55.47	-155.52	1:-1.00
Control	420.88[b]	0.00	54.94	54.94	
F (8, 24)	58.86				
p-value	< 0.0001				

[1] CD = Cyper-diforce®-Cypermethrin 30g/L + Dimethoate 250g/L EC.
[2] NOE = Neem oil emulsion.
[3] Cost of insecticide, neem seed oil, liquid soap, water and insecticide application as applicable.
[4] A ratio of (1)-indicates neither profit or loss, (<1)-indicates loss, (>1)-indicates profit (Shabozoi *et al.,* 2011).

Discussion

Various insects sampling techniques were used in this study to ensure efficient sampling of key arthropods associated with watermelon in the study area. For example, since *A. gossypii* adults are largely immobile and stuck to the abaxial leaf surface where they suck plant sap, a standard visual scale was used for its sampling. For *B. tabaci*, its mobility in the day time can be probed by agitation and hence a yellow sticky board was waved along the 5m length of the middle row per plot on mildly shaking the plants. These methods had been effectively

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used in previous studies by Anaso, 1999, Asante *et al*. (2001) and Egbo (2011). The effectiveness of suction sampler in sampling beetles and beneficials had been showcased in a study conducted by Ndam *et al.* (2012) when sampling for Soybean pests and natural enemies in Nigeria. In addition, since *Helicoverpa* adults are nocturnal in habit, its immature (larvae) which were observed to be feeding in the day time were sampled with the suction sampler.

Generally, NOE at 1, 3 and 5% were as effective as 0.5% CD and were not phytotoxic. Though combination of 0.25% CD with NOE treatments in many instances significantly suppresses pest infestation relative sole Neem oil treatments, leaf injury and ultimately yields were statistically comparable. In addition, though combining 0.25% Cyper-diforce® with Neem Oil Emulsion increased monetary benefits, it resulted in decreased cost:benefit ratios. That neem based treatments have been reported as effective against several field and storage pests. Adnan *et al.* (2014) reported that 3% Neem Oil Emulsion was comparable with Cypermethrin and Endosulfan but was less effective than Imidacloprid at 168 hour post-treatment in suppressing Mango hopper *Idioscopus clypealis* population. Antifeedant effect of Neem Oil on *Nezara viridula* due to mouthpart deformities had also been reported (Singha *et al*., 2007). A 77% nymphal mortality of *Aphis glycines* Matsumura (a pest of Soybean) with increase in development time of surviving adults due to Neem Oil treatment was also reported by Kraiss and Cullen (2008).

However, while the synthetic insecticide, 0.5% Cyper-diforce® did not effectively suppress *A. gossypii* infestation; 3 and 5% NOE did. The ineffectiveness of Cyper-diforce® in this regard may be indicative of resistance as had been reported for Fenvalerate and Acetamiprid in China by Wang *et al.* (2007) and for Chlorpyrifos 20EC in Ghana by Momo (2014). The efficiency of Neem-based insecticides in effecting aphid mortality had been reported on several crops (Kumar *et al*., 2010; Baidoo *et al*., 2012; Egbo and Ilondu, 2012; Khan *et al*., 2013; Murray and Daniels, 2013; Shannag *et al*., 2014; Ivase *et al*., 2017) and this has been linked to its systemic, multiple active ingredients militating against rapid build-up of resistant population with their synergistic and additive effects (Quintela and Pinheiro, 2009; Abdelrahim Satti, 2013; Chaundhary *et al*., 2017). This is in addition to its diverse modes of action: antifeedant, growth regulator, oviposition deterrent and repellent activities (Cox, 2002; Koul and Wahab, 2004; Campos *et al*., 2016).

A. gossypii and *B. tabaci* are known to vector watermelon leaf mosaic and chlorotic stunt virus, respectively (Kheyr-Pour *et al*., 2000; Sydänmetsä and Mbanzibwa, 2016). Though none of the insecticide treatments completely (100%) suppressed their densities, symptoms of their vectored viral diseases were not observed. This may be indicative of the insects being “noncarriers”. However, that the insecticide treatments did not give ≈ 100% protection suggests the need to integrate the neem insecticide with resistant varieties, where available, for sustainable management.

Beneficial arthropods, largely consisting of natural enemies and pollinators are known to play key role in regulating populations of phytophagous insects and ensuring optimum pollination, respectively; leading to higher crop yield. In this study however, sole Neem Oil Emulsion (1, 3 and 5%) were observed not to significantly suppress populations of beneficial arthropods when compared with sole synthetic insecticides or their combinations. This could be attributed to neem’s slow action unlike the synthetic insecticide (Cyper-diforce®) which has a rapid killing effect. Additionally, it is known that under field conditions, the beneficial arthropods are highly mobile and have the capacity to escape to environments that are free from the insecticide and possibly return to their preferred micro-agroecosystem after the insecticide had degraded-which is faster for neem than for synthetics. The activity of neem insecticide largely works when insects feed on sprayed leaves and are repelled by the bitter taste (phagodeterrent) and/or killed (stomach poison). Since the natural enemies are

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not phytophagous, they rarely pick up sufficient concentrations of the neem insecticide that could suppress their population.

The non detrimental effect of neem insecticides on natural enemy species was demonstrated in a study conducted by Tang *et al.* (2002). Similarly, several studies have reported higher natural enemy populations in Neem treated plants relative to Synthetic (Gowri *et al*., 2002; Mishra and Mishra, 2002; Rao and Raguraman, 2005). However, a conflicting finding was reported by Baidoo *et al.* 2012 who showed that mean densities of *Harmonia axydiris* (a predator of aphids) in Neem and Lambdacyhalothrin treated plots were statistically comparable even though 2 X numerically higher in Neem treated plots.

The current study buttressed the fact that, the influence of vine length (cm) and number of leaves on yield is positive. This is because, though statistically comparable, yield was observed to be numerically less in sole NOE application than in the integrated treatments as with sole CD. A similar trend was observed in vine length (cm) and number of leaves even though they were statistically variable. This agrees with the report of Okrikata *et al.*, 2018 which indicates a positive relationship between vine length and yield in watermelon varieties. That Neem Oil treatments in the present study had comparable yields with Cyper-diforce® may be, among others, attributed to its comparative amenability to *A. mellifera* (the key pollinator of Watermelon) as it has been shown that each pistillate Watermelon flower requires a minimum of between 6-8 bee visits to successfully set fruit (Stanghellini *et al*. 1997 cited in Henne *et al*. 2012) and that, fruits become misshapened and undersized when there is insufficient pollination (Erick and Robbin, 2018).

Cost: benefit analysis is essential before any pest management technology is released as it is an indicator of the economic viability of a pest control treatment. In this study, the economic analysis was strictly based on cost of plant protection and the cost:benefit ratio computed relative to the income of the control treatment. This model had been used by Patel *et al.* (1997), Shabozoi *et al.* (2011) and Amoabeng *et al*. (2014). It is however at variance with the model used by Okrikata and Anaso (2008) and Arivudainambi *et al.* (2010) who computed cost of cultivation in addition to that of plant protection. However, the merit of the model used in this study is that, cost for all inputs for cultivation was constant but varied only in plant protection.

The cost of Neem treatments were 54.4 to 388.7% higher than that of Cyper-diforce®. This is attributed to the cost of labour of collecting Neem seeds and the comparatively higher amounts (1, 3 and 5%) of Neem Oil used as against 0.5% Cyper-diforce®. Neem oil treatments have been shown to be more expensive than synthetic insecticides (Dua *et al*., 2009). Ngbede *et al.* (2014) reported that sometimes, botanical pesticides cost as much if not higher than synthetics. The results also show that, even though combining 0.25% Cyper-diforce® with NOE treatments increased marketable yield, as well as gross income and monetary benefits over sole Neem Oil Emulsion; it does reduce returns on investment. The comparatively lesser economic benefits derived from the Neem Oil-based treatments can obviously be attributed to their relatively higher cost per treatment.

The efficiency of Neem Oil in suppressing the pest complex of Watermelon without adversely suppressing the beneficial arthropods highlights the need for the Nigerian government and relevant stakeholders to push for vigorous enlightenment of producers about Neem's potential in checking Watermelon pests. The need for Neem processing industries and subsidising Neem oil is also evident. This is further heightened by recent reports by Akan *et al.* (2015), Mahmud *et al.* (2015) and Omoyajowo *et al.* (2018) which showed residues of organophosphates, pyrethroid and organochlorine pesticides in Watermelon in parts of Yobe and Lagos States of Nigeria to be above the internationally allowable maximum limits.

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Conclusion

In the present study, the insecticidal efficiency of Neem Oil Emulsion was comparable and with respect to *A. gossypii*, surpassed Cyper-diforce®. The ineffectiveness of Cyper-diforce® against *A. gossypii* suggests some show of resistance. However, while Neem Oil Emulsion did not markedly suppress beneficial arthropods, Cyper-diforce® did. Leaf injury and yield among the insecticide treatments (individual and combination of Cyper-diforce® and Neem Oil Emulsion) were comparable. Cyper-diforce® consistently had the highest return on investment and there was no economic advantage in mixing Neem Oil Emulsion with Cyper-diforce®.

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بررسی کارایی و پایداری اقتصادی امولسیون روغنی دانه چریش و حشره‌کش سایپردایفورس در تولید هندوانه در منطقه ساوانای جنوبی در کشور نیجریه

اوکریکاتا امانوئل[1*]، اوگون ولو امانوئل اولودل[2] و اوکولا ماندی اونوابون[2]

۱- گروه علوم زیستی، دانشگاه فدرال ووکاری، ایالت تارابا، نیجریه.
۲- گروه حفاظت از محصول و محیط‌زیست، دانشگاه فدرال کشاورزی، مکوردی، ایالت بنو، نیجریه.
پست الکترونیکی نویسنده مسئول مکاتبه: eokrikata@gmail.com
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چکیده: مطالعات بسیاری در زمینه کارایی حشره‌کش‌ها انجام شده است، با این حال، اطلاعات کمی در مورد نسبت هزینه: سود استفاده از حشره‌کش‌ها، به‌ویژه در تولید هندوانه وجود دارد. این مطالعه، در ۳۶ کرت به طول ۸ متر و عرض ۵ متر در قالب طرح بلوک‌های کامل تصادفی در ۴ تکرار انجام شد. سمپاشی تیمارها به‌طور هفتگی شامل Cyper-diforce® (CD) در غلظت ۰/۵ درصد و امولسیون روغنی چریش (NOE) با غلظت ۱، ۳ و ۵ درصد و ترکیب ۰/۲۵ درصد CD به‌همراه ۱، ۳ و ۵ درصد NOE و هم‌چنین محلول صابون حشره‌کش با غلظت ۱ درصد به علاوه کرت شاهد (کرت بدون سمپاشی) انجام شد. نمونه‌برداری از بندپایان در طول ۵ متر از ردیف با استفاده از تله مکنده و تله‌های زرد چسبناک انجام شد. شدت آسیب به برگ و اندازه کلنی شته‌ها نیز ارزیابی شد. در زمان برداشت، میوه‌های قابل فروش، وزن شدند و برای محاسبه نسبت هزینه-سود مورد استفاده قرار گرفتند. آفات مورد بررسی شامل پنج گونه حشره عبارت‌است از سوسک برگ‌خوار، شته جالیز *Aphis gossypii* Glover، سفید بالک پنبه *Bemisia tabaci* (Gennadius)، مگس میوه کدوئیان *Bactrocera cucurbitae* (Coquillett)، و کرم غوزه پنبه *Helicoverpa armigera* (Hubner) بودند. حشرات مفید شامل زنبور عسل *Apis mellifera* L.، *Cardiochiles niger* Szépligeti و *Cheilomenes sulfurea* (Olivier) بودند. حشره‌کش CD ۰/۵ درصد روی شته‌ها تأثیری نداشت اما چریش ۳ و ۵ درصد مؤثر بود. به‌طور کلی، کاربرد حشره‌کش‌ها آلودگی را به میزان ۲/۹ تا ۹۵/۳ درصد کاهش داد. با وجود این‌که غلظت ۰/۵ درصد CD با تیمار چریش، پیشرفت آلودگی را متوقف نمود اما کارایی روغن چریش در کاهش خسارت و تأثیر بر عملکرد از نظر آماری با کارایی حشره‌کش قابل مقایسه است. استفاده تنها از روغن چریش در مقایسه با حشره-کش تأثیر معنی‌داری روی دشمنان طبیعی آفات ندارند. استفاده از ۰/۲۵٪ درصد حشره‌کش به‌همراه ۵ درصد روغن چریش موجب بالاترین عملکرد در تولید محصول به میزان ۳۹۱۹۲ تا ۴۴۶۴۲ کیلوگرم در هکتار شد که درآمد حاصل از ان بیش از ۳۷۲۴ دلار در هر هکتار بود. تفاوت معنی‌داری میان عملکرد حشره‌کش و روغن چریش در مدیریت آفات هندوانه مشاهده نشد. ناکارآمدی حشره‌کش Cyper-diforce در برابر شته جالیز نشان‌دهنده بروز مقاومت *A. gossypii* به این سم می‌باشد.

کلید واژگان: بندپایان، تجزیه‌وتحلیل هزینه-سود، Cyper-diforce، امولسیون روغنی چریش

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