

IMPACT OF SYNTHETIC AND/OR BIOPESTICIDE FORMULATIONS ON DOMINANT PESTS AND PRODUCTIVITY OF WATERMELON

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Abstract

Impact of a biopesticide formulation, Neem, *Azadirachta indica* A. Juss. (Meliaceae) plus Garlic, *Allium sativum* L. (Amaryllidaceae) Oil Emulsion-NGOE in watermelon production was investigated in early- and late-season field trials of 2020. Data collected include densities of leaf beetle species [*Aulacophora africana* (Weise), *Asbecesta nigripennis* (Weise), *Asbecesta transversa* (Allard), *Monolepta nigeriae* (Bryant)-Coleoptera: Chrysomelidae, and *Epilachna chrysomelina* (Fabricius)-Coleoptera: Coccinellidae], and melon fruit fly [*Bactrocera cucurbitae* (Coquillett)-Diptera: Tephritidae] using a modified Grizzly 2500/8 leaf blower-vac. Data were subjected to variance analysis after appropriate transformation. Results showed that, overall, the most efficient treatment was either 0.125% Magicforce®-Lambda-cyhalothrin 15g/L+Dimethoate 300 g/L (MF)+5% NGOE or 0.25% MF in terms of pest suppression across seasons. Similarly, assessment of change in population densities revealed that either 0.25% MF or 0.125% MF+5% NGOE was the most suppressive of the the pest species across seasons. Same trend was observed with respect to leaf injury, growth parameters and fruit damage. Plots treated with 0.125% MF+5% NGOE consistently produced the highest number of fruits (18,615.06±457.00 and 16,404.02±1,526.25 in the early- and late-season crop), followed by those treated with 0.25% MF (values: 17165.16±488.17 and 15,708.50±1,411.93). The study underscored the effectiveness of Magicforce® in suppressing watermelon pest (leaf beetles and the melon fruit fly) and improving yield, and also highlighted the potential of neem plus garlic oils formulation in suppressing pests of watermelon and their compatibility.

Keywords: Biopesticide formulations, leaf beetle species, melon fruit fly, neem, pest, watermelon

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Introduction

Rapid increase and indiscriminate use of insecticides aimed at maximizing crop performance has triggered the development of resistance by some insect species, the disruption of the biocontrol systems, and the increase of toxic residues in the environment as well as in food (Okrikata *et al.*, 2021). The increase in awareness of the health and environmental implication of this inappropriate use of pesticide in relation to the global change in consumption patterns from conventionally produced foods to organically produced ones has raised the need to search for sustainable and viable pest control options particularly for fruits and vegetables since they are largely eaten raw.

Globally, watermelon, *Citrullus lanatus* Thunb. (Cucurbitaceae) consumption exceeds that of any other cucurbit, and in Nigeria, it is attracting very high consumer interest due to increase in knowledge of its health and nutritional benefits (Okrikata *et al.*, 2020). Nevertheless, as shown in other parts of the world (Lima *et al.*, 2014; Reetu and Tomar, 2017), watermelon can hardly be productive in without pest control interventions in Nigeria (Okrikata *et al.*, 2019). This is due to a complex of insect pests, particularly leaf beetle species [mainly: *Aulacophora africana* (Weise), *Asbecesta nigripennis* (Weise), *Asbecesta transversa* (Allard), *Monolepta nigeriae* (Bryant)-Coleoptera: Chrysomelidae, *Epilachna chrysomelina* (Fabricius) -Coleoptera: Coccinellidae] and the melon fruit fly, *Bactrocera cucurbitae* (Coquillett)-Diptera: Tephritidae which infest the crop (from seedling to fruiting stages) with more than 50% yield losses and sometimes, complete crop failure (Okrikata *et al.*, 2021).

In Nigeria, management of watermelon pests has largely been by synthetic chemical pesticides whose inappropriate use has resulted in the build-up of pesticide residues in the fruits beyond the maximum limits as shown by the studies of Akan *et al.* (2015) and Mahmud *et al.* (2015) in Yobe State, and Omoyajowo *et al.* (2018) in Lagos State.

The use of botanical pesticides is however one of the viable and sustainable pest management alternative that is currently gaining attention globally. There are over 2,500 known plant species from 235 families with pesticidal properties (Stevenson *et al.*, 2017). Of these, neem, *Azadirachta indica* A. Juss. (Meliaceae) followed by chili pepper, *Capsicum frutescens* L. (Solanaceae) and then garlic, *Allium sativum* L. (Amaryllidaceae) are the most recommended (Dougoud *et al.*, 2019) following promising results obtained from their usage.

Neem and garlic are among the botanical pesticides recommended by Natural Extension Partners in 20 countries within the Global Agricultural Plantwise Program with activity against different pest species (Dougoud *et al.*, 2019). Plant-based pesticides have been shown to be used in combination with synthetic pesticides for better performance (due to synergistic effects), and also for environmental and economic advantages (Anis *et al.*, 2010; Okrikata *et al.*, 2019).

Despite the extensive screenings of botanicals for the management of pests of fruits and vegetable crops (Bushra *et al.*, 2014; Abderrahmane and Lahcen, 2015), and the enormous quantity of these important pesticidal plants in Nigeria (neem and garlic in particular), literature shows that, their combination and/or compatibility with synthetic insecticides for the control of insect pests of crops, watermelon inclusive, have received little attention. This study therefore investigates, the impact of the combination of neem and garlic oils formulated biopesticide on major insect pests of watermelon and its compatibility with Magicforce® (Lambda-cyhalothrin 15g/L + Dimethoate 300 g/L).

Materials and Methods

Study Site

The study was conducted on the research field of Federal University, Wukari, Nigeria. Wukari which lies within the southern guinea savanna agro-ecological zone has N7°50'37'', E9°46'31'' coordinates and 187 m altitude. The area is characterized by a warm tropical climate, and well defined rainy- (commencing in April and ending in October with peaks in June and September), and dry-season with average annual rainfall and temperature of 1,205 mm and 26.8°C, respectively (Okrikata *et al.*, 2019).

Field Layout and Experimental Design

Watermelon (var. Sweet Sangria F₁) was sown in 36 plots (each, 5×8 m) on a ploughed and harrowed land that had not been cultivated for three cropping years. This was done during the early- and late-cropping seasons of 2020 (sowing dates: 23rd April and 25th August, respectively). The plots were grouped into four replications of nine treatments (control inclusive) in a Randomized Complete Block Design (RCBD).

The treatments applied and evaluated were: lowest field recommended dose (0.25%) of

Magicroforce®-Lambda-cyhalothrin 15 g/L + Dimethoate 300 g/L [manufactured by Anhui Zhongshen Chemical Industries Co. Ltd., China] - (0.25% MF), neem oil [manufactured by Mai Rana Islamic and Research, Nigeria] + garlic oil [manufactured by El Hawag Chemical Company, Badr City, Cairo, Egypt] emulsion (1:1, v/v) at 1% - (1% NGOE), 3% NGOE, 5% NGOE, 0.125% MF + 1% NGOE, 0.125% MF + 3% NGOE, 0.125% MF + 5% NGOE, 1% Emulsifier (2:1, v/v mixture of liquid soap manufactured by PZ cussions Nig Plc. and gum arabic solution), control (CT)-no spray.

The emulsion was prepared using the method described by Ukeh *et al.* (2007). Spraying at 400 Lha⁻¹ output with the aid of eight litre capacity Maxipro sprayer was done when the leaf beetles reached the economic injury level of five beetles/plant using visual observation (Foster, 2016; Okrikata *et al.*, 2019), and this was maintained until early fruiting stage when the experiment was terminated.

Data Collection

Sampling of Leaf Beetle Species

Sampling of leaf beetles (predominated by *A. africana*, *A. nigripennis*, *A. transversa*, *E. chrysomelina* and *M. nigeriae*) was done using a 5 cm internal diameter inlet coned modified Grizzly 2500/8 leaf blower-vac (Grizzly Gartengeräte GmbH & Co. KG, China) which was powered by a Tiger TG950DC portable generator (Agere *et al.*, 2021). On each plot, the machine was swept through the 5 m length of the middle row at an approximate walking speed of 1 m/sec between the hours of 0600-0800. The insects were collected following the method described by Agere *et al.* (2021), sorted and preserved in 70% alcohol for counting and mean populations were expressed as number/5 m length of row. Pre-treatment insect counts were taken one day before treatment while post-treatment counts were taken at the 1st, 3rd, and 7th day after treatments applications.

The change in population density (CPD) of the insects and the efficacy percentage (EF) of the treatments were assessed using the methods described by Saleem *et al.* (2019) and Henderson and Tilton (1955), respectively:

$$CPD = (X_i - X_0) / X_0 \times 100$$

where:

X_0 = pre-treatment insect counts,

X_i = post-treatment insect counts.

The CPD measures the extent of decrease/reduction (negative values), or increase (positive values) in insect density over time.

$$EF(\%) = 100 \times 1 - (T_a \times C_b / T_b \times C_a)$$

where:

T_a = post-treatment insect count,

T_b = pre-treatment insect count,

C_a = post-treatment insect count in control plots,

C_b = pre-treatment insect count in control plots.

The EF assesses the level at which the treatment suppresses the insect pests in the individual treated plots vis-à-vis the untreated (control) plots - efficiency.

Sampling of Melon Fruit Fly

At the early fruiting stage, infestation by melon fruit fly, *B. cucurbitae* was assessed. Infested fruits were harvested per plot and the number of *B. cucurbitae* larvae in them was counted after splitting the fruits open. The counts were expressed as number ($\pm$ SE) per fruit using the formula described by Barma *et al.* (2013).

Assessment of Leaf Injury and Growth Indices

Ten leaves were randomly selected per plot and from these, the proportion and severity of leaves injured were computed at 50% vegetative, 50% flowering, and 50% fruiting stages as described by Okrikata and Anaso (2008) and Okrikata *et al.* (2020) in which the leaves were scaled 0-4 for severity of injury:

0 = 0% leaf injury,

1 = 1-25% leaf injury;

2 = 26-50% leaf injury,

3 = 51-75% leaf injury,

4 = 76-100% leaf injury.

Scores obtained per plot were transformed to Attack severity (%) using the equation:

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

where:

$\sum n$ = summation of individual injury scores/plot,

N = number of scores taken/plot (= 10),

4 = highest score on the scale.

Three plants were randomly selected/plot and tagged at 6 weeks after emergence (WAE). From these, the main vine length (cm) was assessed and the number of leaves/plant was also computed.

Table 1(a). Individual and combined impact of Magicforce® and/or neem plus garlic oils derived biopesticide on a leaf beetle (*Aulacophora africana*) infestation in Watermelon at Wukari in 2020 (no./5 m row)

Treatment	PD before spray	After 1 day of spray			After 3 days of spray			After 7 days of spray		
		PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)
Early-season										
0.25% MF	4.20	0.64 ^f	-84.76	84.54	0.65 ^h	-84.52	85.70	0.64 ^h	-84.76	86.50
1% NGOE	4.08	1.44 ^c	-64.71	64.18	1.44 ^c	-64.71	67.40	1.56 ^c	-61.76	66.12
3% NGOE	4.20	1.44 ^c	-65.71	65.21	0.94 ^e	-77.62	79.33	1.14 ^d	-72.86	75.95
5% NGOE	4.05	1.37 ^d	-66.17	65.67	0.76 ^g	-81.23	82.67	0.84 ^f	-79.26	81.62
0.125% MF + 1% NGOE	4.24	0.76 ^e	-82.08	81.81	1.06 ^d	-75.00	76.91	1.16 ^d	-72.64	75.76
0.125% MF + 3% NGOE	4.48	0.75 ^c	-83.26	83.01	0.86 ^f	-80.80	82.27	1.07 ^e	-76.11	78.84
0.125% MF + 5% NGOE	4.50	0.73 ^c	-83.78	83.54	0.73 ^g	-83.78	85.01	0.75 ^g	-83.33	86.23
1% Emulsifier	4.11	3.77 ^b	-8.27	6.92	4.04 ^b	-1.70	9.2	3.93 ^b	-4.38	15.28
Control (no spray)	4.12	4.06 ^a	-1.46		4.46 ^a	8.25		4.65 ^a	12.86	
F-value (df = 8, 27)	1.18	48.48			54.54			97.91		
P-value	0.35	<0.01			<0.01			<0.01		
Late-season										
0.25% MF	5.90	1.17 ^e	-80.17	80.69	1.00 ^e	-83.05	84.12	1.59 ^d	-73.05	75.38
1% NGOE	6.04	2.79 ^b	-53.81	55.02	2.76 ^b	-54.30	57.19	3.04 ^b	-49.67	53.94
3% NGOE	5.59	2.27 ^{bc}	-59.39	60.46	1.77 ^{cd}	-68.34	70.34	2.07 ^c	-62.97	66.16
5% NGOE	6.13	1.90 ^{cd}	-69.00	69.81	1.40 ^{de}	-77.16	78.60	1.77 ^{cd}	-71.13	73.62
0.125% MF + 1% NGOE	5.49	2.22 ^{bc}	-59.56	60.63	2.19 ^{bc}	-60.11	62.63	2.65 ^b	-51.73	55.90
0.125% MF + 3% NGOE	6.06	1.65 ^d	-72.77	73.49	1.75 ^{cd}	-71.12	72.95	2.12 ^c	-65.02	68.04
0.125% MF + 5% NGOE	5.90	1.53 ^{de}	-74.07	74.75	1.44 ^{de}	-75.59	77.14	1.78 ^{cd}	-69.83	72.43
1% Emulsifier	5.83	5.96 ^a	2.23	0.46	5.85 ^a	0.34	6.00	6.14 ^a	5.32	3.77
Control (no spray)	5.93	6.09 ^a	2.70		6.33 ^a	6.75		6.49 ^a	9.44	
F-value (df = 8, 27)	0.60	79.85			65.12			88.91		
P-value	0.77	<0.01			<0.01			<0.01		

PD = Population density, CPD = Change in population density, EF = Efficacy percentage. Means are values of four replications; Means 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 1(b). Individual and combined impact of Magicforce® and/or neem plus garlic oils derived biopesticide on a leaf beetle (*Asbecesta nigripennis*) infestation in Watermelon at Wukari in 2020 (no./5 m row)

Treatment	PD before spray	After 1 day of spray			After 3 days of spray			After 7 days of spray		
		PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)
Early-season										
0.25% MF	0.79	0.31 ^c	-60.76	84.23	0.31 ^e	-60.76	85.37	0.32 ^f	-59.49	85.56
1% NGOE	0.82	0.70 ^b	-14.63	65.69	0.71 ^b	-13.41	67.73	0.78 ^c	-4.88	66.09
3% NGOE	0.79	0.70 ^b	-11.39	64.38	0.46 ^{cd}	-41.77	78.30	0.57 ^d	-27.85	74.28
5% NGOE	0.81	0.69 ^b	-14.81	65.76	0.38 ^{de}	-53.09	82.51	0.42 ^e	-48.15	81.51
0.125% MF + 1% NGOE	0.85	0.38 ^c	-55.29	82.03	0.54 ^c	-36.47	76.32	0.56 ^d	-34.12	76.51
0.125% MF + 3% NGOE	0.92	0.37 ^c	-59.78	83.83	0.44 ^{cd}	-52.17	82.17	0.53 ^d	-42.39	79.46
0.125% MF + 5% NGOE	0.99	0.35 ^c	-64.65	85.79	0.36 ^{de}	-63.64	86.45	0.38 ^{ef}	-61.62	86.31
1% Emulsifier	0.82	1.87 ^a	128.05	8.33	2.02 ^a	146.34	8.18	1.95 ^b	137.80	15.22
Control (no spray)	0.82	2.04 ^a	148.78		2.20 ^a	168.29		2.30 ^a	180.49	
F-value (<i>df</i> = 8, 27)	0.46	119.23			126.90			148.97		
P-value	0.87	<0.01			<0.01			<0.01		
Late-season										
0.25% MF	2.95	0.59 ^e	-80.00	80.46	0.50 ^e	-83.05	84.12	0.79 ^d	-73.22	74.51
1% NGOE	3.02	1.39 ^b	-53.97	55.03	1.38 ^b	-54.30	57.19	1.52 ^b	-49.67	53.86
3% NGOE	2.80	1.13 ^{bc}	-59.64	60.57	0.89 ^{cd}	-68.21	70.22	1.03 ^c	-63.21	66.28
5% NGOE	3.07	0.95 ^{cd}	-69.06	69.77	0.70 ^d	-77.20	78.64	0.89 ^{cd}	-71.01	73.43
0.125% MF + 1% NGOE	2.75	1.11 ^{bc}	-59.64	60.57	1.10 ^{bc}	-60.00	62.52	1.33 ^b	-51.64	55.67
0.125% MF + 3% NGOE	3.03	0.83 ^d	-72.60	73.24	0.87 ^{cd}	-71.29	74.00	1.06 ^c	-65.01	67.93
0.125% MF + 5% NGOE	2.95	0.77 ^d	-73.90	74.50	0.72 ^d	-75.59	77.13	0.89 ^{cd}	-69.83	72.34
1% Emulsifier	2.92	2.99 ^a	2.40	-0.04	2.93 ^a	0.34	5.98	3.07 ^a	5.14	3.62
Control (no spray)	2.97	3.04 ^a	2.36		3.17 ^a	6.73		3.24 ^a	9.09	
F-value (<i>df</i> = 8, 27)	0.59	78.47			60.80			80.91		
P-value	0.75	<0.01			<0.01			<0.01		

PD = Population density, CPD = Change in population density, EF = Efficacy percentage. Means are values of four replications; Means 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 1(c). Individual and combined impact of Magicforce® and/or neem plus garlic oils derived biopesticide on a leaf beetle (*Asbecesta transversa*) infestation in Watermelon at Wukari in 2020 (no./5 m row)

Treatment	PD before spray	After 1 day of spray			After 3 days of spray			After 7 days of spray		
		PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)
Early-season										
0.25% MF	0.40	0.15 ^c	-62.50	84.93	0.16 ^d	-60.00	85.09	0.16 ^c	-60.00	85.09
1% NGOE	0.41	0.35 ^b	-14.63	65.69	0.36 ^b	-12.20	67.27	0.39 ^c	-4.88	64.55
3% NGOE	0.40	0.35 ^b	-12.50	64.83	0.23 ^{cd}	-42.50	78.57	0.28 ^d	-30.00	73.91
5% NGOE	0.41	0.34 ^b	-17.07	66.67	0.19 ^{cd}	-53.66	82.73	0.21 ^d	-48.78	80.91
0.125% MF + 1% NGOE	0.42	0.19 ^c	-54.76	81.82	0.27 ^c	-35.71	76.04	0.28 ^d	-33.33	75.15
0.125% MF + 3% NGOE	0.46	0.18 ^c	-60.87	84.27	0.22 ^{cd}	-52.17	82.17	0.26 ^d	-43.47	78.93
0.125% MF + 5% NGOE	0.49	0.17 ^c	-65.31	86.05	0.18 ^{cd}	-63.27	86.31	0.19 ^e	-61.22	85.55
1% Emulsifier	0.41	0.93 ^a	126.83	8.82	1.01 ^a	146.34	8.18	0.98 ^b	139.02	10.91
Control (no spray)	0.41	1.02 ^a	148.78		1.10 ^a	168.29		1.10 ^a	161.90	
F-value (df = 8, 27)	0.42	19.23			103.05			136.29		
P-value	0.90	<0.01			<0.01			<0.01		
Late-season										
0.25% MF	1.48	0.29 ^d	-80.41	80.92	0.25 ^e	-83.11	84.18	0.40 ^d	-72.97	75.31
1% NGOE	1.51	0.70 ^b	-53.64	54.86	0.69 ^b	-54.30	57.20	0.76 ^b	-49.69	54.02
3% NGOE	1.40	0.57 ^{bc}	-59.29	60.36	0.44 ^{cd}	-68.57	70.56	0.52 ^{cd}	-62.86	66.07
5% NGOE	1.53	0.47 ^{cd}	-69.28	70.09	0.35 ^{de}	-77.12	78.57	0.44 ^{cd}	-71.24	73.73
0.125% MF + 1% NGOE	1.37	0.55 ^{bc}	-59.85	60.91	0.55 ^{bc}	-59.85	62.39	0.66 ^{bc}	-51.82	55.99
0.125% MF + 3% NGOE	1.52	0.41 ^{cd}	-73.03	73.74	0.44 ^{cd}	-71.05	72.88	0.53 ^{cd}	-65.13	68.36
0.125% MF + 5% NGOE	1.48	0.38 ^{cd}	-74.32	75.00	0.36 ^{de}	-75.67	77.22	0.44 ^{cd}	-70.27	72.84
1% Emulsifier	1.46	1.49 ^a	2.59	0.63	1.47 ^a	0.68	5.69	1.54 ^a	5.48	3.64
Control (no spray)	1.48	1.52 ^a	2.70		1.58 ^a	6.76		1.62 ^a	9.46	
F-value (df = 8, 27)	0.59	68.13			65.12			78.67		
P-value	0.78	<0.01			<0.01			<0.01		

PD = Population density, CPD = Change in population density, EF = Efficacy percentage. Means are values of four replications; Means 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 1(d). Individual and combined impact of Magicforce® and/or neem plus garlic oils derived biopesticide on a leaf beetle (*Epilachna chrysomelina*) infestation in Watermelon at Wukari in 2020 (no./5 m row)

Treatment	PD before spray	After 1 day of spray			After 3 days of spray			After 7 days of spray		
		PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)
Early-season										
0.25% MF	0.22	0.08 ^c	-63.64	85.06	0.01 ^d	-95.45	98.34	0.09 ^e	-59.09	86.36
1% NGOE	0.22	0.19 ^b	-13.64	64.53	0.20 ^b	-9.09	66.81	0.21 ^c	-4.55	66.74
3% NGOE	0.22	0.19 ^b	-13.64	64.53	0.13 ^{cd}	-40.90	78.43	0.16 ^d	-27.27	74.66
5% NGOE	0.22	0.19 ^b	-13.63	64.52	0.11 ^{cd}	-50.00	81.75	0.12 ^{de}	-45.45	80.99
0.125% MF + 1% NGOE	0.23	0.11 ^c	-52.17	80.36	0.15 ^c	-34.78	76.19	0.16 ^d	-30.43	75.76
0.125% MF + 3% NGOE	0.25	0.10 ^c	-60.00	83.57	0.13 ^{cd}	-48.00	81.02	0.15 ^d	-40.00	79.09
0.125% MF + 5% NGOE	0.27	0.10 ^c	-62.92	84.79	0.10 ^{cd}	-62.96	86.48	0.11 ^e	-59.26	85.80
1% Emulsifier	0.23	0.51 ^a	121.74	8.93	0.57 ^a	147.83	9.52	0.56 ^b	143.48	15.15
Control (no spray)	0.23	0.56 ^a	143.48		0.63 ^a	173.91		0.66 ^a	186.96	
F-value (<i>df</i> = 8, 27)	0.56	68.42			103.05			136.29		
P-value	0.80	<0.01			<0.01			<0.01		
Late-season										
0.25% MF	0.81	0.16 ^e	-80.25	80.95	0.14 ^e	-82.72	83.91	0.22 ^d	-72.84	75.28
1% NGOE	0.83	0.38 ^b	-54.21	55.85	0.38 ^b	-54.22	57.37	0.42 ^b	-49.40	53.95
3% NGOE	0.77	0.31 ^{bc}	-59.74	61.18	0.24 ^{cd}	-68.83	70.98	0.28 ^c	-63.64	66.91
5% NGOE	0.84	0.26 ^{cd}	-69.05	70.15	0.19 ^{de}	-77.38	78.94	0.24 ^{cd}	-71.43	74.00
0.125% MF + 1% NGOE	0.75	0.31 ^{bc}	-58.66	60.14	0.30 ^{bc}	-60.00	62.76	0.36 ^b	-52.00	56.31
0.125% MF + 3% NGOE	0.83	0.23 ^d	-72.29	73.28	0.24 ^{cd}	-71.08	73.08	0.29 ^c	-65.06	68.20
0.125% MF + 5% NGOE	0.81	0.21 ^{de}	-74.04	75.00	0.20 ^{de}	-75.31	77.01	0.24 ^{cd}	-70.37	73.03
1% Emulsifier	0.80	0.82 ^a	2.50	1.16	0.81 ^a	1.25	5.73	0.84 ^a	5.00	4.44
Control (no spray)	0.81	0.84 ^a	3.70		0.87 ^a	7.41		0.89 ^a	9.88	
F-value (<i>df</i> = 8, 27)	0.60	79.85			65.11			88.91		
P-value	0.77	<0.01			<0.01			<0.01		

PD = Population density, CPD = Change in population density, EF = Efficacy percentage. Means are values of four replications; Means 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 1(e). Individual and combined impact of Magicforce® and/or neem plus garlic oils derived biopesticide on a leaf beetle (*Monolepta nigrae*) infestation in Watermelon at Wukari in 2020 (no./5 m row)

Treatment	PD before spray	After 1 day of spray			After 3 days of spray			After 7 days of spray		
		PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)	PD	CPD (%)	EF (%)
Early-season										
0.25% MF	0.99	0.38 ^c	-61.62	84.50	0.39 ^b	-60.61	85.25	0.40 ^e	-59.6-	85.50
1% NGOE	1.02	0.88 ^b	-13.72	65.15	0.89 ^b	-12.76	67.32	0.98 ^c	-3.92	65.52
3% NGOE	0.99	0.87 ^b	-12.12	64.50	0.58 ^b	-41.41	78.06	0.71 ^d	-28.28	74.26
5% NGOE	1.01	0.86 ^b	-14.85	65.61	0.48 ^b	-52.48	82.20	0.53 ^{de}	-47.52	81.17
0.125% MF + 1% NGOE	1.06	0.48 ^c	-54.72	81.71	0.67 ^b	-36.79	76.33	0.70 ^d	-33.92	76.30
0.125% MF + 3% NGOE	1.14	0.46 ^c	-59.65	83.70	0.55 ^b	-51.75	81.93	0.66 ^d	-42.15	79.22
0.125% MF + 5% NGOE	1.23	0.44 ^c	-64.23	85.55	0.44 ^b	-64.23	86.60	0.48 ^e	-62.50	85.99
1% Emulsifier	1.03	2.34 ^a	127.18	8.24	2.52 ^a	144.66	8.36	2.44 ^b	136.89	14.98
Control (no spray)	1.03	2.55 ^a	147.57		2.75 ^a	166.99		2.87 ^a	178.64	
F-value (df = 8, 27)	0.46	119.23			60.09			36.20		
P-value	0.89	<0.01			<0.01			<0.01		
Late-season										
0.25% MF	3.69	0.73 ^e	-80.22	80.69	0.62 ^e	-83.20	84.26	0.99 ^c	-73.17	75.48
1% NGOE	3.78	1.74 ^b	-53.97	55.06	1.72 ^b	-54.50	57.37	1.90 ^b	-49.74	54.07
3% NGOE	3.49	1.42 ^{bc}	-59.31	60.28	1.11 ^{cd}	-68.19	70.20	1.29 ^c	-63.04	66.22
5% NGOE	3.83	1.19 ^{cd}	-68.93	68.67	0.87 ^{de}	-77.28	78.72	1.11 ^c	-71.02	73.52
0.125% MF + 1% NGOE	3.43	1.39 ^{bc}	-59.48	60.44	1.37 ^{bc}	-60.06	62.58	1.66 ^b	-51.60	55.78
0.125% MF + 3% NGOE	3.79	1.03 ^d	-72.82	73.47	1.09 ^{cd}	-71.24	73.06	1.33 ^c	-64.91	67.93
0.125% MF + 5% NGOE	3.69	0.96 ^{de}	-73.98	75.00	0.90 ^{de}	-75.61	77.15	1.11 ^c	-69.92	72.51
1% Emulsifier	3.64	3.72 ^a	2.20	0.22	3.65 ^a	0.27	6.06	3.84 ^a	5.49	3.60
Control (no spray)	3.71	3.80 ^a	2.43		3.96 ^a	6.74		4.06 ^a	9.43	
F-value (df = 8, 27)	0.50	70.75			65.11			90.74		
P-value	0.67	<0.01			<0.01			<0.01		

PD = Population density, CPD = Change in population density, EF = Efficacy percentage. Means are values of four replications; Means followed by the same superscript letter(s) within a column are not significantly different using Student-Newman Keul's (SNK) test ($p \leq 0.05$)

Assessment of Proportion of Plants Reaching Maturity and Yield Parameter

The proportion of plants reaching maturity (PPRM) was computed as described by Okrikata *et al.* (2020). At the early fruiting stage, the number of fruits/treatment were counted and from these, the proportion of fruits damaged (cracked, discolored, infected by blossom end rot, insect damaged and/or misshapen) was also computed.

Analysis of Data

Data collected were subjected to one way variance analysis and significantly different treatment means were separated by Student Newman Keul's (SNK) test at 5% level of probability. However, in order to normalize the data collected and to meet the assumptions of parametric tests; count data were subjected to square root transformation while proportions were log transformed before they were subjected to analysis of variance.

Results and Discussion

Individual and Combined Impact of Magicforce® and/or Neem Plus Garlic Oils Derived Biopesticide on Density Of Leaf Beetle Species

Tables 1(a-e) shows that the differences in population density of leaf beetle species (*A. africana*, *A. nigripennis*, *A. transversa*, *E. chrysomelina* and *M. nigeriae*) across the treatment plots before the treatments were imposed were due to random variations ($p > 0.05$) in both the early- and late-season crop. However, the reverse ($p < 0.01$) was observed post-treatment.

Across the post-spray sampling times of both seasons, density of leaf beetles were least ($p < 0.01$) in 0.25% MF treated plots and was in most instances, statistically comparable with infestations in 0.125% MF + 5% NGOE treated plots.

Tables 1(a-e) also shows that, while CPD ranged from 3.92-95.45%, the EF of the insecticide treatments were more than 50% across the sampling days of both seasons.

For *A. africana*, in the early-season crop, 0.25% MF had the highest population reduction (range: 84.52-84.76%) and efficiency (range: 84.54-86.50%). This was followed by 0.125% MF + 5% NGOE with corresponding range values of 83.33-83.78%, and 83.54-86.23%. In the late-season crops, a similar trend plays out as, 0.25% MF treated plots had the highest population decrease (range: 73.05-83.05%) and efficiency (range: 75.38-84.12%). Also followed by 0.125% MF + 5% NGOE with respective values of 69.83-75.59% and 72.43-77.14% (Table 1(a)). Table 1(a) also shows that, of all the treatments sprayed, 1% emulsifier had the least efficiency (range: 0.46-15.28%). A largely similar trend indicating the superiority of either 0.25% MF or 0.125% MF + 5% NGOE over the other insecticidal treatments was shown across seasons and leaf beetle species (Tables 1(a-e)).

Overall, MF + NGOE (pooled data of 0.125% MF + 1, 3, and 5% NGOE) was 1.15 and 1.06x more suppressive and 1.14 and 1.05x more efficient than sole NGOE (pooled data of 1, 3, and 5% NGOE) with respect to leaf beetles in the early- and late-season crop, respectively. Corresponding values of sole MF (0.25% MF) over sole NGOE was 1.20 and 1.25x, and 1.19 and 1.23x (Tables 1(a-e)).

Individual and Combined Impact of Magicforce® and/or Neem Plus Garlic Oils Derived Biopesticide on a Fruit Fly Density

Table 2 shows that fruits in plots treated with 0.25% MF had the least density of *B. cucurbitae* larvae (1.75 ± 0.06 and 1.40 ± 0.19 for early- and late-season crop, respectively) which were statistically at par with those in 5% NGOE, 0.125% MF + 3% NGOE and 0.125% MF + 5% NGOE in the early-season crop but not with 0.125% MF + 3% NGOE in the late-season crop. Higher and statistically

Table 2. Individual and combined impact of Magicforce® and/or neem plus garlic oils derived biopesticide on *Bactrocera cucurbitae* infestation in Watermelon at Wukari in 2020

Treatment	<i>B. cucurbitae</i> larvae/fruit	
	Early-season	Late-season
0.25% MF	1.75 ± 0.06^c	1.40 ± 0.19^f
1% NGOE	3.09 ± 0.40^b	3.63 ± 0.38^b
3% NGOE	2.80 ± 0.29^{bc}	3.20 ± 0.29^{bc}
5% NGOE	2.15 ± 0.12^{cde}	1.93 ± 0.22^{def}
0.125% MF + 1% NGOE	2.53 ± 0.17^{bcd}	2.58 ± 0.13^{cd}
0.125% MF + 3% NGOE	2.35 ± 0.17^{bcde}	2.28 ± 0.19^{de}
0.125% MF + 5% NGOE	1.96 ± 0.03^{de}	1.70 ± 0.17^{ef}
1% Emulsifier	7.37 ± 0.15^a	6.34 ± 0.31^a
Control (no spray)	7.37 ± 0.33^a	6.17 ± 0.04^a
F-value (df = 8, 27)	79.19	49.53
P-value	<0.01	<0.01

Means ($\pm$ 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 3. Individual and combined impact of Magicforce® and/or neem plus garlic derived biopesticide on leaf damage and growth of Watermelon at Wukari in 2020

Treatment	Proportion of leaves injured (%)	Severity of leaves injured (%)	Main vine length at 6 WAE (cm)	Number of leaves/plant at 6 WAE
Early-season				
0.25% MF	8.34±0.96 ^f	4.55±0.08 ^f	289.45±6.02 ^a	98.07±1.38 ^a
1% NGOE	20.84±2.10 ^b	15.10±0.18 ^b	186.42±6.28 ^d	40.32±1.91 ^f
3% NGOE	14.17±0.84 ^{bcd}	7.50±0.24 ^d	226.13±7.05 ^c	58.10±2.78 ^e
5% NGOE	9.17±0.83 ^{ef}	5.56±0.11 ^{ef}	264.50±4.96 ^b	70.47±1.26 ^d
0.125% MF + 1% NGOE	16.67±1.36 ^{bc}	10.56±0.13 ^c	237.85±5.89 ^c	68.88±1.55 ^d
0.125% MF + 3% NGOE	13.33±1.36 ^{cde}	6.40±0.08 ^{de}	257.80±5.64 ^b	78.04±1.37 ^c
0.125% MF + 5% NGOE	10.00±1.36 ^{def}	4.54±0.11 ^f	279.60±5.73 ^{ab}	86.13±1.30 ^b
1% Emulsifier	46.67±1.93 ^a	30.30±4.08 ^a	141.55±3.55 ^e	28.53±0.24 ^g
Control (no spray)	46.67±7.07 ^a	30.61±4.01 ^a	140.75±3.75 ^e	28.30±0.56 ^g
F-value (df = 8, 27)	31.76	30.49	103.85	269.99
P-value	<0.01	<0.01	<0.01	<0.01
Late-season				
0.25% MF	9.17±0.83 ^e	4.69±0.09 ^g	215.19±0.68 ^a	131.98±4.08 ^a
1% NGOE	24.17±2.85 ^b	19.99±0.42 ^b	162.75±3.04 ^d	46.26±2.98 ^f
3% NGOE	16.67±1.36 ^c	9.30±0.45 ^d	181.74±5.44 ^c	72.32±4.40 ^e
5% NGOE	10.83±1.59 ^{de}	6.41±0.17 ^{ef}	196.67±1.16 ^b	94.85±3.24 ^{cd}
0.125% MF + 1% NGOE	19.17±2.10 ^{bc}	12.40±0.20 ^c	187.63±1.38 ^c	88.90±3.18 ^d
0.125% MF + 3% NGOE	14.17±0.84 ^{cd}	7.00±0.22 ^e	201.14±1.67 ^b	101.91±3.79 ^c
0.125% MF + 5% NGOE	10.83±0.84 ^{de}	5.39±0.21 ^{fg}	209.84±0.51 ^a	114.75±3.68 ^b
1% Emulsifier	50.83±2.85 ^a	41.44±6.11 ^a	105.21±0.65 ^e	37.08±0.69 ^g
Control (no spray)	51.67±3.11 ^a	42.66±5.77 ^a	103.93±1.35 ^e	36.09±0.89 ^g
F-value (df = 8, 27)	42.23	29.16	334.91	114.70
P-value	<0.01	<0.01	<0.01	<0.01

WAE = Weeks after emergence, Means (±SE) 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≤0.05)

comparable infestations were observed in control and 1% emulsifier treated plots in both seasons. The results further show that, sole MF treatment suppressed infestation by *B. cucurbitae* by 72.76% relative to the control in the early-season crop. Suppression rate by sole NGOE, and MF + NGOE were 63.64 and 69.06%, respectively. The corresponding values for the late-season crop were 77.31, 52.67, and 64.51%, respectively.

Synthetic pesticides with its attendant environmental, human health implications have largely been the pest control technique against watermelon pests (Lima *et al.*, 2014). In the study area, as has also been reported in other areas around the world, leaf beetle species are major pests of watermelon (Foster and Brust, 1995; Okrikata *et al.*, 2019). Aside vectoring pathogens, the adults are serious defoliators with the capacity of causing 100% crop loss. Therefore, quick detection and application of pest management strategies is critical in watermelon production.

Individual and Combined Impact of Magicforce® and/or Neem Plus Garlic Oils Derived Biopesticide on a Leaf Damage and Growth of Watermelon

Table 3 shows significant differences among the treatments with respect to leaf damage (proportion and severity) in both seasons. Higher and statistically comparable leaf damage

(proportion and severity) were observed in leaves in control plots and those sprayed with 1% emulsifier.

The lowest proportion of leaf damage was observed in crops sprayed with 0.25% MF which was statistically comparable with 5% NGOE and 0.125% MF + 5% NGOE in both seasons. The pattern of severity of leaf injury was similar (Table 3).

Table 3 also shows significant differences (p<0.01) among the treatments with respect to vine length and number of leaves in both seasons. The shortest vine length was recorded in control plots (140.75±3.75 and 103.93±1.35 cm for early- and late-season crop, respectively) which were comparable with those of crops in 1% emulsifier treated plots. The longest vine length was observed in 0.25% MF sprayed plots (289.45±6.02 and 215.19±0.68 cm for early- and late-season crop, respectively) which do not differ significantly from those of 0.125% MF + 5% NGOE sprayed crops. On the early-season crop, 0.25% MF thus had 2.06x longer vines over control. Values for sole NGOE and MF + NGOE were 1.60 and 1.83x longer. Corresponding values for the late-season crop were 2.07, 1.74, and 1.92x, respectively.

With respect to number of leaves/plant, crops in 0.25% MF sprayed plots had the highest number of leaves/plant. This was followed by those in 0.125% MF + 5% NGOE treated plots. Crops in 1% NGOE treated plots had the fewest number of leaves

Table 4. Individual and combined impact of Magicforce® and/or neem plus garlic derived biopesticide on yield related parameters of Watermelon at Wukari in 2020

Treatment	Proportion of plants reaching maturity (%)	Number of fruits/ha	Proportion of fruits damaged (%)
Early-season			
0.25% MF	90.69±0.47 ^{ab}	17165.16±488.17 ^b	5.21±0.16 ^f
1% NGOE	62.00±3.29 ^c	10137.79±275.29 ^e	22.72±1.14 ^b
3% NGOE	75.17±2.81 ^b	13858.68±158.22 ^d	16.69±0.77 ^c
5% NGOE	82.91±0.68 ^{ab}	15576.75±738.80 ^c	9.91±1.47 ^d
0.125% MF + 1% NGOE	79.38±1.91 ^{ab}	15607.75±455.11 ^c	14.46±0.92 ^c
0.125% MF + 3% NGOE	86.07±0.61 ^{ab}	16336.70±235.57 ^{bc}	10.99±0.42 ^d
0.125% MF + 5% NGOE	96.98±1.66 ^a	18615.06±457.00 ^a	7.15±0.72 ^e
1% Emulsifier	28.63±3.45 ^d	1585.80±52.06 ^f	66.73±0.42 ^a
Control (no spray)	31.07±2.89 ^d	1547.26±48.26 ^f	68.39±0.81 ^a
F-value (df = 8, 27)	70.57	288.07	139.67
P-value	<0.01	<0.01	<0.01
Late-season			
0.25% MF	90.05±3.69 ^a	15708.50±1411.93 ^a	5.01±0.36 ^f
1% NGOE	59.56±3.89 ^b	7596.94±275.51 ^b	30.68±0.68 ^b
3% NGOE	71.03±2.45 ^{ab}	12896.14±382.32 ^a	21.92±1.02 ^c
5% NGOE	79.45±0.43 ^a	14413.84±1162.40 ^a	10.83±1.60 ^d
0.125% MF + 1% NGOE	75.75±2.25 ^a	13946.24±723.80 ^a	19.01±0.61 ^c
0.125% MF + 3% NGOE	81.51±1.02 ^a	14525.08±1073.87 ^a	12.97±1.09 ^d
0.125% MF + 5% NGOE	87.73±0.85 ^a	16404.02±1526.25 ^a	7.92±0.65 ^e
1% Emulsifier	27.09±3.37 ^c	1417.86±85.69 ^c	86.44±1.64 ^a
Control (no spray)	28.84±3.12 ^c	1392.90±82.02 ^c	90.13±0.04 ^a
F-value (df = 8, 27)	53.07	37.27	182.14
P-value	<0.01	<0.01	<0.01

Means (±SE) 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 ($p \leq 0.05$)

among the insecticide treated crops. While MF produced crops with 3.47x more leaves than control in the early-season crop, sole NGOE and MF + NGOE were 1.99 and 2.74 more productive, respectively. Corresponding values for the late-season crop were 3.66, 1.97, and 2.82, respectively (Table 3).

Individual and Combined Impact of Magicforce® and/or Neem Plus Garlic Oils Derived Biopesticide on Yield-Related Parameters

Table 4 shows that approximately 30% of the crops reached maturity without insecticide intervention. Proportion of plants that reached maturity stage in 1% emulsifier sprayed plots was comparable to those in control plots. Table 4 also indicates that overall, 62-96% of the insecticide treated crops reached maturity and was topmost in 0.125% + 5% NGOE treated crops in the early-crop (96.98±1.66) and in 0.25% MF treated plots in the late-season crop (90.05±3.69).

Table 4 further shows that 0.125% MF + 5% NGOE resulted in the production of the highest number of fruits in both seasons. The insecticide treatments resulted in 6.55-12.03x more fruits than control in the early-season crop, and 5.45-11.78x for the late-season crop.

Table 4 also shows that higher and comparable proportions of fruits were damaged in the control plots and those sprayed with 1% emulsifier (range:

66-90%). Among the insecticide treatments, 0.25% MF had the least proportion of damaged fruits (5.21±0.16 and 5.01±0.36% in the early- and late-season crop, respectively). This was followed by 0.125% MF + 5% NGOE with 7.15±0.72 and 7.92±0.65% fruit damage in the early- and late-season crop, respectively. Conversely, the highest fruit damage among the insecticide treatments were observed in 1% NGOE treated plots (22.72±1.14 and 30.68±0.68% in the early- and late-season crop, respectively). This was followed by 3% NGOE sprayed plots on which 16.69±0.77 and 21.92±1.02% fruits got damaged in the early- and late-season crop, respectively.

Neem oil contains a minimum of 100 bioactive compounds reported to be effective against over 550 pest species (Anuradha and Annadurai, 2008). The major ones are the triterpenes also known as limonoids of which azadirachtin is the most important (Campos *et al.*, 2016). Neem has contact and systemic properties (Okrikata and Anaso, 2008) which inhibits feeding, disrupts juvenile hormone functions and suppresses growth and fertility of arthropod pests (Saleem *et al.*, 2019). Though, it also has pathogenicidal properties, findings shows it is less, if at all toxic to pollinators and natural enemies (Mkindi *et al.*, 2017; Dougoud *et al.*, 2019). Garlic oil, on the other hand, possesses an alliaceous compound, allyl-propyl-disulphide which is very pungent and has fumigant, repellent, anti-feedant,

insecticidal properties on a number of pest species (Aziza and Asma, 2015), and also bactericidal in action (Prowse *et al.*, 2006). However, the active ingredient of garlic is known to degrade very quickly (Koch and Lawson, 1996). Garlic is non-selective and as such, it is broad-spectrumed in effect (Xavier *et al.*, 2015).

Observations revealed that none of the rates of sole NGOE and its combination with Magicforce® showed any symptom of phytotoxicity on the crop. However, that all the rates of the insecticidal treatments used suppressed pest infestation was evident. This highlights the efficacy and compatibility of neem with garlic oil, and also with Magicforce®. Pest suppressing effects of the combination of MF and NGOE, and also 5% NGOE largely matched that of sole MF (0.25%). This buttresses the findings of Štefanidesová *et al.* (2017) which showed that botanical pesticides are suppressive of agricultural pests to extents comparable and in certain instances, more efficacious than synthetic chemicals owing to their varied mechanisms of action.

The combination of the synthetic pesticide (Magicforce®) with neem plus garlic oil emulsion, improved the efficacy of the biopesticide formulation. Each of the key biopesticide constituent (neem and garlic oils) has been shown to be efficient in field pest management (Plata-Rueda *et al.*, 2017). Neem-based pesticides have been successful in the control of blattodean, hemipteran, lepidopteran and thysanopteran insect pests (Aziz *et al.*, 2013; Okrikata *et al.*, 2019).

Inclusion of adjuvants aimed at improving the pesticide efficiency via longer persistence and better coverage is a common activity in pesticide formulation (Witt, 2012). Soap (bar flakes or liquid) is the most commonly used adjuvant/emulsifier. Though, laboratory trials showed that small concentrations (approximately 1 ml/l) of domestic soap prepared with distilled water may be highly insecticidal (Lee *et al.*, 2006), field trials showed otherwise (Amoabeng *et al.*, 2014). We however found that, the emulsifier used (liquid soap+gum arabic solution) was not effective in suppressing leaf beetles (*A. africana*, *A. nigripennis*, *A. transversa*, *E. chrysomelina* and *M. nigeriae*) and *B. cucurbitae* infestations at 1%. Nonetheless, it positively influenced the surface tension of the oil mixture by promoting miscibility with water which apparently enhanced coverage and, efficacy of the active ingredient/formulation. Aside causing mortality of insects, the efficacy of the formulated biopesticide as observed by reason of lower leaf damage and fruit damage, higher proportion of plants that reached maturity, and number of fruits produced in relation to the control could be attributed to the feeding

detering activities of the biopesticide constituents, particularly, neem.

A major shortcoming of botanicals however, is the need for frequent applications as a result of their slow action and rapid degradation. This can however be addressed through combination with synthetic insecticide, where compatible. The improved efficacy of NGOE when combined with Magicforce® is indicative of compatibility.

Conclusions

Meaningful fruit production without pest control intervention was hardly achievable in watermelon. Application of Magicforce® at 0.25% which is the lowest field recommended dose was efficient in watermelon pest management. However, 0.125% MF + 5% NGOE was the most efficient treatment as it resulted in significantly lower pest (*A. africana*, *A. nigripennis*, *A. transversa*, *E. chrysomelina* and *M. nigeriae* and *B. cucurbitae*) infestation, lesser leaf injury, more vigour growth and the highest number of fruit production when compared with sole treatments (ie., MF and NGOE). This suggests compatibility. Hence, weekly spraying of same is recommended.

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