



EFFECTS OF SOME BRASSICA AND MORINGA LEAVES IN THE MANAGEMENT OF *Meloidogyne* spp. INFECTING OKRA (*Abelmoschus esculentus* L. MOENCH) IN MAIDUGURI, BORNO STATE, NIGERIA

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ABSTRACT

Root-knot nematodes (*Meloidogyne* spp.) are a major constraint to okra (*Abelmoschus esculentus*) production, causing significant yield losses due to root gall and impaired nutrient uptake. Conventional nematicides are effective but raise environmental and health concerns, necessitating eco-friendly alternatives for sustainable nematode management. This study investigated the nematicidal potential of selected Brassica species (cabbage and broccoli leaves) and Moringa oleifera leaf in suppressing *Meloidogyne* spp. infecting okra in Maiduguri, Borno State, Nigeria. The study was focused on only one species of plant parasitic nematode i.e. *Meloidogyne* spp. infecting okra. The study was conducted at the Teaching and Research Farm of the Faculty of Agriculture, University of Maiduguri, Maiduguri, Borno state during the 2018 and 2019 rainy season. The treatments are 40 and 80 kg/ha cabbage leaves, broccoli leaves, moringa leaves, carbofuran 3 G applied at the rate of 2 kg a. i./ha as a check and untreated plots served as control. The treatments were laid out in a Randomized Complete Block Design (RCBD) with eight treatments replicated three times. Data were collected on shoot height, root length, fresh and dry shoot weight, fresh and dry root weight, fruit weight, gall index, gross margin, initial and final nematode population. Among the bio-fumigants, the highest reduction in nematode population was recorded under cabbage leaves applied at 80kg/ha during the 2018 and 2019 wet season. The minimal occurrence of root galls and highest yield increase were recorded in plots treated with cabbage leaves at the rate of 80 kg/ha in both years. Based on the results of this investigation, it was concluded that in both trials the tested plant bio-fumigant leaves (more especially cabbage leaves at the rate of 80 kg/ha) proved to be potentially promising for the management of root-knot nematodes infesting okra. From this investigation, it was determined that the examined plant biofumigant leaves show significant potential in managing *Meloidogyne* species infecting okra crops.

Keyword: Okra, Brassica, Moringa, Management, Biofumigation

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INTRODUCTION

Okra (*Abelmoschus esculentus*) is an essential vegetable crop valued for its nutritional benefits and industrial applications. According to FAO (2019), the global okra production is estimated at 9.95 million tons, with India accounting for the largest share at 62.07%, followed by Nigeria

at 18.28% and Mali at 5.15%. In 2019, Nigeria's total okra output reached approximately 1,819,018 tons (FAOSTAT, 2019), highlighting its significant role in global okra cultivation. It is rich in vitamins, minerals, antioxidants, and dietary fiber, contributing to human health by supporting digestion, enhancing immunity, and preventing chronic diseases. In addition to its role in human nutrition, okra has industrial significance, particularly in the production of food additives, pharmaceuticals, and biodegradable polymers due to its mucilage properties. Its economic importance extends to global agricultural trade, supporting farmers and food industries worldwide.

Despite its benefits, okra cultivation is threatened by root-knot nematodes (*Meloidogyne* spp.), which cause severe crop damage and yield reduction. These nematodes invade plant roots, inducing gall formation that disrupts water and nutrient uptake, leading to stunted growth and diminished productivity. Nematode infections in okra fields contribute to global agricultural losses, affecting food security and economic sustainability. The impact of *Meloidogyne* spp. on vegetable production is significant, with estimated yield losses ranging from 5% to 43% (Gautam *et al.*, 2014). Specifically, *Meloidogyne* spp. have been reported to reduce okra (*Abelmoschus esculentus*) yields by up to 27% (Anwar and McKenry, 2012). In cases of severe infestation, particularly in soils with prolonged monocropping of okra, yield losses can reach as high as 80% (Singh and Kumar, 2015).

Conventional management of *Meloidogyne* spp. often relies on chemical nematicides, which pose environmental and health risks. Consequently, researchers have focused on sustainable control methods to mitigate nematode impact while preserving ecological balance. Studies have demonstrated that plants in the *Brassica* family contain bioactive compounds, notably glucosinolates, which degrade into nematicidal substances capable of suppressing nematode populations (Fatoki and Fawole, 2000). *Brassica* species serve as biofumigants, releasing volatile compounds that interfere with nematode survival and reproduction (Gimsing and Kirkegaard, 2006). Similarly, *Moringa oleifera*, recognized for its numerous agricultural benefits, exhibits nematicidal activity through its secondary metabolites, which enhance soil health while inhibiting nematode multiplication (Gimsing and Kirkegaard, 2006). The integration of *Brassica* species and *Moringa* leaves in nematode management offers a promising strategy for reducing *Meloidogyne* spp. infections in okra fields. This study evaluated the effectiveness of selected *Brassica* species (cabbage and broccoli leaves) and *Moringa oleifera* in controlling *Meloidogyne* spp. infestations affecting okra cultivation in Borno State, Nigeria.

MATERIALS AND METHODS

Field experiments were conducted at the Teaching and Research Farm, University of Maiduguri, Maiduguri (Latitude 11° 15' and Longitude 13° 51') in Borno State, Nigeria during 2018 and 2019 wet season. The study area is characterized by a tropical climate with distinct wet and dry seasons, making it a suitable environment for nematode infection and management trials.

Okra cultivar Alau was used for the experiment. The treatments were fresh cabbage leaves, broccoli leaves and moringa leaves applied at two different levels of 40 kg/ha and 80 kg/ha. Carbofuran 3 G applied at the rate of 2 kg a.i/ha served as check. Untreated plots served as control. The treatments were laid out in a Randomized Complete Block Design (RCBD) with eight treatments replicated three times.

The leaves were washed, to be free of adhering soil. For easy incorporation of the leaves 20 and 80 grams each of the leaves was finely chopped using knife. Finely chopped fresh cabbage, broccoli and moringa leaves was applied at each stand (spot treatment) at the depth of 15-20cm using hoe. The field was left for two weeks to allow for decomposition of cabbage, broccoli and moringa to release their nematicidal biofumigants. Carbofuran was applied three (3) days after seedling emergence by spot treatment at the rate of 2 g a.i/stand.

Three (3) seeds per hole were sown two weeks after application of cabbage, broccoli and moringa leaves at the depth of 3 to 5 cm and spacing of 50 × 50 cm. The seedlings were later thinned to two (2) per stand two weeks after emergence making a total of 16 plants per plot. Each plots measures 3m x 3m. Weeding commenced two weeks after sowing and subsequent weeding were carried out when necessary to minimize weed interference. Missing stands were supplied to maintain the plant population at the initial stage.

Sources of Materials

Fresh cabbage leaves were collected at the Teaching and Research Farm, University of Maiduguri. Broccoli and moringa leaves were collected at Gamboru market, Maiduguri, Borno state. Carbofuran was purchased from agro chemical store in Maiduguri.

Seeds of Okra cv. Alau were obtained from Borno state Agricultural Development Program (BOSADP) Maiduguri days to sowing. Okra cv. Alau cultivar has semi-dwarf growth habit, similar in height to Clemson but with fewer branches, pods are straight, dark green and ribbed with 6 to 9 locules.

Nematode Population Count

The initial (Pi) and final (Pf) nematode population were determined by taking three core samples of soil using a soil auger to a depth of 20 cm in a zig-zag pattern from each plot, bulked and labeled. The soil samples collected from each plot were analyzed in the laboratory to determine the plant parasitic nematode population. The Baermann tray method (Whitehead and Hemming, (1965) method of nematode extraction was used. The following nematode population data was collected: The initial population (Pi) before application of materials were determined for each plot, final nematode population (Pf) in the soil after termination of the experiment. Reproduction factor (RF): this was determined by dividing the final population (Pf) by the initial population (Pi) that is: $RF = Pf / P$ and Change in nematode population was determined using the following formula by Araya 2012.

$$\frac{Pf - Pi}{Pi} \times 100\%$$

Where:

Pi = Initial nematode population per 250 cm³ of soil

Pf = Final nematode population per 250 cm³ of soil

Data Collection on Growth and Yield of Okra

Sample of five (5) plants per plot was randomly selected for determination of growth and yield parameters (root length, fresh and dry root weight, shoot height, fresh and dry shoot weight and fresh yield weight).

Gall Index

To assess the extent of galling on the roots in each treatment, five samples from each plot were selected randomly and tagged. These were carefully uprooted at the end of the experiment. The roots of the plants were washed in clean tap water to remove soil and dirt. The roots were examined for galls using hand lens. The number of the galls found was counted and indexed according to the indexing scale of Ibrahim and Lewis, (1985).

Gross Margin

Gross margin was determined by employing partial farm budget analysis as adopted by Okoruwa *et al.* (2005), the mathematical expression of which is given as follows:

$$\begin{aligned} \text{GM} &= \text{TR} - \text{VC} \\ \text{TR} &= (\text{Ya} \times \text{Pa}) + (\text{Yb} \times \text{Pb}) \\ \text{VC} &= \text{M} \times \text{L} \end{aligned}$$

Where:

$$\begin{aligned} \text{GM} &= \text{Gross margin/ha} \\ \text{TR} &= \text{Total revenue (Naira)} \\ \text{VC} &= \text{Variable cost (Naira)} \\ \text{Ya} &= \text{Okra pod yield/ha} \\ \text{Pa} &= \text{Price of pod yield/ha} \\ \text{Yb} &= \text{Leaves yield/ha} \\ \text{Pb} &= \text{Price of leaves yield/ha} \\ \text{M} &= \text{Value of material inputs (seeds, cabbage leaves, broccoli leaves, moringa leaves and carbofuran) in Naira} \\ \text{L} &= \text{Value of labour (Land preparation, sowing, incorporation of cabbage leaf, broccoli leaf, moringa leaf and application of carbofuran and harvesting) for husbandry operation in Nigeria.} \end{aligned}$$

Data Analysis

Data collected were subjected to Analysis of Variance (ANOVA) using Statistix Version 10.0. Treatment means were separated using a modified Duncan's Multiple Range Test (DMRT) Gomez and Gomez, (1984) at ($P \leq 0.05$) probability level.

RESULTS

Effect of Plant Biofumigant and Carbofuran on the Total Population of Soil Nematode during 2018 and 2019 Wet Seasons

Suppression of the populations of plant parasitic nematode in both trials (2018 and 2019 wet seasons) were shown in Tables 1 and 2. The results obtained shows that in both trials, the carbofuran and plant biofumigant reduced the population of the soil nematodes while the population increase in the control plots. Plots treated with carbofuran 3G at the rate of 2 g a.i/ha suppressed the population of nematode by 89.0 % in 2018 wet season and 90.79% in 2019 wet season. Furthermore, this treatment was more effective among the treatments with reproduction factor of 0.14 and 0.09 for 2018 and 2019 wet seasons respectively.

Tables 1 and 2 revealed that in general, the total plant parasitic nematode population was reduced by 75.0% under plots treated with cabbage leaves at the rate of 80kg/ha in 2018 and

87.5% in 2019 with reduction factor of 0.25 and 0.13 respectively in 2018 and 2019 wet seasons. In the case of broccoli leaves at the rate of 80 kg/ha suppression was 69.0% in 2018 and 68.0 % in 2019 wet seasons with reduction factor of 0.26 and 0.32 in 2018 and 209 wet seasons respectively. However, the nematode population was suppressed by 49.25% under cabbage leaves at 40kg/ha, 47.72 under broccoli leaves and 53.0% under moringa leaves applied at the same rate of 40kg/ha. Similar trend of results was obtained in 2019 wet season.

On the other hand, increase in the population of the plant parasitic nematode in both trials (2018 and 2019 wet seasons) was observed under control treatment with percentage increase in population of 175 in 2018 and 137.98 in 2019. The reproductive factor recorded under control plots were 1.73 in 2018 and 2.38 in 2019 wet seasons.

Table 1: Effect of Plant Biofumigants and Carbofuran on the Total Population of Soil Nematode during 2018 Wet Season.

| | Initial Population (Pi) | Final Population (Pf) | Percentage Change in Population | Reproduction Factor (RF) (Pf/Pi) |
|---------------------------|--|--------------------------------------|--|---|
| Treatments | | | | |
| 2018 Wet Season | | | | |
| Cabbage Leaf 40 kg/ha | 67 | 34 | - 49.25 | 0.51 |
| Cabbage Leaf 80 kg/ha | 72 | 18 | - 75.0 | 0.25 |
| Broccoli Leaf 40 kg/ha | 88 | 46 | - 47.72 | 0.52 |
| Broccoli Leaf 80 kg/ha | 118 | 31 | - 69.0 | 0.26 |
| Moringa Leaf 40 kg/ha | 91 | 47 | - 53.0 | 0.51 |
| Moringa Leaf 80 kg/ha | 177 | 43 | - 57.0 | 0.24 |
| Carbofuran 3G 2 kg/ha | 79 | 11 | - 89.0 | 0.14 |
| Control (Untreated plots) | 159 | 275 | 175.0 | 1.73 |

Values are means of three replicates

$$\text{Percentage change in population} = \frac{\text{Pf}-\text{Pi}}{\text{Pi}} \times 100$$

+ = Increase in population

- = Decrease in population

Table 2: Effect of Plant Biofumigants and Carbofuran on the Total Population of Soil Nematode during 2019 Wet Season

| | Initial Population (Pi) | Final Population (Pf) | Percentage Change in Population | Reproduction Factor (RF) (Pf/Pi) |
|---------------------------|--|--------------------------------------|--|---|
| Treatments | | | | |
| 2019 Wet Season | | | | |
| Cabbage Leaf 40 kg/ha | 95 | 33 | - 65.26 | 0.35 |
| Cabbage Leaf 80 kg/ha | 160 | 20 | - 87.50 | 0.13 |
| Broccoli Leaf 40 kg/ha | 83 | 42 | - 49.39 | 0.51 |
| Broccoli Leaf 80 kg/ha | 75 | 24 | - 68.00 | 0.32 |
| Moringa Leaf 40 kg/ha | 98 | 48 | - 51.02 | 0.49 |
| Moringa Leaf 80 kg/ha | 119 | 31 | - 73.95 | 0.26 |
| Carbofuran 3G 2 kg/ha | 163 | 15 | - 90.79 | 0.09 |
| Control (Untreated plots) | 129 | 307 | 137.98 | 2.38 |

Values are means of three replicates

$$\text{Percentage change in population} = \frac{\text{Pf}-\text{Pi}}{\text{Pi}} \times 100$$

+ = Increase in population

- = Decrease in population

Effect of Plant Biofumigants on Root Galls during 2018 and 2019 Wet Season.

Table 3 statistically demonstrate the effective effectiveness of different treatments in reducing root galls in okra plants during the wet seasons of 2018 and 2019. Cabbage leaf at 80 kg/ha has the lowest mean root galls (1.68) and is statistically different from the untreated control (36.00), showcasing its superior efficacy. Cabbage leaves at 80 kg/ha were the most effective treatment, reducing root galls significantly. Moringa leaves at 80 kg/ha also showed notable efficacy. Carbofuran, a chemical nematicide performed well. However, biofumigant treatments like cabbage and moringa leaves at higher application rates showed better results, making them promising eco-friendly alternatives. The untreated plots had the highest number of galls. Statistical differences highlight the superior performance of cabbage leaves at 80 kg/ha in reducing root galls compared to other treatments. Scientifically, this suggests that organic treatments are viable alternatives to chemical nematicides in managing nematode infestations in okra.

Table 3: Effect of Plant Biofumigants on Root Galls of Okra in during 2018 and 2019 Wet Season

| Treatments | Root galls | | | Mean ¹ |
|---------------------------|---------------------|--------------------|--------------------|--------------------|
| | 2018 | 2019 | | |
| Cabbage Leaf 40 kg/ha | 9.33 ^{bc} | 7.00 ^b | 8.17 ^{bc} | |
| Cabbage Leaf 80 kg/ha | 1.67 ^d | 1.69 ^b | | 1.68 ^{de} |
| Broccoli Leaf 40 kg/ha | 6.33 ^{bcd} | 3.33 ^b | | 4.83 ^{cd} |
| Broccoli Leaf 80 kg/ha | 10.33 ^b | 8.00 ^b | | 9.17 ^b |
| Moringa Leaf 40 kg/ha | 9.33 ^{bc} | 7.00 ^b | | 8.17 ^{bc} |
| Moringa Leaf 80 kg/ha | 3.33 ^{cd} | 2.33 ^b | | 2.83 ^{de} |
| Carbofuran 3G 2 kg/ha | 4.67 ^{bcd} | 3.33 ^b | | 4.00 ^{de} |
| Control (Untreated plots) | 26.67 ^a | 45.33 ^a | | 36.00 ^a |
| SE ± | 0.53 | 0.69 | | 0.60 |

Values are means of three replicates

Means followed by same superscript in a column are not significantly different ($P \leq 0.05$)

1 = Mean of combined data analysis.

Effect of Plant Biofumigants and Carbofuran on Okra Root Length during the 2018 and 2019 Wet Seasons

Table 3 evaluates the effect of different treatments on the root length of okra during the 2018 and 2019 wet seasons. The longest root was observed under plot treated with Broccoli leaf at the rate of 80kg/ha (27.67 cm in 2018 39.75 cm in 2019) followed by plot treated with carbofuran 3G a.i. at the rate of 2kg/ha in both trials. There is significant difference among the treatments applied at the rate of 80 kg/ha. The cabbage leaf 80 kg/ha treatment resulted in significantly lower root lengths (1.08 cm in 2018, 0.33 cm in 2019, mean: 0.58 cm). Moringa leaf at the rate of 40 kg/ha (mean: 9.92 cm) and carbofuran 3G 2 kg kg/ha (mean: 11.00) fall in the mid-range of effectiveness. The shortest root length was observed in untreated control plot in both trials.

The same trend was observed in combined data analysis (Mean) where the highest mean was recorded under plot treated with Broccoli leaf 80kg/ha and the shortest root length was observed under untreated control plot.

Table 4: Effect of Carbofuran and Plant Biofumigants on Root Length of Okra during 2018 and 2019 Wet Season

| Treatment | Root length (cm) | | Mean ¹ |
|---------------------------|--------------------|--------------------|--------------------|
| | 2018 | 2019 | |
| Cabbage Leaf 40 kg/ha | 6.92 ^b | 6.92 ^b | 6.91 ^b |
| Cabbage Leaf 80 kg/ha | 1.08 ^c | 0.33 ^d | 0.58 ^d |
| Broccoli Leaf 40 kg/ha | 1.83 ^c | 4.58 ^c | 3.21 ^c |
| Broccoli Leaf 80 kg/ha | 27.67 ^a | 39.75 ^a | 34.46 ^a |
| Moringa Leaf 40 kg/ha | 5.67 ^d | 14.17 ^b | 9.92 ^b |
| Moringa Leaf 80 kg/ha | 8.25 ^c | 19.50 ^a | 13.83 ^a |
| Carbofuran 3G 2 kg/ha | 10.83 ^b | 11.33 ^c | 11.00 ^b |
| Control (Untreated plots) | 1.00 ^c | 0.13 ^d | 0.30 ^d |
| SE _± | 0.53 | 0.69 | 0.60 |

Values are means of three replicates

Means followed by same superscript in a column are not significantly different ($P \leq 0.05$)

1 = Mean of combined data analysis.

Effect of Plant Biofumigants and Carbofuran on Fresh Root Weight of Okra during 2018 and 2019 Wet Season.

Table 5 present the effect of the plant biofumigants and carbofuran on the fresh root weight of okra during the wet seasons of 2018 and 2019. Application of plant biofumigants and carbofuran was found to have significant ($P \leq 0.05$) effects on the fresh root weight of okra plants in both trials and mean of combined data analysis.

Application of carbofuran 3G a.i at the rate 2kg / ha in both trails and combined data analysis showed a statistically significant reduction in fresh root weight compared to the control. While effective in reducing nematode-related damage, it did not match the untreated plots in terms of root weight, possibly indicating its direct impact on nematodes but with mild effect on root growth. Cabbage leaves at 80 kg/ha gave the heaviest root weight among the plant biofumigants used in both 2018 and 2019 wet seasons and the lowest root weight was recorded under plot treated with moringa leaf at 40kg/ha. The result also shows that there was significant difference between the treated plots and the untreated plots in both 2018 and 2019 wet seasons.

Table 5: Effect of Plant Biofumigants and Carbofuran on Fresh Root Weight of Okra during 2018 and 2019 Wet Season

| Treatment | Fresh root weight (g) | | Mean ¹ |
|---------------------------|-----------------------|---------------------|---------------------|
| | 2018 | 2019 | |
| Cabbage Leaf 40 kg/ha | 15.67 ^e | 14.67 ^e | 15.16 ^{ef} |
| Cabbage Leaf 80 kg/ha | 32.33 ^c | 37.00 ^c | 34.67 ^c |
| Broccoli Leaf 40 kg/ha | 11.33 ^f | 13.33 ^{ef} | 12.33 ^f |
| Broccoli Leaf 80 kg/ha | 27.33 ^d | 31.33 ^a | 29.33 ^a |
| Moringa Leaf 40 kg/ha | 5.67 ^g | 8.33 ^g | 7.00 ^g |
| Moringa Leaf 80 kg/ha | 16.67 ^e | 15.67 ^e | 16.17 ^e |
| Carbofuran 3G 2 kg/ha | 41.67 ^b | 45.67 ^b | 43.67 ^b |
| Control (Untreated plots) | 54.667 ^a | 54.667 ^a | 54.00 ^a |
| SE _± | 1.57 | 2.45 | 1.52 |

Values are means of three replicates

Means followed by same superscript in a column are not significantly different ($P \leq 0.05$)

1 = Mean of combined data analysis.

Effect of Plant Biofumigants and Carbofuran on Dry Root Weight of Okra during 2018 and 2019 Wet Season

The result on Table 6 shows that dry root weight varied significantly amongst the treated plots and untreated control plots. The heaviest dry root weight was recorded on plots treated the carbofuran in both 2018 and 2019 field experiment. The lowest dry root weight was observed on control plots in both trials.

Significant difference in dry root weight of okra was observed between the plots treated with cabbage leaves at the rate of 80kg/ha, cabbage leaves at 40kg/ha, broccoli leaves at 80kg/ha and broccoli leaves at 40kg/ha in 2018 wet season. There was no significant difference between plots treated with broccoli leaves at 40kg/ha, moringa leaves at 80kg/ha and moringa leaves at 40kg/ha. There was also significant difference between the plots treated with plant biofumigants and carbofuran. The result obtained in 2019 wet season of dry root weight is similar in trend with that of 2018 wet season.

Table 6: Effect of Plant Biofumigant and Carbofuran on Dry Root Weight during 2018 and 2019 Wet Season.

| Treatment | Dry root weight (g) | | Mean ¹ |
|---------------------------|---------------------|---------------------|--------------------|
| | 2018 | 2019 | |
| Cabbage Leaf 40 kg/ha | 7.70 ^e | 9.53 ^{de} | 8.61 ^e |
| Cabbage Leaf 80 kg/ha | 17.27 ^c | 20.40 ^c | 18.83 ^c |
| Broccoli Leaf 40 kg/ha | 4.23 ^f | 5.40 ^g | 4.81 ^g |
| Broccoli Leaf 80 kg/ha | 10.97 ^d | 11.26 ^{7d} | 11.12 ^d |
| Moringa Leaf 40 kg/ha | 4.33 ^f | 7.33 ^{fg} | 5.83 ^{fg} |
| Moringa Leaf 80 kg/ha | 5.43 ^f | 8.03 ^{ef} | 6.73 ^f |
| Carbofuran 3G 2 kg/ha | 26.60 ^b | 29.63 ^b | 28.11 ^b |
| Control (Untreated plots) | 32.40 ^a | 36.37 ^a | 34.38 ^a |
| SE± | 0.85 | 0.94 | 0.58 |

Values are means of three replicates

Means followed by same letters in a column are not significantly different ($P \leq 0.05$)

1 = Mean of combined data analysis.

Effect of Plant Biofumigants and Carbofuran on Shoot Height of Okra during 2018 and 2019 Wet Season

Application of plant biofumigants was found to have significant effects ($P \leq 0.05$) on the shoot height of treated okra plant (Table 7) in both trials. The highest shoot height in 2018 trial was obtained in plot treated with carbofuran 3G a.i 2kg/ha (92.73cm) followed by plot applied with cabbage leaf 80kg/ha (76.73cm). plots applied with Broccoli leaf at 80kg / ha and moringa leaf at the rate of 80kg/ha increased shoot height by 64.00cm and 30.00cm respectively. The lowest shoot height was recorded in control plot (10.67cm).

Almost the same trend was observed in 2019 wet season where plots treated with carbofuran recorded the highest shoot height followed by plot applied with cabbage leaves at the rate of 80kg / ha. The lowest was observed under untreated control plots.

In the combined data analysis (mean) 60.53cm shoot height was observed under plot treated with carbofuran while cabbage leaf gave 48.03cm followed by Broccoli leaf at the rate of

80kg/ha (41.33cm). both cabbage leaf and moringa applied at the rate 40kg/ha recorded 32.53cm and 24.00cm respectively. The shortest shoot height was observed in untreated control plots.

Table 7: Effect of Plant Biofumigants and Carbofuran on Shoot Height of Okra in Maiduguri during 2018 and 2019 Wet Season

| Treatment | Shoot height (cm) | | Mean ¹ |
|---------------------------|--------------------|---------------------|--------------------|
| | 2018 | 2019 | |
| Cabbage Leaf 40 kg/ha | 47.73 ^d | 17.33 ^{bc} | 32.53 ^d |
| Cabbage Leaf 80 kg/ha | 76.73 ^b | 19.33 ^b | 48.03 ^b |
| Broccoli Leaf 40 kg/ha | 36.43 ^e | 13.33 ^d | 24.88 ^e |
| Broccoli Leaf 80 kg/ha | 64.00 ^c | 18.66 ^b | 41.33 ^c |
| Moringa Leaf 40 kg/ha | 21.33 ^f | 6.66 ^e | 14.00 ^f |
| Moringa Leaf 80 kg/ha | 30.00 ^e | 15.33 ^{cd} | 22.66 ^e |
| Carbofuran 3G 2 kg/ha | 92.73 ^a | 28.33 ^a | 60.53 ^a |
| Control (Untreated plots) | 10.67 ^g | 5.00 ^e | 7.83 ^g |
| SE _± | 3.08 | 1.46 | 1.57 |

Values are means of three replicates

Means followed by same letters in a column are not significantly different ($P \leq 0.05$)

1 = Mean of combined data analysis.

Effect of Plant Biofumigants and Carbofuran on Fresh Shoot Weight of Okra during 2018 and 2019 Wet Season

Significant difference was observed in fresh shoot weight of okra in both 2018 and 2019 wet seasons (Table 8). Carbofuran applied at 2kg/ha produced the heaviest fresh shoot weight in both trials (seasons) followed by Cabbage and Broccoli leaves applied at the rate of 80kg/ha. Plots treated with Moringa leaf at the rate of 80kg/ha in 2018 and 2019 recorded 149.67 g and 164 g fresh shoot weight respectively. The lowest fresh shoot weight was observed under control plots.

There was significant ($P \leq 0.05$) difference in fresh shoot weight between all treatments in combined data analysis (Mean) where the highest fresh shoot weight was recorded under plot treated with carbofuran applied at the rate of 2kg / ha (351.00g) followed by plots treated with cabbage leaf at the rate of 80kg/ha. Moringa and Broccoli leaves at the rate of 40kg/ha recorded 87.50 g and 112.67 g respectively while cabbage at the same rate recorded 157.67 g. The lowest fresh shoot weight was observed under untreated control plots.

Table 8: Effect of Plant Biofumigants and Carbofuran on Fresh Shoot Weight of Okra in Maiduguri during 2018 and 2019 Wet Season

| Treatment | Fresh shoot weight (g) | | Mean ¹ |
|---------------------------|------------------------|---------------------|---------------------|
| | 2018 | 2019 | |
| Cabbage Leaf 40 kg/ha | 182.00 ^d | 133.33 ^d | 157.67 ^d |
| Cabbage Leaf 80 kg/ha | 227.67 ^b | 331.33 ^b | 279.50 ^b |
| Broccoli Leaf 40 kg/ha | 126.67 ^f | 98.67 ^f | 112.67 ^f |
| Broccoli Leaf 80 kg/ha | 204.33 ^c | 268.67 ^c | 236.50 ^c |
| Moringa Leaf 40 kg/ha | 104.67 ^g | 70.33 ^g | 87.50 ^g |
| Moringa Leaf 80 kg/ha | 149.67 ^e | 164.00 ^e | 156.83 ^e |
| Carbofuran 3G 2 kg/ha | 250.33 ^a | 451.67 ^a | 351.00 ^a |
| Control (Untreated plots) | 70.33 ^g | 47.33 ^g | 58.83 ^g |
| SE _± | 5.38 | 10.04 | 5.58 |

Values are means of three replicates

Means followed by same letters in a column are not significantly different ($P \leq 0.05$)

1 = Mean of combined data analysis.

Effect of Plant Biofumigants and Carbofuran on Dry Shoot Weight of Okra in Maiduguri during 2018 and 2019 Wet Season

All treatments had significant ($P \leq 0.05$) effect on dry shoot weight of okra plant in both trials and the mean of combined data analysis of 2018 and 2019 wet seasons. The highest shoot weight was observed in plots treated with carbofuran 3G a.i 2kg/ha in both 2018 and 2019 wet seasons followed by plots treated with Cabbage leaf at 80kg/ha and Broccoli leaf at 80kg/ha. The lowest dry shoot weight was recorded under untreated control plots.

All the 8 levels of treatments significantly ($P \leq 0.05$) influenced okra plant dry shoot weight in the combined data analysis where the heaviest dry shoot weight was observed under plot applied with carbofuran 3G a.i 2kg/ha followed by Cabbage and Broccoli leaves applied at the rate of 80kg/ha. The lowest dry shoot weight was observed under untreated control plots.

Table 9: Effect of Plant Biofumigation and Carbofuran on Dry Shoot Weight of Different Varieties of Okra in Maiduguri during 2018 and 2019 Wet Season

| Treatment | Dry shoot weight (g) | | Mean ¹ |
|---------------------------|----------------------|---------------------|---------------------|
| | 2018 | 2019 | |
| Cabbage Leaf 40 kg/ha | 58.67 ^d | 64.33 ^d | 53.00 ^d |
| Cabbage Leaf 80 kg/ha | 82.50 ^b | 94.67 ^b | 70.33 ^b |
| Broccoli Leaf 40 kg/ha | 35.83 ^f | 37.00 ^{ef} | 34.667 ^f |
| Broccoli Leaf 80 kg/ha | 73.17 ^c | 82.67 ^c | 63.67 ^c |
| Moringa Leaf 40 kg/ha | 25.17 ^g | 26.33 ^g | 24.00 ^g |
| Moringa Leaf 80 kg/ha | 46.00 ^e | 46.33 ^e | 45.667 ^e |
| Carbofuran 3G 2 kg/ha | 110.00 ^a | 133.00 ^a | 87.00 ^a |
| Control (Untreated plots) | 14.50 ^h | 13.00 ^g | 16.00 ^h |
| SE \pm | 3.25 | 5.51 | 2.49 |

Values are means of three replicates

Means followed by same letters in a column are not significantly different ($P \leq 0.05$)

1 = Mean of combined data analysis.

Effect of Plant Biofumigants and Carbofuran on Fresh Fruit Weight of Okra in Maiduguri during 2018 and 2019 Wet Season

Table 9 shows that there was significant ($P \leq 0.05$) differences in fresh fruit yield recorded under all the 8 levels of treatments in both 2018 and 2019 wet seasons. In 2018 wet season plots treated with carbofuran 3G a.i 2kg / ha produced the highest fruit weight than the untreated control plot followed by plots treated with Cabbage and Broccoli leaves applied at the rate of 80kg/ha. Similar trends were observed in both 2019 wet season and mean of combined data analysis of both trials. The highest fruit weigh was recorded under plot treated with carbofuran and the lowest fruit weight were recorded in untreated control plots.

Table 9: Effect of Plant Biofumigant and Carbofuran on Fresh Fruit Weight of Okra during 2018 and 2019 Wet Season

| Treatment | Fresh fruit weight (kg) | | Mean ¹ |
|---------------------------|-------------------------|--------------------|-------------------|
| | 2018 | 2019 | |
| Cabbage Leaf 40 kg/ha | 3.06 ^d | 3.17 ^{cd} | 3.11 ^d |
| Cabbage Leaf 80 kg/ha | 4.40 ^b | 4.66 ^b | 4.53 ^b |
| Broccoli Leaf 40 kg/ha | 2.33 ^f | 2.33 ^e | 2.33 ^e |
| Broccoli Leaf 80 kg/ha | 3.44 ^c | 3.83 ^c | 3.63 ^c |
| Moringa Leaf 40 kg/ha | 1.31 ^g | 1.45 ^f | 1.38 ^f |
| Moringa Leaf 80 kg/ha | 2.83 ^e | 3.10 ^d | 2.96 ^d |
| Carbofuran 3G 2 kg/ha | 5.67 ^a | 6.67 ^a | 6.17 ^a |
| Control (Untreated plots) | 1.10 ^h | 1.30 ^f | 1.20 ^c |
| SE± | 0.09 | 0.32 | 0.16 |

Values are means of three replicates

Means followed by same letters in a column are not significantly different ($P \leq 0.05$)

1 = Mean of combined data analysis.

Effect of Plant Biofumigant and Nematicide on Gross Margin

Table 10 a d 11 shows the effect of plant biofumigant and Carbofuran on gross margin. In 2018 wet season, the economic gain for the tested plant biofumigants and carbofuran ranged from N1, 346.00 for control plots to as much as N85, 700.00 for plots treated with carbofuran. The result obtained shows that application of cabbage leaves at 80 kg/ha resulted in economic gain of N53, 954.00 over control in 2018 wet season. Also, application of broccoli leaves at 80kg/ha resulted in N36, 100.00 as against a gross margin of N1,346.00 recorded under control plots. The economic gain over the control was N27, 804.00 for plots treated with moringa leaves at the rate of 80 kg/ha, N30, 904.00 for cabbage leaves at 40kg/ha and N16, 304 for broccoli leaves applied at the rate of 40kg/ha.

In 2019, application of carbofuran 3G at the rate of 2g a.i/ha gave the highest economic gain of N107, 770.00 over control plots followed by plots treated with cabbage leaves at the rate of 80kg/ha which gave economic gain of N58, 450.00 over control. Broccoli leaves applied at the rate of 80 kg/ha ranked third with a gross margin of N41, 020.00 as against control plots. The least economic return of N400.00 was recorded under plots treated with moringa leaves at 40kg/ha over control plots.

Furthermore, the gross margin for the plant biofumigants in 2019 wet season were N32, 150.00 for cabbage leaves at 40kg/ha, N14, 510.00 for broccoli leaves at the rate of 40kg/ha, and N1, 890.00 for moringa leaves applied at the rate of 40kg/ha.

Table 10: Total Cost, Revenue and Gross Margin of Using Plant Biofumigants and Nematicide on Okra Pods in 2018 and 2019 Wet Seasons

| Treatments | Value of Output/ha (₦) | Total Cost/ha (₦) | Gross Margin/ha (₦) |
|---------------------------|------------------------|-------------------|---------------------|
| 2018 Wet Season | | | |
| Cabbage Leaf 40 kg/ha | 44, 850 | 12, 600 | 32, 250 |
| Cabbage Leaf 80 kg/ha | 71, 650 | 16, 350 | 55, 300 |
| Broccoli Leaf 40 kg/ha | 30, 250 | 12, 600 | 17, 650 |
| Broccoli Leaf 80 kg/ha | 52, 450 | 16, 350 | 36, 100 |
| Moringa Leaf 40 kg/ha | 16, 400 | 10, 100 | 6, 300 |
| Moringa Leaf 80 kg/ha | 40, 250 | 11, 100 | 29, 150 |
| Carbofuran 3G 2 kg/ha | 97, 050 | 19, 350 | 77, 700 |
| Control (Untreated plots) | 8, 426 | 7, 600 | 826 |

Table 11: Total Cost, Revenue and Gross Margin of Using Plant Biofumigants and Nematicide on Okra Pods in 2019 Wet Seasons

| Treatments | Value of Output/ha (₦) | Total Cost/ha (₦) | Gross Margin/ha (₦) |
|---------------------------|------------------------|-------------------|---------------------|
| 2019 Wet Season | | | |
| Cabbage Leaf 40 kg/ha | 47, 610 | 15, 460 | 32, 150 |
| Cabbage Leaf 80 kg/ha | 78, 900 | 18, 960 | 59, 940 |
| Broccoli Leaf 40 kg/ha | 29, 970 | 15, 460 | 14, 510 |
| Broccoli Leaf 80 kg/ha | 61, 470 | 18, 960 | 42, 510 |
| Moringa Leaf 40 kg/ha | 11, 490 | 9, 600 | 1, 890 |
| Moringa Leaf 80 kg/ha | 43, 040 | 10, 100 | 32, 940 |
| Carbofuran 3G 2 kg/ha | 90, 110 | 20, 850 | 69, 260 |
| Control (Untreated plots) | 9, 340 | 7, 850 | 1, 490 |

DISCUSSION

In recent years, bio-fumigation has emerged as an effective non-chemical alternative to manage nematode pests. The experimental study indicated that cruciferous bio-fumigants have provided a satisfactory nematode suppression, confirming previous findings of some researchers (Haroutunian, 2013). In plant bio-fumigants, the enzyme (myrosinase)-catalyzed hydrolysis of sulphur-containing substrate (glucosinolate) initially involves cleavage of the thioglucoside linkage, yielding D-glucose and an unstable thiohydroximate- O-sulphonate, which spontaneously rearranges to produce sulphate and a number of reaction products (Zhou *et al.*, 2012). The end products are generally isothiocyanate, thiocyanate, nitrile, epithionitrile, or oxazolidine-thione, depending on substrate, pH, or ferrous ions available (Zhou *et al.*, 2012; Avato *et al.*, 2013).

Effectiveness of plant biofumigant and carbofuran against plant parasitic nematodes and growth and yield of Alau variety of okra has been demonstrated in this research. In both 2018 and 2019 field experiments the final nematode population differed among the different levels of the treatments (biofumigants). The number of plant parasitic nematode increased several folds in the untreated plots while reduction in the population of nematode was recorded under treated plots. Among the treatments, the lowest reproductive factors were observed under control plots while the highest was observed under treated plots.

The result on final nematode population indicated that the control plots had the highest nematode population due to non-treatment. A possible explanation is that nematodes were able to multiply due to non-treatment, which resulted in increase in their population. It is there for

possible that the application of these plant biofumigants have induced leaching of certain compounds after the decay of the leaves and have acted as nematicides inhibiting the invasion activities and reproduction of the nematode in the soil. This result is in conformity with observations made by many researchers. Studies on bio-fumigation have been done with brassicas for the management of nematodes in different cropping systems. (Kumar, 2005; Matthiessen and Kirkegaard, 2006; Henderson *et al.*, 2009; Szczygowska *et al.*, 2011). After the incorporation of cruciferous bio-fumigants into the field, significant reduction in the population of nematode juveniles occurred. Researchers already have proved that after the decomposition of biofumigant, plant tissues mainly release isothiocyanates, in addition to thiocyanates, nitriles, and oxazolidinethiones (Fahey *et al.*, 2001; Devi, 2018). Glucosinolate are sulphur-containing chemicals that are produced by plants as secondary metabolites (Agrios, 2005). Nematode reproduction was reduced in the treated plots with plant bio-fumigants as compared with chemical check. Similar finding was reported by Bello *et al.* (2001) who showed that bio-fumigation has the same effect as methyl bromide on *Meloidogyne javanica* in pepper. As reported by many scientists, field experiments in which *Brassica juncea* and *Brassica rapa* were grown as green manure crops resulted in 91 to 95% mortality of encysted eggs of *Globodera pallida* (Lord *et al.*, 2011). Patil *et al.*, (2020) also reported that the final nematode population in the soil as well in roots was lowest in carbofuran at 1.0 kg a.i/ha (188 J2/200 cc soil) followed by cabbage leaves at 50 t/ha (215 J2/200 cc soil).

Despite the success recorded with synthetic pesticide, they no longer hold future in sustainable agriculture production owing to environmental degradation, toxicity and high cost (Hassan *et al.*, 2013) thus, justifying attempt by various workers to develop non-chemical alternative control technologies using plant biofumigants. Some plant biofumigants used in managing plant parasitic nematode include cabbage, broccoli and moringa leaves to mention but few. In addition, the use of carbofuran in managing nematodes is effective, although it is relatively short-lived, and its conventional solid and liquid formulations are defective for short duration only.

The results obtained in this research showed that okra in treated plots have significantly more fruit weight than the untreated plots. There was significant increase in yield in response to the plant biofumigant treatment, compared to untreated plots. The yield in untreated soil was significantly reduced. This is in agreement with that of Patil *et al.* (2020) who reported that okra yield was significantly highest in the treatment of cabbage leaves at 50 t/ha followed by cauliflower leaves at 50 t/ha. The yield in these two treatments was even better than chemical check, i.e., carbofuran at 1.0 kg a.i/ha. There was 25.3% increase in yield over the check in cabbage leaves at 50 t/ha followed by 16.4% in cauliflower leaves at 50 t/ha.

This study confirms the effectiveness of plant biofumigants in reducing the root galls by root-knot nematodes. The highest mean galling index in both trials (2018 and 2019 wet seasons) was recorded under control plots while the lowest galling index was recorded under plots treated with carbofuran followed by plots treated with cabbage leaves at the rate 80kg/ha.

Heavy galling also added to induced lateral roots and this added to the weight of the roots of okra in untreated soil. Root galls were less noticeable on okra plants grown in treated plots. Although nematode infectivity and root knot disease incidence were significantly reduced in carbofuran treated plots compared to no-treated control plots, the positive effect of this on okra root, shoot and fruit parameters was significant. This research is in line with that of Patil *et al.*, (2020) who reported that cabbage leaves resulted to be significantly more suppressive than cauliflower leaves. Treatments with the four cruciferous bio-fumigants and carbofuran also resulted in a lower number of root galls in comparison with untreated check. As for nematode juveniles, the formation of galls in soil treated with cruciferous bio-fumigants and carbofuran was lower than untreated check. The

carbofuran-treated plots also had significantly lower galling compared with untreated check. Gall indices were detected 2.5 and 3.0 for roots of okra in plots treated with cabbage leaves at 50 t/ha and cauliflower leaves at 50 t/ha, respectively. The findings of this study agree with Youssef and Lashien (2013) report that application of 10 g of crushed cabbage leaf residue before planting was more effective in suppressing number of galls and number of juveniles of *Meloidogyne* spp.

In field environment, both fresh chopped cruciferous bio-fumigants had significantly inhibited the galling of *M. incognita* in okra. This research finding is in agreement with Valdes *et al.* (2012) that show cruciferous bio-fumigants not only reduce galling but are also responsible for the increase in beneficial nematode community in soil profile which is also reported due to brassica bio-fumigation effect. Lopez-Perez *et al.* (2010) also reported that soil incorporation of broccoli was reported to reduce root galling on tomato by 36%.

Results on root length revealed that plots treated with carbofuran produced the longest roots in okra in both 2018 and 2019 wet season experiments, followed by cabbage leaves and broccoli leaves. This was as a result of suppression effect of both carbofuran and plant biofumigants on gall formation on both primary and secondary roots which resulted in longer roots. The control plots had shorter roots because nematodes invaded the roots creating root proliferations.

Okra shoot height and shoot weight were higher for okra plant grown in treated plots compared to increasing levels of the treatment (Plant biofumigants). There was luxuriant plant growth with well-formed stem and green foliage in most treated plots. The okra plant in the untreated control plots appeared stunned, slender and thrifty with small number of chlorotic leaves. This agrees with the findings of Fuglie (2001) whose result of his study have shown that application of moringa leaf powder at different times is effective against *Meloidogyne* spp. under field conditions. Plants treated with moringa leaf powder at 1 WAP had the tallest plants which produced more leaves than those of the other treatments. It is possible that application of the moringa leaf powder promoted plant growth which confirms the report of Fuglie (2001) that moringa leaf extract contains some micronutrients and macronutrients such as calcium, potassium, iron, and magnesium which enhance plant development.

In 2018, the application of carbofuran gave the highest economic gain, followed by plots treated with cabbage leaves at the rate of 80kg/ha while the lowest economic gain was recorded under control plots. In 2019, carbofuran gave the highest economic return of N107, 770.00 over control plots, next to it was plot treated with cabbage leaves at 80kg/ha with economic gain of N58, 450.00 over control plots. The lowest economic gains were observed under control plots.

Considering the high cost of synthetic nematicides, application of cabbage leaves at 80kg/ha is more profitable in okra production when compared with the other treatments used in this research. Cabbage a versatile plant biofumigant with wide application on soil fertility management offers a durable and sustainable solution to soil fertility and nematode problems, especially to resource poor farmers.

CONCLUSION

The findings of this study highlight the potential of selected *Brassica* species and *Moringa oleifera* as effective biological control agents against *Meloidogyne* spp. infecting okra (*Abelmoschus esculentus*). Based on the data in this study, conclusion can be drawn from both experiments that performance of carbofuran, cabbage leaves at the rate of 80kg /ha in both field trials were more effective in suppressing plant parasitic nematode and also profitable. The integration of *Brassica* biofumigation and Moringa extracts into nematode management strategies not only supports

environmentally friendly agriculture but also promotes safer and more cost-effective pest control methods for farmers.

Given the agricultural importance of okra and the global impact of nematode-induced yield losses, adopting botanical-based nematode management approaches can contribute to food security, economic sustainability, and improved soil health in nematode-infested regions. Further research is needed to optimize application methods, dosage, and long-term effects of these treatments under different agroecological conditions. The findings of this study pave the way for the development of integrated pest management strategies that enhance crop productivity while minimizing environmental risks. It is recommended that further research be conducted to ascertain the extent the plant biofumigants spread in soil.

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