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Effectiveness of silver nitrate nanoparticles and plantain peel in improving the productivity of okra (*Abelmoschus esculentus L. Moench)*

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Abstract

This study evaluated the effectiveness of silver nitrate nanoparticles and powdered plantain peel on the productivity of okra (*Abelmoschus esculentus* L. Moench). Randomized experimental design was employed involving two treatments and four levels per treatment with five replicates each. Plant productivity was measured by evaluating the growth parameters, physiological yield (biomass, fiber and chlorophyll) and biological yield (flowering, fruit and seed yield) at 20, 40 and 60 DAP (days after planting). Data were analyzed using Minitab software (17) for analysis of variance while means were separated using the LSD method at $P \leq 0.05$. Results showed no significant differences ($P > 0.05$) in growth parameters prior to treatment application. At 40 DAP, okra plants treated with 10.0g of powdered plantain peel displayed the highest height increase. At 60 DAPs, plants treated with 400 ppm of silver nitrate nanoparticles achieved the tallest height. The application of 7.5 g plantain peel extract yielded the highest fiber content in seeds (4.8%), while 5.0 g of the same extract produced leaves with the highest chlorophyll concentration (21.6 mg/g). Treatments had no effect on biological yield (flowering, pod and seed parameters). Results suggest that the powdered plantain peel extract and silver nitrate nanoparticles could be valuable growth-enhancing agents in okra plant while contributing significantly to the physiological yield of the plant in terms of fiber and chlorophyll content. The study demonstrated the relevance of plantain peel (being solid wastes in the environment) and green-synthesized nanoparticle that could serve as cheap and eco-friendly growth enhancers in okra production.

Keywords: *Silver nitrate nanoparticle, Powered plantain peel, Abelmoschus esculentus, Okra Productivity, Eco-friendliness*

Introduction

Okra (*Abelmoschus esculentus*) is a flowering plant in the mallow family, cultivated for its edible green seed pods. Originating from Africa, okra is now grown in tropical, subtropical, and warm temperate regions worldwide. It is a staple in many cuisines due to its culinary versatility and high nutritional value, being rich in vitamins A and C, fiber, and antioxidants. The pods are low in calories and serve as a good source of dietary fiber, vitamins, and minerals [1]. They are notably high in vitamin C and folate, making them valuable for dietary health. Okra is an important cash crop for smallholder farmers, providing income and employment opportunities in rural areas. It is widely used in soups, stews, and as a thickening agent due to its mucilaginous texture [2]. It is a key ingredient in dishes such as gumbo in the Southern United States and various regional recipes in India, the Middle East, and Africa. Traditionally, okra has been used in herbal medicine for its potential health benefits, including treating inflammation and digestive issues [3]. The productivity of okra (*Abelmoschus esculentus*) is crucial for many smallholder farmers and consumers due to its nutritional and economic significance.

Okra cultivation benefits from balanced fertilization. The application of compost or well-decomposed manure before planting enhances soil fertility [4], while supplemental nitrogen during the growing season promotes vigorous vegetative development. Adequate levels of essential micronutrients like calcium, magnesium, and potassium are important for optimal plant health [5]. Conventional agricultural practices primarily rely on chemical fertilizers and pesticides to enhance crop yield and protect plants from pathogens. However, these practices can have adverse environmental effects, such as soil degradation, water pollution, and harm to beneficial organisms. Maintaining optimal soil fertility is crucial for okra growth and productivity. Chemical fertilizers, while effective, can lead to long-term soil health issues and environmental pollution [6]. Loss of soil fertility, diseases and pests can significantly reduce okra yield. Conventional agrochemicals applied to solve these challenges have been reported to pose risks to human health and the environment [7].

Utilizing organic waste materials, such as plantain peels, can improve soil fertility sustainably. Plantain peels are rich in nutrients and can enhance soil structure and microbial activity [8]. Silver nitrate has been researched for its efficacies as growth and yield enhancers as well as pesticidal properties, which can help manage plant diseases and boost production [9]. However, data on the effectiveness of this nanoparticle on the productivity of okra are limited. Combined efficacies of silver nitrate nanoparticle and plantain peel extracts on the overall performances of the crop are lacking.

This study was therefore designed to address this knowledge gap by evaluating the effectiveness of green-synthesized, eco-friendly silver nitrate nanoparticles and organic powdered plantain peel on the productivity of okra. Specifically, the study assessed their impact on growth parameters, physiological yield (including biomass, fiber, and chlorophyll content), and biological yield (encompassing flowering, pod development, and seed output).

Methods

Study Area

The study was conducted in the Botany Garden, College of Biological Sciences, Joseph Sarwuan Tarka University Makurdi, Benue State. Makurdi town (Longitude 8⁰30'E, 8⁰30'E and Latitude 7⁰30'N, 7⁰43'N) is the Capital of Benue State. The study area has an estimated population of 300, 377 people [10]. The radius is estimated as 16 km, sharing boundaries with four different Local Government Areas namely: Guma (in the North), Gwer West (in the South), Tarka (South-East) and Gwer East (in the South-West). Farming is the primary occupation of the people of Benue State, hence popularly called the "Food basket of the Nation". Among the popularly cultivated food crops are vegetables, tubers, oil crops, cereals and legumes. Production of okra is high in the study area amidst the factors limiting its productivity.

Sample collection and preparation

Viable okra seeds (Spineless variety) were purchased from seed stores of Teryima Seed Company Limited, Makurdi). Ripe plantain peels were collected as wastes in sufficient quantity from different restaurants within the study area. The peels were sun-dried and ground into powder using clean mortar and pistil. Silver nitrate ($AgNO_3$) powder was purchased from Emule Chemical Company, Makurdi. Arable soil, with pre-existing physicochemical properties, was collected from the Botanical Garden of the Joseph Sarwuan Tarka University, Makurdi, Nigeria. Soil was sieved and filled into 45 pots, each with 25 kg of the sieved soil, based on the experimental design, in preparation for seed sowing.

Green synthesis of silver nitrate nanoparticle

The procedures outlined in Fayomi *et al.* [11] were followed. Fresh leaves of *Jatropha tanjorensis* were harvested, prepared, air dried and grinded using electric blender. Exactly 6 g of the product was mixed with 100 mL of double distilled water in a beaker, and heated at 80°C for 1 hour. Then, 1 mM of silver nitrate hexahydrate was added to the extract and allowed to stand for 1 h. The resulting paste was calcined in a furnace at 400 °C for about 2hr then the residual was washed by ethanol and distilled water several times. The powder was then heated at 100 °C to dry

Experimental design

The experiment was designed using a complete randomized method with powdered plantain peel and silver nitrate nanoparticles as treatments, each with five levels replicated five times. The silver nitrate nanoparticle treatment was applied at 200,400,600 and 800 ppm while plantain peel had the following levels: 2.5, 10, 15 and 20 g. There were 45 experimental units in total (40 treated pots and 5 control pots) [12].

Seed sowing

Three okra seeds were sown in each pot and watered twice daily. Pots were protected from external influences using locally constructed nets.

Pre-treatment characterization of seedlings at 20 DAP (day after planting)

At 20 days after planting (20 DAP), seedlings were characterized prior to treatment application. Standard description guide was used in determination of plant height, leaf length, leaf width and number of leaves [13].

Treatment applications

Treatments were applied at the base of the plant stem following the procedures employed by Olasan *et al.*[12]. Treatment levels specified in the experimental design were followed. Silver nitrate nanoparticle was dispensed using the micro pipette while powdered plantain peel of known quantity was applied using the spatula.

Growth Parameter Assessment (40, 60, and 80 DAP)

The procedures outlined in Lamidi *et al.* [13] were used. Plant height was determined using the meter rule in centimeter (cm). All the leaves and branches in the plant stands present in the pot were counted. Leaf length and breadth were measured in centimeter (cm). Stem diameter was determined by measuring the distance between the widest parts of the stem with a meter rule in centimeter (cm).

Flowering and biological yield evaluation

The procedures outlined in Shah *et al.* [14] were used. Day to flowering was determined by recording the day the plant first produced flower after seed sowing. The number of fruits produced by the plant was counted. The pod length was determined using a meter rule the stalk or peduncle in centimeter (cm). After maturity and harvesting, number of seeds present in each fruit was counted per pot. Pod weight and seed weight were determined using the digital weighing balance and recorded in gram (g).

Determination of Physiological Yield

Wet and dry plant biomass

One fresh mature plant collected from each pot was weighed using the weighing balance after soil had been removed from the root. This was taken as the wet plant biomass (g). The plant was oven dried in the oven at 200^{O}C for 12 hours to remove the moisture content. This was recorded as the dry plant biomass (g) [15].

Determination of fiber

The fiber content was determined using the neutral detergent fiber (NDF) method [15]. Approximately 1 gram of dried and ground plant sample was placed in a filter bag, which was then submerged in a neutral detergent solution. The sample was heated for one hour at 100°C to dissolve soluble components, leaving the fibrous material. After cooling, the filter bag was rinsed with hot water and dried in an oven at 105°C for 24 hours. The dried sample was then weighed, and the fiber content was calculated as the percentage of the initial sample weight that remained after the treatment. The fiber content was determined using the formula:

Fiber Content (%) = Weight of dried residue (g) / Initial sample weight (g) × 100 please, use equation editor for all your equations.

Determination of chlorophyll

Chlorophyll concentration was determined following AOAC standard procedures [15]. A quantity of 0.1 g of fresh leaves of Okra seed was collected and placed into a test tube filled with 10 ml of acetone. The test tube was then incubated in a dark environment at 4°C for 24 hours to generate a green extract. Subsequently, the green extract was transferred to a cuvette for spectrophotometric measurement, where the absorbance was recorded at 663 nm for chlorophyll a and at 645 nm for chlorophyll b. The Chlorophyll content was determined using the formula:

Total Chlorophyll Content: Total Chl (mg/g) = (8.2 × A663) + (20.2 × A645) please, use equation editor

Statistical Analysis

Data were analyzed using Minitab version 17. One-way analysis variance was used to determine the variation in performances among the treatments. Mean separation was done using the Fisher's Least Significant Difference (LSD) test at a significance=level of $p \leq 0.05$.

Results

Preliminary characterization of growth parameters of okra plant at 20 days after planting (DAP) before treatment

Table 1 gives the preliminary characterization of growth parameters of okra plants before treatment at day 20. There were no significant differences (P>0.05) in growth characters in all pots evaluated. Plant height varied from 20.16±3.20 to 27.46±1.93 cm. The pots contained an average of 1.8 to 2.8 per pot. There were 4 to 5.2 leaves per plant measuring 5.3 and 7.2 cm in length as well as 6.6 and 9.1cm in width.

Effects of silver or nitrate? nanoparticles and plantain peel manure on the growth parameters of okra plant 40 DAP

Table 2 shows the effect of silver nitrate nanoparticles and powdered plantain peels as organic manure at different concentration on the growth parameters of okra at 40 days after planting (DAP). The treatments had significant effect on the plant height (p<0.05) where pots treated with OG10.0 g (Organic manure) produced the tallest plant (38.48 cm) followed by OG5.0 g (34.02 cm) and NA400 ppm (silver nitrate nanoparticle) with 33.86 cm. The shortest plant was observed in pot treated with NA200 ppm (29.64 cm). All treatment at various levels no significant differences t (P>0.05) on the following parameters: number of plants, number of leaves, leaf sizes, number of branches and stem diameters. However, pots that produced the highest number of plants were NA400 ppm and OG7.5 g (2.8 plant) while the highest number of leaves was counted in NA800 ppm (8.2 leaves). The longest leaf was measured in OG10.0 g pot (10.72 cm). Plants in OG5.0 g and OG10.0 g had the highest number of branches, while NA600 ppm pots produced plants with the widest diameter (4.24 cm).

Effects of silver nitrate and plantain peel manure on growth parameters of okra at 60 DAP

Table 3 illustrates the effect of silver nitrate nanoparticles and powdered plantain peels as organic manure (OG) at different concentrations on the growth parameters of okra at 60 days after planting. The treatments had significant effect on the plant height (P<0.05) where pots treated with NA400 ppm produced the tallest plant (43.86 cm) followed by OG10.0 g (42.28 cm) and OG5.0 with 39.50 cm. The shortest plant was observed in pot treated with NA800 ppm (34.58 cm). All treatment at various levels showed no significant difference (P>0.05) on the following parameters: number of plants, number of leaves, leaf sizes, number of branches and stem diameters. However, pots that produced the highest number of plants were NA400ppm and OG7.5 g (2.8 plant), while the highest number of leaves was counted in NA600 ppm (10.6 leaves). The longest leaf was measured in the control pot (12.75 cm). OG10.0 g plants recorded the highest number of branches (10.4 cm), while NA200 ppm produced the widest leaves (11.62 cm). NA600 ppm pots produced plants with the widest diameter (4.24 cm).

Table 1. Preliminary Characterization of Growth Parameters of Okra Plant before Treatment (20 DAP)

Treatments	Plant height at day 20 (cm)	Number of plants at day 20	Number of leaves at day 20	Leaf Length at day 20 (cm)	Leaf width at day 20 (cm)
Pot 1	22.16 ±3.89	2.60 ±0.55	4.80 ±0.45	7.00 ±1.00	6.88 ±1.07
Pot 2	22.62 ±3.53	2.20 ±0.84	4.40 ±0.55	7.16 ±0.78	9.04 ±0.88
Pot 3	25.34 ±4.91	2.80 ±0.45	4.00 ±0.71	5.30 ±1.96	6.60 ±3.58
Pot 4	22.32 ±3.82	1.80 ±0.84	5.00 ±0.71	6.36 ±0.91	7.62 ±0.97
Pot 5	20.74 ±4.38	2.60 ±0.89	4.00 ±0.00	5.360 ±2.05	6.42 ±2.46
Pot 6	22.36 ±4.62	2.00 ±0.70	5.00 ±1.00	5.56 ±1.44	6.84 ±1.83
Pot 7	24.86 ±4.11	2.40 ±0.54	5.00 ±1.00	6.90 ±1.03	8.56 ±1.32
Pot 8	20.16 ±3.20	2.80 ±0.44	5.20 ±0.85	7.20 ±0.84	9.06 ±1.75
Pot 9	27.46 ±1.92	2.20 ±0.84	4.60 ±0.55	7.22 ±3.71	9.06 ±6.04
P -value	0.113 (P>0.05)	0.288 (P>0.05)	0.075 (P>0.05)	0.391 (P>0.05)	0.539 (P>0.05)
LSD	NS	NS	NS	NS	NS

Legend: NS= Not significant; LSD= Least significant difference

Table 2. Effects of Silver Nitrate Nanoparticles and Powdered Plantain Peels on Growth Parameters of Okra Plants at day 40 of Planting

Treatments (ppm)	Plant height at day 40 (cm)	Number of plants at day 40	Number of leaves at day 40	Leaf Length at day 40 (cm)	Number of branches at day 40	Leaf width at day 40 (cm)	Stem diameter at day 40 (cm)
C	31.94 ±4.02[b]	2.60 ±0.55	6.60 ±0.55	8.60 ±1.67	7.00 ±1.00	7.80 ±1.06	3.24 ±0.69
NA200ppm	29.64 ±3.15[ab]	2.20 ±0.84	7.60 ±1.14	10.44 ±1.05	6.40 ±1.14	9.84 ±0.78	3.92 ±0.44
NA400ppm	33.86 ±4.6[ab]	2.80 ±0.45	6.80 ±1.30	8.54 ±1.06	7.20 ±1.09	8.10 ±3.13	3.84 ±0.42
NA600ppm	31.12 ±5.07[b]	1.80 ±0.83	7.40 ±1.14	8.72 ±1.07	6.40 ±1.14	8.88 ±0.86	4.24 ±0.74
NA800ppm	28.86 ±4.59[b]	2.60 ±0.89	8.20 ±0.84	8.66 ±2.09	7.60 ±1.14	6.82 ±2.74	3.80 ±0.46
OG2.5g	30.22 ±4.63[b]	2.00 ±0.71	7.40 ±1.52	9.14 ±0.99	6.00 ±1.00	6.84 ±1.83	3.76 ±0.50
OG5.0g	34.02 ±4.55[ab]	2.40 ±0.55	7.60 ±0.89	9.36 ±0.92	8.00 ±1.23	8.56 ±1.32	3.72 ±0.33
OG7.5g	28.96 ±3.05[b]	2.80 ±0.45	7.40 ±1.34	9.50 ±1.29	7.20 ±1.30	9.06 ±1.75	3.56 ±0.06
OG10.0g	38.48 ±3.55[a]	2.20 ±0.84	8.00 ±1.00	10.72 ±2.51	8.00 ±1.00	9.06 ±6.04	3.98 ±0.39
P –VALUE	0.017 (P<0.05)	0.288 (P>0.05)	0.428 (P>0.05)	0.217 (P>0.05)	0.070 (P>0.05)	0.651 (P>0.05)	0.152 (P>0.05)
LSD	5.361	NS	NS	NS	NS	NS	NS

Legend: NS= Not significant; LSD= Least significant difference; OG = Organic manure (Plantain peels); NA = Nanoparticles (Silver nitrate)

Table 3. Effects of Silver Nitrate and Powdered Plantain peels on Growth Parameters of Okra Plants at day 60 of Planting

Treatments	Plant height at day 60 (cm)	Number of plants at day 60	Number of leaves at day 60	Leaf Length at day 60 (cm)	Number of branches at day 60	Leaf width at day 60 (cm)	Stem diameter at day 60 (cm)
C	39.20 ±3.42[bc]	2.60 ±0.55	9.40 ±1.14	12.75 ±3.21	9.20 ±2.39	9.96 ±1.37	3.54 ±0.63
NA200 ppm	35.72 ±4.08 [cd]	2.20 ±0.84	8.40 ±0.89	12.20 ±1.33	9.60 ±1.14	11.62 ±0.80	3.92 ±0.44
NA400 ppm	43.86 ±2.34[a]	2.80± 0.45	8.80 ±0.84	10.52 ±1.16	9.80 ±1.79	9.90 ±2.75	3.84 ±0.42
NA600 ppm	39.02 ±5.19[bcd]	1.80± 0.84	10.60 ±1.14	11.00 ±1.54	10.20 ±2.17	10.38 ±1.24	4.24 ±0.73
NA800 ppm	34.58 ±4.63[d]	2.60± 0.89	10.20 ±1.64	11.14 ±1.25	9.20 ±1.93	8.90 ±2.32	3.80 ±0.47
OG2.5 g	38.04 ±2.17[bcd]	2.00 ±0.71	10.20 ±1.09	12.44 ±1.03	9.20 ±1.30	8.80 ±1.52	3.76 ±0.50
OG5.0 g	39.50 ±5.26abc	2.40± 0.55	9.60 ±0.89	12.52 ±1.15	8.75 ±1.26	10.60 ±1.28	3.72 ±0.33
OG7.5 g	37.56 ±2.02[bcd]	2.80 ±0.45	10.00 ±1.58	12.24 ±1.27	8.80 ±1.79	10.62 ±1.84	3.56 ±0.05
OG10.0 g	42.28[ab] ±2.05	2.20 ±0.84	9.20 ±0.84	13.72 ±1.97	10.40 ±2.07	10.40 ±5.64	3.98 ±0.39
P -VALUE	0.009 (P<0.05)	0.288 (P>0.05)	0.082 (P>0.05)	0.114 (P>0.05)	0.854 (P>0.05)	0.756 (P>0.05)	0.437 (P>0.05)
LSD	4.72	NS	NS	NS	NS	NS	NS

Legend: NS= Not significant; LSD= Least significant difference; OG = Organic manure (Plantain peels); NA = Nanoparticles (Silver nitrate)

Effects of silver nitrate nanoparticles *and plantain peel manure on biological yield parameters of okra*

Table 4 presents the effects of silver nitrate nanoparticles and powdered plantain peels on flowering, pod and seed yield of okra. All pots had no variation in the day to flowering. Each okra pots all had one pod. There was no significant difference in the length of pods where control produced the longest pod (7.30 cm) followed by OG5.0 g with pod length of 7.28 cm and OG7.5 g (6.84 cm). All treatment at various levels showed no significant difference (P>0.05) on the following parameters: number of seeds per pod, total pod weight and total seed weight.

Table 4. Effects of Silver Nitrate nanoparticles and Powdered Plantain peels on Flowering and Yield Parameters of okra Plants

Treatments	Day to flowering	Number of pods/fruits	Pod length (cm)	Number of seeds per pod	Total Pod weight (g)	Total seed weight(g)
C	60	1	7.30 ±1.43	10	7.38 ±3.72	0.3
NA200ppm	60	1	5.92 ±0.88	35	5.66 ±2.51	0.7
NA400ppm	60	1	6.16 ±1.79	18	7.720 ±2.13	1.1
NA600ppm	60	1	6.76 ±1.33	15	8.76 ±3.68	0.5
NA800ppm	60	1	6.74 ±1.57	33	9.48 ±1.52	0.8
OG2.5g	60	1	6.3 ±1.45	29	8.04 ±2.18	0.6
OG5.0g	60	1	7.28 ±1.39	12	10.20 ±1.89	0.3
OG7.5g	60	1	6.84 ±1.40	23	6.56 ±2.56	0.5
OG10.0g	60	1	6.14 ±0.95	19	8.14 ±2.05	0.4
P -VALUE	NV	NV	0.726 (P>0.05)	NV	0.201 (P>0.05)	NV
LSD	NS	NS	NS	NS	NS	NS

Legend: NS= Not significant; LSD= Least significant difference; NV = No variation; OG = Organic manure (Plantain peels); NA = Nanoparticles (Silver nitrate)

Effects of silver nitrate nanoparticles and plantain peel manure on physiological yield parameters of okra

Figures 1-4 presents the effects of silver nitrate and powdered plantain peels on the physiological and biochemical yield of okra plants. The control group (C) recorded a wet biomass of 44 g, dry biomass of 17.4 g, fiber content of 3.6%, and chlorophyll content of 20.7 mg/g. silver nitrate treatments showed varying effects, with NA600 ppm recording the highest wet biomass (40.8 g) and NA800 ppm the lowest chlorophyll content (3.8 mg/g). Plantain peel treatments also showed fluctuations, with OG2.5 g achieving the highest wet biomass (43.1 g) but lower chlorophyll (18.2 mg/g). Overall, the treatments led to diverse outcomes in biomass, fiber, and chlorophyll content.

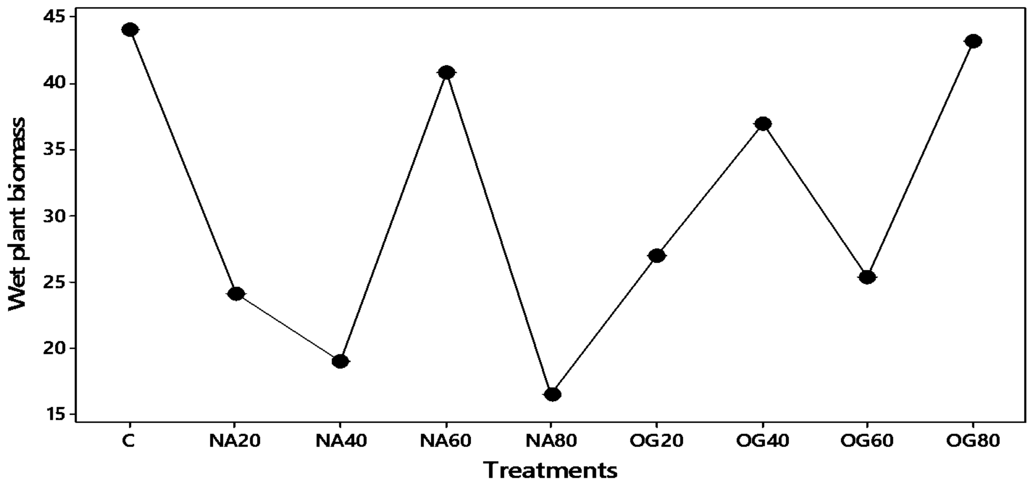

Figure 1. Interval Plot of Wet Biomass (g) of Okra and Treatments

Keys:NA20 = 200 ppm nanoparticle; NA40 = 400 ppm nanoparticle, NA60 = 600 ppm nanoparticle, NA80 = 800 ppm nanoparticle; OG20 = 2.5 g organic plantain peel; OG40 = 5.0 g organic plantain peel; OG60 = 7.5 g organic plantain peel, OG80 = 10 g organic plantain peel

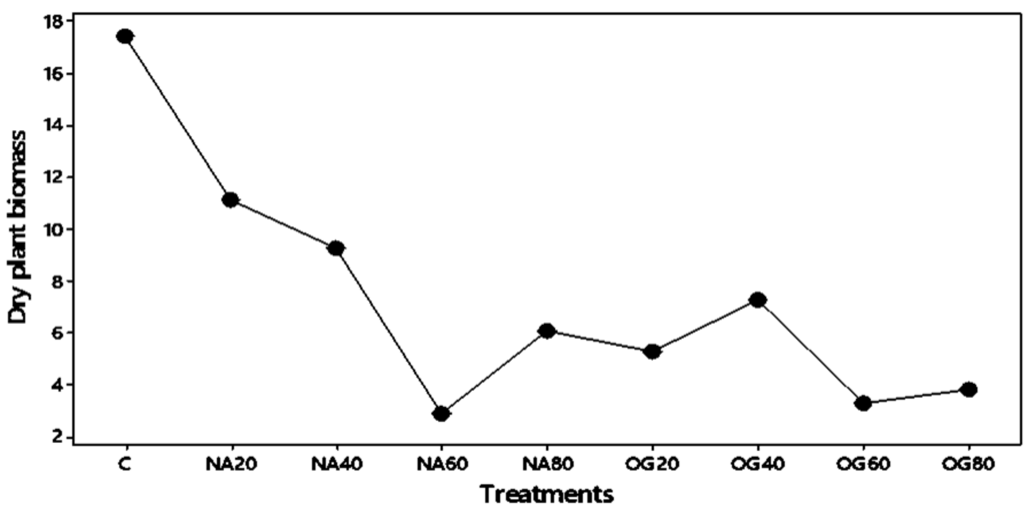

Figure 2. Interval Plot of Dry Biomass (g) of Okra and Treatments

Keys: NA20 = 200 ppm nanoparticle; NA40 = 400 ppm nanoparticle, NA60 = 600 ppm nanoparticle, NA80 = 800 ppm nanoparticle; OG20 = 2.5 g organic plantain peel; OG40 = 5.0 g organic plantain peel; OG60 = 7.5 g organic plantain peel, OG80 = 10 g organic plantain peel

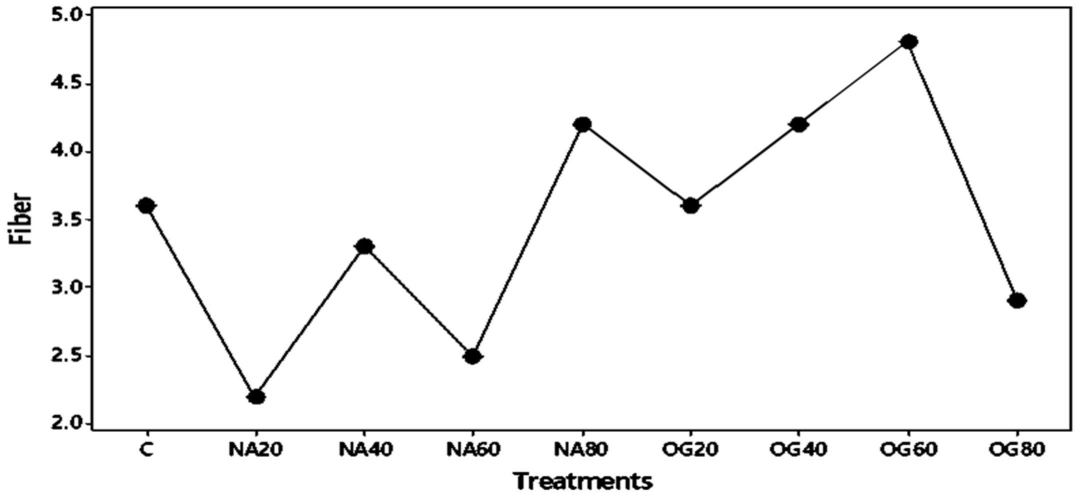

Figure 3. Interval Plot of Okra Seed Fiber and Treatments

Keys: NA20 = 200 ppm nanoparticle; NA40 = 400 ppm nanoparticle, NA60 = 600 ppm nanoparticle, NA80 = 800 ppm nanoparticle; OG20 = 2.5 g organic plantain peel; OG40 = 5.0 g organic plantain peel; OG60 = 7.5 g organic plantain peel, OG80 = 10 g organic plantain peel

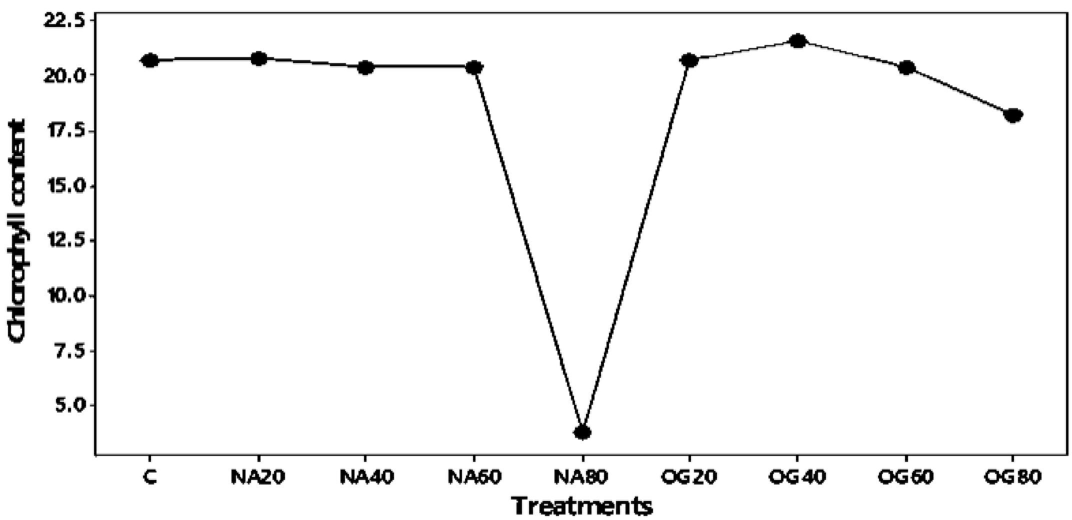

Figure 4. Interval Plot of Leaf Chlorophyll in Okra and Treatments

Keys: NA20 = 200 ppm nanoparticle; NA40 = 400 ppm nanoparticle, NA60 = 600 ppm nanoparticle, NA80 = 800ppm nanoparticle; OG20 = 2.5 g organic plantain peel; OG40 = 5.0 g organic plantain peel; OG60 = 7.5 g organic plantain peel, OG80 = 10 g organic plantain peel

Figures 1-4 should be edited. The caption the interval plot… should be deleted from the top of the figure. Also, the footnote: the pooled standard deviation is wrongly placed.

Discussion

The findings from this research showed that both silver nitrate nanoparticles and powdered plantain peel significantly influenced several growth and physiological yield parameters of okra (*Abelmoschus esculentus*), thus enhancing productivity of the plant. Notably, these treatments affected plant height and biochemical yield more than flowering and pod production.

Powdered plantain peel, as an organic amendment, is rich in essential nutrients such as potassium, calcium, and magnesium [8]. These are macronutrients needed by the plants for physiological processes including cell division, growth and photosynthesis. This possibly explains the observed increases in plant height and leaf chlorophyll levels in okra plant treated with plantain peel. Studies by different authors [16],[17]. reported that plantain peel' high potassium content enhances flowering and fruiting in crops, with potassium aiding in water retention and nutrient transport within plants. Consistent with this, the plantain peel treatment at 7.5 g and 5.0 g in this study produced the highest fiber content in seeds and chlorophyll in leaves, respectively while 10g of the powdered treatment enhanced growth. Similarly, silver nitrate nanoparticles also positively impacted plant height, with the 400ppm concentration producing the tallest plants at 60 DAP. Silver nitrate, known for its antimicrobial properties, ability to protect crops from pathogens, reduce plant stress and allow for better nutrient allocation toward growth. This is supported by Tariq *et al*. [9] who demonstrated that silver nitrate treatments in plants resulted in enhanced vegetative growth and pathogen resistance, highlighting its potential role in sustainable okra production.

While this study showed that both treatments positively influenced vegetative growth and biochemical yields (fiber and chlorophyll), their impact on reproductive traits such as pod and seed yield was minimal. Further investigation may be needed to unravel the effects of the treatments on reproductive yields of okra, because it is expected that physiological yield such as improved chlorophyll content should translate into high primary productivity that may control fruiting. The present finding deviates from previous work that reported the significance of nanoparticles in improving biological yield including fruit and seed production in many crops [9] [11]. The present study aligns with the views of Chittora *et al.* [18] and Lamidi *et al*. [18] who emphasized the benefits of combining organic and inorganic amendments in enhancing the growth of okra. Such a combined application could provide a balanced approach, offering immediate growth benefits while fostering long-term soil health. Both silver nitrate nanoparticles and plantain peel have shown potential as growth-enhancing agents, particularly for vegetative and biochemical yield in okra. Further research on optimizing these treatments could advance sustainable okra cultivation, maximizing both productivity and environmental benefits.

Conclusion

This study demonstrated that while initial growth parameters in okra plants showed no significant variation across treatments, the application of plantain peel extract and silver nitrate nanoparticles notably influenced growth outcomes over time. At 40 DAP, okra plants treated with 10.0 g of powdered plantain peel displayed the highest height increase. At 60 DAP, plants treated with 400 ppm of silver nitrate nanoparticles achieved the tallest height. Additionally, the application of 7.5g plantain peel extract yielded the highest fiber content in seeds, and 5.0 g of the same extract produced leaves with the highest chlorophyll concentration. Despite both treatments showing no substantial impact on flowering or yield parameters (pods and seeds), these findings suggest that powdered plantain peel extract and silver nitrate nanoparticles could be valuable growth-enhancing agents, contributing to the biochemical yield of okra plants, particularly in fiber and chlorophyll content. Future research may further explore their potential in enhancing yield parameters to maximize okra production.

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