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Effects of Biosynthesized Titanium Oxide Nanoparticle (TIO_2 NPs) and Rice Compost on the Productivity of Mungbeans (*Vigna radiata* L.) as Orphan Legume Crop

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ABSTRACT

Background and Objective: Mungbean (*Vigna radiata* L.) plays a crucial role in global food security, making it imperative to explore innovative approaches to enhance its productivity. The study aimed to determine the effects of biosynthesized Titanium Oxide Nanoparticles (TiO_2 NPs) and rice compost on the overall productivity of the crop. **Materials and Methods:** A complete randomized experimental design was set up. Treatments were applied at different levels of concentration. Data were collected on growth, flowering, yield, physiological and biochemical parameters. Data were analyzed on the Minitab 16.0 using the one-way ANOVA. Treatment means were separated using the Fisher LSD method at $p \leq 0.05$ level of significance. **Results:** Significant differential responses to treatments ($p < 0.05$) were recorded in plant height and leaf width at day 40 where rice compost at 7.5 g gave the tallest plant height (23.5 cm) and leaf width (5.2 cm). At day 60, rice compost at 7.5 g increased the number of leaves (23.9) and branches (12.4). The TiO_2 at 400 and 600 ppm influenced stem diameter and pod yield respectively while 200 ppm increased the number of seeds per pod. Rice compost at 5.0 g yielded high seed fiber while TiO_2 at 800 ppm and rice compost at 5.0 g yielded high chlorophyll in the leaf. **Conclusion:** Although the two treatment types did not perform better than the control (without treatment) in the physiological and biochemical yield of the plant, rice compost was found to be an effective growth enhancer at 7.5 g level while titanium oxide nanoparticles at lower doses (20-60 ppm) improved stem diameter and pod production. They are recommended as biofertilizers in the production of mungbean, as an orphan legume crop, to boost food security in Sub-Saharan Africa.

KEYWORDS

Nanoparticle, rice compost, biofertilizers, mungbean, improvement, productivity

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INTRODUCTION

As a vital orphan legume crop, mungbean (*Vigna radiata* L.) plays a crucial role in global food security, making it imperative to explore innovative approaches to enhance its productivity. Titanium oxide nanoparticles (TIO_2 NPs), characterized by their unique physicochemical properties, have been studied in various fields, including agriculture, to decipher their effects on plant growth and development. Titanium oxide nanoparticles possess distinctive characteristics such as high surface area, reactivity, and biocompatibility, making them promising candidates for agricultural applications[1,2]. The small-sized nano fertilizers facilitate efficient water uptake and interaction with plant systems, potentially influencing drought tolerance and other physiological processes[3]. With the increasing demand for mung beans, optimizing mungbean yield becomes paramount. Exploring novel avenues, such as the application of NPs, can contribute to sustainable agriculture and meet the growing demands for this essential crop. Adeyemi *et al.*[4] and Das *et al.*[5] have reported that NPs can influence plant physiology by enhancing photosynthesis, nutrient uptake, and water use efficiency. These nanoparticles may act as nano-carriers, facilitating the delivery of titanium ions directly to plant cells, thereby influencing vital physiological processes. Understanding the biochemical changes induced by TIO_2 NPs is crucial. Research by Mohammadi *et al.*[6] demonstrated that TIO_2 NPs can increase the adaptability of plants to withstand cold conditions and other oxidative stresses. Additionally, alterations in secondary metabolites and nutrient content have been observed, suggesting a multifaceted impact on plant biochemistry. Titanium Oxide Nanoparticles (TIO_2 NPs) have emerged as potential contributors to agricultural innovation due to their unique physicochemical properties[7]. Despite numerous studies investigating the impact of nanoparticles on plant growth[8,9], a significant research gap persists in the determination of the effects of TIO_2 nanoparticles as inorganic amendments and organic manure on the production of legumes.

A primary challenge in mungbean production is poor growth and low yield[10,11]. Conventional fertilizers have been used to improve growth and yield but prove to be detrimental to the environment. Also, the current literature lacks comprehensive insight into the responses of mung beans to titanium oxide nanoparticles and rice compost. The present research sought to fill the existing gaps in knowledge. The use plant waste materials as organic matter as soil amendments has gained much attention due to their environmental friendliness and availability. This study investigated the impact of TIO_2 NPs and rice compost on the productivity of mungbean (*Vigna radiata*) as an important leguminous crop. Specifically, it sought to determine the effects of these inorganic and organic treatments at different levels on the growth, flowering, pod and seed yield, biomass, and biochemical yields of the crop.

MATERIALS AND METHODS

Study area: The study was carried out in the Joseph Sarwuan Tarka University Makurdi, Benue State, North-Central Nigeria. Fieldwork was done between July to December, 2024.

Source of materials: Green synthesized *Jatropha tanjorensis* based TIO_2 NPs were sourced from the Chemistry Department while seeds of mungbeans (SWETA variety) were obtained from Seed Stores of the Department of Plant Breeding and Seed Science, all at the Joseph Sarwuan Tarka University, Makurdi, Nigeria. A surface soil sample of the Botanical Garden of the same university was collected.

Experimental design: A completely randomized design potted experiment was set up. It consisted of 9 treatment levels and 5 replicates with a total of 45 pots as the total experimental units. Titanium oxide nanoparticles (200, 400, 600, and 800 ppm) and rice compost (2.5, 5.0, 7.5, and 10 g) had 4 levels each with the control pot (no application). Approximately, 25 kg of soil sample was weighed into each of the 45 pots in line with the experimental design[12,13].

Seed sowing and preliminary plant characterization: Four seeds were sown at 3 cm depth manually in each pot. They were thinned to three per pot after seedling establishment. Plants were characterized phenotypically at day 20 before treatment applications.

Treatment application: The procedures in Michael *et al.*[13] were used. Powdered titanium oxide was diluted with water and applied to the base of plant materials in part per million (ppm) at different levels (200, 400, 600, and 800 ppm) using the micropipette. Rice compost prepared in solid form was prepared and applied appropriately as specified in the treatment levels (2.5, 5.0, 7.5, and 10 g)[12,13].

Post-treatment evaluation of growth characteristics: Growth data were collected after treatment application at 40 and 60 days of the plant cycle. The following growth parameters data were collected: Number of plants in the pot, plant height (cm), leaf length (cm), leaf width (cm), and stem diameter (cm). All plants in each pot were evaluated and the average values were recorded for each parameter[12,13].

Collection of flowering and yield data: Data were obtained on days to first flowering, pods per plant, seed per pod, pod length (cm), pod weight (g), and seed weight (g). All plants in each pot were evaluated and the average values were recorded for each parameter[12,13].

Wet and dry plant biomass: One fresh mature plant collected from each pot was weighed using the weighing balance after the 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 for 12 hrs to remove the moisture content[14]. This was recorded as the dry plant biomass (g).

Fiber content determination: Fiber content was determined using the standard method of Horwitz and AOAC[14] whereby defatted samples were treated with 200 mL of 1.2% H_2SO_4 and boiled under reflux for 30 min. This was followed by oven drying at 150°C for 3 hrs, cooling in a desiccator, and weighing. The cooled sample was ashed in a muffle at 550°C for 2 hrs, cooled in a desiccator, and reweighed.

The fiber content was calculated using the formula:

$$\text{Fibre (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where:

W_1 = Weight of crucible sample after washing and drying in the oven
W_2 = Weight of crucible+sample

Chlorophyll content determination: Chlorophyll content was determined using standard method[14]. Exactly 0.1 g of fresh mung bean leaves were collected and placed in a test tube filled with 10 mL of acetone and incubated in a dark room for 24 hrs at 4°C to obtain a green extract. The green extract was collected into a cuvette for spectrophotometric measurement to measure the absorbance of the chlorophyll extract at 663 nm for chlorophyll a and 645 nm for chlorophyll b.

The chlorophyll content was determined using the formula:

$$\text{Total Chlorophyll content (mg/g)} = (8.2 \times A_{663}) + (20.2 \times A_{645})$$

Statistical analysis: Minitab 16.0 was used in analyzing the data. One-way ANOVA and Pearson's correlation analyses were applied. Fisher's LSD method was used to separate the means at a 95% confidence limit (p = 0.05 limit).

RESULTS AND DISCUSSION

The result of the preliminary assessment of the growth parameters of mungbean on day 20 of planting (Table 1) showed no significant variation ($p>0.05$) in each of the growth parameters evaluated in all pots. Significant differential responses to treatments ($p<0.05$) were recorded in plant height and leaf width at

Table 1: Preliminary evaluation of mung bean at day 20 of planting (before treatment application)

Treatment	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)	Stem diameter at day 20 (cm)
Pot 1	11.00±0.61^{a}	3.20±0.45^{a}	10.20±0.57^{b}	1.75±0.25^{a}	1.00±0.00^{c}	1.70±0.45^{a}
Pot 2	11.00±0.61^{a}	3.20±0.45^{a}	10.20±0.57^{b}	1.70±0.33^{a}	1.10±0.14^{abc}	1.40±0.42^{a}
Pot 3	10.40±0.55^{a}	3.40±0.55^{a}	10.20±0.76^{b}	1.65±0.22^{a}	1.05±0.12^{bc}	1.50±0.35^{a}
Pot 4	10.90±0.55^{a}	3.40±0.55^{a}	09.80±0.57^{b}	1.55±0.33^{a}	1.15±0.22^{abc}	1.50±0.50^{a}
Pot 5	10.60±0.96^{a}	3.60±0.55^{a}	10.50±0.50^{ab}	1.50±0.35^{a}	1.15±0.14^{abc}	1.60±0.42^{a}
Pot 6	10.00±0.94^{a}	3.20±0.45^{a}	10.30±0.98^{ab}	1.40±0.45^{a}	1.25±0.00^{a}	1.70±0.27^{a}
Pot 7	10.60±0.65^{a}	3.40±0.55^{a}	09.90±1.08^{b}	1.55±0.33^{a}	1.25±0.18^{a}	1.30±0.27^{a}
Pot 8	10.60±1.08^{a}	3.40±0.55^{a}	10.20±0.57^{b}	1.35±0.42^{a}	1.20±0.11^{ab}	1.60±0.42^{a}
Pot 9	10.60±0.96^{a}	3.40±0.55^{a}	11.20±0.91^{a}	1.70±0.33^{a}	1.12±0.13^{abc}	1.60±0.42^{a}
p-value	0.612 ($p>0.05$)	0.947 ($p>0.05$)	0.215 ($p>0.05$)	0.575 ($p>0.05$)	0.070 ($p>0.05$)	0.082 ($p>0.05$)

^{abc}Means that do not share a letter along the column are significantly different at $p\leq0.05$ and cm: Centimeter

Table 2: Effects of titanium oxide nanoparticle and rice compost on growth parameters at day 40 of planting

Treatment	Plant height at day 40 (cm)	Number of plants at day 40	Number 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 at day 40 (cm)
C	21.00±0.71^{c}	3.40±0.55^{a}	16.70±1.15^{b}	5.80±0.57^{a}	6.60±0.55^{ab}	4.30±0.67^{bc}	1.45±0.21^{b}
NA200 ppm	22.60±1.64^{ab}	3.80±0.45^{a}	16.30±0.67^{b}	6.20±0.57^{a}	6.60±0.55^{ab}	4.82±0.43^{ab}	1.60±0.38^{ab}
NA400 ppm	22.50±0.00^{ab}	3.60±0.55^{a}	18.10±1.19^{a}	6.25±0.50^{a}	6.80±0.45^{ab}	4.20±0.72^{bc}	1.55±0.41^{ab}
NA600 ppm	22.60±0.74^{ab}	3.20±0.45^{a}	17.50±0.61^{ab}	5.70±0.57^{a}	7.00±0.71^{ab}	4.00±0.71^{c}	1.55±0.27^{ab}
NA800 ppm	22.30±1.26^{abc}	3.40±0.55^{a}	17.40±1.03^{ab}	6.10±0.22^{a}	6.40±0.55^{b}	4.50±0.61^{abc}	1.60±0.45^{ab}
OG2.5 g	22.00±0.35^{bc}	3.20±0.45^{a}	17.10±1.60^{ab}	6.10±0.65^{a}	6.80±0.45^{ab}	3.90±0.42^{c}	1.90±0.14^{a}
OG5.0 g	21.60±1.92^{bc}	3.80±0.45^{a}	17.30±0.57^{ab}	5.70±0.57^{a}	7.20±0.45^{a}	3.90±0.65^{c}	1.40±0.38^{b}
OG7.5 g	23.50±1.23^{a}	3.80±0.45^{a}	17.10±0.74^{ab}	5.80±0.67^{a}	7.20±0.84^{a}	5.20±0.45^{a}	1.40±0.29^{b}
OG10.0 g	21.30±1.26^{bc}	3.60±0.55^{a}	16.80±0.76^{b}	6.10±0.22^{a}	6.40±0.55^{b}	4.60±0.42^{abc}	1.49±0.32^{ab}
p-value	0.05 ($p = 0.05$)	0.312 ($p>0.05$)	0.225 ($p>0.05$)	0.589 ($p>0.05$)	0.223 ($p>0.05$)	0.012 ($p<0.05$)	0.408 ($p>0.05$)

C: Control treatment, NA: Titanium oxide nanoparticle, OG: Rice compost organic manure, ^{abc}Means that do not share a letter along the column are significantly different at $p\leq0.05$ and cm: Centimeter

Table 3: Effects of titanium oxide nanoparticle and rice compost on growth parameters at day 60 of planting

Treatments	Plant height at day 60 (cm)	Number of plants at day 60	Number 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 at day 60 (cm)
C	23.20±1.44^{c}	3.40±0.55^{a}	19.60±1.34^{de}	5.80±0.57^{a}	9.40±0.55^{d}	4.30±0.67^{bc}	1.80±0.27^{abc}
NA200 ppm	24.90±1.14^{ab}	3.80±0.45^{a}	19.20±1.04^{e}	6.20±0.57^{a}	11.20±1.30^{ab}	4.82±0.43^{ab}	1.90±0.22^{ab}
NA400 ppm	25.10±0.42^{a}	3.60±0.55^{a}	20.80±0.91^{cde}	6.00±0.50^{a}	12.20±0.45^{ab}	4.22±0.69^{bc}	2.00±0.00^{a}
NA600 ppm	24.70±0.45^{ab}	3.20±0.45^{a}	21.90±1.71^{abc}	5.70±0.57^{a}	9.80±0.84^{cd}	4.00±0.71^{c}	1.60±0.22^{cd}
NA800 ppm	24.20±0.45^{abc}	3.40±0.55^{a}	22.10±1.67^{abc}	6.10±0.22^{a}	12.20±0.84^{ab}	4.50±0.61^{abc}	1.80±0.27^{abc}
OG2.5 g	24.60±1.19^{ab}	3.20±0.45^{a}	23.00±2.06^{ab}	6.10±0.65^{a}	12.40±1.52^{a}	3.90±0.42^{c}	1.60±0.22^{cd}
OG5.0 g	24.10±0.82^{abc}	3.80±0.45^{a}	21.40±2.07^{bcd}	5.70±0.57^{a}	11.00±1.00^{bc}	3.90±0.65^{c}	1.50±0.00^{d}
OG7.5 g	24.20±0.57^{abc}	3.80±0.45^{a}	23.90±1.34^{a}	5.80±0.67^{a}	12.40±1.52^{a}	5.20±0.45^{a}	1.60±0.22^{cd}
OG10.0 g	23.80±1.10^{bc}	3.60±0.55^{a}	22.90±2.07^{ab}	6.10±0.22^{a}	12.20±0.45^{ab}	4.58±0.43^{abc}	1.64±0.35^{bcd}
p-value	0.067 ($p>0.05$)	0.312 ($p>0.05$)	0.001 ($p<0.05$)	0.711 ($p>0.05$)	0.001 ($p<0.05$)	0.012 ($p<0.05$)	0.022 ($p<0.05$)

C: Control treatment, NA: Titanium oxide nanoparticle, OG: Rice compost organic manure, ^{abc}Means that do not share a letter along the column are significantly different at $p\leq0.05$ and cm: Centimeter

day 40 (Table 2) where rice compost at 7.5 g gave the tallest plant height (23.5 cm) and leaf width (5.2 cm). At day 60 (Table 3), rice compost at 7.5 g caused a significant increase in the number of leaves (23.9), number of branches (12.4), and leaf diameter (5.2 cm). Titanium oxide nanoparticles (TIO_2 NPs) at 400 ppm positively influenced the stem diameter to the highest value of 2.0 cm. This is under the result of Das *et al.*[5] who demonstrated that TIO_2 NPs positively affect the growth and yield of mungbean.

Table 4 gives the effect of titanium oxide nanoparticles and rice compost on the flowering time, pod, and seed yield of mungbean. Treatments had significant positive effects ($p<0.05$) on the number of pods, number of seeds, and pod weight. The flowering period was shortest at the control treatment (without enhancers). Also, pod weight was highest in the control treatment while TIO_2 NPs at lower doses

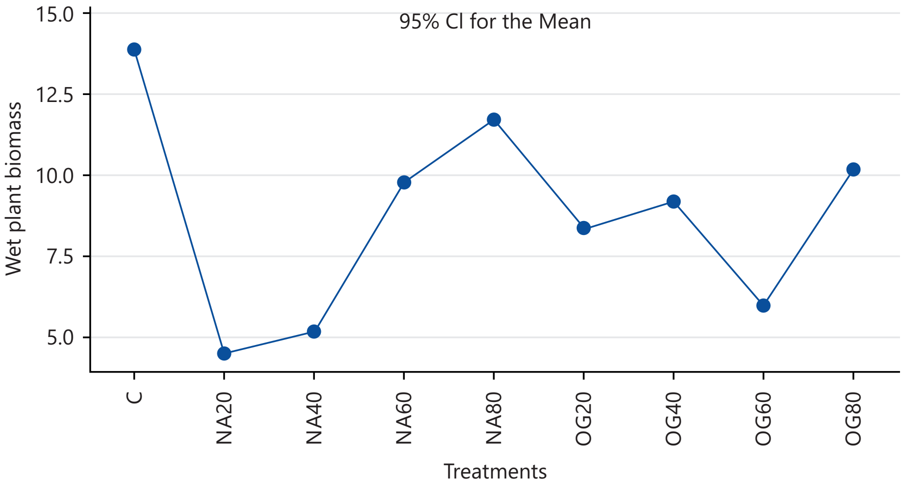

Fig. 1: Interval plot of wet plant biomass vs treatments

C= control treatment, NA: Titanium oxide nanoparticle at 200, 400, 600, and 800 ppm, respectively and OG: Rice compost organic manure (OG20 = 2.5 g; OG40 = 5.0 g; OG60 = 7.5 g and OG80 = 10.0 g)

Table 4: Effects of titanium oxide nanoparticle and rice compost on flowering and yield parameters

Treatment	Day to flowering	Number of pods per plant	Pod length (cm)	Number of seeds per pod	Total pod weight (g)	Total seed weight
C	36.00±0.71^{b}	24.60±5.59^{bc}	5.23±1.16^{a}	5.80±1.10^{ab}	2.00±0.00^{a}	0.12±0.00
NA200 ppm	37.00±1.00^{b}	25.20±6.98^{bc}	5.50±1.41^{a}	6.60±1.67^{a}	1.25±0.00^{e}	0.15±0.00
NA400 ppm	38.00±1.23^{b}	20.60±1.14^{c}	4.79±1.08^{ab}	6.00±0.71^{ab}	1.50±0.00^{d}	0.13±0.00
NA600 ppm	37.60±2.19^{b}	33.20±1.10^{a}	3.92±1.00^{b}	5.00±1.23^{bc}	1.25±0.00^{e}	0.12±0.00
NA800 ppm	37.40±2.41^{b}	19.60±1.82^{c}	4.48±0.73^{ab}	5.60±0.55^{abc}	1.23±0.00^{e}	0.18±0.00
OG2.5 g	36.20±0.84^{b}	19.80±1.92^{c}	4.48±0.77^{ab}	5.00±1.00^{bc}	1.65±0.23^{c}	0.16±0.00
OG5.0 g	37.60±2.19^{b}	26.80±6.91^{b}	4.32±0.56^{ab}	5.00±0.00^{bc}	1.95±0.11^{a}	0.12±0.00
OG7.5 g	43.60±4.93^{a}	24.60±6.07^{bc}	4.42±0.80^{ab}	4.60±0.55^{c}	1.80±0.11^{b}	0.14±0.00
OG10.0 g	43.00±2.74^{a}	30.20±5.02^{ab}	4.50±0.50^{ab}	5.80±0.45^{ab}	1.59±0.09^{cd}	0.20±0.00
p-value	0.000 ($p<0.05$)	0.000 ($p<0.05$)	0.261 ($p>0.05$)	0.041 ($p<0.05$)	0.000 ($p<0.05$)	NA

C: Control treatment, NA: Titanium oxide nanoparticle, OG: Rice compost organic manure, ^{abc}Means that do not share a letter along the column are significantly different at $p\leq 0.05$ and cm: Centimeter

(200-600 ppm) improved pod production. For instance, 600 ppm application significantly yielded the highest number of pods (33.2 pods) per plant while 200 ppm of the nanomaterial produced 6.6 seeds per pod. This result confirmed the suggestion of Al-Khaial *et al.*[15] that biosynthesized nanoparticles may help improve the yield of crops. This is also consistent with findings by Michael *et al.*[13] on the use of zinc oxide nanoparticles to improve the yield of Bambara.

Figure 1-4 presents the effects of TiO_2 (NA200-800 ppm) and rice compost (OG2.5-10.0 g) on the physiological and biochemical yield parameters of mung bean plant. The maximum values of wet biomass (Fig. 1), dry biomass (Fig. 2), fiber (Fig. 3), and chlorophyll (Fig. 4) were recorded in the control treatment. These parameters tend to decrease in both nano and organic treatments. However, rice compost at 5.0 g yielded high seed fiber while TiO_2 at 800 ppm and rice compost at 5.0 g yielded high chlorophyll in the leaf. However, a study by Ko and Hwang[12] contradicts the current finding, reporting no significant improvement in physiological parameters such as biomass with TIO_2 NPs. This implies the need for further investigation into the factors influencing biomass response. Possible reasons for the discrepancy may include experimental conditions and the specific physiological processes affected by TIO_2 NPs. Ahmad *et al.*[16] thought that nanomaterials play key roles in improving the metabolic processes in plants. The present finding also agreed with a study by Dola and Mannan[17] who established a significant impact of zinc oxide nanoparticles on the growth, yield, and drought tolerance of soybeans. Results showed that titanium oxide at 800 ppm and rice compost at 5.0 g yielded high chlorophyll in the leaf. This finding is

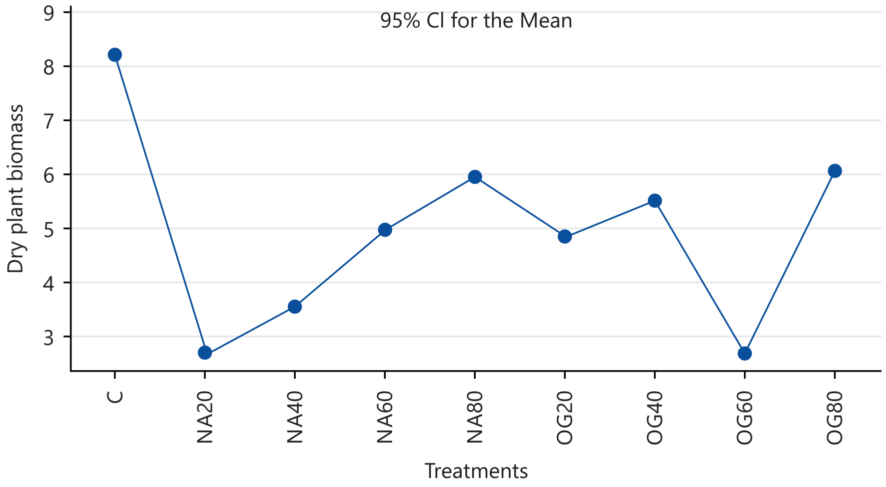

Fig. 2: Interval plot of dry plant biomass vs treatments

C= control treatment, NA: Titanium oxide nanoparticle at 200, 400, 600, and 800 ppm, respectively and OG: Rice compost organic manure (OG20 = 2.5 g; OG40 = 5.0 g; OG60 = 7.5 g and OG80 = 10.0 g)

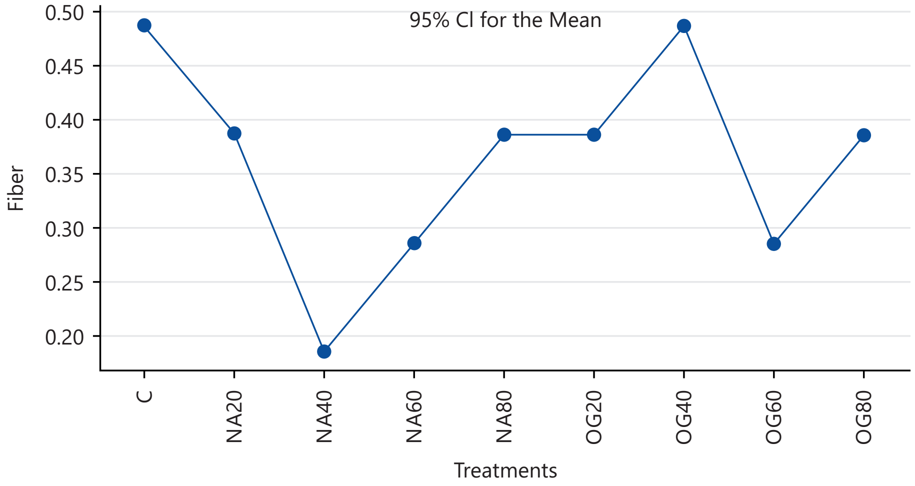

Fig. 3: Interval plot of fiber vs treatments

C= control treatment, NA: Titanium oxide nanoparticle at 200, 400, 600, and 800 ppm, respectively and OG: Rice compost organic manure (OG20 = 2.5 g; OG40 = 5.0 g; OG60 = 7.5 g and OG80 = 10.0 g)

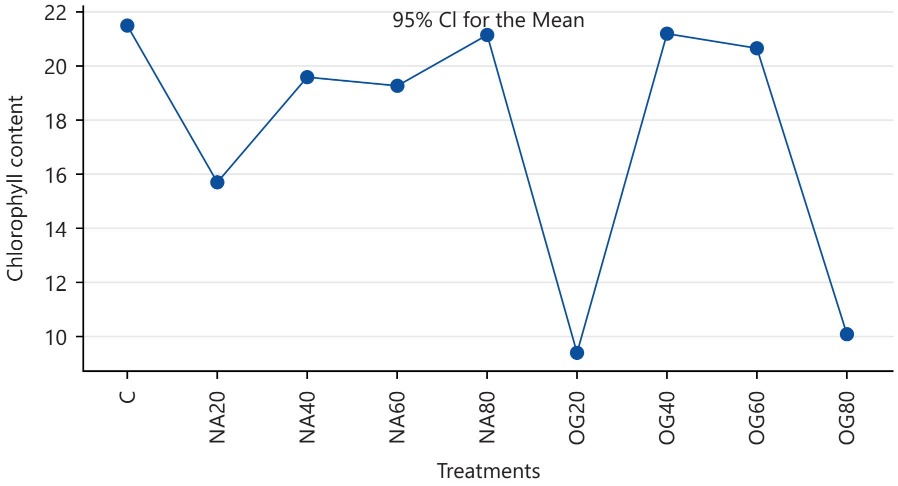

Fig. 4: Interval plot of Chlorophyll content vs treatments

C= control treatment, NA: Titanium oxide nanoparticle at 200, 400, 600, and 800 ppm, respectively and OG: Rice compost organic manure (OG20 = 2.5 g; OG40 = 5.0 g; OG60 = 7.5 g and OG80 = 10.0 g) consistent with a study by Raliya *et al*.[18] who reported a significant increase in physiological and biochemical responses of tomato plants to titanium nanoparticles, including the translocation efficiency, chlorophyll, and protein content. A study by Ramadan *et al*.[19] reported a significant increase in biochemical changes in soybeans in response to iron and magnesium oxide nanoparticles. However, the study highlights the need for further investigation into the specific factors influencing nanomaterial interactions with biochemical changes in mungbean.

CONCLUSION

Results showed that the two treatment types (biosynthesized TIO_2 NPs and rice compost) did not perform better than the control (without treatment) in the physiological and biochemical yield of the plant. However, rice compost was found to be an effective growth enhancer at a 7.5 g level while titanium oxide nanoparticles at lower doses (200-600 ppm) improved stem diameter and pod production. They are recommended as biofertilizers in the production of mungbean, as an orphan legume crop, to boost food security in Sub-Saharan Africa.

SIGNIFICANCE STATEMENT

This study explores eco-friendly alternatives to synthetic fertilizers for enhancing growth and yield in legumes. The findings suggest that green-synthesized titanium dioxide nanoparticles and organic rice compost could serve as effective biofertilizers, potentially boosting mungbean production-a drought-tolerant orphan legume crop-thereby contributing to food security in Sub-Saharan Africa.

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