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Effects of conventional and neem bark-based nano-fertilizer on garden egg (*Solanum aethiopicum* L.) performance

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Abstract

Garden egg (*Solanum aethiopicum* L.), a tropical vegetable crop with nutritional, medicinal, and economic benefits. Addressing its poor growth with conventional fertilizers under depleted soil nutrient conditions often leads to environmental degradation. Therefore, this study determines the optimum neem bark-based nano-fertilizer level for improving plant height and leaf area in two genotypes. Using a 2×6 factorial design, two garden egg varieties (LO1 and LO8) and six fertilizer treatments (control, organic (poultry manure), inorganic (NPK 20:10:10), and nano-fertilizers at 5, 10, 15 mL) were evaluated in a randomized complete block design with three replicates. Plant height and leaf area were analyzed using ANOVA. Varietal differences were non-significant. Fertilizer effects were significant for plant height across all weeks. At 8 WAP, 5 mL produced the tallest plants (18.30 cm) and largest leaf areas (249.75 cm^2), while poultry manure had 11.86 cm and 227.76 cm^2, respectively. The 5 mL nano-fertilizer applications maximize vegetative growth in LO1; LO8 showed higher height at 10 mL and leaf area at 15 mL. Interaction effects revealed LO1 + 5 mL maximized height (19.77 cm) and leaf area (294.64 cm^2) at 8 WAP, indicating synergy. The study concluded that the application of 5 mL nano-fertilizers optimizes garden egg performance.

Keywords: Garden egg, Growth parameters, Inorganic fertilizer, Nano-fertilizer, Neem bark, Organic fertilizer, Screenhouse experiment, Sustainable agriculture.

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Contents

1. Introduction 2
2. Materials and Methods 2
3. Results and Discussion 4
4. Conclusion 6
References 6

Contribution of this paper to the literature
Identifying options to synthetic soil amendments for increasing crop yield is challenging given climate change. This study demonstrate that neem bark-based Nano-fertilizers enhance nutrient delivery and improve garden egg (*Solanum aethiopicum* L.) growth more effectively than conventional fertilizer. This provide eco-friendly alternative that optimizes resource use, support food security and promotes sustainable agriculture.

1. Introduction

Garden egg (*Solanum aethiopicum* L.), which belongs to the Solanaceae family, is a popular vegetable crop grown in the tropics. The crop is one of the most widely consumed fruits and vegetables in many parts of the world, particularly in Africa, Southeast Asia, and Central America. In West Africa, it is probably the third most consumed vegetable in Ghana [1]. The garden egg fruit can be eaten raw or cooked in various ways, including stews, baking, grilling, frying, and boiling. An estimated two million hectares of land are used for garden egg farming worldwide [2]. As demand for garden eggs rises, it is necessary to ensure premium fruits while minimizing the negative effects on the physical and chemical quality of the land.

In Africa, the African eggplant, also known as garden eggs, is a significant fruit and leafy vegetable. According to Ogunka-Nnoka and Ekrika [3], there are four major groups of cultivars of *Solanum aethiopicum*: the first three groups (Shum, Kumba, and Gilo) are native to Africa, while the fourth group is planted in Europe and produces inedible fruits [4]. Nigeria cultivates African eggplant because of the fruit's and leaves' economic, therapeutic, and nutritional importance.

For garden eggplants to establish and produce, the vegetative growth period is essential. It encompasses vegetative maturity, seedling growth, and germination [5]. Seed dormancy: Due to their rigid seed coat, fresh seeds often exhibit signs of dormancy; however, germination can be improved through pre-treatment techniques, such as soaking in warm water for a full day. Germination requires an ideal temperature range of 25–30°C, while germination time is about 5–14 days. For seeds to germinate successfully, they need constant oxygen and moisture. Development of seedlings: After germination, the seedlings take two to three weeks to mature, then after the emergence of cotyledons, real leaves develop. The plant needs enough water, nutrition (phosphorus and nitrogen), and defense against pests like aphids and cutworms during this stage.

Due to population growth and shifting dietary habits, the world's food demand is only going to increase. While traditional fertilizers are good at increasing crop yields, they have a number of negative effects, such as nutrient losses, environmental damage, and a gradual decline in soil fertility. Nanotechnology-based fertilizers, or Nano-fertilizers, offer a sustainable solution to the limitations of traditional fertilizers. By leveraging their unique nanoscale properties, they improve nutrient delivery and overall efficiency [6]. This innovative approach has the potential to boost agricultural productivity by enhancing crop growth, increasing stress tolerance, and promoting healthier soil [7]. The ability of Nano-fertilizers to improve crop yield and quality, while simultaneously reducing environmental pollution, makes them a crucial tool for addressing global food security challenges [8].

Food security, food packaging, and disease detection are just a few applications for silver nanoparticles (SNPs), a material with antibacterial and antifungal qualities. According to Ma, et al. [9] it significantly impacts various plant growth and development processes, including germination, root-shoot ratio, seedling growth, root growth, root elongation, and senescence suppression. The absorption and transportation of N, P, and K to seed and rice yield were greatly enhanced by nitrogen fertilizers coated with Nano-bentonite and Nano-active carbon [4]. The use of mineral fertilizers has been crucial to human existence since it increased yield [10] and maintained soil fertility and productivity [11]. In some developing nations, nutrient depletion is a primary factor in low crop yields. In Pakistan, low nutrient use efficiency accounts for 50% of losses [12]. Furthermore, increasing nutrient use efficiency has become more crucial due to socioeconomic constraints. Thus, improving fertilizer use efficiency remains a significant concern for global agriculture, and nanotechnology may help. It is therefore the objective of the present study to determine the optimum neem bark-based Nano-fertilizer on plant height and leaf area in two contrasting genotypes of garden egg.

2. Materials and Methods

2.1. Site Description

The experiment was conducted under controlled conditions within a screen house at the University of Ibadan's Department of Crop and Horticultural Sciences, Ibadan, Oyo State, Nigeria, at coordinates 7°27'5" N, 3°53'46" E. The screen house helped mitigate environmental variables such as pest infestation, excessive precipitation, and intense solar radiation, which are significant concerns in a climate with distinct wet and dry seasons. This controlled environment was essential for generating reliable and reproducible data, contributing meaningfully to the field of crop and horticultural sciences.

2.2. Experimental Design and Treatments

The experiment was a 2×6 factorial experiment with two garden egg varieties and six levels of fertilizer applications in a completely randomized design with three replicates.

The two garden egg varieties were LO1 (green striped fruit) and LO8 (white fruit with green stripes). The six levels of fertilizer applications were:

T1 = Control.
T2 = Organic (Poultry manure) at 1 kg (Single dose mixed with the soil before planting).
T3 = Inorganic (NPK) at 0.1 kg (Applied in 3 doses at 2-week intervals after planting).
T4 = Nano-fertilizer at 5 mL (Single dose at 2 weeks after planting).
T5 = Nano-fertilizer at 10 mL (Applied in 2 doses at a 2-week interval after planting).
T6 = Nano-fertilizer at 15 mL (Applied in 3 doses at 2-week intervals after planting).

2.3. Source of the Test Crop

Two varieties of open-pollinated seeds were sourced from the National Horticultural Research Institute (NIHORT) in Ibadan, Nigeria.

2.4. Pot Preparation

Thirty-six black polyethylene planting bags were used; each was filled with 5 kg of soil. Topsoil collected from the premises of the screenhouse was sieved with a 2 mm mesh to remove stones, pebbles, and plant root debris. Table 1 shows some physical and chemical properties of the soil used for the experiment.

Table 1. Some physical and chemical properties of the soil used for the experiment.

Properties	Values
Sand (g/kg)	820
Clay (%)	50
Silt (%)	130
Textural class	Sandy loam
pH (1:1, H20)	5.44
Ca (cmol/kg)	2.94
Mg (cmol/kg)	0.61
Na (cmol/kg)	0.66
K (cmol/kg)	0.13
Cu (mg/kg)	1.21
Zn (mg/kg)	9.70
Fe (mg/kg)	19.65
Avail. P (mg/kg)	79.02
Mn (mg/kg)	58.54
Organic C (g/kg)	22.52
Total N (%)	0.12

2.5. Preparation of Plant Extracts

Neem bark was collected from Parry Road at the campus of the University of Ibadan, Ibadan, Nigeria. The bark was air-dried under laboratory conditions for four weeks. The plant part was ground with a pestle and mortar, and later transferred into an electric grinder (Silver Crest heavy-duty commercial grinder blender - 70,000 watts) to achieve a powder form. An electric sensitive scale was used to obtain precise measurements of the materials during the research study. Silver nanoparticles of neem bark (NB-AgNPs), used as nano-fertilizer and nano-insecticides, were synthesized following the modified methods of Ardesana, et al. [13].

The extracts were prepared by heating 5 g of the powdered sample (bark of neem) dissolved in 100 mL of distilled water at 60°C for one hour, then sieved through Whatman No.1 filter paper, and the filtrate was later centrifuged at 4000 rpm for 60 min to obtain the extract.

The biosynthesis was then carried out by reacting about 2 mL of aqueous extract with 40 mL of 1 mM silver nitrate ($AgNO_3$) solution for the synthesis of AgNPs at ambient temperature (30 ± 2°C) under bright light conditions. The biosynthesis was monitored by observing the change in color of the solution, and it was left in the laboratory for 24 hours.

The liquid solution was poured into a 5-liter container and refrigerated to avoid microbial development, enhance stability, and prevent the filtrate from fermenting.

2.6. Application of Treatment

Application of treatments commenced two weeks before planting for poultry manure and Nano-fertilizers, while inorganic fertilizer was applied two weeks after planting. The Nano-fertilizer at three levels (5 mL, 10 mL, 15 mL) was diluted in 1000 mL of water separately and applied to the soil after watering. The inorganic and Nano-fertilizers were applied according to the treatments.

2.7. Agronomic/Horticultural Management Practices

All necessary horticultural management practices were observed during the study. Weed control in the planting bags was achieved through hand weeding.

2.8. Data Collection/Measurement of Growth Parameters

2.8.1. Plant Height (cm)

Plant height measurement was done using a meter ruler at two-week intervals starting two weeks after planting. Plant height was measured from the soil level to the last visible dewlap.

2.8.2. Leaf Area (cm^2)

A leaf area meter was used to measure the length and width of each leaf of the plants in the screen house. The length was measured from the tip to the base, and the width was taken at the widest point. The leaf area was estimated using the formula described by Ogoke, et al. [14] for predicting leaf area in S. macrocarpon: 1.06+0.4731L. The final leaf area was recorded in cm^2, and measurements were repeated for accuracy.

2.9. Statistical Analysis and Mean Separation

The data collected were subjected to analysis of variance (ANOVA), and significantly different treatment means were separated using Duncan Multiple Range Test at a 5% level of probability.

3. Results and Discussion

3.1. Effect of Garden Egg Variety and Fertilizer Application on Plant Height

The result shown in Table 2 indicates that plant height was affected by the variety, although no statistically significant differences ($p > 0.05$) were observed between LO1 and LO8. The height of LO1 consistently surpassed that of LO8 throughout the growth period, with the difference most noticeable at 8 WAP (16.11 cm for LO1 vs. 15.37 cm for LO8). These results suggest that LO1 may have a slight growth advantage; however, the genetic differences between the two varieties do not significantly affect plant height under the tested conditions. The fertilizer treatments had a significant effect on the growth of garden egg plants ($p < 0.05$), as indicated by the varying LSD values. Nano-fertilizer applied at 15 mL (T6) resulted in the highest plant heights, reaching 17.37 cm by 8 WAP. This treatment outperformed both the control and the organic poultry manure (T2), which exhibited the lowest plant growth, with T2 reaching just 11.86 cm at 8 WAP. Among the other treatments, Nano-fertilizers at 5 mL (T4) and 10 mL (T5) produced moderate growth, with heights of 18.30 cm and 16.53 cm at 8 WAP, respectively. The improved nutrient delivery mechanism of Nano-fertilizers, which facilitates the effective absorption and utilization of vital nutrients, is responsible for their excellent performance [15]. These results align with those of Dimkpa and Bindraban [16] who highlighted the benefits of Nano-fertilizers in enhancing plant development and minimizing nutrient losses. Nano-fertilizers had the strongest influence on both LO1 and LO8, according to the interaction effects. The highest plant height was obtained in LO1 treated with T4 (Nano-fertilizer at 5 mL). Conversely, the poor performance of T2 may indicate a nutrient deficiency or imbalance, limiting plant growth.

Table 2. Effect of garden egg variety and fertilizer application on plant height.

Treatment	2 WAP	4 WAP	6 WAP	8 WAP
Variety				
LO1	5.31	9.66	12.71	16.11
LO8	5.64	8.59	12.94	15.37
LSD	NS	NS	NS	NS
Fertilizer				
T1	5.48	9.67	13.21	15.52
T2	3.80	7.00	10.22	11.86
T3	5.03	8.50	11.80	14.83
T4	5.95	10.23	14.52	18.30
T5	6.18	10.28	13.65	16.53
T6	6.40	9.61	13.55	17.37
LSD	1.16	2.74	3.39	4.75

Note: Means separated using LSD = Least Significant Difference; NS = Not significant at $p < 0.05$.
V1=LO1; V2=LO8; T1=Control; T2=poultry manure; T3=NPK; T4=Nano at 5mL; T5=Nano at 10mL; T6=Nano at 15mL; WAP=Weeks after planting.

3.2. Effect of Garden Egg Variety and Fertilizer Application on Leaf Development Area

Table 3 shows that the leaf area of variety LO1 consistently surpassed that of LO8 throughout the research period. At 8 WAP, LO1 reached a mean leaf area of 246.02 cm^2, significantly higher than LO8's 201.08 cm^2. This result suggests a genetic advantage in vegetative growth for LO1, which may support greater biomass accumulation. This attribute could translate to higher biomass accumulation. According to Xu, et al. [17] garden egg varieties with larger leaf areas tend to have improved light interception and carbon assimilation. Such a trait can help reduce weed interference [18]. The leaf area of garden egg plants was significantly impacted by the type of fertilizer used. The treatments with the highest mean leaf area were Nano-fertilizer at 5 mL (T4) at 8 WAP (249.75 cm^2), and Nano-fertilizer at 15 mL (T6) at 228.90 cm^2. This result suggests how well Nano-fertilizers work to encourage leaf growth, most likely due to their improved nutrient delivery systems. Meanwhile, at 8 WAP (227.76 cm^2), poultry manure (T2) generated the smallest leaf area, which was only slightly less than that of the control (T1), which was 229.53 cm^2. At 8 WAP, the NPK fertilizer (T3) produced an average leaf area of 223.60 cm^2, indicating an intermediate performance. At 8 WAP, the treatments with the highest leaf areas were Nano-fertilizers at 5 mL (T4) and 15 mL (T6) (249.75 cm^2 and 228.90 cm^2, respectively). As reported in related studies of Chhipa [19] where phosphorus Nano-fertilizers increased leaf growth and overall plant vigor, the higher leaf expansion under Nano-fertilizer treatments indicated greater photosynthetic potential, and in every treatment, LO1 had a greater leaf area than LO8.

Table 3. Effect of garden egg variety and fertilizer application on leaf area.

Treatment	2 WAP	4 WAP	6 WAP	8 WAP
Variety				
LO1	20.85	100.97	163.63	246.02
LO8	15.03	72.34	123.46	201.08
LSD	NS	NS	NS	NS
Fertilizer				
T1	11.74	87.76	153.02	229.53
T2	11.05	68.71	109.41	227.76
T3	21.45	71.74	122.81	223.60
T4	23.25	115.32	190.75	249.75
T5	16.41	92.30	119.09	181.74
T6	18.77	84.10	190.73	228.90
LSD	11.04	NS	NS	NS

Note: Means separated using LSD = Least Significant Difference; NS = Not significant at $p < 0.05$; WAP=Weeks after planting; V1=LO1; V2=LO8; T1=Control; T2=poultry manure; T3=NPK; T4=Nano at 5mL; T5=Nano at 10mL; T6=Nano at 15mL.

3.3. Interaction Effect of Variety and Fertilizer Application on the Height of Garden Eggplant

Table 4 shows the interaction effect of fertilizer treatments and varieties (LO1 and LO8) on garden eggplant height. Nano treatments showed the best performance. V1T4 (5 mL) recorded the highest growth, increasing from 5.30 cm to 19.77 cm, significantly exceeding other treatments by Week 8. V1T5 (10 mL) started at 5.60 cm and ended at 14.07 cm, while V1T6 (15 mL) grew from 5.50 cm to 16.87 cm, both showing intermediate growth trends. However, for the LO8 variety, Nano treatments performed best. V2T4 (5 mL) grew from 5.10 cm to 16.83 cm, while V2T6 (15 mL) increased from 5.86 cm to 17.67 cm. The highest growth for LO8 was recorded under V2T5 (10 mL), which increased from 4.70 cm to 19.00 cm, significantly surpassing all other treatments by Week 8. These results suggest a cooperative effect between certain fertilizers and varieties, particularly LO1 with T4, which maximizes height. According to Rusu, et al. [20] genotype×environment interactions significantly influence the efficacy of fertilizer treatments in Solanum species, with certain varieties responding better to specific nutrients. The strong performance of V1T4 could indicate that LO1 is more responsive to the nutrient composition of T4, possibly due to higher nitrogen or micronutrient availability, as suggested by Kumar, et al. [21].

Table 4. Interaction effect of variety and fertilizer application on the height of garden egg.

Treatment	2 WAP	4 WAP	6 WAP	8 WAP
V1T1	5.50 ab	10.33ab	13.40ab	17.30ab
V1T2	3.26 c	7.50 ab	9.60 b	11.10 b
V1T3	4.87abc	9.70 ab	12.90ab	17.53ab
V1T4	5.70 ab	11.50 a	15.96 a	19.77 a
V1T5	6.47 a	10.57ab	12.70ab	14.07ab
V1T6	6.03 ab	8.33 ab	11.67ab	16.87ab
V2T1	5.47 ab	9.00 ab	13.03ab	13.73ab
V2T2	4.33 bc	6.50 ab	10.83ab	12.63ab
V2T3	5.20 ab	7.30 ab	10.70ab	12.13ab
V2T4	6.20 ab	8.97 ab	13.07ab	16.83ab
V2T5	5.90 ab	10.00ab	14.60ab	19.00 a
V2T6	6.76 a	9.80 ab	15.43 a	17.67ab

Note: V1=LO1; V2=LO8; T1=Control; T2=poultry manure; T3=NPK; T4=Nano at 5mL; T5=Nano at 10mL; T6=Nano at 15mL at P ≤ 0.05, WAP=Weeks after planting. Figures followed by the same letters in a column are not significantly different by the Duncan Multiple Range Test.

3.4. Interaction Effect of Variety and Fertilizer Application on the Leaf Area of Garden Eggplant

Table 5 shows the interaction effect of fertilizer treatments and varieties (LO1 and LO8) on the leaf area of garden eggplant over eight weeks. Nano-fertilizer treatments had the best results for LO1. V1T4 (Nano at 5 mL) showed the most significant increase, starting at 8.16 cm² and reaching 294.64 cm² by Week 8, outperforming all other treatments. V1T5 (Nano at 10 mL) grew from 4.67 cm² to 228.92 cm², and V1T6 (Nano at 15 mL) increased from 6.08 cm² to 221.90 cm², both showing steady growth but slightly lower than V1T4. Nano treatments again showed superior growth. V2T4 (Nano at 5 mL) increased from 5.17 cm² to 204.89 cm², while V2T6 (Nano at 15 mL) grew from 5.19 cm² to 235.91 cm², both showing good performance throughout the study. The highest growth for LO8 was recorded under V2T2 (poultry manure), which reached 239.35 cm² by Week 8, surpassing all treatments except V1T4, which showed the highest overall leaf area. The observed trends in the results suggest that early-stage interactions between variety and fertilizer are critical for leaf development, but these effects may stabilize over time as plants reach physiological maturity. This claim is supported by Ebert [22] and Olugbemi and Akinrinola [23] that nutrient availability in the early growth stages significantly influences leaf area increase, but as plants mature, genetic factors may dominate.

Table 5. Interaction effect of variety and fertilizer application on the leaf area of garden egg.

Treatment	2 WAP	4 WAP	6 WAP	8 WAP
V1T1	18.50abc	94.22ab	163.45ab	256.75a
V1T2	4.13 c	87.96ab	122.72ab	216.18a
V1T3	27.62 ab	85.78ab	142.24ab	257.73a
V1T4	34.86 a	157.89a	238.92 a	294.64a
V1T5	20.68abc	93.42ab	121.59ab	228.92a
V1T6	19.33abc	86.57ab	153.84ab	221.90a
V2T1	16.99 bc	81.30ab	142.59ab	202.31a
V2T2	17.99abc	49.45 b	96.10 b	239.35a
V2T3	13.26 bc	57.70 b	103.38ab	189.47a
V2T4	11.65 bc	72.75 b	142.54ab	204.89a
V2T5	12.13 bc	91.19ab	117.80ab	134.56a
V2T6	18.22abc	85.3 b	101.55ab	235.91a

Note: V1=LO1; V2=LO8; T1=Control; T2=poultry manure; T3=NPK; T4=Nano at 5mL; T5=Nano at 10mL; T6=Nano at 15mL at P ≤ 0.05, WAP=Weeks after planting. Figures followed by the same letters in a column are not significantly different by the Duncan Multiple Range Test.

However, genotype and purposeful vegetative growth parameter selection for maximizing plant productivity, especially when combined with cutting-edge fertilizer application techniques like Nano-fertilizer, are crucial. Nano-fertilizers had the strongest influence on both LO1 and LO8, according to the interaction effects. The highest plant height and leaf area were obtained in LO1 treated with T4 (Nano-fertilizer at 5 mL). The study showed that Nano-fertilizers are a good alternative to conventional fertilizers, offering better nutrient efficiency and reduced environmental impact. Their ability to increase plant productivity while decreasing the use of inorganic and organic fertilizers aligns with sustainable agricultural practices and the goals of global food security [24]. Hence, promoting the adoption of Nano-fertilizers through farmer education and subsidization programs to lower high costs, and further research on the long-term environmental and health impacts of Nano-fertilizers would be encouraged in the area of farming systems.

4. Conclusion

The study highlights the significant potential of neem bark nano-fertilizers as an innovative and sustainable approach to enhancing the vegetative growth of garden egg (*Solanum aethiopicum*). The application of nano-fertilizers, particularly at the concentration of 5 mL, demonstrated superior performance in promoting plant height and leaf area compared to traditional organic and inorganic fertilizers. All these were attributed to the efficient nutrient delivery mechanisms of nano-fertilizers, which reduce losses and improve plant uptake efficiency.

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