



Growth and yield performance of eggplant (*Solanum melongena* L.) under bat guano tea application in potted conditions

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Abstract

Background and Objective: Eggplant (*Solanum melongena* L.) is an economically important vegetable crop in the Philippines, but productivity is often limited by declining soil fertility and reliance on synthetic fertilizers. Bat guano tea (BG tea), a nutrient-rich organic liquid fertilizer, has the potential to improve crop performance; however, its dose–response relationship under local conditions remains insufficiently quantified. This study aimed to evaluate the effects of different BG tea concentrations on growth, biomass allocation, and yield of eggplant under pot conditions.

Methodology: A randomized complete block design (RCBD) with six treatments (0, 10, 25, 55, 75, and 100 mL pot⁻¹) and three replications was conducted. BG tea was prepared from air-dried guano, diluted, and applied weekly for seven weeks after transplanting. Growth traits, root characteristics, phenology, and yield were measured. Data were analyzed using ANOVA, with mean separation by LSD ($P < 0.05$), and effect size quantified using eta squared (η^2).

Main Results: BG tea application significantly affected vegetative growth and yield ($P < 0.05$). Higher concentrations (75–100 mL pot⁻¹) enhanced plant height, leaf production, root volume, and biomass accumulation. The highest yields were obtained at 75 mL pot⁻¹ (1.43 ± 0.09 t ha⁻¹; +27.68%) and 100 mL pot⁻¹ (1.37 ± 0.08 t ha⁻¹; +22.32%), although these were not statistically different from the control. Lower concentrations (10–55 mL pot⁻¹) resulted in reduced yield. A strong treatment effect was observed ($\eta^2 = 0.97$), indicating that BG tea concentration accounted for most yield variation. Excessive application (100 mL) promoted vegetative

growth without proportional yield gain.

Conclusions: Moderate BG tea application (approximately 75 mL pot⁻¹) optimized growth-yield balance under pot conditions. While BG tea shows promise as an organic nutrient source, further field validation and comparison with conventional fertilization are required before broad recommendations.

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INTRODUCTION

Eggplant (*Solanum melongena* L.) is one of the most widely cultivated vegetable crops in the Philippines, grown primarily for its immature fruits and consumed in various local dishes such as grilled, fried, or stewed preparations. It occupied approximately 21.01 thousand hectares nationwide in 2015 (PSA, 2016) and it also its production serves as an essential source of cash income, particularly for small, resource-poor farmers in the country (Haute *et al.*, 2016). Despite its economic importance, yield performance in regions such as Samar remains suboptimal, with a production deficit of 261 metric tons recorded in 2017 (PSA, 2017). Improving eggplant productivity in these areas requires sustainable nutrient management strategies suited to local soil and resource conditions.

A major constraint to crop productivity is soil degradation, which affects about 70% of the Philippines' total land area (Briones, 2009). Declining soil fertility, particularly N deficiency, limits the growth and yield of solanaceous crops such as eggplant and tomato (Djidji *et al.*, 2010; Abdulmalik *et al.*, 2019). Although synthetic fertilizers can address nutrient imbalances, their prolonged use may deteriorate soil health, increase production costs, and pose environmental risks. These challenges have led to growing interest in organic nutrient sources that enhance soil fertility while maintaining environmental sustainability.

Bat guano (BG), the decomposed excreta of cave-dwelling bats, is rich in macronutrients, especially N, P₂O₅, and K₂O, and has been used traditionally in solid form, either directly or mixed with compost, to improve soil structure and microbial activity (Beltran-Morales *et al.*, 2019; Zhou *et al.*, 2022; Bafadhal *et al.*, 2023; Rahman *et al.*, 2023). Its slow-release nature supports long-term fertility but may not meet crops' immediate nutrient demands during critical growth stages. To address this limitation, BG can be processed into a liquid formulation, known as BG tea, by steeping the solid material in aerated water for a defined period (typically 12–48 hours), allowing the extraction of soluble nutrients and the proliferation of beneficial microorganisms (Scheuerell and Mahaffee, 2002; Ingham, 2005; Kim *et al.*, 2015). This process extracts soluble nutrients and fosters beneficial microbial populations, resulting in a biologically active solution that can be applied as a foliar spray or soil drench. Compared with solid BG, BG tea offers improved nutrient bioavailability, enabling faster uptake and promoting rapid vegetative growth (Kim *et al.*, 2015; Campana *et al.*, 2025). In addition to supplying nutrients, BG tea and other compost teas have shown potential in suppressing soil-borne pathogens such as *Fusarium* spp. and *Ralstonia solanacearum*, which cause major diseases like Fusarium wilt and bacterial wilt in eggplant (St. Martin and Brathwaite, 2012; Mengesha *et al.*, 2017). These

disease-suppressive effects are linked to the microbial diversity present in compost teas, though the consistency and underlying mechanisms of such benefits require further investigation, particularly under field conditions.

In the Philippines, guano is primarily derived from bats and seabirds, with BG being widely harvested and commercialized (Sediyarso, 1999; Furey *et al.*, 2016). Although solid BG has been evaluated in crops such as carrots (Poliquit and Calong, 2018), there is still limited research on its liquid form, particularly in fruit-bearing vegetables like eggplant. The scarcity of empirical data on BG tea in local production systems limits the development of science-based fertilization practices. Bats provide essential ecosystem services, including insect control and pollination, making the sustainable use of BG tea crucial (Kunz *et al.*, 2011). To minimize ecological disturbance, guano should be collected in small amounts, allowing bat populations to recover (Mildenstein *et al.*, 2016). Moreover, the use of alternative organic fertilizers, such as compost or animal manure, can help reduce reliance on guano while sustaining crop productivity and environmental integrity (Agegnehu *et al.*, 2017). Furthermore, studies on the application of liquid BG tea in eggplant production remain insufficient, highlighting the need to develop and optimize application protocols, especially in degraded soil conditions, to improve crop productivity and enhance soil fertility. Furthermore, there is a limited number of studies on the use of liquid BG tea in eggplant production, particularly under degraded soil conditions. This highlights the need to develop and optimize application protocols to enhance crop productivity, improve soil fertility, and ensure the effective and sustainable use of BG tea (Dimande *et al.*, 2023; Rahman *et al.*, 2023).

Therefore, this study aims to evaluate the effects of different concentrations of BG tea on the growth and yield performance of eggplant under Philippine conditions throughout the entire growing period. Specifically, it seeks to measure plant growth

through plant height, number of leaves, leaf width, leaf length, and root length at 56 days after transplanting (DAT). Evaluation of root system characteristics will be conducted at 90 DAT using fresh and oven-dry weights of both root and shoot parts, along with the number of days from transplanting to flowering. In addition, yield performance will be evaluated based on fruit number and total yield at harvest. The study also aims to compare the responses among treatments and identify the optimal concentration of BG tea that maximizes crop productivity while enhancing soil nutrient management in degraded agroecosystems.

MATERIALS AND METHODS

Experimental Design

The experiment was conducted in pots using a randomized complete block design (RCBD), comprising six treatments with three replications per treatment. The treatments were designated as follows: T_0 (control), T_1 (10 mL pot⁻¹), T_2 (25 mL pot⁻¹), T_3 (55 mL pot⁻¹), T_4 (75 mL pot⁻¹), and T_5 (100 mL pot⁻¹) of BG tea application.

Basis for BG Tea Concentration Levels and Application Volume Adjustment

The BG tea concentrations (10–100 mL per application) were based on standard practices in studies of organic liquid fertilizers and compost teas, which use graded rates to determine optimal plant responses (Scheuerell and Mahaffee, 2002; Ingham, 2005). This range was selected to evaluate the effects of increasing BG tea concentrations under controlled conditions. Subsequently, the application volume for T_3 was also increased from 25 to 55 mL pot⁻¹ to improve nutrient availability and plant uptake. Higher volumes of liquid fertilizer enhance nutrient delivery to the root zone, supporting better growth and yield. Fertigation or liquid fertilizer application can improve nutrient availability and uptake efficiency compared with granular fertilizer, particularly during early plant

establishment when root systems are still developing and nutrient acquisition is more limited (Bryla and Machado, 2011; Lynch *et al.*, 2012).

Experimental Location

The study was conducted from July to November 2023 at the San Jorge Campus of Northwest Samar State University (NWSSU), San Jorge, Samar. This site was chosen due to its relevance to local agricultural practices and the availability of natural resources, including BG. The experiment employed six treatments, each with three replications, totaling 90 eggplant plants. Each treatment consisted of 30 plants, with five sample plants randomly selected per replication for data collection.

Pot Distance and Protective Structure

The experiment was conducted with one plant per pot, and each pot contained 10 kg of soil per pot. The bags were made from 12 × 14-inch polyethylene bags. Each pot was spaced 0.5 m × 0.5 m (width × length) apart for planting. Additionally, a protective structure measuring 2.5 m × 5 m with a plastic film roof was constructed to accommodate the experiment.

Preparation and Application of BG Tea

Rationale for the selected concentration of BG tea

The concentrations of BG tea ($T_1 = 10$ mL, $T_2 = 25$ mL, $T_3 = 55$ mL, $T_4 = 75$ mL, and $T_5 = 100$ mL pot⁻¹) were selected to represent a gradient of nutrient availability, allowing for the assessment of dose-dependent effects on plant growth, consistent with approaches used in compost tea and organic liquid fertilizer studies (Ingham, 2005; Kim *et al.*, 2015; Jumao-as *et al.*, 2022). The range was designed to identify the optimal application rate, from minimal (T_1) to potentially excessive (T_5), while ensuring plant

safety and avoiding nutrient toxicity. Likewise, the process involved analyzing chemical properties and nutrient composition, followed by collection, preparation, extraction, and application phases to ensure optimal nutrient content and safe use on plants.

Soil Chemistry Properties and Nutrient Composition

This study began with the biochemical analysis of BG and the initial potting soil to establish a baseline for assessing nutrient improvement. Their chemical properties were evaluated to determine compatibility and potential for enhancing soil fertility.

Chemical properties of BG

As shown in Table 1, BG had a near-neutral pH of 6.30 and was rich in nutrients, including high organic matter (33.78%), total N (5.99%), available P_2O_5 (13.68 mg kg⁻¹), and exchangeable K_2O (0.50 mg kg⁻¹). These values, obtained using standard laboratory methods at the PRC-RTC Laboratory, VSU, indicated that BG was a nutrient-dense organic fertilizer with strong potential as a soil amendment. Accordingly, the interpretation based on Poliquit (2019) confirmed its suitability for improving degraded soils.

Initial soil properties before planting

Table 2 showed that the potting soil was moderately acidic (pH 5.20) and nutrient-deficient, with low levels of organic matter (2.37%), N (19.60 mg kg⁻¹), P_2O_5 (6.33 mg kg⁻¹), and K_2O (152 mg kg⁻¹). Consequently, based on Sabijon and Poliquit (2020), these findings confirmed that the soil was degraded and required nutrient enhancement.

BG Collection

Fifty (50) kilograms of fresh BG were collected from Barangay Bay-ang, San Jorge, Samar, air-dried under shade, and stored in covered containers.

Table 1 Biochemical characteristics of bat guano used in the study

Parameter	Value	Analytical methods
pH (1:2:5 H ₂ O)	6.30	Measured in 1:5 water suspension
Organic matter (%)	33.78	Walkley-Black method (Nelson and Sommers, 1982)
Total N (%)	5.99	Kjeldahl method (Bremner, 1960)
Available P ₂ O ₅ (mg kg ⁻¹)	13.68	Bray P-1 method (Bray and Kurtz, 1945)
Exchangeable K ₂ O (mg kg ⁻¹)	0.50	Flame photometry (Baker and Suhr, 1982)

Note: Interpretations of the soil parameters were guided by classification criteria adapted from Poliquit (2019).

Table 2 Soil properties before planting

Parameter	Value	Interpretation
pH (1:2:5 H ₂ O)	5.20	Moderately acidic
Organic matter (%)	2.37	Low
Available N (mg kg ⁻¹)	19.60	Low
Available P ₂ O ₅ (mg kg ⁻¹)	6.33	Low
Exchangeable K ₂ O (mg kg ⁻¹)	152.00	Low

Note: Soil parameter interpretations were based on classification standards adapted from Sabijon and Poliquit (2020).

BG Tea Preparation and Application

Dried guano was mixed with water (1:1, w/w) and steeped for 14 days. The extract was diluted (1:10) and applied weekly to potted plants from transplanting to seven weeks under an RCBD. A flowchart is shown in Figure 1.

Cultural Management Practices

Seed sowing, seedling preparation, and transplanting

The eggplant seed was planted in a seed box and placed in a shaded area for germination. The seed was irrigated on a regular basis. Pricking was done one week after sowing or when the seedlings reached two true leaves in the seedling tray. After one week, seedlings were hardened or progressively exposed to external conditions to ensure seedling preparation before transplanting. Seedlings were transplanted 21 days after sowing, and a healthy seedling was chosen at random to be transplanted.

Further, three weeks after transplanting, BG tea was applied. It was sprayed once per week via the basal layer at the base of the plant, and the amount of application depended on each treatment. The treatments were applied once per week via basal spraying at the base of the plant, with the volume of application varying according to each treatment. Spraying was conducted weekly and discontinued at 7 weeks after transplanting, resulting in a total of seven applications. The final spray application was administered approximately one week before the initial harvest to avoid potential residue on marketable fruits.

Harvesting

Harvesting was carried out manually at approximately 12 weeks after transplanting, once the eggplants reached physiological maturity, characterized by glossy skin, firm texture, and optimal marketable size. A sharp pruner was used to cut the stem, leaving approximately one inch attached to the fruit.

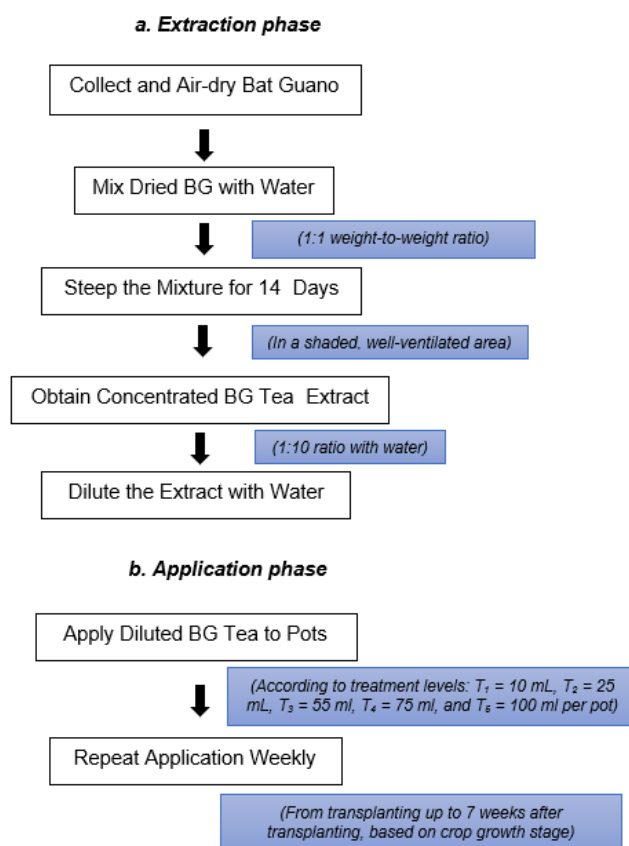


Figure 1 Flowchart of bat guano tea (BG tea) preparation and application process

This method was employed to maintain post-harvest quality and ensure uniformity across all treatments.

Care and management

During the cultivation period, plants were irrigated regularly with 200–350 mL of water per application to maintain adequate soil moisture. Weed management was carried out manually to reduce competition for nutrients and ensure optimal plant growth. The presence of pests and insects was addressed through manual removal to prevent the use of chemical agents and maintain the organic integrity of the experiment.

Data Collection and Gathering

Data collection for eggplant growth and yield was conducted from one week after BG tea application until final harvest. A total of 90 plants were used, with

five randomly selected plants per replication (15 plants per treatment). The same sample plants were used throughout to ensure consistency. Data were grouped into three categories: foliage, root, and yield traits. Foliage measurements included plant height (PH), number of leaves (NL), leaf width (LW), and leaf length (LL), recorded weekly using a ruler or meter stick. At harvest, root length (RL) was measured, root volume (RV) was determined using the water displacement method, and fresh weight [root (RFW) and shoot biomass (SFW)] was recorded. Roots and shoot weight were then oven-dried at 70°C to obtain oven-dry weight [root (RODW) and shoot (SODW)], and the root-to-shoot ratio (R:S ratio) was calculated. Reproductive data included the number of days to flowering, fruiting, and first harvest, recorded from the same plants. Yield was assessed from two harvests (80 to 90 DAT) by summing fruit weights per plant

and averaging them. Total yield per treatment was also converted to yield per hectare (t ha⁻¹) for comparison.

To evaluate treatment effectiveness, the percentage yield increase relative to the control was computed using the following formula (Gomez and Gomez, 2022):

$$\text{Yield increase (\%)} = \frac{[(\text{Treatment yield} - \text{Control yield}) / \text{Control yield}] \times 100}{}$$

Finally, eta squared (η^2), a commonly used measure of effect size in analysis of variance (ANOVA), was computed for the data presented in Table 3. It quantifies the proportion of the total variability in the dependent variable that can be explained or

attributed to the influence of the independent variables or treatments.

$$\eta^2 = \text{SS effect} / \text{SS total} \text{ (Cohen, 1988)}$$

where SS effect is the sum of squares for the treatment (between groups), and SS total is the total sum of squares (between - within)

Statistical Analyses

All collected data were analyzed using analysis of variance (ANOVA) in Statistix 10 software. Treatment means were compared using the Least Significant Difference (LSD) test at $P < 0.05$ level of significance.

Table 3 Effect size interpretation scale in ANOVA

Effect size measure	η^2 value (eta squared)
Small	0.01
Medium	0.06
Large	0.14

Note: 0.01 = only 1% of the variance in the dependent variable is explained by the factor. 0.06 = 6% of the variance is explained (moderate impact), and 0.14 and above = a large portion of the variance explained (strong effect).

RESULTS AND DISCUSSION

Growth Parameter

Foliage features

Table 4 presents the eggplant growth parameters (PH, NL, LW, and LL) at 56 DAT. BG tea application resulted in a significant ($P < 0.05$ and $P < 0.01$) increase in PH for T_4 (29.34 ± 0.90 cm plant⁻¹) and T_5 (29.52 ± 0.90 cm plant⁻¹). In addition, it produced a higher NL in T_3 (22.11 ± 0.63 leaves plant⁻¹) to T_5 (22.67 ± 0.64 leaves plant⁻¹). Higher LW and LL were also recorded in T_3 , with values of 14.13 ± 0.31 and 17.55 ± 0.52 cm plant⁻¹, respectively. In contrast, T_0 , T_1 , and T_2 showed comparatively lower measurements under organic fertilization. Among the treatments, T_4 and T_5 exhibited the greatest increase in PH, whereas T_3 primarily enhanced leaf size (LW and LL). However,

statistical significance was observed only in PH for T_4 and T_5 . This indicated that higher BG tea concentrations more effectively promoted shoot elongation. This effect may have been attributed to improved nutrient availability and the stimulation of cell division and expansion (Díaz-Pérez and Eaton, 2015; Jumao-as *et al.*, 2022). Furthermore, the observed effects may have been linked to the slow nutrient release from organic fertilizers and their dependence on microbial decomposition, which gradually supplies essential nutrient such as N and P_2O_5 , along with their inherent manuring effect (Baghdadi *et al.*, 2018; Dey *et al.*, 2019; Geisseler *et al.*, 2021; Hou *et al.*, 2023; Wang *et al.*, 2023). These factors enhanced plant growth, nutrient uptake, and soil properties (Karagöz and Hanay, 2017; Ünal *et al.*, 2018; Ojobor and

Omovie-Stephen, 2022). Thus, BG tea positively influenced vegetative growth, particularly PH and NL, which are important for photosynthesis and crop productivity (Palita *et al.*, 2021; Setyowati *et al.*, 2021). However, its effects on leaf size (LW and LL) were less consistent, suggesting that responses varied depending on BG concentration and growth conditions.

Root system characteristics

Table 5 shows eggplant growth parameters with root system characteristics such as root length, root volume, shoot biomass (including both SFW and SODW), root weight (including both RFW and RODW), and root-to-shoot ratio observed 56 DAT. The T_5 (100 mL BG tea per pot) produced a significant ($P < 0.05$) increase in RV at 0.60 ± 0.05 mL plant⁻¹ and the highest shoot biomass (SFW at 28.44 ± 1.67 g plant⁻¹ and SODW at 28.35 ± 1.73 g plant⁻¹) of leaves, and root weight (RFW at 13.00 ± 1.19 g plant⁻¹ and RODW at 1.12 ± 0.09 g plant⁻¹) of roots at 56 DAT. Fortunately, the RODW was comparable between T_3 (1.13 ± 0.10 g plant⁻¹) and T_4 (1.11 ± 0.09 g plant⁻¹). Meanwhile, variations in root system characteristics were observed

among the treatments, except for T_2 , T_1 , and the non-treated control (T_0). Nonetheless, RL and R:S ratio did not differ significantly among the treatments. Numerical analysis revealed that the root mass showed either positive or negative interaction on productivity and that the enzyme content probably decomposes organic matter, making essential nutrients more accessible to eggplant roots (Marwa *et al.*, 2021). They probably attributed to better water absorption and enhanced soil physical properties due to organic amendments (Audra *et al.*, 2021; Kang *et al.*, 2022; Xu *et al.*, 2023), as well as improved nutrient transport and uptake mediated by microbial activity and organic matter decomposition (Shang *et al.*, 2020; Marwa *et al.*, 2021). In addition, the treatment had a significantly positive effect on the rapid translocation of nutrients from source tissues (foliage) to sink organs (roots) in eggplant (Taiz *et al.*, 2015). Furthermore, organic fertilizers such as BG tea enhance the activity of beneficial soil microorganisms involved in nutrient cycling (Oo *et al.*, 2019) and promote root symbiosis (Dimkić *et al.*, 2021).

Table 4 Foliage characteristics of eggplant at 56 days after transplanting

Treatments	PH (cm plant ⁻¹)	NL (leaves plant ⁻¹)	LW (cm plant ⁻¹)	LL (cm plant ⁻¹)
T_0 = control	24.18 ± 0.74^b	17.54 ± 0.50^b	11.96 ± 0.27^{bc}	13.95 ± 0.40^c
T_1 = 10 mL of BG tea per pot	23.90 ± 0.13^b	18.06 ± 0.51^b	11.44 ± 0.25^c	14.34 ± 0.42^{bc}
T_2 = 25 mL of BG tea per pot	26.65 ± 0.81^{ab}	19.40 ± 0.55^b	12.12 ± 0.26^{bc}	15.10 ± 0.44^{bc}
T_3 = 55 mL of BG tea per pot	26.65 ± 0.81^{ab}	22.11 ± 0.63^a	14.13 ± 0.31^a	17.55 ± 0.52^a
T_4 = 75 mL of BG tea per pot	29.34 ± 0.90^a	22.21 ± 0.63^a	13.02 ± 0.29^{ab}	16.24 ± 0.47^{ab}
T_5 = 100 mL of BG tea per pot	29.52 ± 0.90^a	22.67 ± 0.64^a	13.17 ± 0.29^{ab}	16.37 ± 0.48^{ab}
P-value	0.02	0.01	0.03	0.01
CV (%)	7.55	6.95	5.48	7.22

Note: Means within the same column followed by different superscript letters (a, b, c) are significantly different at $P < 0.05$ using the LSD level of significance. Values are presented as mean $\pm$ standard error. PH = plant height, NL = number of leaves, LW = width of leaves, LL = length of leaves. CV = coefficient of variation.

Table 5 Root system characteristics of eggplant at 90 days after transplanting

Treatments	RL (cm plant ⁻¹)	RV (mL plant ⁻¹)	Root weight			Shoot biomass		
			RFW (g plant ⁻¹)	RODW (g plant ⁻¹)	SFW (g plant ⁻¹)	SODW (g plant ⁻¹)	R:S ratio	
T ₀	10.98 ± 0.77	0.22 ± 0.28 ^c	4.30 ± 0.39 ^c	0.70 ± 0.06 ^b	11.14 ± 0.66 ^c	15.07 ± 0.92 ^b	0.05 ± 0.004	
T ₁	10.94 ± 0.77	0.46 ± 0.33 ^b	7.96 ± 0.72 ^{bc}	0.93 ± 0.08 ^{ab}	14.22 ± 0.84 ^d	15.71 ± 0.92 ^b	0.06 ± 0.004	
T ₂	10.94 ± 0.77	0.46 ± 0.33 ^b	8.63 ± 0.79 ^b	0.97 ± 0.08 ^{ab}	17.28 ± 1.01 ^{cd}	20.38 ± 1.24 ^b	0.05 ± 0.004	
T ₃	12.90 ± 0.91	0.48 ± 0.33 ^b	10.00 ± 0.92 ^{ab}	1.13 ± 0.10 ^a	24.53 ± 1.44 ^{ab}	20.03 ± 1.22 ^b	0.06 ± 0.004	
T ₄	8.39 ± 0.59	0.55 ± 0.04 ^{ab}	9.82 ± 0.90 ^{ab}	1.11 ± 0.09 ^a	24.73 ± 1.45 ^{ab}	20.00 ± 1.22 ^b	0.06 ± 0.004	
T ₅	7.39 ± 0.52	0.60 ± 0.05 ^a	13.00 ± 1.19 ^a	1.12 ± 0.09 ^a	28.44 ± 1.67 ^a	28.35 ± 1.73 ^a	0.04 ± 0.003	
P-value	0.38	0.02	0.03	0.01	0.02	0.01	0.97	
CV (%)	17.27	20.00	22.46	20.81	14.42	14.96	18.16	

Note: Means within the same column followed by different superscript letters (a, b, c) are significantly different at P < 0.05 using the LSD level of significance.

Values are presented as mean ± standard error. T₀ = control, T₁ = 10 mL of BG tea per pot, T₂ = 25 mL of BG tea per pot, T₃ = 55 mL of BG tea per pot, T₄ = 75 mL of BG tea per pot, T₅ = 100 mL of BG tea per pot, RL = root length, RV = root volume, RFW = fresh weight root, RODW = oven-dried weight root, SFW = shoot fresh weight, SODW = shoot oven-dried weight, R:S ratio = root-to-shoot ratio, CV = coefficient of variation.

Frequency of flowering, fruiting, and harvesting events post-transplanting

Based on Table 6, days to first flowering did not differ significantly among treatments ($P = 0.24$). T_4 recorded the earliest flowering at 49.07 ± 1.40 DAT, followed closely by T_0 (49.32 ± 1.40 DAT) and T_2 (49.38 ± 1.41 DAT), while T_5 showed the latest flowering at 52.33 ± 1.49 DAT. Intermediate values were observed in T_3 (50.06 ± 1.43 DAT) and T_1 (51.70 ± 0.84 DAT). Although not statistically significantly higher concentrations of BG tea (T_1 to T_5) tended to slightly delay flowering compared to the lower concentrations and the control. This suggested that lower BG tea concentrations may have helped reduce the N-induced delay in flowering. According to Vidal *et al.* (2014), excessive N promotes vegetative growth and can delay flowering by altering hormonal signaling pathways, whereas optimal N levels support reproductive development. In this study, flowering occurred at 49.32 ± 1.40 , 51.70 ± 0.84 , 49.38 ± 1.41 , 50.06 ± 1.43 , 49.07 ± 1.40 , and 52.33 ± 1.49 DAT for T_0 , T_1 , T_2 , T_3 , T_4 , and T_5 , respectively. Treatments with higher BG tea concentrations (T_1 , T_3 , and T_5) showed slightly later

flowering than the control and lower treatments, although the differences were minimal. This may have been due to interactions between N and other nutrients or hormones in BG tea, such as K_2O , P_2O_5 , and cytokinins, which could have offset N's delaying effect and promoted flowering (Ye *et al.*, 2019; Akhtar *et al.*, 2020). Furthermore, the nitrate transporter NRT1.1 (CHL1) regulates lateral root development by modulating auxin transport in response to nitrate availability, thereby integrating nutrient signaling with root system architecture (Krouk *et al.*, 2010; Bouguyon *et al.*, 2015), which can indirectly influence flowering by altering resource allocation. In addition, bioactive compounds in guano may have influenced hormonal signaling and gene expression related to flowering, including pathways involving Flowering Locus (FT), Constans (CO), and Suppressor of Overexpression of Constans 1 (SOC1) (Yoo *et al.*, 2005; Andres and Coupland, 2012).

Although ANOVA revealed no significant differences ($P > 0.05$), the observed trends indicated biologically meaningful effects. Similarly, Korn *et al.* (2023) reported that BG application did not negatively affect early reproductive development.

Table 6 Effect of bat guano tea application on the number of days from transplanting to flowering, fruiting, and harvesting in eggplant

Treatments	Number of days from transplanting		
	Flowering duration (day)	Fruiting duration (day)	Harvesting duration (day)
T_0 = control	49.32 ± 1.40	68.31 ± 2.29	86.07 ± 1.70
T_1 = 10 mL of BG tea per pot	51.70 ± 0.84	68.77 ± 2.30	83.33 ± 1.64
T_2 = 25 mL of BG tea per pot	49.38 ± 1.41	68.72 ± 2.30	86.04 ± 1.70
T_3 = 55 mL of BG tea per pot	50.06 ± 1.43	61.01 ± 2.04	80.70 ± 1.59
T_4 = 75 mL of BG tea per pot	49.07 ± 1.40	62.04 ± 2.08	83.33 ± 1.64
T_5 = 100 mL of BG tea per pot	52.33 ± 1.49	61.08 ± 2.04	83.82 ± 1.64
P-value	0.24	0.08	0.66
CV (%)	7.00	8.21	4.83

Note: Values are presented as mean $\pm$ standard error. Means followed by the same letter are not significantly different at $P < 0.05$ using the LSD test. CV = coefficient of variation.

Yield Parameters

Table 7 presents the yield performance of eggplant at 90 DAT under different BG tea concentrations, evaluated across two consecutive weekly harvests. The analysis revealed significant variation in yield among treatments, as indicated by the ANOVA results ($P = 0.02$). Among the treatments, T_4 (75 mL) and T_5 (100 mL) recorded the highest yields at 1.43 ± 0.09 (increase +27.68%) and 1.37 ± 0.08 (increase +22.32%) t ha^{-1} , respectively, and were statistically superior to the lower concentrations (T_1 to T_3). However, these treatments were statistically comparable to the control (T_0), which yielded $1.12 \pm 0.07 \text{ t ha}^{-1}$. Notably, T_4 produced the highest yield and the greatest percentage increase over the control, indicating that T_4 (75 mL of BG tea per pot) was the most effective and resource-efficient application rate. In contrast, the lower concentrations ($T_1 = 10 \text{ mL}$, $T_2 = 25 \text{ mL}$, and $T_3 = 55 \text{ mL}$) recorded lower yields ranging from 0.94 ± 0.05 to $0.96 \pm 0.06 \text{ t ha}^{-1}$, suggesting that insufficient nutrient supply may have limited fruit development and overall productivity. On the other hand, the higher concentrations (T_4 and T_5) enhanced yield, likely due to improved nutrient availability, particularly N and other growth-promoting

elements present in BG tea. However, despite the superior vegetative growth observed at the highest concentration (T_5), this did not result in the highest yield, implying a possible shift in assimilate partitioning toward vegetative structures rather than reproductive organs. This indicated that excessive nutrient application did not always translate into increased yield. Furthermore, the computed effect size ($\eta^2 = 0.97$) showed that approximately 97% of the total variation in eggplant yield was attributed to BG tea treatments (Table 8). According to Cohen (1988), this value represented a large effect size, highlighting the strong influence of BG tea concentration on yield performance and its agronomic significance. Overall, the findings suggested that moderate application of BG tea, particularly T_4 , provided the most favorable balance between nutrient supply and yield optimization, making it the most efficient treatment for enhancing eggplant productivity. Despite these improvements, the overall yields remained lower than typical field yields (10 to 20 t ha^{-1}), primarily due to pot limitations such as restricted root growth and limited nutrient availability (Passioura, 2006; Poorter *et al.*, 2012). Therefore, the results were interpreted as relative treatment effects rather than absolute field performance.

Table 7 Eggplant yields percentage yield relative to the control at 90 days after transplanting under weekly harvesting

Treatments	Mean of times harvested (g plant ⁻¹)	Yield (t ha ⁻¹)	Increase yields (%) vs Control
T_0 = control	3	1.12 ± 0.07^{ab}	-
T_1 = 10 mL of BG tea per pot	5	0.94 ± 0.05^b	-16.07
T_2 = 25 mL of BG tea per pot	4	0.96 ± 0.06^b	-14.29
T_3 = 55 mL of BG tea per pot	6	0.96 ± 0.06^b	-14.29
T_4 = 75 mL of BG tea per pot	4	1.43 ± 0.09^a	+27.68
T_5 = 100 mL of BG tea per pot	5	1.37 ± 0.08^a	+22.32
P-value		0.02	
CV (%)		15.55	

Note: Values are presented as mean $\pm$ standard error. Means followed by the same letter are not significantly different at $P < 0.05$ using the LSD test. CV = coefficient of variation.

Nevertheless, the positive response supported previous findings that compost teas enhanced nutrient availability and plant growth (Scheuerell and Mahaffee, 2002; Ingham, 2005). Hence, field trials were still necessary to validate these results under practical conditions. Meanwhile, the lower yields observed in T_1 to T_3 were likely due to insufficient nutrient supply or weak microbial activity at low concentrations. In contrast, T_4 and T_5 improved N uptake, root-microbe interactions, and nutrient assimilation, which contributed to better yield performance (Ouyang *et al.*, 2022; Liu *et al.*, 2024). However, since synthetic fertilizer was not included in the study, direct comparison with conventional systems remained limited. Even so, the

observed yields fell within the lower to mid-range of NPK-based yields under tropical conditions, supporting the potential of properly concentrated organic inputs (Arancon *et al.*, 2004; Agegnehu *et al.*, 2017).

Finally, crop responses to BG tea varied across species, as reported in previous studies showing both high and low yield outcomes. This emphasized the need for crop-specific and site-specific application strategies. Moreover, alternative organic inputs such as vermicompost or fortified compost teas should also be explored to ensure sustainability and reduce environmental impact (Atiyeh *et al.*, 2000; Scheuerell and Mahaffee, 2002; Arancon *et al.*, 2004; Agegnehu *et al.*, 2017).

Table 8 ANOVA decomposition and effect size (η^2) showing treatment effects on yield

Source	Sum of square (SS)	Value
Between treatments	SS Effect	0.7451
Within (error)	SS Within	0.0235
Total	SS Total	0.7686
Eta squared (η^2)	SS Effect / SS Total	0.9694

CONCLUSIONS

This study demonstrated that BG tea, particularly at 75–100 mL pot⁻¹ (T_4 to T_5), effectively enhanced the growth and yield of eggplant under controlled pot conditions. The T_4 provided the most balanced response, producing the highest yield while maintaining strong vegetative growth, indicating an efficient allocation of nutrients between shoot biomass development and fruit production. These findings emphasize the affordability, effectiveness, and practicality of BG tea as a locally available organic fertilizer that can lessen reliance on synthetic inputs while promoting sustainable nutrient management among smallholder farming systems. However, the study was conducted under pot culture, which inherently restricts root growth and limits the expression of plant responses compared to open-field conditions. The controlled environment

also reduces the influence of natural variability such as rainfall, soil heterogeneity, and pest dynamics. In addition, the absence of a direct comparison with conventional inorganic fertilizer treatments limits the ability to fully assess the relative agronomic and economic advantages of BG tea.

Future research should therefore focus on multi-location field trials to validate these results under diverse soil types and climatic conditions. It is also recommended to evaluate BG tea in combination with reduced rates of synthetic fertilizers to determine integrated nutrient management strategies that optimize yield while maintaining soil health. Further studies should include economic analysis, long-term soil fertility assessment, and microbial dynamics to better understand the sustainability and scalability of BG tea application in eggplant production systems.

CONFLICT OF INTEREST

The authors declare that they have no financial or non-financial conflicts of interest to disclose.

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in supporting the successful conduct of the study on the use of bat guano tea. Furthermore, the study was conducted in pots under a protective structure, which limits the extrapolation of results to open-field conditions due to the absence of natural variability in weather, soil, and pest pressures. Consequently, the findings should be interpreted with caution and further validated through field trials. Finally, the authors express their gratitude to the anonymous reviewers and the editors of TJAS for their helpful comments and constructive suggestions.

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