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RESEARCH ARTICLE

Mitigating High-Temperature Stress through Organic Manure Amendments on the Growth of Lunuwila (*Bacopa monnieri* (L.) Wettst.)

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ABSTRACT

Lunuwila (Bacopa monnieri), typically found in semi-aquatic environments, is increasingly threatened by habitat loss due to environmental degradation and rising temperatures associated with global warming. This study aimed to identify an optimal organic manure treatment to counteract the adverse effects of increased temperatures on Lunuwila growth. The experiment was conducted at The Open University of Sri Lanka, Nawala, inside a temperature-controlled polytunnel designed to simulate the increased (34-35°C) temperature conditions and plant house at ambient (27-32°C) temperature. A two-factor factorial completely randomized design (CRD) with three replications was used to assess the interaction between temperature and organic manure on Lunuwila growth. The treatments included two temperature levels: ambient temperature (T1) and increased temperature (T2), and four organic manure levels: 100% compost (M1), 50% compost with 50% cow dung (M2), 100% cow dung (M3), and a no-fertilizer control (M0). Organic manure was applied at a rate equivalent to 10 tons per hectare for 100% treatments. Growth parameters were analysed using R Studio software (version 4.2.1), with treatment differences tested by Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) for mean comparison at a significance level of $p=0.05$. Results indicated that 100% compost under elevated temperature significantly ($p<0.05$) enhanced shoot length (90.7% increase), leaf count (674.4 ±39.5), branch count (13.93±1.01), leaf area index (43.05±2.45), root length (8.54±0.05 cm), chlorophyll content (41.7±0.27 SPAD), fresh shoot weight (2583.84±0.56 g/m^2), dry shoot weight (267.45±0.22 g/m^2), fresh root weight (70.41±0.26 g/m^2), and dry root weight (8.79±0.03 g/m^2) compared to the control at $p\leq0.05$. Conversely, stem diameter (0.381±0.01 cm) was greatest under ambient temperature with 100% cow dung, and root diameter (0.43±0.004 cm) was highest with 50% compost and 50% cow dung under ambient conditions. Therefore, even in a global warming situation 100% compost is favourable for the sustainable cultivation of Lunuwila.

Keywords: *Bacopa monnieri, Compost, Cow dung, Organic manure, Increased temperature*

INTRODUCTION

Sri Lanka's traditional medicinal system encompasses four primary practices, Unani, Ayurveda, and Deshiya Chikitsa-of which Ayurveda and Deshiya Chikitsa prominently rely on plant-based remedies (Weragoda, 1980). Medicinal plants play a crucial role in these practices, serving as essential sources of therapeutic compounds, with several modern drugs derived from natural plant sources (Mohotti *et al*., 2020). In recent years, Ayurvedic medicine has gained popularity, as an increasing number of people are opting for it over Western medicine, often due to concerns about potential side effects associated with the latter (Gurib-Fakim, 2006).

Bacopa monnieri, commonly known as Lunuwila in Sri Lanka and Brahmi in India, is a revered herb in Ayurveda, primarily recognized for its neuroprotective and cognitive-enhancing properties. This small, creeping herb, belonging to the Plantaginaceae family, thrives in tropical and subtropical regions, including South Asia, the USA, and the Mediterranean Basin (Li *et al*., 2020). With over 1,400 years of traditional medicinal use, *B. monnieri* is considered beneficial for memory enhancement, anxiety reduction, and epilepsy management (Sebestian, 2013). The plant's memory-boosting effects are attributed to its saponins, particularly bacosides A, B, C and D, which are often referred to as "memory chemicals" (Rastogi, 1994). Traditionally, the entire plant has been used as a nerve tonic to treat mental disorders, rheumatism, blood disorders, and urinary tract infections (Das, 2006).

Despite its significant medicinal value and demand, *B. monnieri* remains largely reliant on natural habitats in Sri Lanka, with an estimated annual requirement of 1,700 kg in the Ayurvedic pharmaceutical industry (Anon, 2004). However, its natural populations face threats from habitat destruction, contamination, and climate change. The plant's semi-aquatic nature renders it vulnerable to heavy metal accumulation, which is exacerbated by the increasing destruction of wetland ecosystems due to rising global temperatures (Abdussalam and Ratheesh-Chandra, 2009).

Considering these environmental challenges, this study focuses on exploring how organic manure can mitigate the adverse effects of high temperatures on the growth and yield of Lunuwila. Organic manure is known to improve soil properties and enhance plant resilience, making it a promising solution for sustainable cultivation under climate stress (Agbede *et al*., 2013; Arslanoğlu, 2022). Given the essential role of Lunuwila in traditional medicine and the ongoing threats from climate change, understanding the plant's response to organic amendments is vital. This experiment specifically investigates whether organic manure can counteract the negative impacts of increased temperatures on Lunuwila, thereby supporting its sustainable cultivation amid global warming.

MATERIALS AND METHODS

Experimental site

This study was carried out in a temperature-regulated polytunnel and a plant house at the Open University of Sri Lanka, Nawala, Nugegoda. The polytunnel mimics the global warming situation, while the plant house mimics the ambient temperature. These temperatures were selected based on the IPCC result on global climate (IPCC, 2007) and the HadCM3 predictions of Sri Lankan air temperature in 2050 for the A2 scenario of IPCC (De Silva, 2006; De Silva *et al*., 2007). When the internal temperature of the polytunnel exceeds the maximum, the ventilation fans start automatically and continue running until the temperature decreases to the set maximum on the thermostat (Figures 1 and 2). The temperature inside the polytunnel was always higher than in the net house. Godawatte and De Silva (2014) found no significant differences in relative humidity (RH) between inside and outside environments, despite higher partial pressure of water due to elevated daytime air temperatures inside the polytunnel. This was regulated with an open-top vent roof structure. The study used a similar polytunnel with the same conditions.

Figure 1: Polytunnel with open top

Figure 2: Front view of the plant house

Nursery propagation and potting medium preparation

Selected healthy mother plants were vegetatively propagated in a nursery to obtain plantlets for the experiment. For the nursery media, a mixture of 3 parts of reddish-brown earth (RBE) soil,1 part coir dust, and 1 part compost was used. Pot soil water capacity was maintained using continuous irrigation until the pot became saturated. The nursery potting medium was saturated by fully watering it until water started draining from the bottom. Nursery pots were 20 cm in diameter and 25 cm in height.

Experiment design and treatment combinations

This experiment was conducted using a Two-factor factorial Complete Randomized Design (CRD) with three replications. Considered two factors are, two temperature levels, ambient temperature: T1 (27-32°C) and temperature stress: T2 (35-36°C); three organic manure types, Compost: M1, Cow dung: M2, and 50% Compost with 50% Cow dung: M3 with the control No fertilizer: M0. Treatment combinations are as follow T1M0, T1M1, T1M2, T1M3 in the plant house, and T2M0, T2M1, T2M2, T2M3 in the polytunnel. Reddish brown earth soil was used as the soil type and fertilizer treatments were applied at the initial stage. The experiment was repeated thrice to replicate the temperature and polytunnel effects.

Table 1: Initial pH, electrical conductivity, total nitrogen, available phosphorous and exchangeable potassium of compost, and cow dung

Organic Manure	pH	Electrical Conductivity (dS/m)	Nitrogen (%)	Available phosphorous (%)	Exchangeable potassium (%)
Compost	6.35	0.39	0.6	0.08	0.77
Cow dung	8.28	0.973	1.25	0.33	1.68

Soil media preparation and plantlet transplantation

Each pot was filled with about 9 kg of soil. Compost and cow dung were applied to the soil mixture at a 10 ton/ha rate in 100% manure application, while half from both in mixed application. Per one pot 9 kg of soil and 1 kg of compost and Cow dung were added as 100% manure application in M1 and M3 and 500 g of compost and 500 g of cow dung mix were added to M2 (Gupta *et al.*, 2016; Filipović *et al.*, 2023). Plantlets which have a height of about 5-6 cm were transplanted to the experiment pots as 5 plantlets per each. They were maintained for 3 months until the harvest.

Irrigation

Plants were irrigated daily until the pot became saturated. The potting medium was saturated by fully watering it until water started draining from the bottom.

Temperature

The temperature within both the polytunnel and the plant house was meticulously documented during three distinct intervals (Figure 3). A systematic recording was conducted with the aid of the thermometer, ensuring a comprehensive understanding of the temperature dynamics within these experimental environments ensuring that the temperature inside the polytunnel was always higher than the plant house ambient temperature (Figure 3).

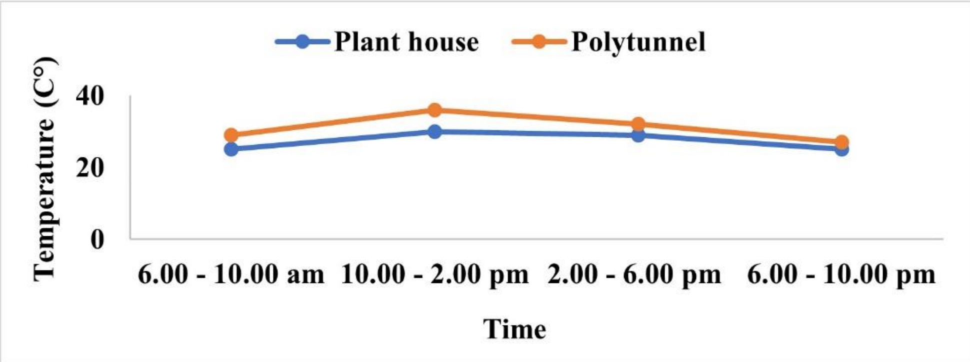

Figure 3: Temperature fluctuation in polytunnel and plant house in the morning, noon and evening

Data collection

Growth parameters were measured in a two-week interval and yield parameters were evaluated after harvest.

Soil and organic manure analysis

Soil and organic manure parameters were analyzed at the beginning of the study. The pH and electrical conductivity (EC) of soil, compost, and cow dung were measured using a multi-parameter analyzer (HACH HQ40d). The pH was determined using a 1:2.5 soil-to-water suspension (Rowell, 1994), while EC was measured with a 1:5 soil-to-water suspension (Black, 1965). Total nitrogen (N) was quantified using the Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus (P) was assessed using the ascorbic acid colourimetric method and a spectrophotometer (Watanabe and Olsen, 1965). Exchangeable potassium (K) was measured via the NH_4OAc extraction method and a flame photometer (Jackson, 1958).

The potting mixture, composed of reddish-brown earth (RBE) soil, had a pH of 5.25, an electrical conductivity of 1.48 dS/m, 0.76% total nitrogen, 0.008% available phosphorus, and 0.001% exchangeable potassium (Table 1). Both compost and cow dung exhibited good levels of available phosphorus and exchangeable potassium, with cow dung showing a higher total nitrogen content compared to compost (Table 1).

Growth and yield parameters

The growth of Lunuwila was assessed using some selected growth parameters such as plant height (cm), number of leaves, leaf area (cm^2), number of branches, stem diameter (cm), root length (cm), root diameter (cm), chlorophyll content, and SPAD values in two-week intervals. The yield parameters, including fresh shoot weight per m^2, dry shoot weight per m^2, fresh root weight per m^2, and dry root weight per m^2, were evaluated after harvest. After transplanting plants from the nurseries, the impact of the treatment on shoot length increment was evaluated as the difference between the initial shoot length and the shoot length after the treatment effect as a percentage. The leaf area index (LAI) is the total one-sided area of all the leaves above a given ground area divided by the ground area (Bréda, 2003).

Data analysis

All measured data were analyzed by using the R studio software version 4.21. The R software version 4.2.1 was used to display the means and SE of the dataset. The significance or otherwise of the differences between treatments was tested by Analysis of Variance (ANOVA). The mean comparison was performed with Duncan's Multiple Range Test (DMRT) to evaluate the significance between all possible pairs of treatment means at p=0.05.

RESULTS AND DISCUSSION

The experiment was conducted to test the single effects of organic manure (compost and cow dung) effect and temperature effects together with the interaction effect of organic manure on the growth and yield of Lunuwila. All the tested growth and yield parameters show significant differences with the treatment interaction effect at a significance level of $p \leq 0.05$ (Table 2). This indicates that the effect of temperature on the growth parameters of the Lunuwila plant varies significantly with the type of organic manure.

Growth parameters

Increase in shoot length

The interaction effect of the 100% compost treatment under elevated temperature conditions yielded a significantly higher increase in shoot length, with a mean increase of 90.7±4.13% at a significance level of $p \leq 0.05$, compared to the control under the same increased temperature, which showed a growth of only 56.5±4.13% (Table 2). However, there was no statistically significant difference at $p \leq 0.05$ between the 100% compost treatment under ambient temperature (78.2±4.13%) and the same treatment under increased temperature. These results align with findings from other studies that have demonstrated a positive relationship between compost application and enhanced shoot and root growth in medicinal plants (Singh and Mallick, 2020). For example, *B. monnieri* showed notable increases in plant length when treated with vermicompost at concentrations of 5, 10, and 15%, with the highest growth observed at the 15% dose (Singh and Mallick, 2020). Additionally, the succulent nature of *B. monnieri* may support its resilience to temperature stress, aiding acclimation under elevated temperatures (Jain *et al.*, 2016). This indicates that compost application, particularly under higher temperatures, can significantly boost shoot growth, potentially offering a sustainable approach to enhance biomass production in medicinal plants under climate-stressed conditions.

Table 2: Analysis of Variance results for interactive effects of temperature and organic manure on growth parameters (mean±SD) with p-values for treatment effects

OM: Temperature	Increase in shoot length (%)	Number of leaves	Number of branches	Leaf area index	Stem diameter (cm)	Root diameter (cm)	Root length (cm)	Chlorophyll content (SPAD)
M0T1	79.7±4.13[a]	47.2±39.5[c]	0.88±1.75[c]	2.12±2.45[c]	0.20±0.02[c]	0.22±0.007[b]	3.62±0.09[d]	31.0±0.27[e]
M1T1	78.2±4.13[a]	122.2±39.5[bc]	2.08±1.01[bc]	5.81±2.45[bc]	0.22±0.01[c]	0.17±0.004[c]	3.62±0.05[d]	37.0±0.27[c]
M2T1	81.7±4.13[a]	81.6±39.5[bc]	3.31±1.01[bc]	3.41±2.45[c]	0.32±0.01[b]	0.43±0.004[a]	4.67±0.05[c]	41.0±0.27[ab]
M3T1	86.6±4.13[a]	90.6±39.5[bc]	3.05±1.01[bc]	3.98±2.45[c]	0.38±0.01[a]	0.17±0.004[c]	7.04±0.05[b]	40.1±0.27[b]
M0T2	56.5±4.13[b]	61.1±39.5[bc]	1.86±1.75[bc]	2.93±2.45[c]	0.05±0.02[d]	0.03±0.007[d]	1.20±0.05[f]	36.4±0.27[d]
M1T2	90.7±4.13[a]	674.4±39.5[a]	13.93±1.01[a]	43.05±2.45[a]	0.31±0.01[b]	0.24±0.004[b]	8.54±0.05[a]	41.7±0.27[a]
M2T2	58.0±4.13[b]	46.3±39.5[c]	1.54±1.01b[c]	2.49±2.45[c]	0.06±0.01[d]	0.03±0.004[d]	2.56±0.05[e]	41.2±0.27[ab]
M3T2	86.6±4.13[a]	224.2±39.5[b]	6.07±1.01[b]	15.58±2.45[b]	0.36±0.01[ab]	0.17±0.004[c]	8.68±0.09[a]	37.8±0.27[c]
P value								
OM	0.52	0.61	0.58	0.76	0.00	0.00	0.00	0.00
Temperature	0.00	0.80	0.69	0.81	0.00	0.00	0.00	0.00
OM × Temperature	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: The mean within each column followed by the same letter is not significantly different with each treatment effect. OM – organic manure. Treatment effects with p value≤0.05 were considered as significant on growth parameters.

Number of leaves

The interaction effect of the 100% compost treatment under elevated temperature conditions significantly increased the number of leaves, reaching an average of 674.4±39.5 leaves at a $p \le 0.05$ significance level. This represents a tenfold increase compared to the control group at elevated temperatures (Table 2). Under ambient temperature, the same 100% compost treatment produced only 122.2±39.5 leaves, which is about 5.5 times fewer than under increased temperature with compost. These results suggest that the combination of elevated temperature and compost application positively impacts leaf production. Studies support this finding, showing that increased soil nitrogen and the plant's temperature acclimation capacity can promote leaf emergence (Kriby, 1995). The addition of compost may enrich the soil nitrogen levels, enhancing the leaf count and aiding resilience to temperature stress (Rejeb *et al.*, 2014). Furthermore, plant's succulent characteristics may improve its adaptability to temperature fluctuations (Jain *et al.*, 2016).

Number of branches

The 100% compost treatment under elevated temperature conditions resulted in the highest recorded number of branches, with an average of 13.93±1.01 branches at a $p \le 0.05$ significance level. This represents a sevenfold increase compared to the control under increased temperature (Table 2). In contrast, the same compost treatment under ambient temperature produced only 2.08±1.01 branches, which is nearly seven times less than in the elevated temperature with compost. These results indicate that the combined effects of elevated temperature and compost application significantly promote branching in Lunuwila (*B. monnieri*). Several studies support this finding, showing that soil amended with compost enhances growth in medicinal plants by improving nutrient availability (Kim *et al.*, 2010; Yadav *et al.*, 2014). Additionally, *B. monnieri* is known to respond positively to abiotic stresses, such as elevated temperatures and water scarcity, which can further stimulate growth under optimal nutrient conditions (Jain *et al.*, 2016; Singh *et al.*, 2021). This suggests that temperature stress, in combination with sufficient nutrient supply from compost, can significantly increase the number of branches in Lunuwila, enhancing its growth potential under such conditions.

Leaf area index (LAI)

LAI was highest with the 100% compost treatment under elevated temperature, reaching 43.25±2.45, significantly ($p \le 0.05$) surpassing the control by 14-fold and the ambient compost treatment by sevenfold (Table 2). This increase in LAI is primarily due to the higher number of leaves produced under elevated temperatures with compost, as nutrient-rich soil and temperature stress have been shown to promote leaf proliferation (Kirby, 1995; Rejeb *et al.*, 2014). The compost's slightly acidic pH (6.35) contrasts with the strongly acidic (8.28) potting soil, which could also contribute to these differences in LAI. Research has shown that *B. monnieri* thrives in saline and low-pH soils, enhancing its growth in compost-amended soil (Pankaj *et al*., 2020). Additionally, adequate nitrogen levels in organic fertilizers have been linked to greater leaf area expansion during the vegetative stage (Sanni, 2016). Studies on corn further support these findings, showing that warmer temperatures increase leaf area, with the greatest growth observed at 35/27°C compared to 20/12°C (Walne and Reddy, 2022). These results collectively indicate that the combination of optimal nutrient supply, soil pH, and temperature stress positively influences LAI in Lunuwila.

Stem diameter

The highest stem diameter in Lunuwila, recorded at 0.381±0.01 cm, was achieved under ambient temperature with the 100% cow dung treatment, which significantly exceeded the control diameter of 0.201±0.02 cm at $p \leq 0.05$ (Table 2). This unique increase in stem diameter with cow dung can likely be attributed to its specific nutrient profile, which includes growth-promoting compounds like auxins, gibberellins, and cytokinin (Dania *et al*., 2014). Cow dung's high organic content has been shown to enhance plant growth and yield across various species, including Amaranthus hybridus (Sanni, 2016), sweet maize (Uwah and Eyo, 2014), and maize (Audu, 2020).

Furthermore, cow dung's live microorganisms play a key role by releasing phytohormones and improving nutrient availability, which supports plant structural growth (Mohammed *et al*., 2019). Compared to other organic manures, cow dung is rapidly mineralized, enhancing the physical and chemical properties of the soil and thereby promoting stem robustness (Audu, 2020). Additionally, soil microorganisms present in organic matter, like those in cow dung, contribute to nutrient cycling, indirectly benefiting plant growth and stem thickness (Ramadhani and Nuraini, 2018).

Interestingly, while 100% compost under increased temperature promoted higher growth in all other parameters, stem diameter peaked with 100% cow dung under ambient conditions. This suggests that Lunuwila may respond differently to specific organic amendments depending on environmental conditions. Cow dung's nutrient release patterns and microbial activity may favour structural development in stable temperatures, leading to thicker stems, whereas the comprehensive nutrient profile of compost might better support other growth parameters under the stress of increased temperature. This differentiation highlights the importance of selecting organic treatments tailored to specific growth objectives and environmental conditions in Lunuwila cultivation.

Root diameter

The highest root diameter in Lunuwila was recorded at 0.430±0.004 cm with a 50% cow dung and 50% compost mixture under ambient temperature, significantly surpassing the control diameter of 0.220±0.007 cm at $p \leq 0.05$ (Table 2). This improvement in root diameter with the mixed treatment can be attributed to the synergistic effects of cow dung and compost, which create a balanced nutrient environment that favours root growth. Cow dung contains natural growth-promoting hormones like auxins, which enhance root development (Dania *et al.*, 2014), while compost contributes a steady supply of organic nutrients, optimizing soil conditions and nutrient accessibility (Audu, 2020).

Together, these organic amendments not only deliver essential nutrients but also improve soil texture and moisture-holding capacity, which are critical for robust root structure. Organic manure mixtures, such as the cow dung and compost combination, provide both rapid and slow nutrient release, creating a more balanced environment that supports thicker root growth. This contrasts with treatments using 100% compost or cow dung individually, where nutrient release patterns may be less optimized for root development specifically.

The difference in root diameter under ambient temperature with 50% compost with 50% cow dung, while other parameters peaked under 100% compost with increased temperature, suggests that root growth in Lunuwila may rely on steady nutrient availability and stable temperature conditions rather than higher temperatures alone. This could imply that while increased temperature and 100% compost are ideal for general growth, root diameter specifically benefits from a mixed organic input and ambient conditions, perhaps due to root tissues' sensitivity to nutrient and water balance. This highlights the potential for customized organic treatments to maximize different growth aspects in temperature-sensitive medicinal plants like Lunuwila.

Root length

The longest root length in Lunuwila was observed with 100% cow dung (8.68±0.04 cm) and 100% compost (8.54±0.04 cm) under increased temperature, with no statistically significant difference between the two treatments at $p \leq 0.05$ but significantly higher than the control (Table 2). These findings suggest that organic manure, whether cow dung or compost, in combination with elevated temperatures, can significantly enhance root growth. This growth increase can be attributed to both physiological and environmental interactions induced by organic amendments and temperature stress.

Root length expansion under high temperatures is supported by previous studies indicating optimal growth at moderately high temperatures (e.g., 35/27°C for corn), whereas excessively high temperatures tend to limit root development (Walne and Reddy, 2022). Elevated temperatures can alter root architecture, including changes in nutrient uptake efficiency, by modifying root diameter and length (Luo *et al.*, 2020). Brassinosteroid signalling pathways have been identified as responsive to temperature changes, suggesting a link between thermal conditions and root growth adaptation under sustained environmental stress (Martins *et al.*, 2017). Physiologically, *B. monnieri*'s root growth under high-temperature stress with compost or cow dung may be due to enhanced nutrient uptake facilitated by these organic inputs. Heat stress is known to stimulate root growth, enabling the plant to seek resources over a larger soil volume in response to increased cellular and metabolic demands (Poór *et al.*, 2022). Organic manure, especially compost, provides a steady nutrient source that enhances root proliferation by supplying nitrogen and other essential elements crucial for root expansion (Samanhudi *et al.*, 2021). Furthermore, the genetic mechanisms in *B. monnie*ri likely contribute to its stress tolerance, as certain genes and metabolic pathways become activated to support root growth in response to environmental stressors like temperature elevation (Arshad *et al.*, 2020).

The absence of a significant difference between 100% cow dung and 100% compost applications under increased temperature may stem from the complementary roles of these organic amendments, both of which create nutrient-rich and stable soil environments conducive to root development. Organic manures help plants mitigate the adverse effects of temperature stress by improving soil fertility, moisture retention, and nutrient bioavailability, providing a conducive environment for root growth (Cohen *et al.*, 2020). This combined impact of temperature and organic inputs, leveraging *B. monnieri's* genetic and physiological resilience, underscores the plant's enhanced root response as a natural adaptation to heat stress when supported by sufficient organic nutrients (Suzuki *et al.*, 2016).

Chlorophyll content

Plants treated with 100% compost under increased temperature conditions exhibited significantly higher chlorophyll content, measuring 41.7±0.268 SPAD, compared to the control treatment, which recorded 36.4±0.268 SPAD at a significance level of $p \leq 0.05$ (Table 2). But no significant difference between the 50% compost with 50% cow dung treatment at increased temperatures. The application of organic manures, particularly compost, has been shown to have a notable impact on chlorophyll content. For instance, research indicates that the use of organic fertilizers can significantly enhance chlorophyll synthesis, which is essential for photosynthesis and overall plant health (Hossain *et al.*, 2021; Idris and Idris, 2023).

Research shows that organic amendments like compost can boost chlorophyll content and improve crop resilience to environmental stress (Purbajanti *et al.*, 2019). Additionally, compost enhances microbial activity in the soil, promoting nutrient uptake and supporting chlorophyll production (El-Agrodi *et al.*, 2016). Overall, these findings highlight the beneficial effects of compost on chlorophyll content and plant growth under elevated temperatures.

Yield parameters

Fresh shoot weight

The fresh shoot weight of *B. monnieri* was significantly higher in plants treated with 100% compost under increased temperature, measuring 2,583.84±0.56 g/m^2 at a significance level of $p \leq 0.05$. This is in stark contrast to the control treatment under increased temperature, which recorded only 46.25±0.56 g/m^2

(Table 3). The increase in fresh shoot weight can be attributed to several factors. First, the application of organic compost positively influences plant growth and phytochemical accumulation (Machado *et al.*, 2021). Compost supplies essential nutrients and improves soil structure, which collectively enhances plant growth. The nitrogen availability from organic fertilizers, including compost, is critical for plant development, contributing to the increased fresh shoot weight of *B. monnieri* (Gutser *et al.*, 2005).

Additionally, Lunuwila is known for its neuroprotective and antioxidant properties, which may help the plant, tolerate high-temperature stress (Neto *et al.*, 2024). The substantial nutrient content of compost, particularly in nitrogen, phosphorus, and potassium, supports robust plant growth (Rahman *et al.*, 2014).

Furthermore, the significant increases in the number of leaves and branches observed in the 100% compost treatment under elevated temperatures likely contributed to the enhanced fresh shoot weight. The interaction between organic manure and increased temperature may also create favourable conditions for physiological processes, leading to increased fresh shoot weight (Hazarika *et al.*, 2021). Overall, the combined effects of organic compost and elevated temperatures promote biochemical and physiological responses in Lunuwila, resulting in substantial growth enhancements.

Table 3: Analysis of Variance results for interactive effects of temperature and organic manure on yield parameters (mean±SD) with p-values for treatment effects

OM: Temperature	Fresh shoot weight per m^2 (g/m^2)	Dry shoot weight per m^2 (g/m^2)	Fresh root weight per m^2 (g/m^2)	Dry root weight per m^2 (g/m^2)
M0T1	18.50± 0.98^{g}	3.08±0.38^{h}	6.17±0.45^{f}	1.85±0.05^{g}
M1T1	176.72±0.56^{e}	38.80±0.22^{d}	10.92±0.26^{e}	3.56±0.03^{e}
M2T1	338.08±0.56 ^{d}	23.88±0.22^{f}	13.38±0.26^{d}	3.09±0.03^{f}
M3T1	612.13±0.56^{c}	71.88±0.22^{c}	15.35±0.26^{c}	6.18±0.03^{b}
M0T2	46.25±0.98^{f}	30.83±0.38^{e}	9.25±0.45^{e}	1.85±0.05^{g}
M1T2	2583.84±0.56^{a}	267.45±0.22^{a}	70.41±0.26^{a}	8.79±0.03^{a}
M2T2	18.55±0.56^{g}	12.63±0.22^{g}	2.50±0.26^{g}	4.55±0.03^{d}
M3T2	1265.76±0.56^{b}	104.37±0.22^{b}	42.77±0.26^{b}	5.82±0.03^{c}
P value				
OM	0.00	0.00	0.00	0.00
Temperature	0.00	0.00	0.00	1.00
OM × Temperature	0.00	0.00	0.00	0.00

Note: The mean within each column followed by the same letter is not significantly different with each treatment effect. OM – organic manure. Treatment effects with p value≤0.05 were considered as significant on growth parameters.

Dry shoot weight

The interaction effect of 100% compost with increased temperature on dry shoot weight of Lunuwila is significant at $p \leq 0.05$. Plants treated with 100% compost under increased temperature recorded a significantly higher dry shoot weight 267.45±0.21 g/m^2, compared to 30.83±0.21 g/m^2 for the control (Table 3).

This increase can be attributed to several factors. Organic compost has been shown to enhance plant growth by improving soil properties such as pH and nutrient availability (Alvarenga *et al.*, 2009; Danial *et al.*, 2014). The beneficial effects of compost on nutrient uptake can lead to increased biomass under temperature stress (Machado *et al.*, 2021). Moreover, the application of compost can mitigate heavy metal bioavailability, promoting better growth conditions (Novak *et al.*, 2019). These factors combined likely contributed to the significant increase in dry shoot weight observed in Lunuwila under the combined treatment of compost and high temperature.

Fresh root weight

The fresh root weight of Lunuwila significantly ($p \leq 0.05$) increased under 100% compost treatment at elevated temperatures, measuring 70.41±0.26 g/m^2 compared to 9.25±0.21 g/m^2 in the control group (Table 3). This enhancement can be attributed to several factors. Organic manure is known to supply essential nutrients, positively impacting vegetative growth across various plant species (Thierry *et al.*, 2019; Qadir and Sheikh-Abdullah, 2023). Additionally, it enhances physiological activity and nutrient availability, leading to improved growth of both leaves and roots (Tovihoudji *et al.*, 2015). High-temperature stress can stimulate physiological and biochemical processes, resulting in increased biomass accumulation (Smith *et al.*, 2014).

Furthermore, the neuroprotective and antioxidant properties of *B. monnieri* contribute to its resilience under stress, promoting growth through the mitigation of oxidative stress (Kishore *et al.*, 2016; Neto *et al.*, 2024;). Compounds like bacosides and saponins in the plant may also support its development (Gupta *et al.*, 2014). Thus, the synergistic effect of compost and elevated temperature significantly enhances the fresh root weight of Lunuwila.

Dry root weight

The dry root weight of Lunuwila was significantly higher under 100% compost treatment at increased temperatures, measuring 8.79±0.21 g/m^2 compared to 1.85±0.21 g/m^2 in the control group ($p \leq 0.05$) (Table 3). This increase can be attributed to several factors. The application of organic manure, such as compost, is known to enhance soil properties and nutrient availability, leading to improved plant growth and higher yields (Agbede *et al.*, 2013, 2017; Novak *et al.*, 2019). Organic compost improves soil physical and chemical characteristics, which can promote root development and biomass accumulation (Ahmadpour and Armand, 2020; Arslanoğlu, 2022).

Additionally, high-temperature stress has been shown to stimulate physiological and biochemical processes in plants, enhancing growth and biomass (Niu and Xiang, 2018). The interaction between organic manure and temperature stress can have synergistic effects, as the combination may improve nutrient availability, water retention, and metabolic activity, all of which contribute to better root development (Novak *et al*., 2019; Ahmadpour and Armand, 2020). Thus, the combined effect of 100% compost and elevated temperatures significantly enhances the dry root weight of Lunuwila.

CONCLUSIONS

This study underscores the significant impact of compost and temperature treatments on the growth and yield of the medicinal plant Lunuwila. The findings reveal that treating plants with 100% compost under increased temperature conditions leads to notable improvements in various growth parameters, such as shoot length, number of leaves, number of branches, leaf area index, root length, and chlorophyll content.

Yield parameters also showed substantial enhancements, with increased fresh and dry weights of both roots and shoots under higher temperature conditions with 100% compost. Interestingly, while stem diameter was greatest under ambient temperature with 100% cow dung treatment, root diameter significantly increased with a combination of 50% cow dung and 50% compost under ambient temperature.

These results suggest that using 100% compost is highly beneficial for the sustainable cultivation of Lunuwila, even in the face of global warming. The study results support the experiment's objective to explore the potential of organic manure in mitigating the adverse effects of increased temperatures on Lunuwila growth. The positive outcomes in growth and yield parameters indicate that organic manure, especially compost, can enhance plant resilience to changing environmental conditions, thereby informing agricultural practices aimed at optimizing plant growth and productivity.

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