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Evaluation of some organic ameliorants in mitigating drought stress and enhancing agronomic and physiological traits in Watermelon (*Citrullus lanatus* L.)

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Abstract
Water hyacinth bokashi, manure, and rice husk biochar are organic ameliorants known for their potential to improve productivity, particularly under drought stress. This study aimed to evaluate the effectiveness of some important organic ameliorants in reducing the negative effects of drought on watermelon (*Citrullus lanatus* L.). A factorial randomized block design (FRBD) was used, involving two factors: (1) combination of organic ameliorants —water hyacinth bokashi + manure (BoM), water hyacinth bokashi + rice husk biochar (BoBi), manure + rice husk biochar (MBi), and a mixture of all three (BoMBi); and (2) four levels of drought stress (100%, 75%, 50%, and 25% of field capacity, FC). The results showed that under optimal moisture conditions (100% FC), BoBi and BoMBi treatments significantly enhanced plant height, leaf area, and fruit weight, indicating their strong growth-promoting effects. However, under moderate to severe drought stress (50% and 25% FC), the ameliorants provided limited mitigation, with reductions in stomatal size and only modest improvements in growth. Notably, the highest total soluble solids (TSS) were observed under 25% FC in BoMBi50 (12.00°Brix) and MBi25 (11.33°Brix), suggesting a stress-induced increase in fruit quality. . Overall, the study identifies BoBi and BoMBi as the most effective treatments for enhancing watermelon productivity under normal to moderate drought conditions. These combinations show potential for practical application by farmers, especially in areas with intermittent water availability. However, under severe drought, their effectiveness is limited, highlighting the need for additional drought mitigation strategies.

Keywords*:* abiotic stress, phenolic content, stomatal conductance, water retention, agronomic traits

Introduction

Drought constitutes a critical and escalating threat to agricultural productivity ranking among the most severe abiotic stresses encountered by crops worldwide (Wang et al., 2020; Mohammed et al., 2022; Makuya et al., 2024; Khadka et al., 2024). Projections suggest that by 2050, approximately 30% of the global freshwater supply may be depleted, with the spatial extent of drought-affected regions expected to double (Prudhomme et al., 2013; Van Loon et al., 2016; Islam & Karim, 2020). The increasing frequency and severity of drought events present substantial threats to food security and the long-term sustainability of agricultural systems, particularly within arid and semi-arid regions (Zhang et al., 2018; Haghighi et al., 2020; Pan et al., 2024). Drought stress adversely affects numerous physiological and biochemical processes in plants, thereby impeding growth and development (Liu et al., 2021; Aslam et al., 2022; Ahmad et al., 2023). The multifaceted impacts of water scarcity include deminished photosynthetic capacity, disrupted nutrient acquisition, and a general decline in plant vigor, all of which contribute to significant yield reductions (Widiyanto et al., 2023; Zhao et al., 2023; Park et al., 2024; Rolando et al., 2025).
Although plants can endure brief periods of water deficiency, prolonged drought typically results in reduced biomass and productivity due to inhibited photosynthesis, impaired growth, and disruptions to key physiological functions (McDowell et al., 2022; Cerqueira et al., 2023; Figueiredo et al., 2023; Novrimansyah, 2024). These adverse effects are particularly pronounced in drought-sensitive crops like watermelon, which requires substantial water inputs to support vegetative growth and fruit development. Even short-term water deficits can cause marked yield reductions. Consequently, there is increasing concern among researchers and agricultural stakeholders regarding the development of effective strategies to mitigate drought-induced stress and enhance watermelon resilience. Plants employ a range of adaptive mechanisms to cope with water scarcity, including alterations in stomatal conductance,

leaf morphology, and osmotic regulation (Koźmińska et al., 2019; Kumar et al., 2022; Alsharafa, 2023). Nevertheless, such responses are frequently inadequate to sustain high levels of productivity under prolonged or severe drought conditions.

One promising strategy to alleviating the adverse effects of drought stress in watermelon is the application of organic ameliorants. These materials —including composts and biochars—are recognized for their ability to improve soil structure, enhance water-holding capacity, and increase nutrient availability, thereby contributing to improved plant resilience under abiotic stress conditions (Rashad et al., 2018; Edeh et al., 2020; Carvalho et al., 2020). A number of studies have demonstrated the beneficial effects of organic amendments such as manure, water hyacinth bokashi, and rice husk biochar on crops performance under drought stress, reporting enhancements in plant growth and yield (Semida et al., 2014; Abd El-Mageed et al., 2019). However, the synergistic effects of these amandements when applied in combination remain insufficiently investigated d—particularly in crops like watermelon, which exhibit high sensitivity to water deficit.

This study seeks to address this knowledge gap by evaluating the combined efficacy of water hyacinth bokashi, manure, and rice husk biochar as organic soil ameliorants in mitigating drought-induced stress in watermelon. Given watermelon's substantial water requirements and sensitivity to drought, the study focuses on determining how various combinations of these amendments influence key agronomic and physiological traits—such as plant height, leaf area, and fruit yield—under different levels of water availability. The findings are expected to inform the development of sustainable cultivation practices that support drought resilience while maintaining productivity. Ultimately, this research will contribute to a deeper understanding of how integrated organic soil management strategies can be employed to enhance the resilience and sustainability of watermelon production systems, particularly in regions prone to water scarcity.

Results and Discussion

Effect of Ameliorants and Drought on Plant Length

The results, as presented in Table 1, indicate that plant length did not differ significantly among treatments up to 14 days after transplantation (DAT). However, significant differences began to emerge between 21 and 28 DAT. At 21 DAT, the BoM100 treatment—comprising water hyacinth bokashi and manure under full field capacity (100% FC)—produced the longest plants, averaging 133.23 cm in height. By 28 DAT, the treatments BoBi100 and BoMBi100—involving water hyacinth bokashi + rice husk biochar, and water hyacinth bokashi + manure + rice husk biochar, respectively, both under 100% FC—exhibited the greatest plant lengths, measuring 248.87 cm and 248.90 cm, respectively. These findings suggest that the combination of organic ameliorants under optimal water availability (100% FC) significantly promotes vegetative growth, particularly in terms of plant length.

Plant growth and development are fundamentally governed by processes such as cell division, elongation, and differentiation, all of which are highly dependent on adequate water availability (Li et al., 2017; Wang & Callaway, 2021; Flynn et al., 2023; Mahlare et al., 2023). Water functions not only as a medium for essential physiological and metabolic processes but also as a critical vehicle for the transport of nutrients from the soil to plant tissues. A deficiency in water can disrupt these activities, ultimately inhibiting growth and development. In particular, limited water availability can reduce nutrient uptake by the roots, thereby impairing overall plant performance (Xue et al., 2017; Huang et al., 2020; Raj et al., 2023). In the present study, plant length was positively correlated with field capacity (FC), even when organic ameliorant combinations were applied. Under drought stress conditions, plant length consistently decreased, likely due to disrupted mitotic activity, increased rates of leaf abscission, and impaired cellular development (Elnaggar et al., 2018). These findings reinforce the importance of water availability in maintaining optimal vegetative growth, particularly during the early developmental stages of watermelon.

Effect of Ameliorants and Drought on Leaf Area

The data presented in Fig. 2 indicate that significant differences in leaf area among treatments emerged at 21 and 28 days after transplantation (DAT), whereas minimal variations were observed at 7 and 14 DAT. During the initial stages (7–14 DAT), all treatments exhibited nearly identical leaf areas, likely because the plants were still in the early phase of vegetative development and the effects of the ameliorant combinations and drought stress had not yet manifested physiologically. As the plants progressed in maturity, treatment differences became more pronounced. At 21 and 28 DAT, the BoMBi100 treatment—comprising water hyacinth bokashi, manure, and rice husk biochar under full field capacity (100% FC)—produced the largest leaf area, measuring 354.33 cm^2 and 447.40 cm^2, respectively. In contrast, the BoM25 and MBi25 treatments, both subjected to 25% FC (representing severe drought stress), resulted in the smallest leaf areas at both observation points. These findings suggest that optimal water availability, in combination with synergistic organic amendments, enhances leaf expansion and canopy development in watermelon.

These findings highlight that the combination of all three ameliorants under non-stress conditions (100% field capacity) provided optimal conditions for leaf development, aligning with the results observed for plant length. As discussed in the previous section, the BoM100, BoBi100, and BoMBi100 treatments—none of which were subjected to drought stress—produced the longest plant lengths. The similar trend observed in leaf area reinforces the positive correlation between adequate water availability and vegetative growth. Together, these results underscore the crucial role of sufficient soil moisture in promoting both stem elongation and leaf expansion in watermelon plants.

Drought stress is widely recognized for its detrimental effects on plant growth, particularly on leaf expansion, as it disrupts critical physiological processes such as photosynthesis (Batool et al., 2020; Kumar et al., 2021; Wu et al., 2023). As water availability declines, the efficiency of photosynthesis is significantly reduced, leading to a decrease in leaf area and overall plant biomass (Moonmoon & Islam, 2017). Numerous studies have reported that drought conditions result in a concurrent decline in photosynthetic capacity and growth parameters such as leaf number and biomass accumulation (Umami et al., 2021; Wu et al., 2023). For instance, both *Triticum aestivum* L. and *Oryza sativa* L. have shown substantial reductions in leaf area under drought stress (Naz & Perveen, 2021). Similarly, in maize (*Zea mays* L.), drought-induced stress has been associated with leaf curling and reduced leaf expansion (Cai et al., 2020). These findings are consistent with the results of the present study, where drought stress—particularly at 25% field capacity—significantly limited leaf area development, reinforcing the critical role of water availability in sustaining vegetative growth.

Thus, the superior leaf growth observed in the BoMBi100 treatment can be attributed to the synergistic effect of combined organic ameliorants and optimal water availability at 100% field capacity (FC). In contrast, severe drought stress conditions at 25% FC significantly impaired the plant's ability to sustain adequate leaf expansion, thereby limiting both leaf area and overall vegetative development. These results underscore the vital role of water availability in supporting healthy plant growth. Moreover, the leaf area data corroborate the findings from the plant length analysis, collectively highlighting that sufficient soil moisture is essential for maximizing leaf development and enhancing the plant's photosynthetic capacity.

Effect of Ameliorants and Drought on Fruit Fresh Weight

The fruit fresh weight data from this study further demonstrate the significant effects of drought stress and ameliorant combinations on watermelon growth. As shown in Fig. 3, the BoM75, MBi75, and BoMBi100 treatments produced the heaviest fruits, with average weights of 1.30 kg, 1.27 kg, and 1.22 kg, respectively. These treatments, which were maintained at up to 75% Field Capacity (FC), yielded significantly heavier fruits compared to other treatments that were either not exposed to drought stress or subjected to severe drought stress (25% FC). Notably, the fruit weights in treatments experiencing 25% FC were considerably lower, underscoring the detrimental effects of extreme drought stress. This finding aligns with previous results on plant length and leaf area, both of which also showed significant reductions under severe drought stress, particularly in treatments at 25% FC.The physiological relationship between water availability and crop yield is complex, involving a range of interrelated processes. Drought stress negatively impacts photosynthesis, resulting in reduced carbon assimilation and smaller fruit size (Farooq et al., 2009; Sakoda et al., 2021; Qi et al., 2023; Sandiasa et al., 2024).

As observed in the plant length and leaf area data, an adequate water supply supports optimal cell elongation and photosynthetic activity, both of which are critical for fruit development. The application of organic ameliorants—such as bokashi, manure, and biochar—significantly enhanced soil water retention and nutrient availability. These amendments strengthened the plants' resilience to moderate drought stress (up to 75% Field Capacity), ultimately contributing to the production of larger fruits under suboptimal watering conditions.Organic amendments such as bokashi, manure, and biochar are well known for enhancing soil fertility and improving plant productivity (Nasar et al., 2019). The application of these materials not only increases nutrient availability but also enhances the soil's water retention capacity, thereby improving plant resilience under water-limited conditions. This was evident in the present study, where the BoM75 and BoMBi100 treatments resulted in larger fruit production under drought stress, largely due to the ameliorants' ability to improve soil structure and facilitate nutrient uptake (Abdallah et al., 2019). Moreover, the improved groundwater retention associated with biochar application further supported plant tolerance to drought conditions (Saffari et al., 2021), reinforcing the observed positive impact on fruit weight.

This trend—where moderate drought stress coupled with organic amendments resulted in higher fruit weight—is consistent with earlier findings on plant length and leaf area. In those cases, sufficient moisture and amendment application enhanced plant growth and photosynthetic efficiency. However, under more severe drought conditions (25% FC), all growth parameters, including fruit weight, were significantly reduced, underscoring the importance of maintaining balanced water availability for optimal plant growth and yield.

Effect of Ameliorants and Drought on Total Dissolved Solids

The total dissolved solids (TDS), measured in degrees Brix (°Brix), serve as an indicator of sugar content in watermelon and are closely associated with the plant's capacity to tolerate drought stress and maintain water balance. As shown in Fig. 4, the highest TDS values were observed in the BoMBi50 and MBi25 treatments, with readings of 12.00 °Brix and 11.33 °Brix, respectively. These findings underscore the important role of organic ameliorants—such as bokashi, manure, and biochar—in enhancing sugar accumulation in watermelon, particularly under drought stress conditions.

Interestingly, the high TDS values observed in the BoMBi50 and MBi25 treatments are consistent with the trends noted in plant length, leaf area, and fruit fresh weight. The combination of organic amendments and moderate water supply appears to enhance the plant's physiological processes, supporting improved growth and metabolic function. As discussed earlier, plants exposed to moderate drought stress (75% FC) showed the most favorable growth outcomes, particularly in terms of plant length and fruit weight. These findings correspond with the elevated sugar content recorded in these treatments, suggesting that drought stress may trigger protective responses in the plant—such as increased sucrose production—to help maintain cellular function and stability.

Soluble sugars such as sucrose play a crucial role in protecting plant cells from water loss during drought stress (Dien et al., 2019; Chen et al., 2022; Luo et al., 2022; Li et al., 2024). These sugars function as osmolytes, helping to stabilize membrane structures and preserve enzymatic activity under dehydrated conditions (Kabiri et al., 2018). In watermelon, the significant increase in TDS under moderate drought stress likely reflects the plant's enhanced capacity to accumulate sugars as an adaptive response to water scarcity. This observation aligns with previous studies on drought-resistant crops such as wheat and quinoa, where elevated levels of sucrose and starch were found under water-limited environments (Yuan et al., 2019).

The results from this study highlight that watermelon plants exposed to moderate drought stress exhibit higher production of soluble sugars, as indicated by increased total dissolved solids (TDS), which may contribute to their improved drought tolerance. This protective response, combined with the beneficial effects of organic ameliorants, aids in maintaining water balance and supports critical growth parameters such as leaf area, plant length, and fruit fresh weight—all of which showed enhanced outcomes under 75% field capacity (FC) with organic amendments.

The observed increase in TDS serves as a key indicator of the plant's physiological adaptation to drought stress. The correlation between TDS and growth parameters such as plant length, leaf area, and fruit weight underscores the complex interplay between water availability, nutrient uptake, and plant development under varying environmental conditions. These findings also suggest that the application of organic ameliorants significantly enhances soil water retention and promotes metabolic activity, leading to improved growth performance and fruit quality in watermelon production, even under suboptimal water conditions.

Stomatal Density in Response to Drought Stress and Their Impact on Plant Growth Parameters

Fig. 5 illustrates the number and density of stomata under different treatment conditions, offering valuable insights into how watermelon plants physiologically adapt to drought stress. Stomatal number and density play a crucial role in regulating water loss through transpiration and controlling carbon dioxide (CO_2) intake—both of which are fundamental processes influencing

Table 1. Physicochemical and Biological Properties of Soil Before Treatment.

Parameter	Method	Result
Total Nitrogen (N)	Kjeldahl	0.21%
Total Phosphorus (P)	HNO_3 and $HClO_4$ Extraction	0.10%
Available Phosphorus	Olsen	11.44 ppm
Total Potassium (K)	HNO_3 and $HClO_4$ Extraction	0.08%
Exchangeable Potassium	1N Ammonium Acetate, pH 7.00	0.27 me%
Exchangeable Sodium	1N Ammonium Acetate, pH 7.00	0.49 me%
Exchangeable Calcium	1N Ammonium Acetate, pH 7.00	1.76 me%
Exchangeable Magnesium	1N Ammonium Acetate, pH 7.00	1.76 me%
Cation Exchange Capacity (CEC)	1N Ammonium Acetate, pH 7.00	25.64 me%
Organic Carbon	Walkley & Black	2.04%
Organic Matter	Walkley & Black	3.52%
C/N Ratio	Calculation	9.71
Electrical Conductivity	Glass Electrode	0.48 mmhos
pH (H_2O)	Glass Electrode	6.36
Total Bacterial Count	Plate Count	7.3×10^6 cfu/g
Soil Texture	Pipette Method	
• Silt		34.26%
• Clay		49.21%
• Sand		16.53%
Texture Class	-	Clayey
Soil Type	-	Grumusol
Land Use Type	-	Dryland (upland)

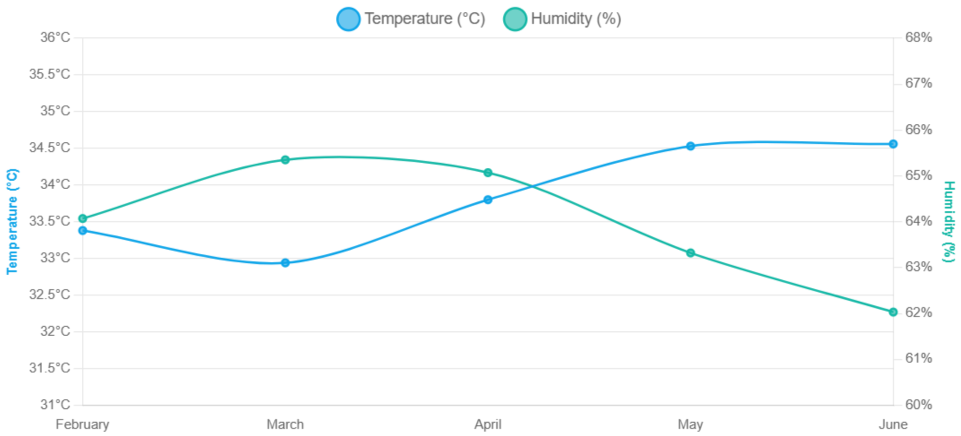

Figure 1. Trends in Average Temperature (°C) and Humidity (%) from February to June 2025.

Table 2. Length of watermelon plant in various treatments and observation ages.

Treatment	Plant length (cm)	Treatment	Plant length (cm)
BoM100	242.10 de	MBi100	219.43 bcde
BoM75	217.47 abcde	MBi75	195.57 abc
BoM50	208.53 abcde	Mbi50	202.10 abcd
BoM25	178.00 ab	Mbi25	176.90 ab
BoBi100	248.87 e	BoMBi100	248.90 e
BoBi75	229.37 cde	BoMBi75	212.33 abcde
BoBi50	204.00 abcd	BoMBi50	207.90 abcde
BoBi25	197.23 abc	BoMBi25	174.77 a

Note: Numbers accompanied by the same letter mean not significantly different at p=0.05. The experiment has two factors: the first is Type of Organic Ameliorant Combinations, with four levels: BoM (water hyacinth bokashi + manure), BoBi (water hyacinth bokashi + rice husk biochar), MBi (manure + rice husk biochar), and BoMBi (water hyacinth bokashi + manure + rice husk biochar). The second factor is Drought Stress Levels, with four levels representing 100%, 75%, 50%, and 25% of Field Capacity (FC).

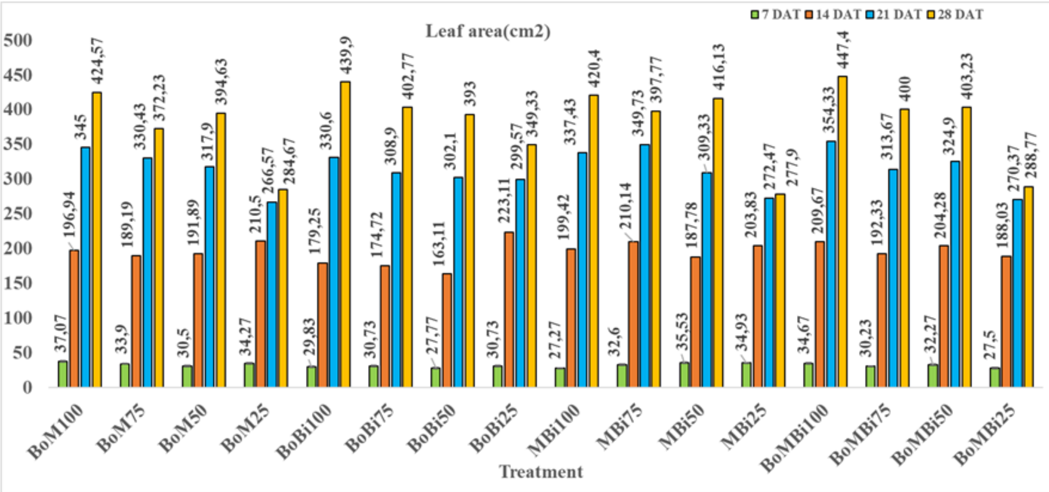

Figure 2. Watermelon leaf area at various treatments and observation ages. Notes: The experiment has two factors: the first is Type of Organic Ameliorant Combinations, with four levels: BoM (water hyacinth bokashi + manure), BoBi (water hyacinth bokashi + rice husk biochar), MBi (manure + rice husk biochar), and BoMBi (water hyacinth bokashi + manure + rice husk biochar). The second factor is Drought Stress Levels, with four levels representing 100%, 75%, 50%, and 25% of Field Capacity (FC).

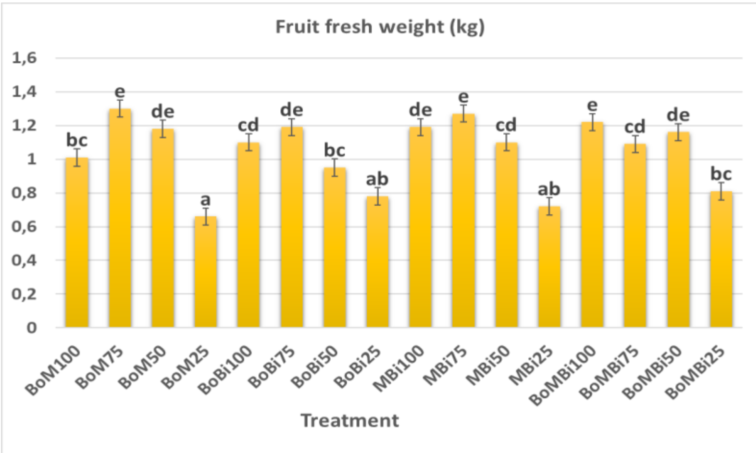

Figure 3. Fruit weight in various treatments. Notes: The experiment has two factors: the first is Type of Organic Ameliorant Combinations, with four levels: BoM (water hyacinth bokashi + manure), BoBi (water hyacinth bokashi + rice husk biochar), MBi (manure + rice husk biochar), and BoMBi (water hyacinth bokashi + manure + rice husk biochar). The second factor is Drought Stress Levels, with four levels representing 100%, 75%, 50%, and 25% of Field Capacity (FC).

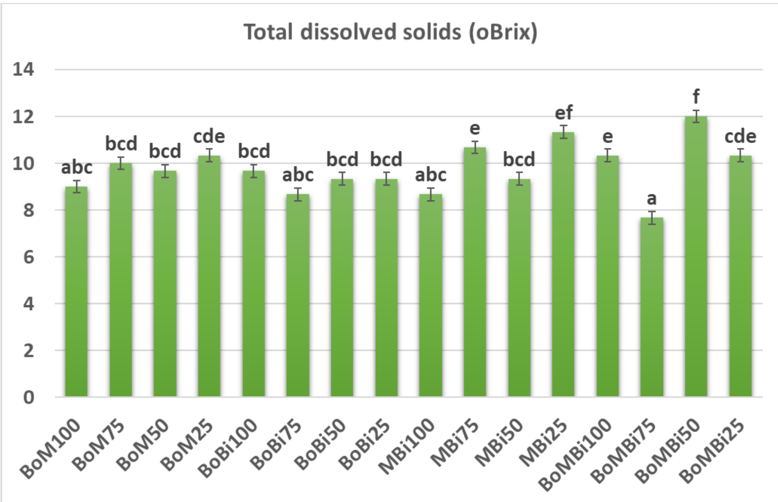

Figure 4. Total soluble solids content in various treatments. Notes: The experiment has two factors: the first is Type of Organic Ameliorant Combinations, with four levels: BoM (water hyacinth bokashi + manure), BoBi (water hyacinth bokashi + rice husk biochar), MBi (manure + rice husk biochar), and BoMBi (water hyacinth bokashi + manure + rice husk biochar). The second factor is Drought Stress Levels, with four levels representing 100%, 75%, 50%, and 25% of Field Capacity (FC).

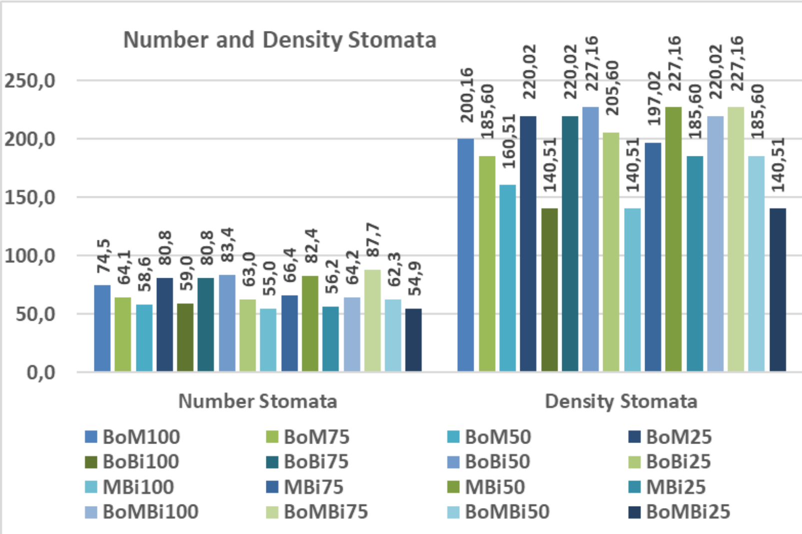

Figure 5. Number and density of stomata in various treatments. Notes: The experiment has two factors: the first is Type of Organic Ameliorant Combinations, with four levels: BoM (water hyacinth bokashi + manure), BoBi (water hyacinth bokashi + rice husk biochar), MBi (manure + rice husk biochar), and BoMBi (water hyacinth bokashi + manure + rice husk biochar). The second factor is Drought Stress Levels, with four levels representing 100%, 75%, 50%, and 25% of Field Capacity (FC).

photosynthesis and overall plant growth. Variations in these parameters reflect the plant's ability to modulate gas exchange in response to water availability, highlighting their importance as indicators of drought tolerance.

The results from this study reveal a clear trend: drought stress significantly influences stomatal behavior. In treatments with low irrigation levels (25% and 50% field capacity), stomata were generally smaller and more closed. This response is a well-known adaptation mechanism in plants under drought conditions, as stomatal closure minimizes water loss through transpiration (Agurla et al., 2018; Ding et al., 2022; Manandhar et al., 2024). This effect was particularly noticeable in the BoM25 and MBi25 treatments, where both stomatal number and density were markedly lower compared to treatments with higher irrigation. In contrast, the BoM100 treatment, which received full irrigation (100% field capacity), exhibited the highest stomatal number and density. This indicates that adequate water availability promotes more open stomata, thereby supporting efficient gas exchange and photosynthesis.

This pattern aligns with the results observed for plant length, leaf area, and total dissolved solids (TDS). In treatments with optimal irrigation, such as BoM100 and BoMBi100, favorable stomatal characteristics contributed to enhanced plant growth. The BoM100 treatment, in particular, demonstrated the greatest plant length, the largest leaf area, and the highest TDS values—indicators of improved plant health and productivity. In contrast, treatments with low irrigation and reduced stomatal activity, such as BoM25 and MBi25, showed stunted growth, smaller leaf areas, and lower TDS levels, underscoring the adverse effects of insufficient water on plant development.

Furthermore, plant media such as bokashi made from water hyacinth and rice husk biochar have been shown to enhance the soil's water-holding capacity (Tampubolon et al., 2024). This improvement supports better stomatal function, which in turn promotes plant performance under drought stress. Organic amendments not only help retain moisture but also stimulate microbial activity in the soil (Li et al., 2017), which is essential for nutrient cycling and overall plant health.

These findings directly relate to earlier observations on fruit fresh weight, where plants exposed to favorable stomatal and irrigation conditions—such as those in the BoM100 treatment—produced higher fruit yields. Optimal stomatal function is vital for efficient photosynthesis, which influences the production of soluble sugars (as shown in the TDS results), leading to healthier plants and greater fruit development.

In summary, stomatal number and density are closely associated with plant water regulation and overall growth. Optimal stomatal conditions enhance photosynthesis, water retention, and nutrient uptake—factors that collectively explain the improved leaf area, plant length, and fruit yield observed under treatments with adequate water and organic media. Thus, stomatal characteristics not only reflect a plant's ability to tolerate drought stress but also serve as reliable indicators of growth performance under different environmental conditions.

Materials and Methods

Experimental Design

This experiment was conducted in a greenhouse, from February to June 2024, using watermelon (Citrullus lanatus var. Golden Inden-F1) as the experimental plant. A Factorial Randomized Block Design (FRBD) was applied, involving two main factors. The first factor was the type of organic ameliorant combination, which consisted of four treatments: water hyacinth bokashi + manure (BoM), water hyacinth bokashi + rice husk biochar (BoBi), manure + rice husk biochar (MBi), and water hyacinth bokashi + manure + rice husk biochar (BoMBi). The second factor was drought stress, applied at four levels based on field capacity (FC): 100%, 75%, 50%, and 25% FC. The treatments were arranged in randomized blocks to control environmental variation within the greenhouse. Prior to treatment, a comprehensive analysis of the soil was conducted to determine its initial physicochemical and biological properties, the results of which are presented in Table 1. Additionally, environmental conditions such as temperature and humidity were monitored throughout the study period and are illustrated in Figure 1.

Preliminary Study

A preliminary study was conducted to determine the appropriate field capacity (FC) level for watermelon cultivation under drought conditions. In this phase, watermelon was planted in a medium containing each of the four organic ameliorant combinations, with six polybags (40 cm x 50 cm) used per treatment. The plants were irrigated daily for three weeks, after which irrigation was discontinued until temporary wilting symptoms appeared. Soil samples were then collected to measure the FC at the point of wilting. Based on the observations, wilting was found to occur at 25% FC, which was subsequently selected as the drought stress level for the main experiment to evaluate critical threshold for watermelon productivity.

Planting procedure

Each polybag (40 cm x 50 cm) was filled with a planting medium composed of soil and a 1:1 mixture of organic ameliorants according to the designated treatment. Each treatment combination was replicated three times with five plant samples per replicate. The polybags were arranged in the greenhouse with a spacing of 60 cm x 70 cm spacing and initially irrigated to reach 100% Field Capacity (FC), allowing the medium to settle over a period of three weeks. Prior to planting, Furadan 3 was applied to control potential pest infestations. Watermelon seeds were sown and nurtured to ensure successful germination before transplanting one healthy seedling into each polybag. Irrigation was managed using the gravimetric probe method, in which soil samples were taken from a depth of 20 cm, weighed, and oven-dried to calculate the soil's water content. Irrigation volumes were then adjusted based on the weight differences of the polybags to maintain the intended FC levels, with watering carried out either in the morning or evening according to the specific treatment schedule.

Observational parameters

Agronomic characteristics, including plant length and leaf area, were observed non-destructively once a week until the generative phase, which occurred at 28 days after transplantation (DAT). Plant length was measured from the tip of the main stem to the soil surface. Leaf area assessment began at two weeks after planting and was calculated using the correction factor method. In contrast, measurements of fruit sweetness (using a refractometer), fruit weight, and stomatal characteristics were conducted destructively at harvest. The mean values of each treatment were analyzed using one-way analysis of variance (ANOVA), followed by Duncan's multiple range test at a significance level of $p < 0.05$ to determine statistical differences among treatments.

Conclusion

This study demonstrates that water availability and the application of organic ameliorants play a critical role in mitigating the adverse effects of drought stress on the growth and productivity of watermelon plants. Plants maintained at 100% field capacity (FC), particularly those receiving BoM100 and BoMBi100 treatments, exhibited optimal performance, characterized by greater plant height, larger leaf area, and higher total dissolved solids (TDS), likely due to enhanced stomatal function and photosynthetic efficiency. In contrast, plants subjected to lower irrigation levels (25% and 50% FC) experienced reduced growth, diminished leaf area, and lower TDS content, attributable to stomatal closure that restricts gas exchange and nutrient uptake. The incorporation of bokashi, biochar, and manure as soil ameliorants contributed to improved soil moisture retention, thereby supporting plant growth even under water-limited conditions. These findings underscore the importance of optimal irrigation management combined with organic amendments to enhance vegetative growth, fruit quality, and yield—offering practical recommendations for improving crop performance in drought-prone agricultural systems.

Declaration of Competing Interest

The authors declare that they have no competing interests related to the content of this manuscript. There are no financial or personal relationships that could inappropriately influence the research presented in this study.

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Contribution of Authors

Conceptual idea: Amiroh, A.; Yunus, A.; Edi, P.; Eddy, T.; Methodology design: Amiroh, A.; Yunus, A.; Edi, P.; Data collection: Eddy, T; Amiroh, A.; Yunus, A.; Edi, P.; Data analysis and interpretation: Eddy, T.; Amiroh, A.; Yunus, A.; Edi, P.; and Writing and editing: Amiroh, A.; Yunus, A.; Edi, P.; Eddy, T.

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