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Effect of Terminal Drought and Biochar Plus N and P on Growth and Fruit Yield of Watermelon (*Citrullus vulgaris* Schard)

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Abstract The current study aimed at investigating the effect of terminal drought and biochar plus nitrogen and phosphorus (NP) on growth and yield of watermelon (*Citrullus vulgaris schard*). The research was delivered in a rice field at Laleia on the northeast coast of Timor-Leste during dry season from July to November 2019. The experiment used a split-plot design with two factors (terminal drought and biochar plus NP) repeated in three blocks. The terminal drought treatments were well-watered control (WW), water withheld from flower initiation to maturity (TD1) and water withheld from fruit set to maturity (TD2). The biochar plus NP treatments were 0 t/ha biochar plus 0 kg/ha N and 0 kg/ha P as control (B0), biochar 3 t/ha plus N 60 kg/ha and P 30 kg/ha (B1), and biochar 5 t/ha plus N 100 kg/ha and P 50 kg/ha (B2). The measured parameters included soil water content, plant growth and development, yield and yield components. The experiment revealed a terminal drought x biochar plus NP interaction for volume/fruit ($p = 0.009$) and fruit yield ($p < 0.001$). The highest fruit yield of 38.82 t/ha obtained from treatment combination of well-watered control and biochar 5 t/ha plus N 100 kg/ha and P 50 kg/ha (WW–B2) and the lowest fruit yield of 9.19 t/ha obtained from treatment combination of terminal drought started from flower initiation and treatment without biochar plus NP (TD1–B0). The application of biochar plus NP to plots exposed to terminal drought at flower initiation increased fruit yields by 52.65% (TD1–B1) and 57.94% (TD1–B2) relative to TD1–B0. This study revealed that the application of biochar in combination with NP fertilizers at a rate of 3 t/ha of biochar along with 60 kg/ha of N and 30 kg/ha of P, exhibited a promising enhancement in both growth and fruit yield of watermelon plants exposed to terminal drought stress during the reproductive stage.

Keywords Terminal Drought, Biochar Plus N and P, Growth, Fruit Yield and Yield Components

1. Introduction

In Timor-Leste, horticulture production occurs especially during the dry season from May to October. The main challenge in producing horticulture is limited water availability during the dry season. There is residual water available for growing crops after rice harvest [1]. This residual water might be sufficient for watermelon (*Citrullus vulgaris schard)* production. Watermelon has a high economic value with high demand in Timor-Leste. Despite this, production of watermelon in this country remains low (there was no national data available). Field research with an irrigation supplement conducted at the northeast coast of Vemase showed yield of watermelon between 12 t/ha and 28.4 t/ha [2]. Yield of watermelon varied between varieties ranging from 23.63 t/ha (Bali

Flower) to 22.01 t/ha (Fifa) [3]. These yields were still far below than other reported yields of melon (same family as watermelon) of 52.9 t/ha [4] and watermelon of 49.9 t/ha [5]. Yield of watermelon over 100 t/ha was also reported [6]. Yield variability between 10 and 118 t/ha was also reported for Namibian landraces of watermelon [7].

In Timor-Leste, terminal drought is one of the most yield limiting factors for crops grown after rice harvest [1]. Few studies have shown that watermelon production decreased by 38.2% and 61.4% in moderate and severe water deficits, respectively [8]. Another study on melon showed that irrigation deficits decreased yields ranging from 29% in a terminal drought during the reproductive stage to 84% in a non–irrigated treatment [3]. No study has done to investigate the impact of terminal drought on growth and yield of watermelon after rice harvest in Timor-Leste.

Some studies have shown that the application of biochar to soil amends soil physics and fertility [9]. Biochar improves soil water balance that enhances nutrient availability to plant. Application of biochar increased soil P availability by 45%, but decreased NO_3^-N and NH_4^+N by 12% and 11%, respectively [10], and these nutrients slowly released for plants to absorb and thus enhance nutrient use efficiency sustainably [11,12]. Biochar which has high adsorption capacity can capture toxic coming from the application of such as pesticides and thus limits its impact on crops [13]. Addition of inorganic fertilizer N and P together with the organic biochar would be beneficial to watermelon production in the northeast coast of Timor-Leste where the site has been regarded as a very low soil organic matter (1.5%) and soil P (Olsen P) (5.6 mg P/kg) [1]. The objectives of current research were to investigate i) the impact of terminal drought and biochar plus NP fertilizers on growth and yield of watermelon, and ii) the impact of biochar plus NP fertilizers in enhancing growth and fruit yield of watermelon exposed to terminal drought stress during reproductive stage.

2. Materials and Methods

2.1. Research Site and Design

The experiment was conducted in the village of Lifau, post Administrative of Laleia, Manatuto Municipality on the northeast coast of Timor-Leste (8°31'32.5"S 126°10'34.2"E). The experiment was undertaken in a paddy field after rice harvest from July to November 2019. The long–term average rainfall and soil information of the research site was previously reported [1]. The experiment used a split plot design with two factors repeated in three blocks. The first factor (main factor) was terminal drought (TD) with three levels of treatments; well-watered control (WW), water withheld from flower initiation to maturity (TD1), and water withheld from fruit set to maturity (TD2). The second factor (sub-factor) was rate of biochar plus NP (B) with three levels of treatments; biochar 0 t/ha plus N 0 kg/ha and P 0 kg/ha (control) (B0), biochar 3 t/ha plus N 60 kg/ha and P 30 kg/ha (B1), and biochar 5 t/ha plus N 100 kg/ha and P 50 kg/ha (B2).

2.2. Land Preparation and Seed Sowing

The site had been used for rice production by local farmers during the rainy season from January to May 2019. After rice harvest, the land was prepared using a hand tractor to form 2 m x 3 m plots arranged into three blocks. Seeds of watermelon were pregerminated in a mixture media of soil–animal manure in small containers made of banana leaves for two weeks before being transplanted to the research plots at a planting distance of 80 cm x 80 cm (12 plants in each plot).

2.3. Terminal Drought Treatment

Plants were well-watered from sowing to flower initiation when TD1 treatment initiated and to fruit set when TD2 treatment initiated to maturity, while the control plants continued with a well-watered (WW) until research was completed.

2.4. Investigated Parameters

2.4.1. Environmental Parameters

The environmental parameters measured were soil temperature, pH and the soil water content. The soil temperature was measured using a portable soil temperature probe (Henan Wanbang EP Tech Co., LTD, Henan, China). The equipment inserted into the soil at about 10 cm deep and left for about five minutes before recording the temperature. The soil temperature was measured at three different locations within each plot, and readings were taken three times daily (morning, midday and afternoon) on 46^{th} days after sowing (DAS) and maximum growth of watermelon at 70^{th} DAS. Similar measurement method was used to determine soil pH using a portable pH tester. Similarly, soil water content was observed at the same time as of the soil temperature and pH. Soil samples from each plot were collected using a ¾-inch PVC pipe at a depth of 10 cm. These samples were transported to the laboratory to determine their fresh weight (FW). After being dried in an oven (Model YCO-010, Gemmy Industrial Corp., Taiwan) at 105^0 C for 48 hours, the samples were re–weighed (DW). The gravimetric soil water content (Θ_m) was determined using the following formula:

$$\Theta_m = ((FW-DW)/DW)*100\%$$

Where: Θ_m = gravimetric soil water content (%), FW = fresh soil weight (g), DW = dried soil weight (g).

2.4.2. Growth Parameters

Plant length, basal diameter and leaf and branch numbers have been done at 14, 28 and 42 DAS to investigate treatments impact. The measurements were done from three pre-randomly selected samples in each plot. Plant length was determined using a role meter from the soil level to the top of the longest part of the plant. The plant basal diameter was determined approximately 5 cm above soil level using a caliper. Number of branches were determined by counting number of existed branches on each plant sample. Similarly, number of leaves were also determined by counting all existed plant leaves on each plant sample. At harvest, plant biomass excluding fruits were dried at 80ºC for 48 hours and weighed for dry biomass.

2.4.3. Yield and Yield Components

Yield and yield components included flower production and abortion per plant, fruit per plant, fruit weight per plant, fruit volume and fruit yield. Number of flowers were manually counted daily from plant samples until the plant stopped flowering. The difference between total flower and fruit produced indicated aborted flower. Number of fruits per plant were quantified from plant samples at harvest followed by weighing them to determine fruit weight per plant. The total weight of fruits per plot was then converted to fruit yield (t/ha).

2.5. Data Analysis

Analysis of variation ANOVA was performed using statistical package of GenStat version 18 to compare treatments.

3. Results

3.1. Environmental Factors

Results of the environmental measurements showed no terminal drought x biochar plus NP interaction ($p > 0.05$) (Tables 1, 2). At 46 days after sowing (DAS), terminal drought increased soil temperature by 9.38% (TD2) and 10.14% (TD1) relative to the WW control (27.91ºC) ($p = 0.007$) (Table 1). At 70 DAS, terminal drought increased soil temperature by 3.28% (TD2) and 5.55% (TD1) relative to the WW control (27.73ºC) ($p < 0.001$). At 46 DAS, the application of biochar plus NP decreased soil temperature by 7.65% (B1) and 7.36% (B2) relative to the BO control (31.50ºC) ($p = 0.004$). At 70 DAS, biochar plus NP decreased soil temperature by 1.96% (B1) and 2.79% (B2) relative to the BO control (29.05ºC) ($p = 0.002$).

At 46 DAS, terminal drought decreased soil pH by 6.98% (TD2) and 6.89% (TD1) relative to the WW control (6.93) ($p = 0.013$) (Table 1). At 70 DAS, terminal drought increased soil pH by 4.41% (TD2) and 6.60% (TD1) relative to the WW control (7.00) ($p = 0.005$). At 46 DAS, application of biochar plus NP decreased soil pH by 12.40% (B2) and 9.50% (B1) relative to the BO control (7.13) ($p = 0.002$). At 70 DAS, application of biochar plus NP decreased soil pH by 9.18 % (B1) and 9.18 % (B2) relative to the BO control (7.19) ($p < 0.001$).

At 46 DAS, terminal drought decreased soil water content by 27.24% (TD1) and 20.27% (TD2) relative to the WW control (38.33%) ($p < 0.001$) (Table 2). The soil water content of TD1 and TD2 continued to decline until the last measurement at 70 DAS, when they were 36.75% (TD1) and 29.07% (TD2) less than WW control (34.78%) ($p < 0.001$). At 46 DAS, application of biochar plus NP increased soil water content by 14.80% (B1) and 15.90% (B2) relative to the BO control (34.22%) ($p < 0.001$) (Table 2). The soil water content of B1 and B2 maintained higher at the last measurement 70 DAS, when they were 4.45% (B1) and 5.62% (B2) more than BO control (26.22%) ($p < 0.001$).

Table 1. Effect of terminal drought and biochar plus NP on soil temperature (ºC) and soil pH observed at 46 and 70 days after sowing (DAS)

Treatments	Soil temperature (ºC)		Soil pH	
	46 DAS	70 DAS	46 DAS	70 DAS
Terminal drought				
well-watered control (WW)	27.91a	27.73a	6.93b	6.500a
Water withheld from flower initiation to maturity (TD1)	31.06b	29.36c	6.45a	6.959b
Water withheld from fruit set to maturity (TD2)	30.80b	28.67b	6.44a	6.800b
LSD (5 %)	1.445	0.2454	0.2779	0.1798
Biochar plus NP				
0 biochar plus 0 NP (B0)	31.50b	29.05b	7.13b	7.19b
Biochar 3 t/ha + N 60 kg/ha and P 30 kg/ha (B1)	29.09a	28.48a	6.45a	6.53a
Biochar 5 t/ha + N 100 kg/ha and P 50 kg/ha (B2)	29.18a	28.24a	6.24a	6.53a
LSD (5 %)	1.394	0.3945	0.4412	0.1587

3.2. Growth, Yield and Yield Components

There was no terminal drought x biochar plus NP interaction for plant length (p > 0.05) observed at 42 DAS (Table 3). Terminal drought decreased plant length by 34.6% (TD1) and 32.00% (TD2) relative to the WW control (229.4 cm/plant) (p = 0.037). Application of biochar plus NP increased plant length by 43.53% (B1) and 43.61% (B2) relative to the B0 control (117.9 cm) (p < 0.001). Terminal drought decreased plant node number by 33.33% (TD1) and 28.32% (TD2) relative to the WW control (73.33 nodes/plant) (p = 0.016). Plant node number of B1 and B2 increased by 35.23% (B1) and 38.60% (B2) relative to the B0 control (41.89 nodes/plant) (p < 0.001). Terminal drought did not significantly affect the basal diameter, but application of biochar plus NP increased basal diameter by 16.97% (B1) and 19.31% (B2) relative to the BO control (6.50 mm) (p = 0.005). Plant branch numbers were decreased by 28.31% (TD1) and 25.66% (TD2) relative to the WW control (4.19 branches/plant) (p = 0.013). Application of biochar plus NP increased branch number by 43.53% (B1) and 44.04% (B2) relative to the B0 control (2.26 branches/plant) (p < 0.001).

There was no terminal drought x biochar plus NP interaction for flower number and aborted flower per plant (p > 0.05) (Table 3). Terminal drought decreased flower number by 15.07% (TD1) and 9.59% (TD2) relative to the WW control (8.11 flowers/plant) (p = 0.042), but it increased aborted flower by 8.32% (TD1) and 8.93% (TD2) relative to the WW control (39.76 flowers) (p = 0.008). Flower number per plant increased by 31.95% (B1) and 38.76% (B2) relative to the BO control (5.44 flowers) (p < 0.001). Application of biochar plus NP did not affect the aborted flower per plant (p > 0.05).

There was no terminal drought x biochar plus NP interaction for dry matter production (p > 0.05) and there was no terminal drought impact on the dry matter production (p > 0.01). Application of biochar plus NP increased dry matter production by 22.99% (B1) and 25.19% (B2) relative to the BO control (0.5540 t/ha) (p < 0.001).

There was no terminal drought x biochar plus NP interaction for fruit number per plant (p > 0.05) (Table 3). Terminal drought decreased fruit number per plant by 31.51% (TD1) and 29.89% (TD2) relative to the WW control (2.04 fruits) (p = 0.010). Application of biochar plus NP did not affect the fruit number per plant (p > 0.01).

Table 2. Effect of terminal drought and biochar plus NP on soil water content (%) observed at 46 DAS and 70 DAS

Treatments	Soil water content (%)	
	46 DAS	70 DAS
Terminal drought		
well-watered control (WW)	38.33c	34.78c
Water withheld from flower initiation to maturity (TD1)	27.89a	22.00a
Water withheld from fruit set to maturity (TD2)	30.56b	24.67b
LSD (5 %)	0.9081	1.652
Biochar plus NP		
0 biochar plus 0 NP (B0)	28.78	26.22a
Biochar 3 t/ha + N 60 kg/ha and P 30 kg/ha (B1)	33.78a	27.44b
Biochar 5 t/ha + N 100 kg/ha and P 50 kg/ha (B2)	34.22b	27.78b
LSD (5 %)	0.5040b	0.576

There was a terminal drought x biochar plus NP interaction for volume per fruit (p = 0.009) (Table 3, Figure 1A). The treatment combination WW–B2 yielded the highest volume per fruit at 1.98 L, followed by WW–B1 at 1.67 L, and TD2–B2 at 1.21 L. The volume obtained from the latter did not significantly differ from that of TD1–B2, which measured 1.02 L. The lowest volume per fruit obtained from the treatment combination TD1–B0 (0.22 L) and this was comparable to the treatment combinations TD2–BO (0.31 L) and WW–BO (0.41 L).

There was a terminal drought x biochar plus NP interaction for fruit weight per plant (p < 0.001) (Table 3). The treatment combination WW–B2 produced the highest fruit weight per plant at 2.57 kg, followed by WW–B1 at 2.57 kg and TD2–B2 at 1.50 kg. The latter did not significantly differ from that of TD2–B1, which measured 1.30 kg. The lowest fruit weight per plant obtained from the treatment combination TD1–BO (0.33 kg).

There was a terminal drought x biochar plus NP interaction for fruit yield (p < 0.001) (Table 3, Figure 1B). Treatment combination WW–B2 had the highest fruit yield (38.82 t/ha) followed by WW–B1 (33.11 t/ha) and TD2–B2 (23.74 t/ha). The latter did not significantly differ from the treatment combinations TD2–B1 (22.93 t/ha) and TD1–B2 (21.85 t/ha). The lowest fruit yield obtained from the treatment combination TD1–BO (9.19 t/ha) and this was comparable to the treatment combination TD2–B0 (9.81 t/ha).

Table 3. Significance of sources of variation for water treatment, biochar plus NP and their interactions. There were three water treatments and three biochar plus NP treatments. n.s. not significant, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$. Least significant differences of means (LSD) values at $p = 0.05$ are in parenthesis

Sources of variation	Water treatment	Biochar plus NP	Interaction
Plant length (cm)	* (60.16)	*** (35.95)	n.s.
Node number (/plant)	* (13.99)	*** (8.67)	n.s.
Basal diameter (mm)	n.s.	** (0.891)	n.s.
Branch number (/ plant)	** (0.65)	*** (0.40)	n.s.
Flower number (/plant)	* (0.87)	*** (1.06)	n.s.
Aborted flower (%)	** (1.89)	n.s.	n.s.
DM (t/ha)	n.s.	*** (0.05)	n.s.
Fruit number (/plant)	** (0.33)	n.s.	n.s.
Fruit volume (/fruit)	** (0.28)	*** (0.17)	** (0.32)
Fruit weight (kg/plant)	*** (0.24)	*** (0.12)	*** (0.26)
Fruit yield (t/ha)	*** (1.83)	*** (1.27)	*** (2.26)

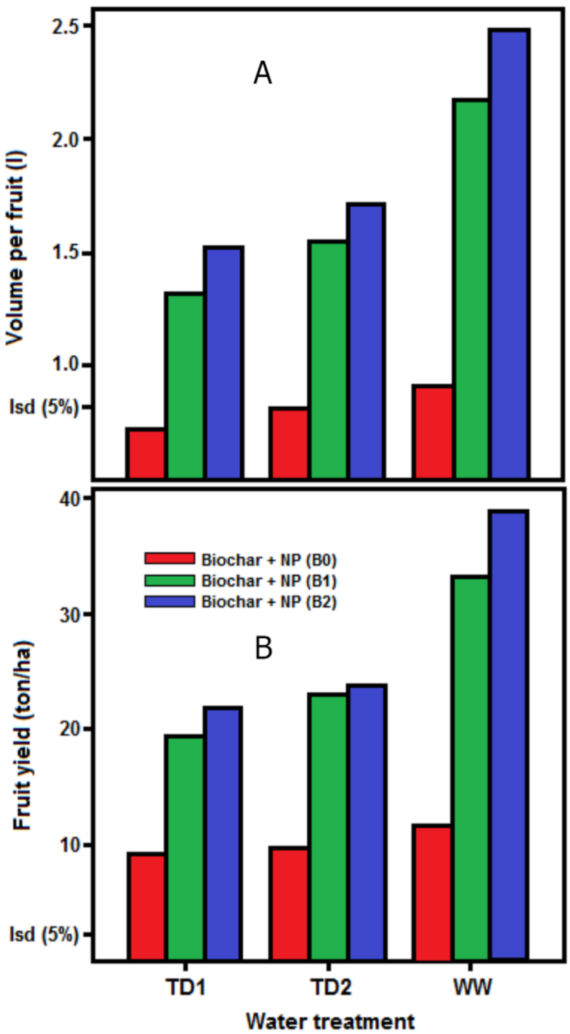

Figure 1. Terminal drought x biochar plus NP interaction for (A) volume per fruit (L) ($p = 0.009$) and (B) fruit yield (t/ha) ($p < 0.001$). WW, TD1, and TD2 refer to well-watered control, water withheld from flower initiation and fruit set to maturity, respectively. B0, B1, B2 refer to biochar 0 t/ha plus 0 kg/ha N 0 kg/ha and P (control), biochar 3 t/ha plus N 60 kg/ha and P 30 kg/ha, and biochar 5 t/ha plus N 100 kg/ha and P 50 kg/ha, respectively

4. Discussion

4.1. Effect of Terminal Drought on Growth Environment

Drought stress at any stage of crop development affects crops' yields [14]. In grain legumes, terminal drought occurred during the reproductive stage decreased yield most [1,15]. Current study showed that application of terminal drought significantly decreased soil water content (Table 2), but increased soil temperature (Table 1). These results were consistent with other studies that decreased in soil water content led to increase soil temperature as observed in grain legumes such as soybean [16] and soybean, mung bean and grass pea [1] and other various grain legumes [17]. Drought and heat stress are two major yield limiting factors that affect plants' growth and reproduction [18]. The current study observed a decrease in soil pH in response to the reduction of soil water content (Tables 1, 2) consistent with another study reported by Siebielec et al. [19]. Nonetheless, the pH range was still neutral [20], allowing crops to absorb nutrients as possible.

4.2. Effect of Biochar Plus NP on Growth Environment

Biochar has been identified as a source of soil amendment that improves soil physics and fertility and thus improves soil water holding capacity that enhances nutrient availability to plant [9]. This is consistent with the current study that the application of biochar plus NP improved soil water content (Table 2) and reduced soil temperature (Table 1). Improved soil water availability in a droughted condition during the reproductive stage is essential to enhance nutrients availability to plants. A study showed that the application of biochar increased soil P availability and N use efficiency [10,12] as observed in the current study.

4.3. Effect of Terminal Drought on Growth, Yield and Yield Components

Various studies have shown that reduction in soil water content brings a negative impact on growth and yield of watermelon [4,8,21]. Current study showed that the application of terminal drought decreased growth components of watermelon plant including plant height, number of leaves and branches, and plant basal diameter (Table 3). Drought was more severe in plants exposed to terminal drought at flower initiation than at fruit set (Table 2). Severe drought leads to decrease photosynthesis as reported for wildtype watermelon where severe drought decreased CO_2 assimilation up to 80.91% [21] and this could lead to a severe decrease in growth and development [22].

Reduction in growth components due to terminal drought resulted in low fruit production. Current study showed that production of fruits per plant decreased by 39.69% and 32.48% for the terminal drought applied at flower initiation and fruit set, respectively, compared to the controls (Table 3, Figure 1A, B). The yield reduction in the current study was less than the study on a non–irrigated treatment which decreased fruit yield up to 84% [3]. Variation in fruit yields depends on genotypes adaptation to drought. Drought tolerance genotypes produced better fruit yield with less water than drought sensitive genotypes [23]. The drought tolerance genotypes/varieties might be associated with the accumulation of proline, abscisic acid (ABA), total phenol and citrulline that contribute to drought tolerance [22].

4.4. Effect of Biochar Plus NP on Growth, Yield and Yield Components

Application of biochar and plant nitrogen and phosphorus are essential in a non-fertile soil for crop production. This is particularly important in the northeast coast of Timor-Leste where the soil was identified as heavy clay with low soil fertility particularly N and P availability [1]. Several studies have reported that the application of biochar to soil amends soil physics and fertility [9]. Biochar improves soil water balance that enhances nutrients N and P availability to plants to absorb [10–12]. Biochar application to soil decreased soil bulk density, but increased soil pH (in acid soil), exchangeable K, Ca and Mg and soil porosity [24]. A study reported that under deficit irrigation application of humic substances significantly increased the soil organic carbon content and watermelon fruit yield and water use efficiency [25]. The current study showed evidence of improving soil water availability under terminal drought (Table 2) and possibly nutrients availability to watermelon that improved plant growth and fruit yield (Table 3). Application of biochar plus NP significantly increased fruit production per plant by 28.62% and 31.90% for B1 and B2 treatments, respectively, compared to the B0 controls. These results were consistent with other studies on watermelon [24] and soybean [26]. The application of rice–husk biochar improved watermelon fruit yield by 8.14% [24]. In soybean, application of rice-husk biochar at rates of 3 t/ha and 6 t/ha increased seed yield by 10.47% and 15.85%, respectively, compared to the controls [26].

4.5. Terminal Drought and Biochar Plus NP Interaction for Yield and Yield Components

Study results showed terminal drought x biochar plus NP interaction for watermelon volume per fruit and fruit yield (Figure 1A, B). The highest watermelon volume per fruit was produced from the treatment combination of well-watered control and biochar plus NP (WW–B2) (Table 3, Figure 1A). Terminal drought decreased volume per fruit by 48.04% (TD1) and 36.69% (TD2), compared to the well-watered control, however these reductions were improved with the presence of the rice-husk biochar. When treatments TD1 and TD2 were added with biochar plus NP at the rate of biochar 3 t/ha plus N 60 kg/ha and P 30 kg/ha (B1), the watermelon volume per fruit increased by 72.97% (TD1–B1) and 78.73% (TD2–B1), compared to the TD1–B0 and TD2–B0, respectively. Increased rate of biochar plus NP to 5 t/ha plus N 100 kg/ha and P 50 kg/ha (B2) did not make a further improvement compared to B1. The presence of biochar plus NP conserve soil water for plant to absorb with nutrients N and P [12] and thus increases fruit volume.

Similarly, the application of terminal drought significantly decreased fruit yield by 39.69% (TD1) and 32.48% (TD2). These yield reductions were improved through the addition of biochar plus NP. Application of biochar plus NP at the rate of biochar 3 t/ha plus N 60 kg/ha and P 30 kg/ha (B1) increased fruit yield by 52.65% (TD1–B1) and 59.92% (TD2–B1) compared to TD1–BO and TD2–B1, respectively (Figure 1B). These results were consistent with another study where the combination of biochar plus compost increased watermelon yield compared to biochar or compost alone through enhancing K and P availability to plant [27]. Further, application of biochar increases N and P use efficiency and more sustainable by plant [12] as observed in cucumber [28]. Moreover, other studies with various biochar resources and plants confirmed that application of biochar increased N content in plant leaves and thus enhanced plant growth [29] and increased chlorophyll content [30] and photosynthesis as observed in rice crop [31] which contributed to plant biomass production and fruit yield.

5. Conclusions

In summary, the findings of this study indicate that terminal drought had a notable impact on the growth and fruit yield of watermelon (*Citrullus vulgaris* Schard). It was observed that terminal drought, initiated from flower initiation, had a more significant adverse effect on growth and fruit yield compared to its onset at the fruit set stage. Moreover, the application of biochar in combination with NP fertilizers, specifically at a rate of 3 t/ha of biochar along with 60 kg/ha of N and 30 kg/ha of P, exhibited a promising enhancement in both growth and fruit yield of watermelon plants exposed to terminal drought stress during the reproductive stage.

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