Hindawi
International Journal of Agronomy
Volume 2023, Article ID 2626225, 15 pages
https://doi.org/10.1155/2023/2626225

Research Article

Effect of Moisture Stress on Physiological and Yield Responses of Common Bean Varieties at Lath House Condition, Hawassa University, Southern Ethiopia

Mitike Mulatu Alemu,[1] Andargachew Gedebo,[1] Amsalu Gobena Roro ,[1] and Tatek Tamiru Geletu [2]

[1]*Plant and Horticultural Science, Hawassa University College of Agriculture, P.O. Box 05, Hawassa, Ethiopia*
[2]*Plant Science, Wolkite University, P.O. Box 07, Welkite, Ethiopia*

Correspondence should be addressed to Tatek Tamiru Geletu; tatektamiru2010@gmail.com

Received 1 September 2022; Revised 2 November 2022; Accepted 28 November 2022; Published 14 January 2023

Academic Editor: Mehdi Rahimi

Common bean is one of the most traditional foods, with social and economic importance, and is suitable for food security due to its short growing cycle and adaptability to different cropping systems. However, various constraints like biotic and abiotic factors reported for the low productivity of the crop. Therefore, the study was designed to identify the common bean varieties' response on physiological properties and yield performance under different irrigation intervals in Lath House condition at Hawassa University, Ethiopia, from June, 2020, to September, 2020. The experiment was laid out in a completely randomized design with a factorial combination of seven common bean varieties (Awash-1, Awash-2, Dursitu, Fedis, Gofta, Nasir, and Tinike) and three moisture levels, eight day irrigation interval, four day irrigation interval, and daily watering with three replication. There was a significant main and interaction effects among the measured parameters. From those significantly affected parameters, the highest stomata numbers (25) were recorded from the Dursitu variety with a daily irrigation interval. The longest stomata aperture was observed with Gofta (133.76 nm) and Fedis varieties (131.13 nm) to daily irrigation and four day irrigation intervals, respectively. A wider stomata aperture was found in the Awash-1(12.6 nm) variety on a daily irrigation interval, and maximum stomata conductance (193.67) was obtained in the Tinike variety treated with a four day irrigation interval. The maximum relative leaf moisture content (96%) was found on the Awash-1 variety at a four day irrigation interval. Maximum water use efficiency was obtained from the Awash-1 (3.95) variety, which is an insignificant variation with the Awash-2 (3.85) and Gofta varieties (3.85) at a four day irrigation interval. Among the varieties, the highest photosynthesis rate (10.43 μmol·m^{-2}·s^{-1}) and transpiration rate (5.42 mmol·m^{-2}·s^{-1}) were obtained in the Gofta variety treated by a four day irrigation interval. In the photosynthetic pigment analysis, the highest leaf chl-a, chl-b, and chl-a + b concentration was recorded at 2.4 μg/ml, 1.53 g/ml, and 3.93 μg/ml, respectively, in the Gofta variety irrigated at a four days interval. The highest (0.586) chlorophyll fluorescence was obtained in the eight day irrigation interval. The highest proline content was found from the Awash-1 (0.78) variety regarding to drought stress condition. The highest pods plant^{-1} (9) and seed pod^{-1} (5) was found in the Awash-2 and Awash-1 varieties, respectively, at a four days irrigation interval and the highest main effect of 100 SW (39.48 g), (28.6 g) was found in the Fedis variety and at a four day irrigating interval, respectively. The maximum yield was obtained from the varieties Awash-1 (7.8 g plant^{-1}) and Gofta (7.36 g plant^{-1}) with a four day irrigated interval and they are also superior at drought condition and Awash-2 varieties are enhanced at waterlogging condition as compared to the other varieties.

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is a prominent legume crop farmed around the world and is a member of the *Fabaceae* family [1]. The crop is one of the most traditional foods, with significant social and economic importance; it is also the most important crop legume for human consumption, accounting for half of all grain legumes consumed globally [2]. In Ethiopia, smallholder farmers predominantly raise common bean as a food crop and a source of income. It is one of the fastest-growing legume crops in the world, providing a vital portion of the country"s daily food as well as foreign revenues [3]. Thus, beans play an essential role in the sustainable livelihoods of smallholder farmers by providing both food security and income generation and have a high potential for reducing malnutrition in poor families [4].

Through the growing season, the common bean needs a lot of water to develop and generate seeds in accordance with its genetic potential [5]. Moisture stress affects crop growth and yield by lowering chlorophyll pigments, photosynthetic rate, stomatal conductance, and transpiration rates [6]. Crops cultivated in a dry environment have improved stomata conductance, in order to conserve moisture. Drought stress reduced grain yield of common bean cultivars by 50% [7].

Moisture stress, on the other hand, is caused not only by a lack of water but also by excess of water due to root uptake inaccessibility. In waterlogged soils, gas exchange between root systems and soil pore spaces is limited due to oxygen diffusion resistance that is around 10,000 times higher in water than in the air [8]. Since oxygen diffuses through uninterrupted water much more slowly than through a well-drained soil, when soils are saturated, oxygen requirements rapidly exceed available concentrations [9]. As a result, under a water logged condition, plant roots suffer from hypoxia (deficiency of O_2) or anoxia (absence of O_2), which affect nutrient uptake and crop productivity [8]. Waterlogging causes crop damage such as necrosis, stunting, defoliation reduced N fixation, and plant death. While the degree varies from genotype to genotype, the previous report indicated that common bean productivity significantly reduced due to waterlogging [10]. Systems to facilitate the identification of drought tolerant genotypes have become important in modern agriculture [10]. However, the mechanism of how common bean varieties are adapting to different irrigation interval is not well addressed. As a consequence, the rationale of this research is to study the effect of moisture stress on different physiological, yield, and yield components of common bean varieties to moisture stress and to identify tolerant varieties; therefore, the experiment has the following objectives:

(i) To evaluate the effect of different water levels on yield and yield components of common bean varieties in Lath House condition

(ii) To study the physiological response, stomatal conductance, stomatal aperture and conductance, photosynthesis rate, chlorophyll content, proline content, RLWC, WUE, and chlorophyll fluorescence of common bean varieties to different water levels

(iii) To select a common bean variety that tolerates drought and water logging stress.

2. Materials and Methods

2.1. Description of the Experimental Site. A study was carried out at Hawassa University College of Agriculture in the Lath House condition from March, 2020, to June, 2021. The area was located at a longitude of 7°3′N and latitude of 38°28′E with an altitude of 1708 m.a.s.l and 273 km far from Addis Ababa. The city receives 1076 mm of precipitation per year and the annual average temperature is 26°C.

2.2. Experimental Design and Treatments. The experiment was designed to be completely randomized, with three replications. The primary treatment included three levels of moisture; waterlogging stress (daily watering interval); optimum watering (four days watering interval); and drought stress (eight days watering interval) and seven common bean varieties (Gofta, Fedis, Awash-2, Tinike, Awash-1, Dursitu, and Nasir) combined to form twenty-one treatment combination. Nine pots per experimental unit were considered as one plot and each pot contains one plant, so 567 total pots were used for the experiment.

2.3. Experimental Management and Procedures. Top soil was collected from Hawasa University College of agriculture, up to 30 cm soil depth and 1.701 ton soil composite was prepared. Then, the composite soil was air-dried for 21 days to have a constant weight. Then, a total of 567 experimental pots having 5 liters volume with a perforated bottom were filled up to 4.5 L water and 3 kg soil. Then, after watering all pots with an equal amount of water, two seeds of each variety were directly sowed in experimental pots, and the seedlings were reduced to one seedling per container two weeks later. Irrigation interval therapy was applied 21 days after seeding. The amount of water applied for each treatment was measured in cups per liters, and the soil moisture content at field capacity was assessed using a moisture censer Delta-T-Device, Model HH2.

2.4. Physicochemical Properties of the Experimental Soil. The physicochemical properties of experimental soil sampling and the preparation of 1 kg composite soil for laboratory analysis were used. Soils were air-dried to a constant weight, ground and mixed thoroughly, and then passed through a 2 mm sieve. The soil analysis was performed at Hawassa University College of Agriculture"s soil laboratory. The soils were tested in the laboratory for particle size, total N, available P, organic carbon, pH, and CEC. Each parameter was subjected to standard procedures. The ammonium distillation method was used to determine cation exchange capacity [11]. Meanwhile, pH was determined using the potentiometric water extraction method [12]. The [13] method was used to determine available P, and the [14] method was used to determine total N. The soil"s textural class and organic carbon content were determined using a hydrometer and the [11] wet combustion method, respectively.

2.5. Physiological Parameters

2.5.1. Stomatal Aperture. Stomata number and aperture (width and length) measurement was made using the protocol proposed by the authors of [15] starting at the pod setting stage. On the lower surface of fresh intact leaves, a thin layer of transparent nail polish was uniformly stained and allowed to stand for 10 minutes until the nail polish dried to capture the epidermal imprint of the leaves; thereafter, a thin layer covering a surface on the leaves was peeled off using a transparent tape and attached on the microscope slide. Automated Upright Leica Microscope DM5000 B with a 40x magnification lens fixed with a digital Leica DFC425/DFC425C image processing camera was used to count the stomata number and to measure the aperture.

2.5.2. Gas Exchange Parameters. The photosynthetic rates were measured using a Li-6400 portable photosynthesis equipment (LICOR Inc., Lincoln, NE, USA). During the vegetative growth stage, photosynthesis (a), stomata conductance (gs), and transpiration rate (E) were measured on fully grown leaves (40 days after sowing). The measurements were made between the hours of 10:00 a.m. and 12:00 p.m., with the following parameters in mind: The ratio of net CO_2 assimilation rate (A) to transpiration rate (E) was used to calculate water use efficiency [16].

2.5.3. Determination of Leaf Chlorophyll Concentration. At the mid-pod fill stage, leaf chlorophyll concentration was measured on completely developed juvenile leaves of three plants in each plot. Sampling was done at 8:00 AM and leaves were placed in a bag sealed with aluminum foil and transported to the plant cell laboratory immediately. 0.5 g of fresh leaf discs were placed in 15-mL tubes containing 95% (v/v) ethanol and homogenized with ethanol using a pestle and mortar. The homogenized sample mixture was centrifuged in the dark for 15 minutes at room temperature at 10,000 rpm. The supernatant was separated and 0.5 ml of each concentration level was analyzed in triplicate for chlorophyll-a and chlorophyll-b at an absorbance of 664 nm and 648 nm wavelength region, respectively, in spectrophotometer UV-2450 (Hitachi, Tokyo, Japan). The following equations were used for the quantification of chlorophyll-a and chlorophyll-b [17].

$$\text{Ch a}\left(\frac{\mu g}{ml}\right) = 13.36\ A_{664} - 5.19\ A_{648},$$
$$\text{Ch b}\left(\frac{\mu g}{ml}\right) = 27.43\ A_{648} - 8.12\ A_{664}, \qquad (1)$$
$$\text{Total chl}\left(\frac{\mu g}{ml}\right) = \text{chl a} + \text{chl b},$$

where A = absorbance, Ch a = chlorophyll a, and Ch b = chlorophyll b.

2.5.4. Determination of Leaf Chlorophyll Fluorescence. The efficiency of photosystem II (Fv/Fm) was measured from well-developed leaves at the third node from randomly selected vegetative parts at the age of thirty days following which sowing was used to evaluate the plants' performance. The measurements were taken between 4:00 a.m. and 6:00 p.m. using a Handy-PEA fluorimeter (Hansatech, Kings Lynn, UK) and the methodology outlined in reference [18]. The leaves in the leaf clip were dark-adapted for 30 minutes before measurement. Light was subsequently provided by an array of three high-intensitylight-emitting diodes, which was set to 1500 mol·m^{-2}·s^{-1} to guarantee that photosynthesis was saturated during the measurements.

2.5.5. Determination of Proline Concentration. At the pod filling stage, leaf samples were obtained from each unit to assess proline content using the method of reference [19]. First, 50 mg fresh leaf samples were placed in 1 ml of ethanol and allowed to overnight at 4°C; the samples were centrifuged at 14000 g for 5 minutes in the next day. 100 μl of reaction mix ((1% ninhydrin (w/v) + 60% Glacial acetic acid (v/v) + 20% ethanol (v/v)) was pipetted to each and the sample was heated at 95°C for 20 minutes. After cooling at room temperature, the supernatant was centrifuged down quickly (1 min. 2500 rpm). Then, 100 μl of the supernatant was transferred to a microplate reader and quantified at 520 nm using Multisken FC. Using a calibration curve, the concentration of proline was determined and expressed as (μg/g) leaf fresh weight.

2.5.6. Leaf Temperature. Using an infrared thermometer, daily leaf temperatures were measured three times a day (morning, midday, and evening) on ten randomly selected days from June to September, 2020.

2.5.7. Relative Leaf Water Content (RLWC). Three fully expanded leaves were collected from representative plants and 5 leaf disks (9 mm in diameter) were collected from each leaf and immediately weighted (leaf fresh weight). The samples were then hydrated to full turgidity in a closed 15-ml tube with double distilled water for 24 hours at room temperature (25°C). Afterward, the water droplet left on the surface of the leaf disc was carefully removed with tissue paper and reweighted to obtain fully turgid mass (leaf turgid weight). To attain a consistent dry mass, samples were oven-dried for 24 hours at 75°C (leaf dry weight). Finally, we calculated the relative leaf water content as follows [20]:

$$\text{RLWC} = \left[\frac{(\text{leaf fresh weight} - \text{leaf dry weight})}{(\text{leaf turgid weight} - \text{leaf dry weight})}\right] \times 100. \qquad (2)$$

2.6. Data Collection on Yield and Yield Components. Yield and yield component parameters were collected from physiologically matured plants when 90% of the pods had lost their green color and turned yellow [21]. Counting pods from five randomly selected plants per plot and noting the average value gave us the average number of pods per plant. To obtain the average number of seeds per pod, we divide the number of seeds per plant by the number of pods per plant. The 100 seed weight was determined by carefully counting the grains and weighing them using a sensitive balance after adjusting 12% seed moisture content. The average grain yield in gram was measured from five randomly taken plants after harvesting the crop in each plot by a digital electronic balance, after seed moisture was corrected to 14 percent, with a precision scale of +0.00001 g [22].

2.7. Metrological Data. The Lath House used for the experiment was enclosed with a metal wire to protect the entrance of any undesirable body. The transparent grooved tin covered the roof of the Lath House. The meteorological measurements recorded during the experiment are as follows: air temperature, leaf temperature, and relative humidity.

2.7.1. Air Temperature and Relative Humidity. On 30 randomly selected days, temperature and relative humidity data were obtained using tiny data recorders (Testo 174, Version 5.0.2564.18771, and Lenzkirch, Germany). To minimize direct sunlight and moisture, the data logger was hung closer to the plant canopy (30 cm above the ground) and covered from the top with a flat carton. The data were collected for a period of 15 days.

2.8. Statistical Analysis. All collected data were statistically evaluated using analysis of variance (ANOVA) in SAS software version 9.3 [23]. The mean separation was calculated using the LSD test at (P0.05).

3. Result and Discussion

3.1. Physicochemical Characteristics of the Experimental Soil. The experimental field"s soil textural class was sandy loam, with average proportions of 14% clay, 32% silt, and 54% sand (Table 1). The pH of the experimental soil was 7.74, which is within the optimal range for crop production [12]. According to reference [12], a soil"s total nitrogen content (TN) classification, the total nitrogen content of the soils was (0.26) found to be high [14, 13], established an indicative range of available phosphorus content was 13 ppm, which was found to be low. According to reference [11], 3–5 percent organic matter (OM) is considered as high; therefore, the soil organic carbon (OC) was (4.67) which ranges between 3 and5 percent, indicating a high organic carbon content. The high organic matter content was related to environmental conditions, specifically vegetation, climate, and cultivation history [11]. Cation exchange capacity (CEC) was found to be 35.73, which is classified under high CEC (25–40 cmol·kg^{-1}).

3.2. Air Temperature and Relative Humidity. From the result, it was observed that the daily average temperature was recorded 31.8°C during the middle of the day (12:00 am–1:00 pm) (Table 2). About relative humidity, Lath House daily maximum relative humidity (66.62%) was recorded at 6:18 am which coincided with Lath House minimum temperature (30.13°C), and the minimum vapor pressure difference was (2.14). Likewise, Lath House daily minimum relative humidity (50.22%) was recorded at 12:18 pm, which coincided with maximum daily temperature (33.5%) and maximum daily vapor pressure deficit (3.56).

3.3. Physiological Response

3.3.1. Leaf Relative Water Content. The effects of variety and irrigation interval on leaf relative water content were significant (P0.05) and there was a significant interaction effect of varieties and irrigation interval ($P > 0.05$). The Awash-1 variety obtained the maximum relative leaf moisture content (96%) at four days irrigation interval, which is an insignificant difference compared with Gofta, Awash-2, Tinke, and Awash-1 varieties under drought condition (eight day interval), while Nasir variety obtained the lowest (10%) leaf relative water content at waterlogging condition (Table 3). According to reference [24], the improved performance of common bean cultivars with water deficit tolerance is also due to well water use efficiency. This finding adds to the evidence that the maintenance of RWC above 50% was most likely due to stomata closure and leaf senescence, which could have reduced transpiration rates and thus protected the photosynthetic apparatus [25]. Previous research has found that when plants are waterlogged, their leaf water content decreases significantly. The authors of references [26, 27] reported that water content decreased primarily because root uptake capacity was limited due to a lack of oxygen caused by water logging. Reducing water loss through stomatal closure, rolling or abscission of the leaf, and increased plant water up-take through enhanced root development are mechanisms playing a role in maintaining the leaf water status [28]. Similarly, plants which maintain the water status (high water potential) have been found to be productive under stress condition with low reproductive abortion [29].

3.3.2. Leaf Temperature. There was no significant difference in average temperature between the varieties in the morning and midday, but there was a slight difference in leaf temperature among the varieties in the evening (Table 4). The maximum leaf temperature (20.88°C) was recorded during the evening time on the Nasir variety, while the minimum value (20.00°C) was obtained on the Awash-2 variety (Table 4). This might be due to the difference of varieties (genetic makeup) of leaf on their morphology and anatomy to respond temperature. As a result, irrigation interval varied

Table 1: Physicochemical characteristics of the experimental soil.

Sand (%)	Clay (%)	Silt (%)	Class	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (ppm)	PH-(H_2O)	CEC (MEQ/100 gsoil)
54	14	32	Sandy loam	4.67	0.26	13	7.54	35.73

Table 2: Climatic condition and vapor pressure deficit (VPD) of the Lath House on 15 randomly selected days (average of 15 days).

Hours	Temperature (°C)	RH (%)	VPD (KPa)
11:30:00 am	32.13	56.34	2.78
12:30:00 pm	31.8	64.83	2.61
1:30:00 pm	30.86	65.8	2.25
2:30:00 pm	30.13	66.62	2.14
3:30:00 pm	32.43	58.91	2.71
4:30:00 pm	32.83	58.8	2.86
5:30:00 pm	32.36	61.71	2.85
6:30:00 am	32.06	61.86	2.87
7:30:00 am	31.33	61.26	2.82
8:30:00 am	32.66	60.07	3.04
9:30:00 am	33.1	56.02	3.04
10:30:00 am	32.63	56.58	3.02
11:30:00 am	32.36	58.41	2.98
12:30:00 pm	32.6	55.9	3
1:30:00 pm	32.26	58.55	2.68
2:30:00 pm	33.5	50.22	3.56
3:30:00 pm	30.46	65.3	2.7
4:30:00 pm	32.03	60.2	2.81
5:30:00 pm	33.1	56.69	2.86
6:30:00 am	32.03	58.61	3.14
7:30:00 am	31.93	64.18	2.83
8:30:00 am	32.5	56.8	3.06
9:30:00 am	32.9	55.33	2.93
10:30:00 am	33.1	52.8	3.42

Table 3: Interaction effects of common bean varieties and soil irrigation interval on leaf relative water content (LRWC) under lath house, from June to September, 2020.

Varieties	*Irrigation interval (LRWC (%))*		
	Drought	Optimum	Waterlogging
Gofta	86.66^{abcd}	92.33^{ab}	83^{bcd}
Fedis	84.33^{bcd}	83^{bcd}	63.33^{ef}
Awash-2	87.33^{abcd}	90.66^{ab}	66.66^{e}
Tinike	86.66^{abcd}	88.66^{abc}	58.33^{ef}
Awash-1	88.66^{abc}	96^{a}	80^{cd}
Dursitu	63.33^{ef}	77^{d}	53.33^{f}
Nasir	56.66^{ef}	80^{cd}	30^{g}
CV	8.33		
LSD	10.315		

significantly depending on leaf temperature. At drought stress treatment during the morning, midday, and evening time, the maximum leaf temperatures of 19.85°C, 24.67°C, and 21.07°C were recorded, respectively. Changes in leaf temperature may be caused by water loss via transpiration. As a result, changes in leaf water content and transpiration may be reflected indirectly in leaf temperature. According to reference [30], leaf water content and temperature are related; leaf temperature is influenced not only by transpiration but also by air temperature.

3.3.3. Effect of Different Irrigation Intervals on Stomata Anatomy. The result indicates that stomata number, length, and width of stomata aperture significantly ($P \leq 0.001$) responded. Interaction effect of varieties and irrigation intervals was also significant (Table 5). The highest stomata numbers were recorded from the Dursitu variety (20.66) and the lowest stomata number were recorded from Awash-2 varieties (6.66) with a combination of daily irrigation interval and eight days irrigation interval, respectively. The longest stomata aperture was

Table 4: The effect of leaf temperature on common bean varieties and water irrigation interval under lath house June to September, 2020.

Variety	Morning	Midday	Evening
Gofta	19.4^{a}	22.878^{a}	20.522^{ab}
Fedis	19.133^{a}	22.956^{a}	20.622^{a}
Awash-2	18.978^{a}	23.089^{a}	20.00^{b}
Tinike	19.467^{a}	22.644^{a}	20.633^{a}
Awash-1	19.611^{a}	23.111^{a}	20.778^{a}
Nasir	19.644^{a}	22.756^{a}	20.878^{a}
LSD	0.7203	0.9433	0.5767
Moisture level			
Drought stress	19.852^{a}	24.667^{a}	21.067^{a}
Optimum	19.081^{b}	22.138^{b}	20.371^{b}
Logging stress	19.281^{b}	21.625^{c}	20.329^{b}
CV	3.9	3.8	2.94
LSD	0.4715	0.5461	0.3776

Within the column means with the same letter are not statistically significant.

Table 5: Interaction effects of varieties and soil irrigation interval on stomata aperture of common beans under Lath House during June to September, 2020.

Irrigation interval	Varieties	Stomata number	Stomata length (nm)	Stomata width (nm)
Drought stress	Gofta	7.66^{hi}	99.67^{efghi}	6.233^{ijk}
	Fedis	8.66^{gh}	100.26^{defgh}	7.42^{i}
	Awash-2	6.66^{ij}	101.65^{defgh}	9.85^{defg}
	Tinike	8.33^{h}	119^{bc}	9.23^{efgh}
	Awash-1	8.66^{gh}	89.23^{i}	9.99^{cdef}
	Dursitu	7.2^{i}	111.67^{cd}	10.58^{bcde}
	Nasir	9^{gh}	104.5^{def}	11.03^{bcd}
Control	Gofta	15^{e}	103.25^{defg}	10.48^{bcde}
	Fedis	7.66^{hi}	131.13^{a}	8.73^{ghi}
	Awash-2	9^{gh}	95.9^{fghi}	11.01^{bcd}
	Tinike	10.66^{f}	123.33^{ab}	9.6^{efgh}
	Awash-1	19.33^{cd}	108.93^{cde}	10.82^{bcd}
	Dursitu	20.66^{c}	92.05^{ghi}	10.58^{cde}
	Nasir	11.33^{f}	91.6^{hi}	11.09^{bcd}
Water logging	Gofta	14^{e}	133.76^{a}	11.76^{ab}
	Fedis	10^{fg}	124.8^{ab}	9.13^{fgh}
	Awash-2	19^{d}	111.4^{abc}	6.4^{i}
	Tinike	14.66^{e}	126.05^{ab}	7.91^{hi}
	Awash-1	18.66^{d}	109.95^{cde}	12.6^{a}
	Dursitu	25^{a}	96.95^{fghi}	9.91^{defg}
	Nasir	22^{b}	130^{ab}	11.1^{bcd}
CV		1.64	11.6	9.047
LSD		7.5	6.36	6.85

Within the column means with the same letter are not statistically significant.

observed with Gofta (133.76 nm) and Fedis varieties (131.13 nm) in daily irrigation interval and four days irrigation interval, respectively, whereas the shortest stomata aperture was recorded with Awash-1 variety (89.23 nm) in eight days irrigation interval treatment. However, a wider stomata aperture was recorded with Awash-1 (12.6 nm) obtained through daily irrigation interval, while the narrowest stomata aperture was recorded in Gofta variety (6.23 nm) in eight days irrigation interval (Table 5). So, varieties have different stomata anatomies in different irrigation intervals. According to a previous report, reducing stomata width and length reduces transpiration and photosynthetic rates, which leads to a reduction in overall plant growth [31]. Similarly, reference [15] indicated that plant exposed to water deficiency significantly reduced stomata opening and transpiration rate as compared to an unstressed plant. However, the closure of the stomata limits transpiration, which in turn limits CO_2 influx, resulting in a decreased photosynthetic activity [32]. Furthermore, the partial closing of the stomata under moisture stress condition is one of the strategies for plant to tolerate water stress. According to reference [15], in addition to stomata closure, plants can reduce stomata size and adjust their number, length, and width in response to prolonged water deprivation.

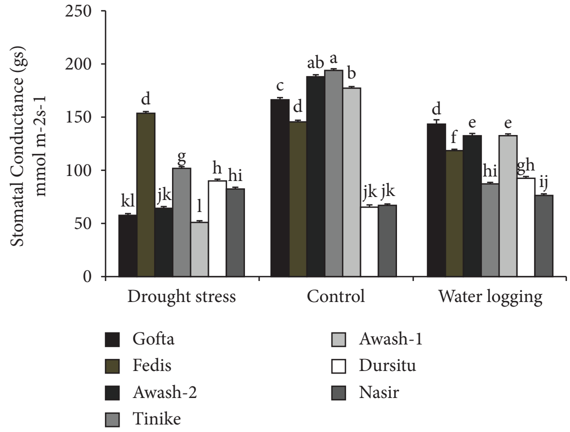

Figure 1: Interaction effect of common bean varieties and soil irrigation interval on stomatal conductance under lath house, 2020.

3.3.4. Stomatal Conductance (gs) mmol·m^{-2}·s^{-1}. Stomatal conductance in different irrigation intervals and varieties were significantly influenced ($P \leq 0.001$) and there was also a significant interaction between them. The maximum stomatal conductance was recorded in Tinike variety (193.67) treated with four day irrigated treatment, while the lowest stomatal conductance was observed with Awash-1 variety (65.33) subjected to drought stress (Figure 1). Under water stress (eight day irrigation interval), root hydraulic conductivity normally drops, resulting in stomatal closure to limit water loss. This could be due to a decrease in the amount of water in the cell, which causes turgor loss and stomatal closure [33]. Furthermore, reduced stomatal conductance is thought to be a water-scarcity adaptation mechanism that allows the plant to reduce evapotranspiration area [6]. Different authors suggested that stomata conductance reactions could be caused by hypoxia-inducedstress-related responses related to ethylene production, which could result in stomata closure [34, 35]. In line with this finding, similar observation also investigated by the authors of reference [36], who reported that a plant that reduced stomatal conductance has a potential to reduce water loss through transpiration and this can be a mechanism to tolerate drought than plants that failed to regulate stomatal conductance.

3.3.5. Instantaneous Water Use Efficiency (IWUE). Water use efficiency also had significantly influenced ($P \leq 0.001$) on different irrigation intervals and varieties and there was also a significant interaction between them (Figure 2). Maximum water use efficiency was recorded from Awash-1 variety (3.95), which is an insignificant variation with Awash-2 (3.85) and Gofta varieties (3.85). While Fedis (1.65) and Tinke (1.76) varieties had the lowest IWUE at a four day irrigation interval. At eight day irrigation interval, Awash-2 (0.8), Gofta (1.02), Awash-1 (1.14), and Dursitu (1.22) varieties were observed to have the lowest water use efficiency, while Fedis (3.26) and Tinke (3.46) obtained the highest IWUE. Under daily irrigation interval, Nasir (1.37), Gofta (1.37), Awash-2(1.46), and Dursitu (1.5) varieties obtained the lowest water use efficiency, while Fedis (3.19) and Tinke (3.38) recorded the maximum (Figure 2). This finding is similar to that of the authors of reference [37], who noticed that stomata closure was associated with increased water use efficiency in stressed plants, implying that stomata closure assisted plants in absorbing carbon by reducing water loss in water stress conditions, thereby contributing to photosynthesis maintenance. In agreement with reference [38], the authors also reported that again instantaneous water use efficiency in wheat cultivars declined significantly when plants were subjected to drought stress. According to reference [26], the improved performance of common bean cultivars with water deficit tolerance is also due to well water use efficiency.

3.3.6. Photosynthesis (A) μmol·m^{-2}·s^{-1}. The interaction of varieties and irrigation interval had a significant effect (Figure 3). Among measured varieties, the highest photosynthesis rate (10.43 μmol·m^{-2}·s^{-1}) was obtained with the Gofta variety treated by a four day irrigated interval, whereas the lowest photosynthesis rate was recorded with the Nasir variety (3.5 μmol·m^{-2}·s^{-1}) subjected to waterlogging stress (Figure 3). Photosynthetic decline is most likely caused by an increase in vapor pressure deficit (leaf-air) and high temperature. As a result, plants grown in extreme water scarcity reduce their photosynthetic rate significantly [39]. Tinike, Fedis, and Nasir varieties showed a significant decline under water logging stress when compared to Awash-2, Awash-1, and Dursitu varieties. This could be due to the fact that plants exposed to waterlogged conditions exhibit certain changes in physiological performance, as well as a significant decrease in PSII photochemistry, indicating the plants' inability to restore RUBISCO under adverse conditions [40]. Water logging stress may also harm the photosynthetic electron–transport pathway, resulting in lower CO_2 assimilation rates. Moreover, the authors of reference [41] found that stomata closure reduces transpiration and photosynthesis rates, and that this drop in photosynthesis rate might be employed as a stress-relieving mechanism. Molecular oxygen acts as a catalyst in plant photosynthetic reactions, facilitating the assembly of energy compounds

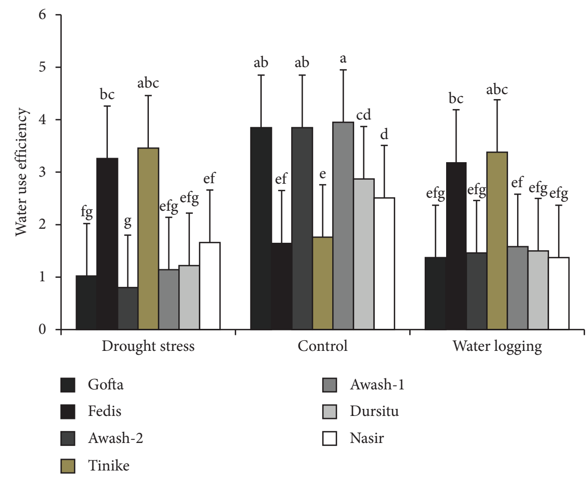

Figure 2: Interaction effect of common bean varieties and soil irrigation interval on water use efficiency under Lath House, 2020.

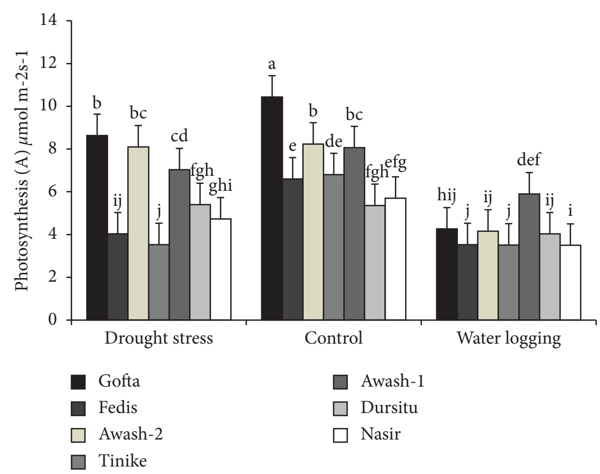

Figure 3: Effects of variety and irrigation interval interaction on the photosynthesis rate under Lath House 2020.

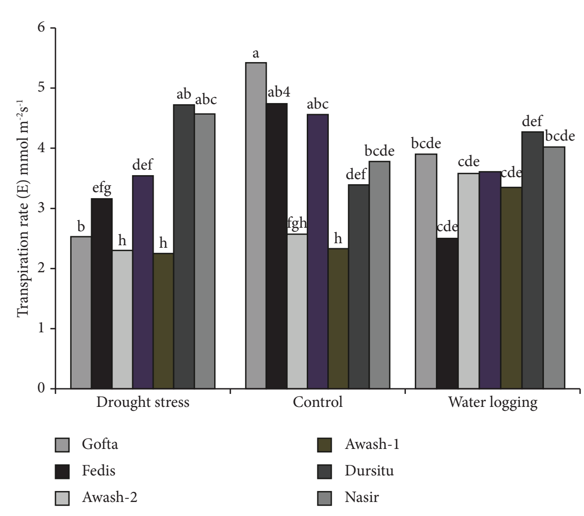

Figure 4: Varieties and irrigation interval interactions on the transpiration rate under lath house 2020.

that lead to the production of glucose [42], who found that high soil water levels cause oxygen deficiency, resulting in stomata closure, photosystem II damage, and reduced photosynthesis.

3.3.7. Transpiration Rate (E) mmol·m^{-2}·s^{-1}. Different irrigation intervals and varieties, as well as their interactions, had a significant effect on the transpiration rate (Figure 4). The highest transpiration rate (5.42 mmol·m^{-2}·s^{-1}) was recorded from the Gofta variety at a four day irrigation interval, while the lowest (2.25 mmol·m^{-2}·s^{-1}) was recorded from the Awash-1 variety to an eight day irrigation interval. Water deficit treatment resulted in a significant decrease in the transpiration rate. As a result of water loss from plant shoots, the vapor pressure difference between the ambient air and the leaf may increase, increasing the rate of transpiration. This could be attained by reducing transpiration, retaining leaf water content, and lowering the risk of loss of moisture. Similarly, the authors of reference [43] reported that genotypes of a plant species differ in the transpiration rate and degree of response to water stress. Lower transpiration rates resulted from a decrease in leaf water content [44] investigated the physiological responses of common bean plants to water scarcity and found that non-irrigated plants had up to 90% lower transpiration rates than irrigated plants. According to reference [42], the decrease in transpiration rate is a plant response to water stress.

3.3.8. Leaf Chlorophyll Concentration. The result revealed the variety and irrigation interval and interactions between them showed a significant variation in concentration of chl a ($P < 0.001$), chl b ($P < 0.001$), and chl ab ($P < 0.001$) (Table 6). In the photosynthetic pigment analysis, statistically, the joint highest mean leaf chl-a concentration was recorded from the variety Gofta (2.4 μg/ml) irrigated every four days interval. On the other hand, the variety Awash-2, which was irrigated daily, had the lowest leaf chlorophyll concentration (0.576 μg/ml). Adjustments in chloroplast concentration and ultrastructure of functional leaves were mostly associated with decreased chlorophyll content and photosynthetic activity. This result was also consistent with a previous study that found under water logging, reduced chlorophyll content, resulting in a decrease in crop leaf photosynthesis [45], indicating that water logging affected common bean leaf chlorophyll content and weakened the photosynthetic assimilation capacity. This might be due to decreases in soluble protein content and destruction of the chloroplast membrane structure [46]. Moreover, decrease in leaf chlorophyll under waterlogging condition might be directly related to nitrogen deficiency caused by leaching and denitrification of the available nitrogen [47]. Under drought stress, the lowest chlorophyll concentration (0.836 μg/ml) was recorded on the Tinike variety. This could be seen as a drought-resilient adaptive mechanism. Plants that are deprived of water show adaptive mechanisms such as reduced leaf chlorophyll concentration and increased proline synthesis [24].

Maximum chlorophyll b (1.53 μg/ml) and chlorophyll (a + b) (3.93 μg/ml) were obtained at four day irrigation interval on Gofta variety. Whereas, statistically, the Fedis variety (0.4747 μg/ml) and Tinike variety (0.48 g/ml) treated with a daily irrigated interval had the lowest mean chl b concentration and Awash-2 variety (1.267 μg/ml) obtained the lowest mean concentration of chl a + b treated with daily irrigated interval (Table 6). References [48, 49] indicated that chlorophyll a and b and total chlorophyll content in sunflower and wheat plants declined in response to water stress. This finding is similar with that of the authors of reference [50] who reported that total chlorophyll content was reduced during drought stress in cowpea. The highest chlorophyll concentration was recorded from the Gofta variety treated with the control irrigation interval (four day irrigation interval), in all chlorophyll cases (chl-a, chl-b, and chl-a + b), and there was a significant decline for all varieties subjected to logging stress followed by drought stress (eight day irrigation interval), but the reduction varies among varieties. The authors of reference [51] revealed that the decrease in chlorophyll during drought stress is predominantly due to active oxygen species damage to chloroplasts. It suggests that the amount of chlorophyll in the bean leaf is related to the plant''s water status, resulting in high chlorophyll synthesis.

3.3.9. Leaf Chlorophyll Fluorescence. The irrigation interval influenced the leaf chlorophyll fluorescence (FV/FM) significantly (P0.01), but the variety was not significantly influenced by leaf chlorophyll fluorescence. The Variety and irrigation interval had no significant effect on chlorophyll fluorescence (Table 7). Regarding moisture level, the eight day irrigation interval recorded higher (0.586) chlorophyll fluorescence, while the lowest chlorophyll fluorescence (0.48) was observed from daily irrigation interval (waterlogging stress) (Table 7). The decline in FV/FM was observed in waterlogging stress treatment, indicating that waterlogging damage to PSII of common bean varieties [52] noted that in waterlog condition chlorophyll break down and lowered photosynthesis and chlorophyll fluorescence. As a result, PSII''s photosynthesis potential energy was reduced, resulting in decreases in photosynthetic rate and photosynthetic characteristics [53]. Similarly, various studies have stated that chlorophyll fluorescence is a useful technique for monitoring changes in photosynthetic apparatus capabilities that can be affected by water logging stress [54, 55]. In our overall result revealed that strong reduction in FV/FM was observed under waterlogging condition than eight day and four day irrigation interval.

3.3.10. Proline Concentration. Proline content was significantly ($P < 0.01$) affected by varieties, irrigation interval, and interaction of irrigation interval and varieties (Table 8). The result indicated that the highest proline content was found in variety Awash-1 (0.78) subjected to drought stress condition, whereas the lowest proline content was observed in Dursitu (0.154) and Awash-1 (0.16) varieties subjected to water logging stress condition (Table 8). The Awash-1

Table 6: Interaction effects of common bean varieties and soil irrigation interval on chlorophyll a, b, and a + b under Lath House from June to September, 2020.

Moisture level	Varieties	Chl a (μg/ml)	Chl b (μg/ml)	Chl a + b (μg/ml)
Drought stress	Gofta	0.925[ghi]	0.52[ijk]	3.128[bc]
	Fedis	1.35[defgh]	0.68[fgh]	1.444[ij]
	Awash-2	1.446[defg]	0.64[ghij]	1.833[fghij]
	Tinike	0.836[hi]	0.858[cde]	1.8717[f]
	Awash-1	1.231[efgh]	0.866[cde]	2.874[bc]
	Dursitu	2.052[ab]	0.79[efg]	2.68[cd]
	Nasir	1.59[bcdef]	0.964[cd]	2.556[cde]
Control	Gofta	2.4[a]	1.53[a]	3.93[a]
	Fedis	2.03[ab]	0.944[cd]	3.328[b]
	Awash-2	2.016[abc]	0.855[cde]	2.29[defg]
	Tinike	1.234[efgh]	0.82[def]	2.3[def]
	Awash-1	2.13[ab]	0.99[c]	2.965[c]
	Dursitu	1.814[bcd]	0.95[cd]	3.122[bc]
	Nasir	1.766[bcde]	0.964[cd]	3b[c]
Waterlogging	Gofta	1.47[cdefg]	0.62[hijk]	2.551[cde]
	Fedis	1.14[fgh]	0.4747[k]	1.656[hij]
	Awash-2	0.576[i]	0.692[fgh]	1.2677[j]
	Tinike	1.23[efgh]	0.482[k]	1.709[ghij]
	Awash-1	1.25[efgh]	0.661[ghi]	1.907[fghi]
	Dursitu	1.032[ghi]	0.498[jk]	1.531[hij]
	Nasir	0.814[hi]	0.56[hijk]	1.373[ij]
CV		23.02	11.66	15.86
LSD		0.547	0.153	0.585

Within the column means with the same letter are not statistically significant.

Table 7: Main effects of common bean varieties and soil irrigation interval on leaf chlorophyll fluorescence under lath house from June to September, 2020.

Variety	FV/FM
Gofta	0.5461[a]
Fedis	0.5303[a]
Awash-2	0.55[a]
Tinike	0.5481[a]
Awash-1	0.5751[a]
Dursitu	0.5426[a]
Nasir	0.5299[a]
CV	14.91
LSD	0.07
Moisture level	
Drought stress	0.586[a]
Control	0.572[a]
Water logging	0.48[b]
CV	14.91
LSD	0.508

Within the column means with the same letter are not statistically significant.

variety''s high accumulation of proline content suggests a possible high-stress tolerance mechanism when compared to others and it produced the highest yield. Higher proline concentration under water scarcity conditions is a useful predictor of plant tolerance, and these properties can be used to select tolerant varieties [54, 55]. Furthermore, during drought stress, proline acts as a signaling compound to regulate mitochondrial function and cell proliferation by activating specific genes that are required for stress recovery [58]. Proline accumulation in stressed plants is an oxidative stress tolerance mechanism and the major approach of plants to prevent the detrimental consequences of drought stress [59].

3.4. Yield and Yield Components

3.4.1. Number of Pod Plant^{-1} and Seed Pod^{-1}. The number of pods plant^{-1} and seeds pod^{-1} were significantly affected by moisture and variety. There was also a significant interaction effect between irrigation interval and variety. Awash-2

Table 8: Effects of common bean varieties and irrigation intervasl on proline *c* (μg/g) content under lath house from June to September, 2020.

Varieties	*Moisture level*		
	Drought	Optimum	Logging stress
Gofta	0.6476^{b}	0.4247^{cd}	0.2045^{jkl}
Fedis	0.4362^{c}	0.2486^{hij}	0.1855^{kl}
Awash-2	0.6299^{b}	0.3364^{fg}	0.2331^{ijk}
Tinike	0.4173^{cd}	0.3580^{ef}	0.2518^{hij}
Awash-1	0.78^{a}	0.3428^{ef}	0.1590^{l}
Dursitu	0.3748^{def}	0.2898^{gh}	0.1543^{l}
Nasir	0.3927^{cde}	0.2721^{hi}	0.1893^{kl}
CV	9.1		
LSD	0.524		

Means with the same letter are not statistically significant.

Table 9: Interaction effects of common bean varieties and irrigation interval on pods plant^{-1} and seeds pod^{-1} under lath house from June to September, 2020.

Moisture level	*Varieties*						
	Gofta	Fedis	Awash-2	Tinike	Awash-1	Dursitu	Nasir
Pods plan^{-1}							
Eight days irrigation	4^{f}	3^{g}	5^{e}	3^{g}	6^{d}	4^{f}	3^{g}
Four day irrigation	6^{d}	6^{d}	9^{a}	6^{d}	8^{b}	7^{c}	5^{e}
Daily irrigation	3^{g}	2^{h}	4^{f}	2^{h}	4^{f}	2^{h}	1^{i}
CV	2.65						
LSD	0.21						
Seeds pod^{-1}							
Eight days irrigation	5.33^{c}	4.33^{e}	6.33^{ab}	4.33^{ef}	6.66^{ab}	4.33^{e}	4.33^{e}
Four day irrigation	6.73^{a}	4.33^{e}	6.33^{ab}	4^{gf}	5^{cd}	4.66^{dce}	5^{cd}
Daily irrigation	3^{g}	2^{h}	4^{gf}	2^{h}	3^{g}	2^{ih}	2^{h}
CV	9.01						
LSD	0.64						

varieties (9) had the highest pods plant^{-1} with four day irrigation interval, while the Nasir variety had the lowest (1) pod plant^{-1} at daily irrigation (Table 9). Four day irrigation interval treatment was reliably better performed than water logging stress and drought stress condition. Moisture deficit, according to reference [60], affects yield components such as the number of pods plant^{-1}.

The maximum number of seeds pod^{-1} was recorded by Awash-1 variety (6.73), but Fedis, Tinike, Dursitu, and Nasir varieties were statistically similarly accounted for the minimum number of seeds pod^{-1}(2) (Table 9). Four day irrigation interval treatment reliably performed better than water logging stress and drought stress conditions. Water stress causes plants to close their stomata, influencing other variables such as the photosynthesis rate and transpiration rate, ultimately reducing the number of seeds per pod. Under similar drought-stressed conditions [61], observed significant decreases in pod number plant^{-1}; seed number pod^{-1}, 100 seed weight, and seed yield of common beans.

3.4.2. Hundred Seed Weight. Variety and irrigation interval showed a significant (*P*0.001) influence on hundred seed weight, but their interaction had no significant effect on hundred seed weight. The highest 100 SW (39.48 gm) was recorded in Fedis variety; while the lowest (16.88 gm), was recorded in Awash-2. According to the moisture level, the highest product of 100 SW per gram was recorded in a four day irrigation interval. However, the lowest result of hundred seed weight was recorded by water logging stress (daily watering) (Table 10). This might be due to the photosynthetic rate, stomatal conductance, and transpiration rate having a direct effect in the accumulation of food to the seed. The authors of reference [50] noted that most of yield components exhibited a highly significant variance for the varieties. According to reference [62], cell proliferation, protein production, solute accumulation, stomatal closure, and photosynthetic inhibition were also found under more severe drought circumstances.

3.4.3. Grain Yield. Varieties and moisture level, as well as the interaction effect of between them, had a significant (*P*0.01) effect on grain yield (Figure 5). On control irrigation interval (four day irrigation interval), the Awash-1 variety (7.8 g) and Gofta variety (7.36 g) produced the highest yield, while the Fedis variety (1.43 g) produced the lowest yield (Figure 5). This might be due to the physiological response and the yield components having a direct effect on yield of common bean. Four-day irrigation interval produced the

Table 10: Effects of common bean varieties and irrigation interval on hundred seed weight under lath house from June to September, 2020.

Variety	Hundred seed weight
Gofta	29.71[b]
Fedis	39.48[a]
Awash-2	16.88[d]
Tinike	32.21[b]
Awash-1	31.28[b]
Dursitu	20.72[c]
Nasir	20.25[c]
LSD	2.9596
Moisture level	
Drought stress	28.81[a]
Optimum	28.6[a]
Logging stress	24[b]
CV	15.92
LSD	1.9375

Within the column means with the same letter are not statistically significant.

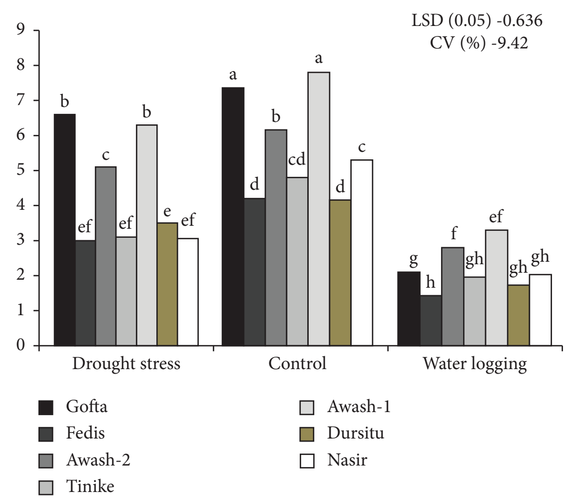

Figure 5: Interaction effects of common bean varieties and irrigation interval on grain yield under lath house 2020.

highest pods plant^{-1}, seeds pod^{-1}, and hundred seed weight which directly relate to the total yield. The authors of reference [63] identified the number of productive pods per plant as one of the most reduced yield components in water-stressed legumes. The authors of reference [61] also reported a decrease in common bean seed per pod and seed weight under moisture stresses resulted yield reduction. The yield losses are also attributed to lower achievement of physiological responses such as a decrease of stomatal conductance, stomatal number, chlorophyll content, and photosynthetic activity in moisture stressed treatment. A similar result was reported by the authors of reference [9] that drought and waterlogging stress conditions were found to have a strong effect on grain yield in two types of bean, with yield reduced by 25.5 percent when compared to the non-stressed treatment.

4. Conclusion

Drought and waterlogging treatments reduced common bean yield regardless of varieties; while plants have diverse mechanisms for response and adaptation to water stress. Physiological parameters like transpiration rate, photosynthesis rate, stomata number, stomatal length, stomata width, stomatal conductance, leaf relative water content, water use efficiency, and proline content had a significant interaction effect on varieties and irrigation interval, whereas leaf chlorophyll fluorescence and hundred seed weight were affected only by the main effect. Regarding varieties and moisture level, Gofta variety was superior in the transpiration rate and photosynthesis rate treated by four day irrigation interval, whereas the lowest were Fedis, Tinike, and Nasir varieties that were subjected to drought stress and waterlogging stress. In the present study, significant decreases in transpiration rate and photosynthesis rate were associated with a significant decrease in yield and yield components. A significant loss of stomatal conductance was also observed under waterlogging stress growing conditions. Accordingly, the reduction in stomatal conductance was related with an increase in the water use efficiency, which indicates that stomatal closure contributed to optimizing water use efficiency under stress, which may have enabled to absorb carbon by decreasing the loss of water in the water stress condition, contributing to photosynthesis maintenance. Lower stomatal conductance is also considered to be the mechanism of adaptation to water shortage, allowing reduction in the evapotranspiration area. The optimum watering interval (four day interval) obtained the maximum leaf relative water content on Awash-2 variety and under drought (eight day irrigation interval) also obtained the highest value of leaf relative water content due to stomata closure and leaf senescense, which could have reduced transpiration rates and thus protected the photosynthetic apparatus. The highest values of grain yield on Awash-1 (7.8 g plant^{-1}) and Gofta (7.36 g plant^{-1}) varieties were due to the highest values in photosynthesis rate, chlorophyll content, proline content, leaf relative water content, pods plant^{-1}, seeds pod^{-1}, which highly contribute to the maximum grain yield at four day irrigation interval, and they also obtained the highest yield at drought condition. Awash-2 and Awash-1 varieties were tolerant to waterlogging due to better photosynthesis and stomatal conductance.

Data Availability

The data used to support the findings of this study are available from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors thank the Hawassa University College of Agriculture for facilitating and supplying materials for the success of this research.

References

[1] T. G. A. Assefa, F. Chemeda, T. Bulti, and A. R. M. Al-Tawaha, “Participatory bean breeding with women and small holder farmers in eastern Ethiopia,” *World Journal of Agricultural Sciences*, vol. 1, no. 1, pp. 28–35, 2005.

[2] G. Bekana, E. Girma, A. Abebe et al., “Evaluating the genetic variations among improved haricot bean varieties (<i& gt;Phaseolus vulgaris</i> L.) based on their agronomic traits and performing their half diallel cross,” *American Journal of BioScience*, vol. 9, no. 5, pp. 168–174, 2021.

[3] G. Abebe, “Effect of Np fertilizer and moisture conservation on the yield and yield components of Common bean (Phaseolus Vulgaris L.) in the semi-arid zones of the Central Rift Valley in Ethiopia,” *Advances in Environmental Biology*, vol. 3, no. 3, pp. 302–307, 2009.

[4] V. Chekanai, R. Chikowo, and B. Vanlauwe, “Response of common bean (Phaseolus vulgaris L.) to nitrogen, phosphorus and rhizobia inoculation across variable soils in Zimbabwe,” *Agriculture, Ecosystems & Environment*, vol. 266, pp. 167–173, 2018.

[5] S. E. Beebe, I. M. Rao, M. W. Blair, and J. A. Acosta-Gallegos, “Phenotyping common beans for adaptation to drought,” *Frontiers in Physiology*, vol. 4, p. 35, 2013.

[6] L. Taiz, E. Zeiger, I. M. Møller, and A. Murphy, *Plant Physiology and Development*, Sinauer Associates Incorporated, Sunderland, MA, USA, 6TH edition, 2015.

[7] J. C. Molina, V. Moda-Cirino, N. Fonseca Junior, R. Faria, and D Destro, “Response of common bean cultivars and lines to water stress,” *Cropp Breeding and Applied Biotechnology*, vol. 1, pp. 363–372, 2001.

[8] A. A. Muhammad, “Waterlogging stress in plants: a review,” *African Journal of Agricultural Research*, vol. 7, no. 13, pp. 1976–1981, 2012.

[9] N. Ntukamazina, R. N. Onwonga, R. Sommer, C. M. Mukankusi, J. Mburu, and J. C. Rubyogo, “Effect of excessive and minimal soil moisture stress on agronomic performance of bush and climbing bean (Phaseolus vulgaris L.),” *Cogent Food & Agriculture*, vol. 3, Article ID 1386769, 1 page, 2017.

[10] D. Todaka, K. Shinozaki, and K. Yamaguchi-Shinozaki, “Recent advances in the dissection of drought-stress regulatory networks and strategies for development of drought-tolerant transgenic rice plants,” *Frontiers of Plant Science*, vol. 6, p. 84, 2015.

[11] A. Walkley and I. A. Black, “An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method,” *Soil Science*, vol. 37, no. 1, pp. 29–38, 1934.

[12] J. L. Havlin, J. D. Beaton, S. L. Tisdale, and W. L. Nelson, “An introduction to nutrient management,” *Soil Fertility and Fertilizers*, p. 499, 6th edition, Prentice-Hall, Upper Saddle River, NJ, USA, 1999.

[13] S. R. Olsen, *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*, US Department of Agriculture, Washington, D.C, USA, 1954.

[14] C. Kjeldahl, “A new method for the determination of nitrogen in organic matter,” *Zeitschrift für Analytische Chemie*, vol. 22, p. 366, 1883.

[15] Z. Xu and G. Zhou, “Responses of leaf stomatal density to water status and its relationship with photosynthesis in a grass,” *Journal of Experimental Botany*, vol. 59, no. 12, pp. 3317–3325, 2008.

[16] F. Z. Bertolde, A. A. F. D Almeida, R. X. Correa et al., “Molecular, physiological and morphological analysis of waterlogging tolerance in clonal genotypes of Theobroma cacao L,” *Tree Physiology*, vol. 30, no. 1, pp. 56–67, 2010.

[17] H. K. Lichtenthaler and C. Buschmann, “Chlorophylls and carotenoids: measurement and characterization by UV-VIS spectroscopy,” *Current protocols in food analytical chemistry*, vol. 1, no. 1, pp. F4.3.1–F4.3.8, 2001.

[18] R. J. Strasser, T. M. Merope, and A. Srivastava, “Analysis of the chlorophyll a fluorescence transient,” in *Chlorophyll a Fluorescence*, pp. 321–362, Springer, Dordrecht, Netherlands, 2004.

[19] L. S. Bates, R. P. Waldren, and I. D. Teare, “Rapid determination of free proline for water-stress studies,” *Plant and Soil*, vol. 39, no. 1, pp. 205–207, 1973.

[20] Turner and C. Neil, “Techniques and experimental approaches for the measurement of plant water status,” *Plant and Soil*, vol. 58, no. 1, pp. 339–366, 1981.

[21] C. G. MuñozPerea, H. Terán, R. G. Allen, J. L. Wright, D. T. Westermann, and S. P. Singh, “Selection for drought resistance in dry bean landraces and cultivars,” *Crop Science*, vol. 46, no. 5, pp. 2111–2120, 2006.

[22] E. H. Roberts, Ed., *Viability of Seeds*, Springer Science & Business Media, Heidelberg, Germany, 2012.

[23] R. Cody, *An Introduction to SAS university Edition*, SAS Institute, Cary, NC, USA, 2018.

[24] M. A. Rosales, E. Ocampo, R. Rodríguez-Valentín, Y. Olvera-Carrillo, J. Acosta-Gallegos, and A. A. Covarrubias, "Physiological analysis of common bean (Phaseolus vulgaris L.) cultivars uncovers characteristics related to terminal drought resistance," *Plant Physiology and Biochemistry*, vol. 56, pp. 24–34, 2012.

[25] V. Bala Subramanian and M. Maheswari, "Compensatory growth responses during reproductive phase of cowpea after relief of water stress," *Journal of Agronomy and Crop Science*, vol. 168, no. 2, pp. 85–90, 1992.

[26] D. Kumutha, R. K. Sairam, K. Ezhilmathi, V. Chinnusamy, and R. C. Meena, "Effect of waterlogging on carbohydrate metabolism in pigeon pea (Cajanuscajan L.): upregulation of sucrose synthase and alcohol dehydrogenase," *Plant Science*, vol. 175, no. 5, pp. 706–716, 2008.

[27] T. L. Setter, I. Waters, S. K. Sharma et al., "Review of wheat improvement for waterlogging tolerance in Australia and India: the importance of anaerobiosis and element toxicities associated with different soils," *Annals of Botany*, vol. 103, no. 2, pp. 221–235, 2009.

[28] B. Jongdee, S. Fukai, and M. Cooper, "Leaf water potential and osmotic adjustment as physiological traits to improve drought tolerance in rice," *Field Crops Research*, vol. 76, no. 2-3, pp. 153–163, 2002.

[29] G. Pantuwan, S. Fukai, M. Cooper, S. Rajatasereekul, and J. C. O'toole, "Yield response of rice (Oryza sativa L.) genotypes to drought under rainfed lowlands: 2. Selection of drought resistant genotypes," *Field Crops Research*, vol. 73, no. 2-3, pp. 169–180, 2002.

[30] Y. P. Liu, Si Shen, Y. U. Q. Pan et al., "Diurnal variation in leaf-air temperature difference and leaf temperature difference and the hybrid difference in maize under different drought stress," *Journal of China Agricultural University*, vol. 19, no. 5, pp. 13–21, 2014.

[31] A. Sobhkhizi, M. F. Rayni, and N. Mohsen, "Influence of drought stress on photosynthetic enzymes, chlorophyll, protein and relative water content in crop plants," *International Journal of Biosciences*, vol. 5, no. 7, pp. 89–100, 2014.

[32] Y. Limin, H. Mei, Z. Guangsheng, and L. Jiandong, "The changes in water-use efficiency and stoma density of Leymuschinensis along Northeast China Transect," *Actaecologicasinica*, vol. 27, no. 1, pp. 16–23, 2007.

[33] A. Y. Kamara, A. Menkir, B. Badu-Apraku, and O. Ibikunle, "The influence of drought stress on growth, yield and yield components of selected maize genotypes," *The Journal of Agricultural Science*, vol. 141, no. 1, pp. 43–50, 2003.

[34] L. C. Costa, L. M. Luz, V. L. Nascimento et al., "Selenium-ethylene interplay in postharvest life of cut flowers," *Frontiers of Plant Science*, vol. 11, Article ID 584698, 2020.

[35] K. Bashar, Q. Hossen, M. Tareq et al., "Phytohormone-mediated stomatal response, escape and quiescence strategies in plants under flooding stress," *Agronomy*, vol. 9, pp. 43–2, 2019.

[36] L. E. Arve, S. Torre, J. E. Olsen, and K. K. Tanino, "Stomatal responses to drought stress and air humidity," *In Abiotic Stress in Plants-Mechanisms And Adaptations*, IntechOpen, London, UK, 2011.

[37] L. S. Broeckx, R. Fichot, M. S. Verlinden, and R. Ceulemans, "Seasonal variations in photosynthesis, intrinsic water-use efficiency and stable isotope composition of poplar leaves in a short-rotation plantation," *Tree Physiology*, vol. 34, no. 7, pp. 701–715, 2014.

[38] T. Boutraa, A. A. Al AbdellahAkhkha, A. M. Alhejeli, and A. A. Al-Shoaibi, "Effect of water stress on growth and water use efficiency (WUE) of some wheat cultivars (Triticum durum) grown in Saudi Arabia," *Journal of Taibah University for science*, vol. 3, no. 1, pp. 39–48, 2010.

[39] P. Romero, R. Gil-Muñoz, F. M. del Amor, E. Valdes, J. I. Fernandez, and A Martinez-Cutillas, "Regulated Deficit Irrigation based upon optimum water status improves phenolic composition in Monastrell grapes and wines," *Agricultural Water Management*, vol. 121, pp. 85–101, 2013.

[40] C. F. Smethurst, T. Garnett, and S. Shabala, "Nutritional and chlorophyll fluorescence responses of lucerne (Medicago sativa) to waterlogging and subsequent recovery," *Plant and Soil*, vol. 270, no. 1, pp. 31–45, 2005.

[41] M. Ashraf and M. Arfan, "Gas exchange characteristics and water relations in two cultivars of Hibiscus esculentus under waterlogging," *Biologia Plantarum*, vol. 49, no. 3, pp. 459–462, 2005.

[42] E. N. da Silva, R. V. Ribeiro, S. L. Ferreira-Silva, R. A. Viégas, and J. A. G. Silveira, "Comparative effects of salinity and water stress on photosynthesis, water relations and growth of Jatrophacurcas plants," *Journal of Arid Environments*, vol. 74, no. 10, pp. 1130–1137, 2010.

[43] S. HongBo, L. ZongSuo, and S. MingAn, "Changes of anti-oxidative enzymes and MDA content under soil water deficits among 10 wheat (Triticumaestivum L.) genotypes at maturation stage," *Colloids and Surfaces B: Biointerfaces*, vol. 45, no. 1, pp. 7–13, 2005.

[44] E. P. Lima and E. Ld Silva, "Temperatura base, coeficientes de cultura e graus-dia para cafeeiro arábica em fase de implantação," *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 12, no. 3, pp. 266–273, 2008.

[45] E. Pociecha, J. Kościelniak, W. Filek, and F. Władysław, "Effects of root flooding and stage of development on the growth and photosynthesis of field bean (Viciafaba *L. minor*)," *ActaPhysiologiaePlantarum*, vol. 30, no. 4, pp. 529–535, 2008.

[46] B. Ren, J. Zhang, X. Li et al., "Effects of waterlogging on the yield and growth of summer maize under field conditions," *Canadian Journal of Plant Science*, vol. 94, no. 1, pp. 23–31, 2014.

[47] G. Kaur, P. P. Motavalli, K. A. Nelson, G. Singh, and B. Taghi, "Soil waterlogging and nitrogen fertilizer source effects on soil inorganic nitrogen," *Journal of the Mississippi Academy of Sciences*, vol. 65, pp. 300–318, 2020.

[48] P. Manivannan, C. A. Jaleel, B. Sankar et al., "Growth, biochemical modifications and proline metabolism in Helianthus annuus L. as induced by drought stress," *Colloids and Surfaces B: Biointerfaces*, vol. 59, no. 2, pp. 141–149, 2007.

[49] S. Saeedipour and F. Moradi, "Comparison of the drought stress responses of tolerant and sensitive wheat cultivars during grain filling: impact of invertase activity on carbon metabolism during kernel development," *Journal of Agricultural Science*, vol. 3, no. 2, p. 32, 2011.

[50] S. K. Singh and K. Raja Reddy, "Regulation of photosynthesis, fluorescence, stomatal conductance and water-use efficiency of cowpea (Vignaunguiculata [L.] Walp.) under drought," *Journal of Photochemistry and Photobiology B: Biology*, vol. 105, no. 1, pp. 40–50, 2011.

[51] A. Mafakheri, A. F. Siosemardeh, B. Bahramnejad, P. C. Struik, and Y. Sohrabi, "Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars,"

Australian Journal of Crop Science, vol. 4, no. 8, pp. 580–585, 2010.

[52] R. K. Sairam, D. Kumutha, K. Ezhilmathi, P. S. Deshmukh, and G. C. Srivastava, "Physiology and biochemistry of waterlogging tolerance in plants," *Biologia Plantarum*, vol. 52, no. 3, pp. 401–412, 2008.

[53] M. Irfan, S. Hayat, Q. Hayat, S. Afroz, and A. Ahmad, "Physiological and biochemical changes in plants under waterlogging," *Protoplasma*, vol. 241, no. 1-4, pp. 3–17, 2010.

[54] D. Waldhoff, B. Furch, and W. J. Junk, "Fluorescence parameters, chlorophyll concentration, and anatomical features as indicators for flood adaptation of an abundant tree species in Central Amazonia: Symmeriapaniculata," *Environmental and Experimental Botany*, vol. 48, no. 3, pp. 225–235, 2002.

[55] M. S. Mielke, A.-A. F. de Almeida, F. P. Gomes, M. A. G. Aguilar, and P. A. O. Mangabeira, "Leaf gas exchange, chlorophyll fluorescence and growth responses of Genipaamericana seedlings to soil flooding," *Environmental and Experimental Botany*, vol. 50, no. 3, pp. 221–231, 2003.

[56] H. Liu, M. A. R. F. Sultan, and H. X. Zhao, "The screening of water stress tolerant wheat cultivars with physiological indices," *Global Journal Of Biodiversity Science And Management*, vol. 3, pp. 211–218, 2013.

[57] A. D. Sánchez-Reinoso, G. Garcés-Varón, H. Restrepo-Díaz, and H. Restrepo-Diaz, "Biochemical and physiological characterization of three rice cultivars under different daytime temperature conditions," *Chilean Journal of Agricultural Research*, vol. 74, no. 4, pp. 373–379, 2014.

[58] J. K. Solanki and S. K. Sarangi, "Effect of drought stress on epicuticular wax load in peanut genotypes," *Journal of Applied Biology & Biotechnology*, vol. 3, no. 4, pp. 0–4, 2015.

[59] E. C. G. Vendruscolo, I. Schuster, M. Pileggi et al., "Stress-induced synthesis of proline confers tolerance to water deficit in transgenic wheat," *Journal of Plant Physiology*, vol. 164, no. 10, pp. 1367–1376, 2007.

[60] K. Darkwa, D. Ambachew, H. Mohammed, A. Asfaw, and M. W. Blair, "Evaluation of common bean (Phaseolus vulgaris L.) genotypes for drought stress adaptation in Ethiopia," *The crop journal*, vol. 4, no. 5, pp. 367–376, 2016.

[61] A. Asfaw and M. W. Blair, "Quantification of drought tolerance in Ethiopian common bean varieties," *Agricultural Sciences*, vol. 05, no. 2, pp. 124–139, 2014.

[62] L. Taiz and E. Zeiger, "Photosynthesis: physiological and ecological considerations," *Plant Physiology*, vol. 9, pp. 172–174, 2002.

[63] S. Gebeyehu, H. Wiese, and S. Schubert, "Effects of drought stress on seed sink strength and leaf protein patterns of common bean genotypes," *African Crop Science Journal*, vol. 18,2 pages, 2011.