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Rice Straw Vermicompost Enriched With Cellulolytic Microbes Ameliorate the Negative Effect of Drought in Wheat Through Modulating the Morpho-Physiological Attributes

Ali Ahmad[1], Zubair Aslam[1], Saddam Hussain[1], Amir Bibi[2], Abdul Khaliq[1], Talha Javed[1,3], Sadam Hussain[4], Saqer S. Alotaibi[5], Hazem M. Kalaji[6,7], Arkadiusz Telesiński[8], Chuleemas Boonthai Iwai[9] and Uttam Kumar[10]*

[1]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan, [2]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan, [3]College of Agriculture, Fujian Agriculture and Forestry University, Fuzhou, China, [4]College of Agronomy, Northwest A&F University, Yangling, China, [5]Department of Biotechnology, College of Science, Taif University, Taif, Saudi Arabia, [6]Department of Plant Physiology, Institute of Biology, Warsaw University of Life Sciences—SGGW, Warsaw, Poland, [7]Institute of Technology and Life Sciences—National Research Institute, Raszyn, Poland, [8]Department of Bioengineering, West Pomeranian University of Technology, Szczecin, Poland, [9]Integrated Land and Water Resource Management Research and Development Center in Northeast Thailand, Khon Kaen University, Khon Kaen, Thailand, [10]College of Plant Protection, Fujian Agriculture and Forestry University, Fuzhou, China

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***Correspondence:**
Zubair Aslam
zauaf@hotmail.com

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Wheat growth and productivity are unfavorably pretentious by a lack of sufficient water (drought or water deficit) worldwide. Drought stress significantly affects all the morpho-physiological and biochemical characteristics and the agronomical yield of wheat. Different management approaches have been adopted to cope with the negative effects of water deficit. Soil-applied vermicompost is helpful in improving the growth and developmental processes of wheat under water deficit conditions. Therefore, a trial was carried out to optimize the best amount of vermicompost and to assess its role in ameliorating the negative effects of drought for sustainable crop production. The treatments consisted of 1) two contrasting wheat cultivars Faisalabad-08 (drought-tolerant) and Galaxy-13 (drought-sensitive), 2) drought with three levels [D_0 = 70% of field capacity (no drought), D_1 = 45% of field capacity (mild drought), and D_2 = 30% of field capacity (severe drought)] and 3) cellulolytic microbe-enriched vermicompost prepared from rice straw with four levels (VT_0 = Control, VT_1 = 4 t ha^{-1}, VT_2 = 6 t ha^{-1} , and VT_3 = 8 t ha^{-1}). Data on various morphological, physiological, and biochemical parameters were recorded from sowing to crop harvesting. In this study, it was demonstrated that all these parameters were negatively affected by moisture deficit conditions. The application of vermi-fertilizer significantly increased ($p < 0.05$) the aforementioned parameters of wheat in both the absence and presence of drought. Under severe drought, VT_2 treatment increased the seedling length by 14.02–26.14%, fresh weight by 15.16–22.91%, and dry weight by 0.37–28.20% in both cultivars compared with control. In addition, VT_2 treatment reduced the leaf water potential by 6.36 and 3.36%, leaf osmotic potential by 1.74 and 1.68%, and increased the turgor potential by 4.83 and 3.36%, and photosynthetic rate by 18.59 and 26.42% in Faislabad-08 and Galaxy-13, respectively, over control. We concluded that the application of vermicompost is a valuable approach to alleviate the adverse impacts of water stress on wheat.

Keywords: abiotic stress, cellulolytic microbes, straw, vermicompost, water deficit, wheat

1 INTRODUCTION

Wheat (*Triticum aestivum* L.), the most important member of the family Poaceae, is the first domesticated cereal and used as a staple food by billions across the globe. It is one of the most economically important crops and is known as the king of cereals which is cultivated under a wide range of environmental conditions (Giraldo et al., 2019). Wheat mainly consists of two species viz. the hexaploid wheat (commonly known as bread and durum wheat, respectively). Bread wheat is the most widely cultivated cereal crop throughout the world (Braun et al., 2010; Shewry and Hey, 2015; and Ahmad et al., 2021). Wheat grain contains about 70% carbohydrates, 21% protein, and 2% fat and minerals. This vitally important cereal fulfills 19% of the daily needed dietary calories of nearly 40% of the global population. Globally, the demand for wheat flour is increasing constantly owing to its unique nutritional properties (Braun et al., 2010; Peng et al., 2011).

Environmental stresses including elevated temperature, drought, heavy metals, salinity, and waterlogged conditions, negatively affect the morpho-physiological processes of plants, and thus the agronomical yield of agricultural crops (Hussain et al., 2020; Hussain et al., 2021; Naseer et al., 2021; Zahra et al., 2021; and Iqbal et al., 2022). Among these climatic factors, drought (also termed deficient precipitation) has emerged as one of the most threatening challenges due to climate change (Hussain et al., 2018; Hussain et al., 2019; Ahmad et al., 2021; and Mubarik et al., 2021).

Drought stress mainly occurs in plants when water absorption rates are less than water loss through transpiration. Plants are sessile in nature and sensitive to drought, affecting various developmental and physiological processes including photosynthesis (Ilyas et al., 2021; Mubarik et al., 2021; and Ahmad et al., 2022a). Under drought, the first sign of stress that appears in plants is the reduced turgor pressure of leaves and stem, consequently leading to a reduction in cell division, volume, and elongation (Flexas et al., 2004; Ahmad et al., 2021; and Mubarik et al., 2021). Moreover, insufficient water supply also reduces the photosynthesis process via reduced absorption of CO_2 and thus retards glucose biosynthesis (Lawlor and Cornic, 2002; Tang et al., 2002; and Kaur et al., 2021). Under drought conditions, plants markedly increase free radical production which further impairs the photosynthesis process, biosynthesis of protein, and many other constitutes in the plant. The plants can tolerate drought stress and overcome its induced injury mainly by reducing the size of its roots, shoots, and leaves (Mitchell et al., 1998; Khatun et al., 2021). Drought tolerant mechanisms also vary among wheat genotypes (Khakwani et al., 2011; Ateş Sönmezoğlu and Terzi, 2018; Ahmad et al., 2021; Chowdhury et al., 2021; and Wasaya et al., 2021).

Furthermore, drought stress also enhances the accumulation of reactive oxygen species (ROS) for oxidative damage, reduction in leaf gasses exchange and carbon assimilation rates (Hussain et al., 2019; Moreno-Galván et al., 2020), inhibits the activities of various enzymes, ionic absorption, and severe reduction in seedling growth, which ultimately lead to reduced crop productivity (Anjum et al., 2017; Todaka et al., 2017; Chowdhury et al., 2021; Mubarik et al., 2021; and Wasaya et al., 2021). During the last decade, several drought management strategies, including the integrated use of nutrients and cultivating drought-tolerant plant species, have been tested to minimize the effects of drought on field-grown crops (Ihtisham et al., 2020; Bukhari et al., 2021; and Ahmad et al., 2022b). As an integrated nutrient management practice, numerous studies have indicated that the application of vermicompost is a viable and easy-to-adapt method to enhance crop performance under drought stress because of its higher porosity and capability to absorb moisture for a longer period of time (Hosseinzadeh et al., 2016; Ahmed et al., 2022a). Additionally, micro-fauna in vermicompost also helps plants to uptake more water through the roots and helps to increase their nutrient use efficiencies (Amiri et al., 2017). Vermicompost can provide a good source of compatible compounds, including soluble sugars, betaine, sorbitol, and some organic acids and different essential nutrients including nitrogen (N), phosphorus (P), calcium (Ca), boron (B), magnesium (Mg), sulfur (S), and iron (Fe), which are essential for plant growth and development and to increase crop productivity (Hosseinzadeh et al., 2016; Hussan et al., 2021).

In recent years, farmers have relied mainly on better nutrition for optimum plant growth and enhanced agronomical yield and maintaining soil fertility. In this context, vermicompost provides a great potential to enhance crop productivity besides protecting soil health and environmental sustainability (Varghese and Prabha, 2014). Its application also enhances the physico-chemical, as well as the organic properties of the soil. Vermicompost is a solid product of organic residues enriched with earthworms and other micro-faunas that provide a significant source of growth regulator hormones, degrading enzymes (such as chitinase, cellulase, lipase, amylase, and proteases), and some essential vitamins. Earthworms help in the secretion of essential enzymes (including nitrate reductase) in the waste. These organisms are also involved in the fragmentation of organic residues through the reduction of C/N ratio and increasing the exposed area for micro-fauna to react with cellulolytic degrading micro-flora for complete degradation. Earthworms produce vermicompost through humus which is the bacterial excrement of their guts (Dominguez and Edwars, 2004). According to previous reports, the epigeic earthworm (*Eisenia fetida*) (Zhang et al., 2000) and various other species including *Polipheretima elongate* (Lattaud et al., 1997b), *Millsonia anomala* (Urbasek and Pizl, 1991; Lattaud et al., 1997a), and *Pontoscolex corethurus* (Zhang et al., 1993) have significant potential to excrete humus material.

In recent years, various reports evaluated the potential of vermicompost application for enhancing drought tolerance in crop plants and reported that when mixed with organic fertilizers, it significantly ameliorated the drought tolerance through improving the morpho-physiological and biochemical attributes of crop plants (Aboelsoud and Ahmed, 2020; Hafez et al., 2020). It is further reported that humic acid, which is an extract of vermicompost, has the potential to enhance drought tolerance in rice through enhancing the activities of various antioxidant enzymes, including catalase and superoxide to remove excessive levels of the ROS system under stress conditions to alleviating the oxidative damage (García et al., 2012; Kiran, 2019). Similarly, considerable accumulation of antioxidant enzymes was also reported for chickpea (Gholipoor et al., 2011; Hosseinzadeh et al., 2018), mungbean (Mahmoudi et al., 2016), lentil (Ahmadpour and Hosseinzadeh, 2017), and oilseed crops, including canola (Rashtbari et al., 2012). However, the effect of rice straw vermicompost enriched with cellulolytic microbes to ameliorate the negative effect of drought stress remains less known. Therefore, this study was conducted with the objective to examine the impact of rice straw vermicompost enriched with cellulolytic microbes on the morphological and physiological traits of wheat cultivars under drought conditions. The performance of two contrasting wheat cultivars, i.e., drought-tolerant and drought-sensitive was also examined under different rates of vermicompost and drought stress. We hypothesized that the application of rice straw vermicompost enriched with cellulolytic microbes could mitigate the deleterious effects of drought stress on wheat seedling performance.

2 MATERIALS AND METHODS

2.1 Experimental Site and Plant Material

The study site was located at the student research farm of the Department of Agronomy, Faculty of Agriculture, University of Agriculture, Faisalabad (Latitude = 31°-04′ N, longitude = 73°-06′ E, Altitude = 184.4 m) where a pot experiment was conducted in the wire-house during winter-2020. Soil-filled plastic pots were used for this work in which the seed of wheat cultivars viz. Faisalabad-08 (drought-tolerant) and Galaxy-13 (drought-sensitive), procured from the Directorate of Farms, University of Agriculture, Faisalabad, and the Wheat Research Institute, Ayub Agricultural Research Institute, Faisalabad, respectively, were sown.

2.2 Preparation of Vermicompost Enrichment With Cellulolytic Microbes

In this study, *Eisenia fetida* (an epigeic species), the most used earthworm for vermicomposting, was used as the test species. To prepare the best vermi-fertilizer with good characteristics of enhanced nutrient availability and functional microbiota with a high reproduction rate, cellulose-degrading bacteria were added as inoculants. These bacteria were isolated from the gut of tested earthworms by using the protocol of Shankar *et al.* (2011) and Goteti *et al.* (2013). To screen the active bacteria, they were isolated in half-nutrient agar media by using a serial dilution method at 28 ± 1°C. Out of 100, only 8 strains were found to be active for cellulose degradation and the most active strain C-21 (**Figure 3**) was cultured in a large quantity in the broth media. It was then inoculated with the pre-composting material. The fully prepared vermicompost was sieved and applied to the wheat crop (**Figure 1**).

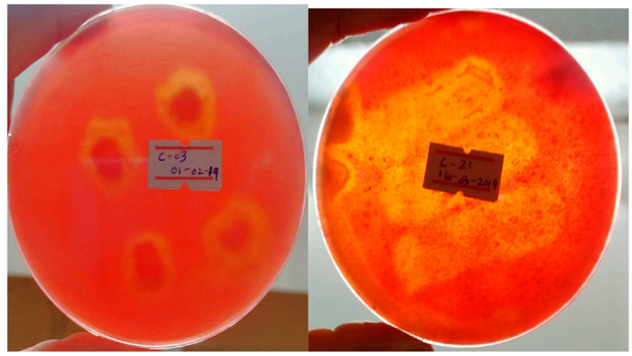

FIGURE 1 | The detection of cellulase activity of the tested strains C-03 and C-21.

2.3 Analysis of Raw Materials and Vermicompost

The potential of hydrogen (pH), electrical conductivity (EC, dSm^{-1}), ash (%), N, P, K, Ca, Mg, Fe, S contents, and heavy metals concentrations (i.e., cadmium, nickel, lead, mercury, and chromium) in raw material (rice–straw), rice straw vermicompost and cellulose-enriched vermicompost were determined according to the prescribed standard protocols for each. Results are shown in **Table 1**.

2.4 Soil Analysis

To fill the pots, soil from the top layer (0–15 cm) was collected from the student research farm area of the Department of Agronomy, University of Agriculture, Faisalabad. It was first analyzed for the aforementioned characteristics from the Soil and Water Testing Laboratory, Ayub Agricultural Research Institute, Faisalabad. The pots were thereafter filled with this soil. The physico-chemical properties of the soil are presented in **Table 2**.

2.5 Meteorological Data

During the growth season of crops (October 2020–January 2021), weather data (**Figure 2**) was collected from the meteorological observatory located near the experimental trial.

2.6 Crop Husbandry and Treatments

Wheat seeds of both cultivars were sown in pots (having a measurement of 20 cm × 20 cm filled with 5 kg of soil) during the first week of October 2020. For each treatment, a dose of NP to be applied per kg was calculated and then applied at 60: 57 mg kg^{-1} soil, respectively. Fifteen (15) seeds of each cultivar were sown at uniform depth and distance. After complete emergence, ten seedlings were kept for further experimentation. All other practices were kept uniform for each treatment of the experiment. A drought was imposed by maintaining field capacity (FC), and three treatments were as 70%

TABLE 1 | Analysis of raw material, vermicompost, and cellulolytic microbe-enriched vermicompost.

Treatments	pH	EC (dS m^{-1})	Ash (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Rice straw	7.81	4.32	26.00	0.32	0.13	0.26	1.19	0.26
Rice straw vermicompost	7.09	2.61	32.66	0.99	0.62	0.94	3.37	0.68
Rice straw + microbial strains vermicompost	6.51	2.56	40.50	1.25	0.92	1.45	4.55	0.86
—	Fe (%)	S (%)	Cd (ppm)	Ni (ppm)	Pb (ppm)	Hg (ppm)	Cr (ppm)	Sn (ppm)
Rice straw	0.19	0.14	0.96	20.00	49.00	2.51	20.00	0.35
Rice straw vermicompost	0.34	0.29	0.45	9.00	14.00	1.26	9.50	0.12
Rice straw + microbial strains vermicompost	0.44	0.42	0.17	7.00	11.00	0.87	6.00	0.09

EC, electric conductivity; N, nitrogen, P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; Fe, iron; S, sulphur; Cd, cadmium; Ni, nickel; Pb, lead; Hg, mercury; Cr, chromium; Sn, tin.

TABLE 2 | Physico-chemical characteristics of the experimental soil.

Characteristics	Quantity (Status)
pH (1:25)	8.6 (basic)
EC (1:25) ds m^{-1}	1.73 (medium)
Ex. Na (mmole 100 g^{-1} soil)	2.58 (high)
Organic matter (%)	1.34 (low)
Nitrogen (%)	0.069 (low)
Available P (ppm)	33 (very low)
Exchangeable K (ppm)	340 (very high)
Texture by feel method	Clay loam

FC (no drought), 45% FC (mild drought), and 30% FC (severe drought). Cellulolytic rice vermicompost was applied as soil application with four application rates: control (VT_0), 4 t ha^{-1} (VT_1), 6 t ha^{-1} (VT_3), and 8 t ha^{-1} (VT_4).

Drought was imposed at 25 days after sowing. After stress imposition, soil moisture of each experimental pot was determined daily where a soil moisture meter (TZS-W) was installed to measure the moisture content. In each pot, water losses were reimbursed by adding water (in measured amount) to achieve the desired level of FC. Plant samples, from each replicated pot, were collected after 35 days of stress imposition for ascertaining various morpho-physiological (including seedlings growth and leaf- and water-potentials) and biochemical attributes. The study was laid out under factorial arrangements of a completely randomized design where each treatment had three replications under a glasshouse environment.

2.7 Data Recording

2.7.1 Morphological Growth

Plants from each replication were harvested and divided into above- and below-ground parts. A meter scale was used to measure the root and shoot length and the leaf width. Seedling (root- and shoot-) fresh weights, just after harvesting, were recorded by using an electrical balance. Later, in order to ascertain the dry weights of root and shoot, these were first dried under shade and then in an electric oven at 70°C for 72 h till constant weight. The weight was recorded using an electrical balance. Total number of leaves were counted and averaged thereof.

2.7.2 Physiological Attributes

2.7.2.1 Water Potential (-MPa, Ψ_w)

The water potential was quantified at the booting stage. Firstly, the fully emerged flag leaf was incised, and then the water potential apparatus (model Chas-W. Cook and Sons. Birmingham B 42, ITT England) was used to measure the leaf

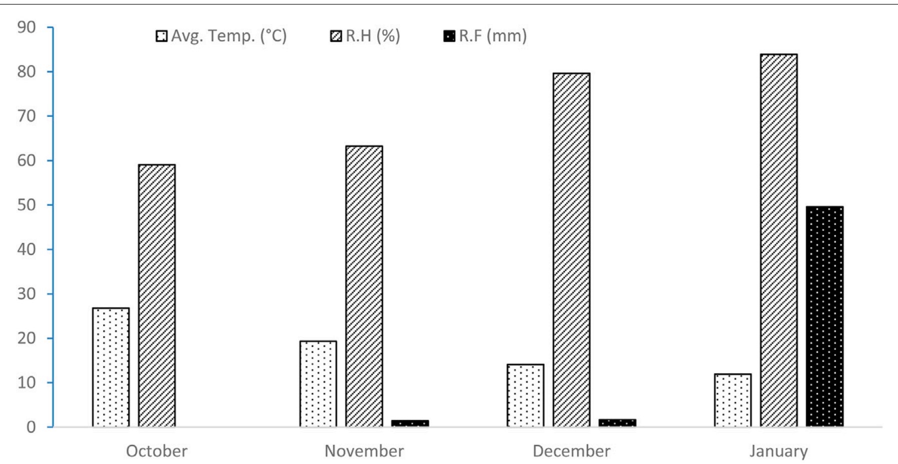

FIGURE 2 | Average temperature (Avg. temp., °C), relative humidity (RH, %), and rainfall (RF, mm) during the growing season of wheat.

water potential by following the protocol of Scholander et al. (1964). With the cut surface popping out of the opening, a single leaf (flag leaf was used for this measurement) was sealed in a pressure chamber and pressure-filled gas was exerted to the leaf till the xylem components became visible on the cut section. The sampling was carried out between 6.00 and 8.00 a.m. to avoid evaporative losses. Three measurements were taken from each treatment and averaged thereof.

2.7.2.2 Leaf Osmotic Potential (-MPa, Ψs)

To determine the leaf osmotic potential, at first, fresh leaves were harvested and frozen for 7 days at -20°C. Then, the sap of these leaves was extracted and used directly to assess the osmotic potential by using an osmometer (Wescor-5500).

2.7.2.3 Turgor Pressure (MPa, Ψp)

The difference of water- and osmotic-potential was measured as turgor pressure.

$$\Psi p = \Psi w - \Psi s$$

2.7.2.4 Canopy Temperature, Photosynthesis, and Transpiration Rates

Canopy temperature, an indicator of energy emitted by wheat plants, was measured by using IRIS infrared temperature sensors. Furthermore, IRGA-infrared gas analyzer was used to measure the photosynthesis and transpiration rates, following the procedure of Singh *et al.* (2018) and Rosolem *et al.* (2019) where five measurements were taken. An average value was used thereafter.

2.7.2.5 Stomatal and Sub-Stomatal Conductance (Ci)

Stomatal conductance, an indicator of leaf water status and the degree of stomatal opening, was measured using an open system LCA-4 ADC portable infrared gas analyzer (Analytical Development Company, Hoddeson, England) with the following adjustments: leaf surface area and ambient CO_2 concentration (Cref) of 6.25 cm^2 and 371 μmol mol^{-1}, respectively. The temperature of the leaf chamber (Tch) varying from 25 ± 3°C, gas flow rate and molar gas flow rate (U) of chamber (v) of 296 ml min^{-1} and 400 μmol s^{-1}, respectively, and an ambient pressure (P) of 97.95 kPa and PAR (Q_{leaf}) at leaf surface of 770 μmol m^{-2} s^{-1} were also adjusted and then, the measurements were made on a third leaf from the top (young fully emerged leaf) of each plant. The fully expanded leaves were used to determine the Ci, and measurements were taken by using a CIRAS-2 (PP system®) portable gas exchange system connected to a gas exchange chamber (Parkinson Leaf Cuvette).

2.8 Statistical Analysis

All accumulated data as a mean of three replicates were tested by Fisher's analysis of variance technique. The Tukey's honest significance test was used to test the comparative significance of treatments, including drought, cellulolytic vermicompost and their interaction, with the help of Statistix version 8.1 (Analytical Software ©, 1985–2005), according to Steel *et al.* (1997).

3 RESULTS

3.1 Morphological Growth

As shown in **Table 3** and **Figure 3**, wheat plants were adversely affected by moderate and severe drought; hence, lower seedling length and weights were recorded as compared to well-watered conditions in both cultivars. Among cultivars, Galaxy-13, being susceptible to drought, demonstrated more weight and growth loss than Faisalabad-08. Cellulolytic microbe-enriched rice straw vermicompost significantly increased the seedling length and their weights under control, and drought stress conditions where the values were increased with the increasing rate of vermicompost, and maximum values were recorded for VT_2 treatment under moderate, severe droughts as well as in well-watered conditions of both cultivars. Under severe drought, VT_2 treatment increased the root length by 18.51 and 26.14%, shoot length by 14.02 and 15.67%, root fresh weight by 21.67 and 15.16%, shoot fresh weight by 18.34 and 22.91%, root dry weight by 28.20 and 0.37%, shoot dry weight by 24.19 and 28%, and maximum leaf width by 11.17 and 22.53% in Faislabad-08 and Galaxy-13, respectively, compared with control.

3.2 Physiological Attributes

Drought stress significantly increased the leaf water and osmotic potentials and canopy temperature while it decreased the turgor potential, photosynthetic and transpiration rates, stomatal conductance, and sub-stomatal CO_2 concentration in both wheat cultivars (**Figure 4** and **Table 4**). Among wheat cultivars, Faisalabad-08 performed better than Galaxy-13 under well-watered and drought conditions. Soil-applied cellulolytic microbe-enriched rice straw vermicompost significantly and positively affected the physiological traits of wheat cultivars under various drought levels where VT_2 treatment (vermicompost application at 6 t ha^{-1}) performed better than other treatments. Under severe drought stress, VT_2 treatment maximum increased the leaf water potential by 6.36 and 3.36%, leaf osmotic potential by 1.74 and 1.68%, and decreased the canopy temperature by 6.95 and 7.89% and increased the turgor potential by 4.83 and 3.36%, photosynthetic rate by 18.59 and 26.42%, transpiration rate by 18.45 and 19.48%, stomatal conductance by 24.29 and 33.46%, and sub-stomatal CO_2 concentration by 5.56 and 8.65% in Faislabad-08 and Galaxy-13, respectively, compared with control (**Figure 4**).

4 DISCUSSION

Results of the experiment highlighted the positive role of cellulolytic microbe-enriched rice straw vermicompost through soil application to cope with drought stress. The morphological and physiological attributes were significantly reduced under moderate and severe drought stress. However, soil application

TABLE 3 | Mean sum of squares regarding the effect of soil-applied cellulolytic microbe-enriched rice straw vermicompost on the morphological growth of wheat cultivars under different drought levels.

SOV	DF	Root Length (cm)	Shoot Length (cm)	Root Fresh Weight (g)	Shoot Fresh Weight (g)	Root Dry Weight (g)	Shoot Dry Weight (g)	Maximum Leaf Width (mm)	Number of Leaves
Drought stress (DS)	2	1101.39**	2186.79**	38.98**	155.17**	1.85**	2.70**	480.78**	38.09**
Vermicompost (VT)	3	71.57**	289**	2.56**	14.07**	0.07**	0.20**	31.78**	4.05**
Wheat (W)	1	112.50**	122.72**	5.01**	8.86**	0.08**	0.01^{ns}	25.68**	0.68*
DS×VT	6	1.46*	25.74**	0.01**	0.52**	0.00**	0.03^{ns}	1.07**	0.85**
DS×W	2	28.17**	72.68**	1.61**	5.20**	0.03**	0.18**	7.65**	0.68*
VT×W	3	0.09^{ns}	0.61^{ns}	0.01^{ns}	0.19*	0.00^{ns}	0.01^{ns}	0.02^{ns}	0.16^{ns}
DS×VT×W	6	0.09^{ns}	0.85^{ns}	0.01^{ns}	0.13^{ns}	0.00^{ns}	0.02^{ns}	0.04^{ns}	0.32^{ns}
Error	46	0.65	2.10	0.00	0.06	0.00	0.02	0.21	0.16

*= p≤ *0.05,* **p *= 0.01, ns = no significant.*

of vermicompost significantly ameliorated the drought stress by improving the morphological and physiological parameters of wheat cultivars. Soil-applied vermicompost improved the seedling growth and physiological attributes in tested wheat cultivars, including drought-susceptible and drought-tolerant, under well-watered as well as water-stress conditions. The maximum improvement was observed for VT_2 treatment in which vermicompost was applied at $6\ t\ ha^{-1}$. Similar findings were reported in previous studies of Bellitürk *et al.* (2020), in which authors have reported that vermicompost significantly increased the emergence and growth in wheat. Similar findings were also reported for other field crops, for example, in maize (Aslam et al., 2020) and some grass species, i.e., *Cenchrus ciliaris* (buffel grass), *Panicum antidotale* (blue panicgrass), and *Echinochloa crusgalli* (barnyard grass) (Amiri et al., 2017).

Drought stress influences morphological traits, including seedling growth of major field grown crops, for example, wheat (Ahmad et al., 2019), rice (Farooq et al., 2009a; Kim et al., 2020), and maize (Osakabe et al., 2014; Mehmood et al., 2021). It is evident from the results of this experiment that the root and shoot, fresh as well as their dry weights, were significantly ($p \leq 0.05$) and negatively affected by drought treatments, including moderate (45% FC) and severe drought (30% FC), and reduced values were recorded when compared with well-watered conditions (70% FC) in both wheat cultivars. Similar to that, previous studies also well established that drought stress or limited-water conditions caused a significant ($p \leq 0.05$) reduction in seedling fresh and dry weight of wheat crops (Patade et al., 2011; Ramegowda et al., 2014). In this work, our data also demonstrated a significant decline in seedling length in terms of root and shoot length under a limited supply of water, similar evidence was provided in a recent study by Kazeminasab *et al.* (2016) where drought caused a significant decline in the seedling growth of wheat. Among the cultivars used in this experiment, Galaxy-13, a drought-sensitive cultivar, showed more susceptibility to deficit water conditions due to more reduction in the number of leaves, leaf width, seedling length in terms of root and shoot length, and their fresh and dry weights in comparison to Faisalabad-08 (drought-tolerant cultivar) under drought conditions. However, under well-watered conditions (70% FC), Galaxy-13 showed better results than the Faisalabad-08. A similar trend was reported by Kaya and Higgs (2003) for wheat crops where tolerant cultivars performed better than the susceptible ones. Higher drought stress tolerance of Faisalabad-08 cultivar might be due to the expression of some drought stress-responsive genes that are involved in and controlled certain biochemical phenomena under the water shortage condition that included the maintenance of relative water contents, ionic balance, cell osmotic adjustment, photosynthesis, and the leaves' chlorophyll contents, membrane stability index, the activities of enzymatic antioxidant activities, and proline content (Jaleel et al., 2009; Gulen et al., 2018; and Mubarik et al., 2021).

Also at the physiological level, in our work, recorded data showed an increase in physiological traits (i.e., leaf-water-potential, solute-potential, turgor potential (hydrostatic pressure), photosynthetic rate, transpiration rate, and stomatal- and sub-stomatal-CO_2 concentrations) showed beneficial effects of vermicompost application under drought stress for the wheat crop. Vermicompost when applied to the soil-filled pots significantly mitigated the detrimental effects of drought stress by improving these traits of both cultivars in VT-containing pots as compared to the untreated control where vermicompost was not supplemented. A significant increment in these traits was also noticed under normal conditions, showing that vermicompost supplementation into the soil-filled pots enhanced the crop biomass production not only under drought stress but also under well-watered conditions. The results of our work were supported by a previous study by Nayyar and Gupta (2006), who observed a significant improvement in the physiological traits in barley under stress as well as control treatment. Similar findings were also depicted in a recent study by Mibei *et al.* (2016) for rice crop where the authors have recorded a significant improvement in the physiological traits under drought as well as under well-watered conditions. Vermicompost application increased all the aforementioned traits significantly in both cultivars under drought stress and well-watered conditions (**Figure 4**). However, a non-significant increase with an increase in soil-applied cellulolytic-enriched vermicompost rates was also recorded for some traits. Similar to that, previous studies also showed that drought-stressed plants had higher canopy temperatures than

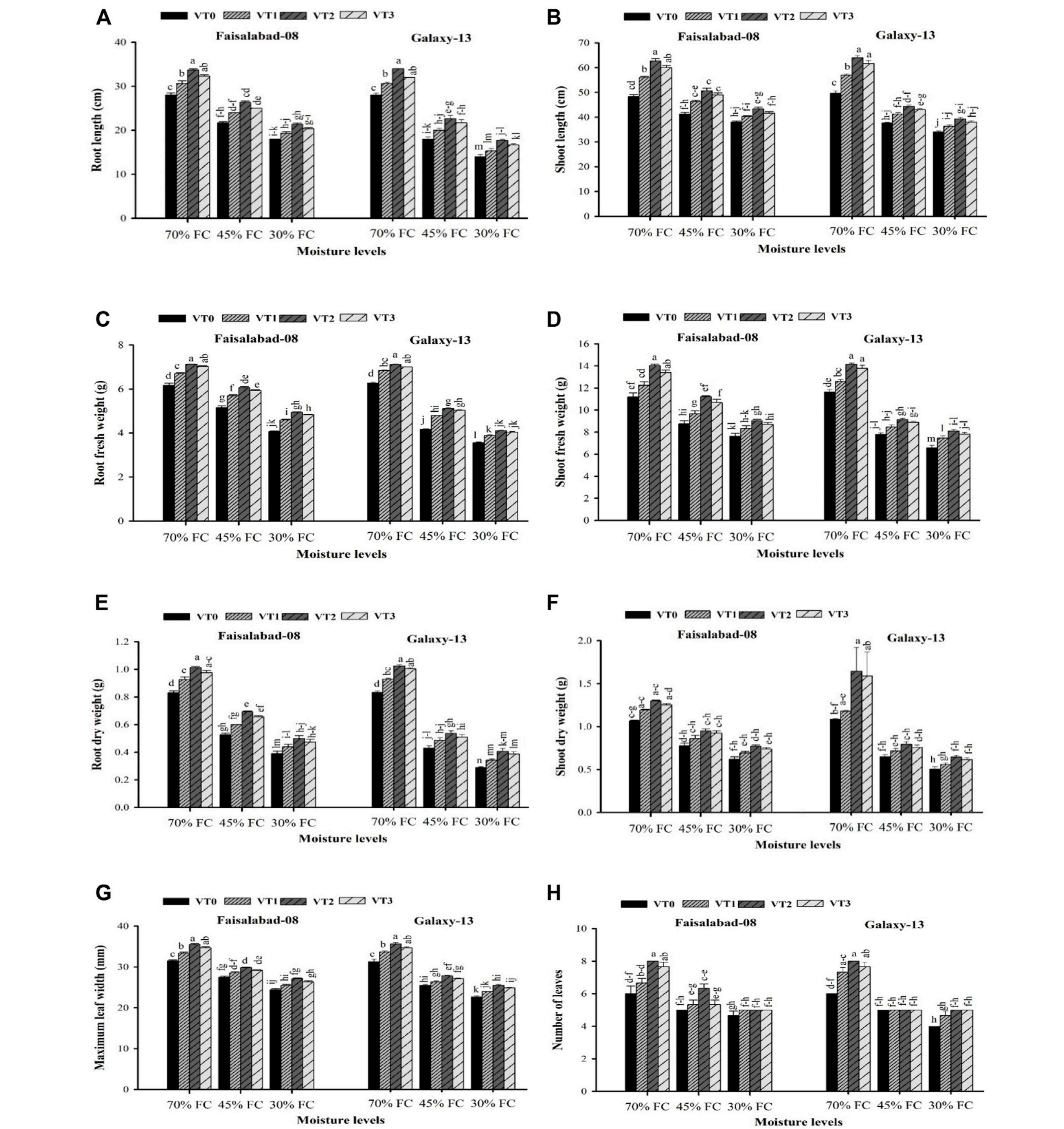

FIGURE 3 | Effect of soil-applied cellulolytic microbe-enriched rice straw vermicompost on root length **(A)**, shoot length **(B)**, root fresh weight **(C)**, shoot fresh weight **(D)**, root dry weight **(E)**, shoot dry weight **(F)**, maximum leaf width **(G),** and number of leaves **(H)** of the two wheat cultivars Faiasalabd-08 and Galaxy-13 under different drought levels, well-watered condition (70% field capacity-FC), moderate drought (45% FC), and severe drought (30% FC). Bars with different small letters show significant differences at a 5% probability level according to Tukey's HSD test.

non-stressed ones (Azarmi et al., 2008; Bowden et al., 2010; Cetinkaya et al., 2014; and Bai and Purcell, 2018). The highest canopy temperature was recorded in plants without vermicompost application under severe drought stress (30% FC) in both cultivars. Vermi-fertilizer decreased the canopy temperature in tomato plants (Aslam et al., 2020). In our study, a decrease in canopy temperature was recorded as a result of the vermicompost application (**Figure 4**).

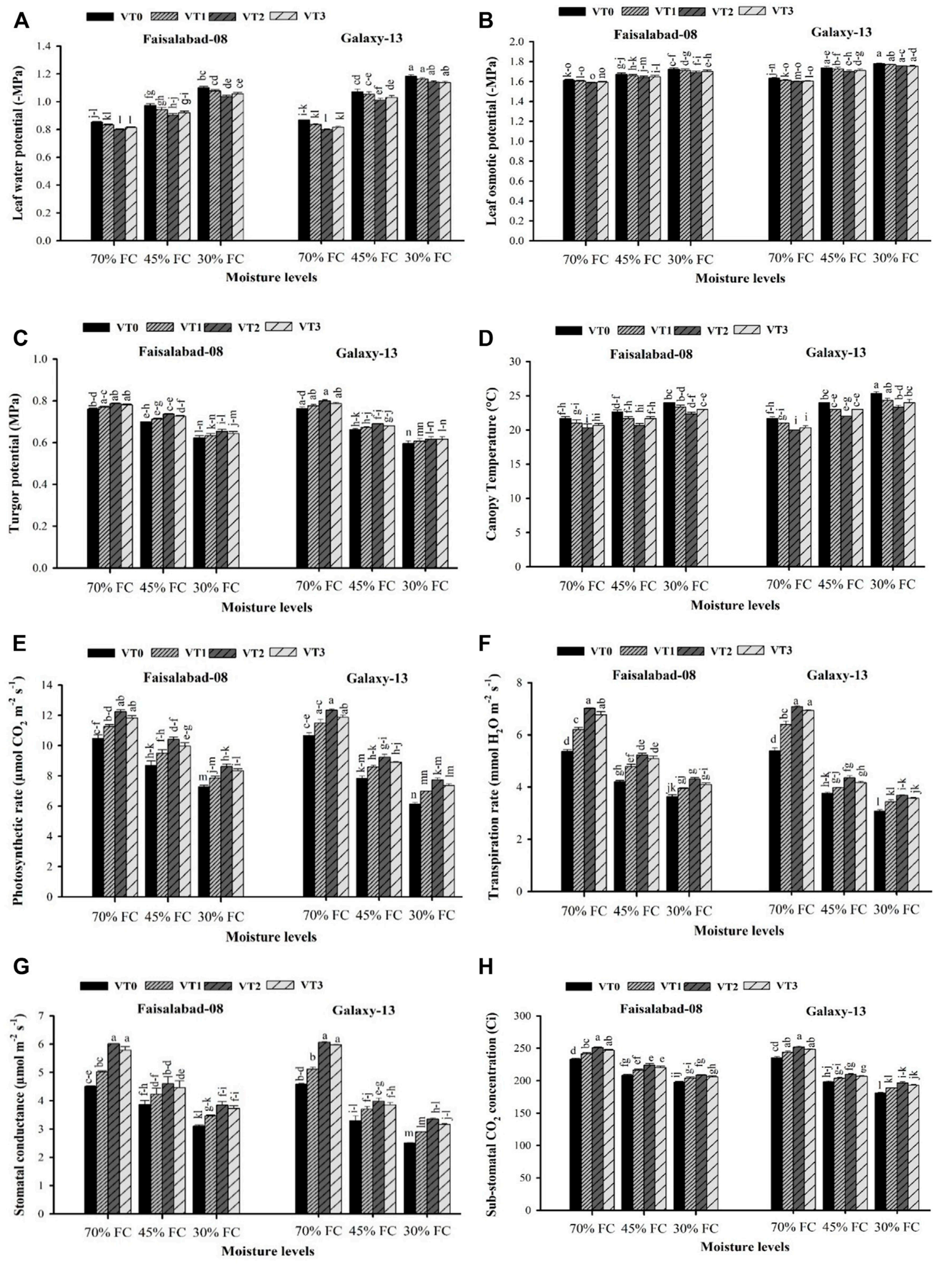

FIGURE 4 | Effect of soil-applied cellulolytic microbe-enriched rice straw vermicompost on leaf water potential **(A)**, leaf osmotic potential **(B)**, turgor potential **(C)**, canopy temperature **(D)**, photosynthetic rate **(E)**, transpiration rate **(F)**, stomatal conductance **(G)**, and sub-stomatal CO_2 concentration **(H)** of the two wheat cultivars Faislabad-08 and Galaxy-13 under different drought levels: well-watered condition (70% field capacity-FC), moderate drought (45% FC), and severe drought (30% FC). Bars with different small letters show significant differences at a 5% probability level according to Tukey's HSD test.

TABLE 4 | Mean sum of squares regarding the effect of soil-applied cellulolytic microbe-enriched rice straw vermicompost on the physiological attributes of wheat cultivars under different drought levels.

SOV	DF	Leaf Water Potential (Ψ_w) [-MPa]	Leaf Osmotic Potential (Ψs) [-MPa]	Turgor Potential (Ψp) [MPa]	Canopy Temperature (°C)	Photosynthetic Rate (*An*) (µmol CO_2 m^{-2} s^{-1})	Transpiration Rate (*E*) (mmol H_2O m^{-2} s^{-1})	Stomatal Conductance (*gs*) (µmol m^{-2} s^{-1})	Sub-stomatal CO_2 Concentration (C_i) [µmol CO_2 Mol air^{-1}]
Drought stress (DS)	2	0.48**	0.10**	0.14**	49.62**	96.28	45.96**	27.92**	14,062.50**
Vermicompost (VT)	3	0.01**	0.00**	0.00**	9.75**	8.27	3.73**	3.65**	712.80**
Wheat (W)	1	0.08**	0.03**	0.00**	0.12**	6.59	2.87**	2.10**	1258.30**
DS×VT	6	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.14^{ns}	0.01^{ns}	0.40**	0.30**	5.70^{ns}
DS×W	2	0.01**	0.00**	0.00**	3.87**	2.49	1.24**	0.90**	471.40**
VT×W	3	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.05^{ns}	0.02^{ns}	0.02^{ns}	0.00^{ns}	0.30^{ns}
DS×VT×W	6	0.00^{ns}	0.00^{ns}	0.00^{ns}	0.02^{ns}	0.02^{ns}	0.03^{ns}	0.00^{ns}	6.50^{ns}
Error	46	0.00	0.00	0.00	0.16	0.10	0.02	0.00	6.90

*= p≤ *0.05*, **p = *0.01*, *ns = no significant.*

5 CONCLUSION

In summary, the findings of this experiment indicate that the growth of both wheat cultivars, drought-sensitive and drought-tolerant, was significantly affected by drought stress in the pot experiment. Nonetheless, vermicompost application to soil-filled pots significantly and positively influenced the growth of both cultivars under well-watered as well as irrigation-deficient conditions, indicating its positive role as mineral nutrition for wheat. Among application rates, better results were achieved with the application of rice straw vermicompost at 6 t ha^{-1}. In addition, the results of this experiment also enabled us to select the most effective rate (6 t ha^{-1}) of vermicompost used against drought stress. Among the tested cultivars, Faisalabad-08 showed a better growth performance than Galaxy-13 under drought conditions and confirmed its drought tolerance.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Conceptualization: AA, ZA, and SH; data curation and formal analysis: AA; funding acquisition: SA, HK, AT, CBI; investigation: AA; methodology: AA and ZA; project administration: ZA, and SH; software: AA, and SHu; supervision and validation: ZA, and SH; roles/writing—original draft: AA; writing—review and editing: AK, AB, SH, SHu, TJ, UK. All authors have read and approved the final version of the manuscript.

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