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Impact of Growing Conditions and Water Stress on Turmeric

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ABSTRACT

This study investigated the effects of three growing conditions and four water levels on turmeric yield and quality parameters (*Curcuma longa* L.) under a greenhouse condition in Bati Akdeniz Agricultural Research Institute, Türkiye, in the years 2021 and 2022. The experiment was designed as a split-block design, with the main factor being three growing conditions (GC_1: 25% perlite +75% cocopeat, GC_2: 50% perlite + 50% peat, and GC_3: 75% peat + 25% zeolite). The sub factor was four irrigation water levels (IL_1:100%, IL_2: 75%, IL_3: 50%, and IL_4:25%) with three replications. Turmeric plants were irrigated based on daily solar radiation values reaching the greenhouse. It was found that irrigation levels affect plant height, tillers number, leaf width, leaf length, leaf area, rhizome weight, curcumin, total phenolic, and total flavonoid content. Fresh weight of rhizome for IL_1, IL_2, IL_3, and IL_4 treatments was measured as 426.9, 398.9, 308.6, and 253.1 g in 2021 and 608.0, 505.3, 380.0, and 219.7 g in 2022, respectively. It is concluded that decreasing irrigation levels has a positive effect on curcumin, total phenolic and flavonoid content, oil, ar-tumerone, alpha-tumerone, beta-tumerone, and alpha-zingiberene but had an adverse effect on rhizome weight, plant height, tillers number, and leaf area.

1. INTRODUCTION

Turmeric (*Curcuma longa* L.) is one of the world's most valuable and imperative spices. It is also commonly used as a coloring agent in the textile, food, and confectionery industries. In Indian traditional medicine, it is used as an anti-inflammatory, hepatoprotective, antitumor, and antiviral agent to heal wounds, prevent cancer, and relieve gastrointestinal and respiratory disorders (Nandakumar et al., 2022). It's cultivated throughout tropical Asian areas, particularly India, China, Indonesia, Jamaica, Peru, and Pakistan. Turmeric cultivation thrives both as a standalone crop and as an intercrop with coconut cultivation, particularly in regions with high potential like wet and middle zones. Traditionally cultivated turmeric has many local varieties and is known by village names (Salimath 2014; Nandakumar et al., 2022).

India has a unique position in the global spice market as the world leader in turmeric production, consumption, and exporting. It accounts for 78% of global production and 60% of global exports. In the year 2023, turmeric production was 1350000 tonnes, with an area and productivity of 369250 hectares. The global turmeric market size is forecast to be valued at USD 4 419.3 million. The growth pattern of the area, production, and productivity of turmeric over a period of time indicate the growing contribution of production to the area expansion and increased yield. The United States of America, United Kingdom, Australia, Saudi Arabia, and Canada are the major importers of turmeric (Sravani et al., 2023; Reddy, 2023). Market proximity is a significant factor in the competitive landscape of the global spice market. Türkiye proximity to the European market gives it a significant advantage over its Far Eastern competitors. Although there is no precise information on turmeric production in Türkiye, 28483 kg of turmeric was exported in 2023, generating an income of USD 113692 (EİB, 2023).

A substantial body of research has been conducted on the impact of climate change on agricultural products (Gonzalez-Zeas et al., 2014; Lionello et al., 2014; Chandio et al., 2020; Omar et al., 2021; Habib-ur-Rahman et al., 2022). In particular, researchers have highlighted the low yield of agricultural products, emphasizing the importance of creating new crop patterns. According to the projected climate change analysis in Türkiye, the air temperature is projected to increase by 2-5°C and precipitation is projected to decrease in some regions (Aydinsakir, 2023). In order to enhance and sustain agricultural productivity, it is vital to advance technologies and innovations that can mitigate environmentally and agriculturally sensitive climate fluctuations, as well as facilitate the development of novel cropping patterns. Plants are often exposed to adverse environmental conditions due to natural disasters and global climate change. The effects of environmental stress on plants can mainly reduce photosynthesis, chlorophyll content, water content, stomatal closure, and carbohydrate metabolism (Siddique et al., 2016; Sherin et al., 2022). Increased water stress due to climate change is one of the critical abiotic stresses causing most crop losses and can alter a plant at the morphological, anatomical, physiological, biochemical, and molecular levels (Seleiman et al., 2021). It also reduces photosynthetic efficiency by damaging the thylakoid membrane and reducing chlorophyll content (Song et al., 2010).

In Mediterranean countries such as Türkiye, where the climate is subtropical, adapting tropical plants could be considered a means of turning increasing temperatures into an opportunity. Once more, the necessity of controlled use of water resources, which is a consequence of global warming, has made it obligatory. Consequently, the cultivation of species that require a specific water consumption under controlled conditions will prevent the occurrence of excessive water consumption.

Swain et al. (2007) reported that irrigation is the greatest factor affecting crop growth, yield, and quality parameters among agronomic practices. Rathod et al. (2010) argued that soil moisture plays a vital role in turmeric cultivation. Producers often over-irrigate by increasing irrigation frequency and consequently the amount of water applied, which has a detrimental effect on applied nutrients, water, and soil properties. Venkatesha & Siddalingayya (2014) showed that upper soil moisture and nutrient uptake lead to greater growing factors as indicated by upper leaf area, plant height, and chlorophyll content at the top growing period and full dry matter at maturity, which could help in improving turmeric yield characteristics.

Some scientists informed effects of deficit irrigation water levels for turmeric. Numerous studies have demonstrated the positive impact of optimized irrigation regimes (Singte et al., 1997; Wiwatpinyo & Detpiratmongkol, 2008; Rathod et al., 2010; Mohamed et al., 2014; Kaur & Brar, 2016; Chitra et al., 2017; Ravindra et al., 2020; Tripathi et al., 2021; Santosh et al., 2021; Jayakumar et al., 2024), with weekly or controlled irrigation leading to enhanced fresh and dry rhizome weight, leaf width and height, leaf number, total carbohydrates, oil and curcumin content, number of leaves and tillers, height of the plant, leaf area, dry matter production and plant health.

The soilless culture systems, the most intensive production method in agriculture, are based on environmentally friendly technology, which can result in higher yields, even in areas with adverse growing conditions. Soilless systems can produce higher yields even in limited and unfavorable growing conditions. Water availability, nutrition, moisture, and soil aeration are key to plant growth in soilless culture systems (Tuzel et al., 2019). To avoid soil-borne bacterial diseases, turmeric production is moving towards soilless culture. The preferred substrates for turmeric production are those that provide good aeration and can retain moisture and nutrients (Kuehny et al., 2005). Anitha et al. (2022) argued that rhizome rot and other soil-borne diseases can have a detrimental effect on traditional crops, reducing yield, curcumin content, and other quality indicators. The key to its effectiveness in soilless culture is the maintenance of an almost constant water profile in the root medium. This means that growing soilless can automatically increase yield and quality. Abdullah et al. (2018) evaluated those three different growing conditions (C: sand and cocopeat, B: sand and burned rice husk, M: cocopeat, burned rice husk and sand) on rhizomes of *Curcuma alismatifolia* and they reported that rhizome yield was not affected by growing conditions. However, turmeric plants cultivated in M produced a maximum number of marketable rhizomes m^{-2} (54.5), the highest number of marketable rhizomes clump^{-1} (2.9), and a high number of storage roots rhizome^{-1} (8.9).

A substantial body of research has been conducted on turmeric's cultivation and biochemical composition. Nevertheless, no study has been identified in which all subjects were discussed. Furthermore, this study represents the inaugural investigation of its kind in Türkiye. Several studies about turmeric have been conducted around the world. However, no research on how water stress and growing conditions affect turmeric has been found in Türkiye. Therefore, the present study aimed to (i) assess the impact of water stress on turmeric, (ii) determine the influence of different soilless cultivation systems, and (iii) analyze the total phenolic and flavonoid content, as well as oil components, of turmeric grown under greenhouse conditions.

2. MATERIAL AND METHODS

Research site and climate

The research was carried out in a plastic unheated greenhouse (36°56′North latitude, 30°53′East longitude, and an altitude of 28 m above sea level) at the Bati Akdeniz Agricultural Research Institute (BATEM) in Antalya, Türkiye, in the years 2021 and 2022. Figure 1 shows the greenhouse's relative humidity and average temperature during the study period. Average relative humidity and temperature range from 13.4°C to 32.9°C and 28.6% to 83.8% in 2021. In 2022, temperatures and relative humidity fluctuated between 11.1°C and 34.9°C and 31.6% and 78.0%, respectively.

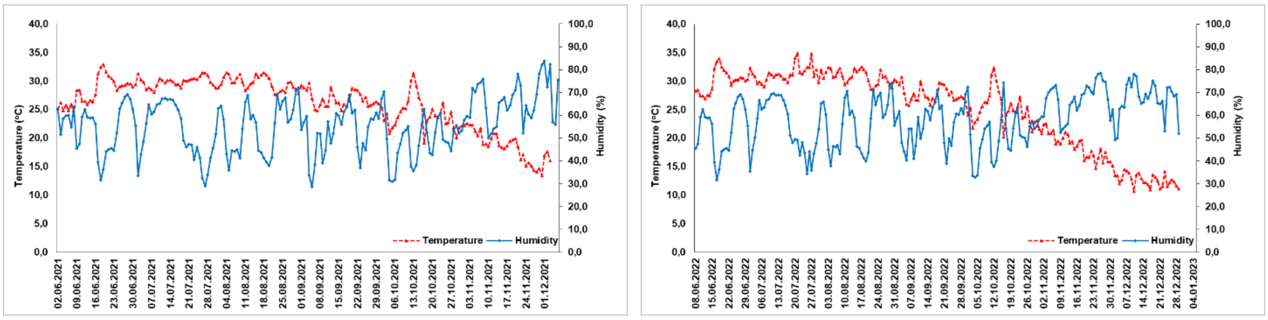

Figure 1. Average temperature and relative humidity measured inside greenhouse.

Treatments and statistical design

The study involved three growing conditions, each consisting of a volumetric mixture of cocopeat (C) and perlite (P) (GC_1: 25% C + 75% P), peat (Pe) and perlite (GC_2:50% Pe + 50% P), and zeolite (Z) and peat (GC_3:25% Z + 75% Pe). The four irrigation water amounts (IL_1:100%, IL_2: 75%, IL_3: 50%, and IL_4:25%) were also included. Table 1 provides an overview of the properties of the various substrates used in the study. The various growing conditions used in the main plot were arranged in a split block design, while the irrigation levels were arranged in subplot form. The design was a 4 × 3 split plot with three replications of each treatment.

Table 1. Some properties of different growing conditions used in study.

Properties	GC_1	GC_2	GC_3
pH	5.50	6.10	6.20
Electrical Conductivity (micromhos cm^{-1})	940.00	445.00	340.00
Humidity (%)	14.60	10.30	18.50
Dry Matter (%)	85.40	89.70	81.50
Organic Matter (%)	29.20	78.80	66.80
Ash (%)	70.80	21.20	33.20
Total Nitrogen (%)	0.17	0.83	0.52
Carbon (%)	16.90	45.70	38.80
Carbon/Nitrogen	100.30	54.80	74.90
Total Iron (ppm)	929.00	844.00	1593.00
Total Manganese (ppm)	14.00	27.00	28.00
Total Zinc (ppm)	6.00	11.00	7.00
Total Copper (ppm)	0.00	8.00	6.00

GC_1: 25% Cocopeat + 75% Perlite, GC_2:50% Peat + 50% Perlite, and GC_3:25% Zeolite + 75% Perlite

Planting and growing conditions

Turmeric rhizomes obtained from genotype 99-5 in the gene pool of BATEM were used as plant material. Turmeric seedlings were implanted in 2.43 m^3 polypropylene bags (12.0 m length × 0.45 m width × 0.45 m depth) with one row (0.45 m × 0.45 m spacing, 5 plants m^{-2}) on the 2nd of June 2021 and on the 8th of June 2022 in the experiment. The distance between two adjacent polypropylene bags was set at 0.5 m. Three different types of growing conditions were placed in the polypropylene bags. There were 27 plants in each of the polypropylene bags. To collect the drainage water, the polypropylene bags were placed in a gutter.

Managing nutrients and irrigation

Hoagland and Arnon's (1950) nutrient solution was used to irrigate all treatments ensuring balanced nutrient levels. A nutrient solution tank (1,000 liters) and pump were installed at each irrigation level. Nitric acid was added to the solution in each irrigation tank to adjust the pH to between 5.5 and 6.0. All of the treatments were irrigated at the same time of day. The plants were irrigated using a drip irrigation system with a capacity of 1.6 L h^{-1} and a pressure of 0.1 MPa. The solar radiation received in the greenhouse was used to determine the irrigation frequency. The solar radiation received was used to calculate the amount of water applied. A digital timer was used to schedule the irrigation automatically. The irrigation water application rate was determined by the radiation-based evapotranspiration method. For this purpose, the four irrigation rates of 100% (IL_1), 75% (IL_2), 50% (IL_3), and 25% (IL_4) times the standard rate were applied using a solar radiation device located in the greenhouse. The following equation (Guyot, 1998) was used to calculate the irrigation water amount (L).

$$I = \frac{R_i}{\lambda} \times A \quad (1)$$

Where I is the amount of irrigation water (L), R_i is the received solar radiation inside the greenhouse (MJ m^{-2} day^{-1}), λ is the latent heat of water vaporization (MJ kg^{-1}), and A is the polypropylene bag area (m^2).

The following equation was used to calculate the water consumption of the turmeric plant (L $plant^{-1}$).

$$WC = \frac{I-D}{PN} \quad (2)$$

where WC is the water consumption (L $plant^{-1}$), I is the amount of the irrigation water (L), D is the drainage water (L) and PN is the number of plants inside the polypropylene bags.

Harvest and measurements

Harvesting was done when the leaves turned yellow and started to dry 50%. On 6 December 2021 and 5 January 2023, 20 plants were harvested from each plot. Fresh rhizome weight was recorded after cleaning the rhizomes under running water. Dry weight was determined after drying in an oven at 40°C until a constant weight was achieved. Plant height and tiller number were measured at harvest for 20 selected plants per plot.

Analysis of total phenolic, flavonoid, and essential oil

The chemical analyses were conducted to determine the effects of water stress and growing media on key bioactive compounds in turmeric, which are linked to its nutritional and medicinal properties. The turmeric rhizomes were dried in an air-circulated oven (Venticell-404 Standard, MMM Group, Germany) at 40°C (7.272 m^3 h^{-1}) until humidity reached about 10% and ground before the extraction process. The grinding was carried out in a grinding machine (Retsch Grindomix, GM 200) at 10,000 rpm for 1 minute.

The total phenolic content of the samples was determined by Folin-Ciocalteu solution with some adjustments in the method proposed by Spanos & Wrolstad (1992). Accordingly, 900 µL distilled water, 5 mL 0.1 N Folin-Ciocalteau solution, and 4 mL 7.5% sodium bicarbonate (Na_2CO_3) solution was added to 100 µL sample extract, and the mixture was kept in the dark for 90 min. The absorbance of the mixture was measured in a spectrophotometer (Shimadzu UV 1800, Japan) at a wavelength of 765 nm. Total phenolic content was expressed as mg GAE (Gallic Acid Equivalent) g^{-1} dry matter.

The total flavonoid content of the sample extracts was determined spectrometrically by the method proposed by Zhishen et al. (1999). Accordingly, 4 mL of distilled water and 0.30 mL of 5% sodium nitrite ($NaNO_2$) solution were added to 1 mL of sample extract. After 5 min, 0.60 mL of 10% aluminum chloride ($AlCl_3$) solution and at the 6th min later 2 mL of 1 M sodium hydroxide (NaOH) solution were added to the mixture and the volume was completed to 10 mL with distilled water. Absorbance values were read in a spectrophotometer at 510 nm wavelength and the results were given as mg CE (Catechin Equivalent) g^{-1} dry matter.

For the determination of curcumin, the extraction process was carried out by revising the technique of Paulucci et al. (2013). Accordingly, 2.5 g of dried and ground turmeric powder was weighed and transferred to 50 mL falcon tubes. 15 mL of 70% ethanol-water mixture was added. After mixing in a vortex device, shaking was carried out in a temperature-controlled shaker at room temperature for 12 hours. The extracts, which were extracted and centrifuged, were first passed through 0.45 µm membrane filters and transferred to amber vials by diluting at appropriate ratios in order to be injected into the device to be analyzed. The amount of curcumin was determined using gas chromatography (Agilent 1290) and mass spectrometry (6430 Triple Quadropole) (LC-MS/MS) on a Zorbax RRHD Eclipse Plus C18 column (3µm2.1×100mm) (Fischer et al., 2011). The first step was to prepare calibration solutions of curcumin. The parameters of the MS (polarity, fragmentation voltage, fragmentation ions, collision energies) were determined. Using the calibration solutions and MS parameters, the calibration curve of curcumin was constructed. Calibration curves were used for quantification.

The essential oils of turmeric used in the study were obtained using the hydro-distillation method in the Clevenger apparatus. Approximately 20 g of dry powder was added to 200 ml of distilled water and distillation was carried out for 2 hours and the essential oil ratio was calculated using the amount of essential oil obtained (Anonymous, 2011). To determine the constituents of the essential oils obtained, the essential oils were diluted 1:100 with hexane.

Analysis of the essential oil components was performed by GC/GC-MS (gas chromatography (Agilent 7890A) - mass detector (Agilent 5975C)) using a capillary column (HP Innowax Capillary; 60.0 m × 0.25 mm × 0.25 µm). Helium gas was used as the carrier gas for analysis at a flow rate of 0.8 ml min^{-1}, and samples were injected into the instrument at a 40:1 split ratio in 1 µL injection volume. The injector system temperature was maintained at 250°C. The column temperature program was programmed as 60°C (10 min), 60°C to 220°C at 4°C min^{-1} and 220°C (10 min). Using this temperature program, the total analysis time was 60 minutes. The scan range (m/z) for mass detection was 35-450 atomic mass units and the electron bombardment ionization was 70 eV. The results of the Wiley and Oil Adams libraries were used to identify the essential oil components. The percentages of the components obtained were determined using the FID detector and the components were identified using the MS detector (Uysal Bayar & Cinar, 2021).

Statistical analyses

36 experimental plots were used in a split block design with three growing media (main plot factor) and four irrigation levels (subplot factor), replicated three times for each treatment. During the experiment, the fresh and dry weight of the rhizome (g $plant^{-1}$), the plant height (cm), leaf length (cm), leaf width (cm), leaf area per plant (cm^{-2}), the tillers number (per plant), the evapotranspiration (L $plant^{-1}$), the essential oil, phenolic and flavonoid content (%), and essential oil compounds were determined. SPSS Statistics Program (SPSS Inc., Chicago, IL, USA) was used for data analysis and LSD test was used to compare significant differences between averages ($p < 0.05$) (Dean et al., 2017).

3. RESULTS AND DISCUSSION

Plant water consumption

The daily average solar radiation and the plant water consumption of the turmeric are shown in Fig. 2. During the 2021 and 2022 growing seasons, solar radiation ranged from 1.98 to 12.00 MJ m^{-2} day^{-1}, and 0.18 to 17.97 MJ m^{-2} day^{-1}, respectively. The highest solar radiation was measured on the 14th of June 2021 and on the 16th of June 2022. Turmeric is considered to be a shade-loving plant. Therefore, excessive solar radiation in a region where latitude, climate, and weather patterns have a strong influence on the amount of sunlight, could limit the production of turmeric. Common signs of radiation stress in turmeric plants include leaf-tip burn and stunting, which have a direct impact on the rhizome yield.

Studies have shown that growing turmeric under shade or greenhouse improves leaf area, nutrient uptake, and photosynthetic rate, and reduces leaf temperature and transpiration, ultimately improving plant growth and yield (Hossain et al., 2009; Nair, 2019; Sharangi et al., 2022).

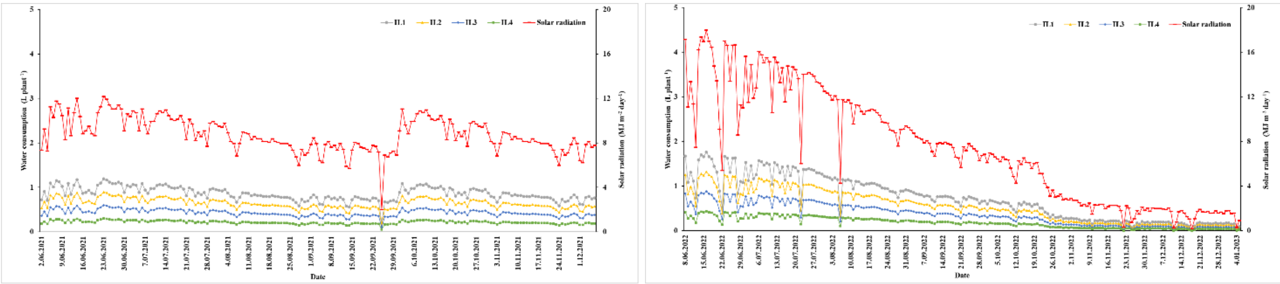

Figure 2. Daily solar radiation and cumulative water consumption.

Water consumption per plant ranged from 40.3 to 161.2 L (201 to 806 mm) in 2021 and from 63.2 to 253.0 L (316 to 1265 mm) in 2022. Rathod et al. (2010) and Sadarunnisa et al. (2010) showed improved turmeric growth and yield by using improved irrigation scheduling. Chitra et al. (2017) report that water is the major limiting factor of curcuma production, arguing that the timing and intensity of water stress during the growing period reduces photosynthesis and stunts growth, significantly reducing yield and yield parameters. Kaur & Brar (2016) reported that irrigation water applied between 515 and 936 mm was conducive to turmeric crop development, yielding the highest total and cured rhizome yields, the highest average mass for export-grade rhizomes and the lowest small rhizome production. Ravindra et al. (2020) measured that the irrigation water amount of turmeric varied between 1487 and 1835 mm in open field and surface irrigation conditions, while the irrigation water amount of turmeric varied between 498 and 706 mm in open field and drip irrigation conditions. Somdutt et al. (2022) determined the influence of deficit irrigation amounts (I_1: 100% PE, I_2: 80% PE, I_3: 60% PE and I_4: surface irrigated control plot) on turmeric and found that water consumption was 365.8, 322.6, 279.3 and 583.4 mm, respectively.

Effects of treatments on morphological parameters

The results with respect to yield and quality of turmeric, together with statistical analysis, are presented in Table 2. Considering the interactions, it was found that leaf width, were statistically different at $p < 0.05$ in 2021 whereas plant height and leaf length were statistically different at $p < 0.05$ and $p < 0.01$ in 2022. The average the plant height, tiller number, leaf length and width, and leaf area of turmeric plants under different growing conditions and irrigation levels and their variance analysis were given in Table 2. The different irrigation levels in both years influenced the plant height, tiller number, leaf length, and width significantly ($p < 0.01$). There is a significant effect of growing conditions ($p < 0.05$) and irrigation level ($p < 0.01$) on plant height in both experimental years, but growing conditions × irrigation level interaction was not significant in 2021. Plant heights determined under irrigation levels were 117.3, 104.8, 91.8, and 75.4 cm for IL_1, IL_2, IL_3, and IL_4, respectively in 2021 while 108.7, 89.8, 80.5, and 72.8 cm for IL_1, IL_2, IL_3, and IL_4, respectively in 2022 (Table 3). The highest plant height was achieved by the GC_1IL_1 treatment in 2021 and 2022, depending on the interaction between growing conditions and irrigation level. The highest plant height was achieved in the GC_1IL_1 treatment at 130.0 and 130.2 cm, while the lowest plant height was achieved in the GC_3IL_4 treatment at 73.7 and 56.0 cm in the study. With increasing water stress, plant height decreased. Plant height is one of the most important parameters affecting plant weight and is a good indicator of the effect of water stress on the plant. Water stress, an abiotic stress, causes an increase in root zone osmolality, which inhibits root uptake of water and plant nutrients (Sonneveld et al., 1999). Sadarunnisa et al. (2010) observed significantly higher plant height of turmeric on drip irrigation than on check-basin irrigation, leading to an increase of 91.7% in the benefit/cost ratio for the former compared to the latter. Mohamed et al. (2014) studied three treatments of irrigation spacing (weekly, bi-weekly, and tri-weekly) for *C. aromatica* and *C. domestica* and found that plant heights were 91.7, 88.3, and 60.3 cm for *C. aromatica* and 81.7, 66.7, and 46.7 cm for *C. domestica*, respectively, in Egypt. Tripathi et al. (2021) determined the plant height of turmeric (*Curcuma longa* L.) as 126.1, 128.8, 127.1, and 115.8 cm under 0.6, 0.9, 1.2 IW/CPE and rainfed conditions in West Bengal, India, respectively. On the other hand, Kaur & Brar (2016) reported the plant height of turmeric (*Curcuma longa* L.) as 29.6, 31.9, 33.4, and 35.4 cm under 0.6, 0.8, 1.0, and 1.2 IW/CPE in Ludhiana, India, respectively. Chitra et al. (2017) determined the seven different irrigation programs on *Curcuma longa* L. var. CO_2 and they measured plant height as 90.7, 93.3, 95.6, 84.1, 86.2, 79.3, and 93.4 cm for surface irrigation, 0.09 irrigation water/cumulative pan evaporation, drip once in a day at 80% PE, drip once in two days at 80% PE, drip once in a day at 60% PE, drip once in two days at 60% PE, drip once in a day at 40% PE, and drip once in two days at 40% PE in Coimbatore, India, respectively.

Table 2. Variance analysis results for yield and quality of turmeric.

Source of variation	df	2021														
		PH	TN	LW	LL	LA	FW	DW	C	TP	TF	EO	T	AT	BT	AZ
Replication	2	250.1	2.53	4.23	63.2	5311416	15257.2	203.3	0.03	0.65	3.78	0.03	40.4	19.3	20.46	3.96
Growing Conditions (GC)	2	1234.3*	2.03^{NS}	13.06**	110*	23002082**	150182**	10127.1**	0.77**	0.71^{NS}	3.41**	10.58**	33.3*	17*	0.92^{NS}	1.91^{NS}
Error (GC)	4	505.7	1.53	0.52	23.7	2150103	24065.4	356.7	0.05	0.54	0.04	0.1	3	2	0.67	0.17
Irrigation Level (IL)	3	2896.2**	4.69**	22.64**	174.7**	6392465^{NS}	58114.7*	2945**	0.83**	2.17**	1.95*	4.45**	36.3**	42.8**	8.95*	7.57**
GC × IL	6	323.4^{NS}	0.58^{NS}	4.79*	14.8^{NS}	1609496^{NS}	8669^{NS}	577.4^{NS}	0.08^{NS}	0.47^{NS}	0.14^{NS}	0.19^{NS}	6.8^{NS}	1.5^{NS}	0.89^{NS}	0.47^{NS}
Error (GC × IL)	18	918.9	1.93	7.84	62	5533046	38441	2022.8	0.28	0.84	1.25	2.12	18.2	12.8	4.57	2.23
Total	35															

Source of variation	df	2022														
		PH	TN	LW	LL	LA	FW	DW	C	TP	TF	EO	T	AT	BT	AZ
Replication	2	158	3.8	3.47	3.4	23112410	15906.1	1160.4	0.02	13.29	22.56	3.47	19.7	115.26	4.02	27.23
Growing Conditions (GC)	2	411.4*	2.93^{NS}	4.07^{NS}	24.4^{NS}	71258083^{NS}	110568.3*	6585.7**	0.13^{NS}	2.65^{NS}	4.27^{NS}	1.5^{NS}	20.52^{NS}	2.28^{NS}	1.52^{NS}	3.67^{NS}
Error (GC)	4	394.2	1.01	2.49	37.4	27744781	26261.6	1683.8	0.03	0.63	0.56	0.83	22.58	5.2	1.13	4.27
Irrigation Level (IL)	3	2150.2**	5.19**	30.58**	307.9**	329643804*	252260.9**	12334.3**	0.75**	2.63^{NS}	2.39*	5.7*	32.8*	15.8^{NS}	12.16**	8.81^{NS}
GC × IL	6	577.2*	0.28^{NS}	3.96^{NS}	63.5**	28803598^{NS}	42706.9^{NS}	2174.9^{NS}	0.03^{NS}	0.22^{NS}	0.2^{NS}	0.55^{NS}	7.67^{NS}	0.87^{NS}	1.67^{NS}	0.91^{NS}
Error (GC × IL)	18	742.9	2.04	8.27	88.8	85969007	80648.2	4251.7	0.17	2.56	3.78	1.98	18.54	18.15	3.65	6.52
Total	35															

PH: Plant height (cm), TN: Tillers number (number plant^{-1}), LW: Leaf width (cm), LL: Leaf length (cm), LA: Leaf area (cm^2), FW: Fresh weight (g), DW: Dry weight (g), Curcumin (%), TP: Total phenolic (mg GAE g^{-1}), TF: Total flavonoid (mg CE g^{-1}), EO: Essential oil content (%), T: ar-tumerone (%), AT: alpha-tumerone (%), BT: beta-tumerone (%), AZ: alpha-zingiberene (%)
NS: not significant, *: significant at p < 0.05, **: significant at p < 0.01.

Table 3. Means of plant height, tillers number, leaf width, leaf length, and leaf area determined in different growing conditions and irrigation levels.

Treatment	Years									
	2021					2022				
	PH	TN	LW	LL	LA	PH	TN	LW	LL	LA
Growing Conditions (GC)	12.92*	NS	1.05**	4.3*	1427**	11.43*	NS	NS	NS	NS
GC$_1$	105.0 a	3.3	6.0 a	42.2 a	6670. 0 a	88.5 ab	2.7	11.1	30.7	13713.0
GC$_2$	85.8 b	2.5	4.5 b	36.2 b	4067.6 b	81.8 b	2.0	10.3	33.4	10515.9
GC$_3$	101.2 a	3.2	4.0 b	39.0 ab	4549.5 b	93.5 a	2.9	9.9	32.9	15300.0
Irrigation Level (IL)	14.91**	0.96**	1.22**	4.97**	NS	13.20**	0.91**	1.25**	3.96**	4492.2**
IL$_1$	117.3 a	4.0 a	7.2 a	44.5 a	6305.1	108.7 a	3.4 a	12.2 a	38.9 a	20010.3 a
IL$_2$	104.8 ab	2.9 b	4.4 b	40.4 b	4996.3	89.8 b	2.9 ab	11.5 a	34.4 a	15560.4 b
IL$_3$	91.8 b	2.6 b	4.0 b	37.7 bc	4685.9	80.5 bc	2.1 bc	10.1 b	31.0 a	11306.8 bc
IL$_4$	75.4 c	2.3 b	3.7 b	34.0 c	4395.5	72.8 c	1.7 b	8.0 c	25.0 b	5827.9 c
GC×IL	NS	NS	2.09*	NS	NS	22.87*	NS	NS	6.85**	NS
GC$_1$IL$_1$	130.0	4.0	10.1 a	45.5	9133.6	130.2 a	3.5	13.5	43.8 a	21385.9
GC$_1$IL$_2$	122.0	3.0	5.6 bc	44.8	6285.4	90.0 bc	3.5	12.9	32.2 bc	16492.3
GC$_1$IL$_3$	90.0	3.0	4.3 c	42.7	5847.3	89.0 bc	2.0	9.7	23.7 d	11714.4
GC$_1$IL$_4$	78.0	3.0	4.0 c	36.0	5413.7	87.8 bc	1.8	8.2	23.1 d	5259.2
GC$_2$IL$_1$	94.3	3.7	7.0 b	40.3	4614.7	91.0 bc	2.7	12.0	35.6 b	14062.9
GC$_2$IL$_2$	88.0	2.0	3.6 c	38.0	4154.4	87.2 bc	2.2	10.4	35.4 bc	10792.5
GC$_2$IL$_3$	86.3	2.3	3.8 c	34.2	3914.3	74.5 cd	1.5	9.7	33.9 bc	9694.4
GC$_2$IL$_4$	74.7	2.0	3.6 c	32.2	3587.0	74.7 cd	1.5	9.2	28.6 cd	7513.9
GC$_3$IL$_1$	127.7	4.3	4.5 c	47.6	5167.1	104.8 b	3.9	11.0	37.3 ab	24582.1
GC$_3$IL$_2$	104.3	2.0	4.0 c	38.4	4549.2	92.3 bc	3.2	11.2	35.7 b	19396.3
GC$_3$IL$_3$	99.0	2.7	3.9 c	36.2	4296.1	78.0 cd	2.7	10.8	35.3 bc	12511.6
GC$_3$IL$_4$	73.7	3.7	3.6 c	33.9	4185.8	56.0 d	1.8	6.7	23.4 d	4710.6

PH: Plant height (cm), TN: Tillers number (number plant^{-1}), LW: Leaf width (cm), LL: Leaf length (cm), LA: Leaf area (cm^2)
GC$_1$: 25% Perlite + 75% Cocopeat, GC$_2$:50% Peat + 50% Perlite, GC$_3$:25% Zeolite + 75% Peat, IL$_1$: Irrigated at 100%, IL$_2$: Irrigated at 75%, IL$_3$: Irrigated at 50%, and IL$_4$: Irrigated at 25%.
NS: not significant, *: significant at p < 0.05, **: significant at p < 0.01.
^{x} : Within each column, the levels containing the same letter form a group of means within which there are no statistically significant differences (95% confidence level).

As seen in the analysis of variance given in Table 2, only the effect of water amounts on tillers number was significant ($p < 0.01$). Tillers number was not influenced significantly by growing conditions and growing conditions × irrigation interaction. The highest tiller number (4.0) was determined in IL_1 irrigation treatments, whereas the lowest tiller number (2.3) was determined in IL_4 irrigation treatments in 2021 (Table 3). Similar results were obtained in 2022. The tiller number of turmeric consistently decreased with reduced irrigation amounts. Satyareddi & Angadi (2014) argued that appropriate quantities of water maintain the soil water balance in the effective root depth throughout the growing stage, resulting in high growth traits due to ideal cellular turgor, leading to cellular elongation and development of cellular walls, and thus maintaining acceptable soil physical conditions for plant growth. Aydinsakir et al. (2024) reported that reducing water amount adversely affects plant growth by reducing soil moisture content, which limits root water availability. Water stress also reduces plant growth through reduced photosynthetic rates and cell expansion. Gatabazi et al. (2019) argued that the primary marks of water stress generally lead to a reduction in cell growth, leading to decreased cell growth, especially the number of the tiller and leaf. Singte et al. (1997) measured maximum tillers/plant and turmeric yield with 100% evaporative replenishment than with 80% and 60% evaporative refill. Tripathi et al. (2021) stated that the tiller numbers varied between 2.1 and 2.5, while Kaur & Brar (2016) reported that the tiller numbers varied between 2.1 and 2.8. Chitra et al. (2017) found that the tiller number was 4.1 and 3.1 under drip once a day at 80% pan evaporation and drip once in two days at 40% pan evaporation conditions, respectively.

Leaf width, leaf length, and leaf area are the most critical morphological parameters directly associated with photosynthesis and increased crop yield and parameters. The effects of water levels, growing conditions, and water levels ×growing conditions on leaf width were found statistically significant in 2021 (Table 2). On the other hand, the effects of water levels and water levels × growing conditions on leaf width were not statistically significant in 2022. The longest leaf width of 7.2 cm in 2021 and 12.2 cm in 2022 was obtained from the leaves of plants grown under the treatment of IL_1. The shortest leaf width of 3.7 cm in 2021 and 8.0 cm was obtained from the leaves of plants grown under the treatment of IL_4 (Table 3). In general, leaf width values increased as water stress decreased. The influences of deficit irrigation amount on leaf length were statistically significant at a 1% level. The longest leaf length of 44.5 cm in 2021 and 38.9 cm in 2022 was obtained from IL_1 treatment. The shortest leaf length of 34.0 cm in 2021 and 25.0 cm in 2022 was obtained from IL_4 treatment. As with the leaf width, leaf length values decreased as water stress increased. The values of plant height, leaf width and length, tillers number, and leaf area under the IL_1 treatment were higher than the IL_4 treatment by 52%, 85%, 64%, 41%, and 157%, respectively. Mohamed et al. (2014) argued that water stress decreased leaf width and they found leaf widths ranging from 12.7 to 18.3 cm for *C. aromatica* and 10.9 to 14.3 cm for *C. domestica.* Chungloo et al. (2024) found turmeric leaves to be the longest under well-watered conditions (17.1 cm) and significantly shorter under drought conditions (12.1 cm), with a 29% reduction in leaf length. Satyareddi & Angadi (2014) argued that compared to other irrigation methods evaluated (furrow irrigation: 4210 $cm^2 plant^{-1}$ and sprinkler irrigation: 4460 $cm^2 plant^{-1}$), drip irrigation applied at 50% available soil moisture depletion resulted in higher leaf area (4650 $cm^2 plant^{-1}$). Chitra et al. (2017) reported that the leaf area during the all-growing periods is an important aspect of turmeric, as it is closely related to the efficiency of photosynthesis, which is reflected in biomass production. They determined the leaf area as 3690, 3025, and 2357 cm^2 $plant^{-1}$ under drip irrigation daily at 80% pan evaporation, 60% pan evaporation, and 40% pan evaporation. The reason for the reduction in leaf area with water stress can be explained by the decrease in photosynthetic area due to the lack of adequate moisture in the root zone and the slow accumulation of photosynthetic substances. Findings are in confirmation with the results of Jirali (2001), Sadarunnisa et al. (2010), Deshmukh et al. (2009), and Rathod et al. (2010) in turmeric.

On the other hand, Beardsell et al. (1979) argued that adequate moisture in growing conditions is one of the most critical issues for crop growth and development. On the contrary, Abdullah et al. (2018) stated that the total rhizome yield of *Curcuma alismatifolia* was not affected by different growing conditions and they found that rhizome numbers per square meter as 76.2, 81.8, and 99.3 for cocopeat: sand, burnt rice husk: sand, and coco peat: burnt rice husk: sand, respectively. Gayathiri & Narendhiran (2020) studied the effects of 11 different growing conditions (GC_1: Coir pith + garden soil, GC_2: garden soil + farmyard manure, GC_3: garden soil + vermicompost, GC_4: neem cake + garden soil, GC_5: garden soil + coir pith+ farmyard manure, GC_6: garden soil + coir pith + vermicompost, GC_7: garden soil + coir pith + neem cake, GCT_8: garden soil + farmyard manure + vermicompost, GC_9: garden soil + farmyard manure + neem cake, GC_{10}: garden soil + vermicompost + neem cake, and GC_{11}: garden soil only) on turmeric minisetts in portray nursery. They found that the morphological features such as plant height (44.9 cm), leaf number (4.0), leaf length (20.0 cm), and leaf area (113.73 cm^2) were measured in the highest GC_6 treatment. Vidanapathirana et al. (2022) determined the highest plant height from plants grown in cow dung: topsoil: sand (GC_1= 1: 1: 0.5) medium with 111.1 cm, while the lowest plant height was obtained from cow dung: topsoil (GC_2= 1:1) conditions with 97.8 cm. They also found fresh rhizome weight as 267.4 and 326.5 g $plant^{-1}$ under GC_1 and GC_2 growing conditions.

Effects of treatments on yield of rhizome, curcumin, total phenolic and flavonoid

Growing conditions × irrigation level interactions were found not to be statistically different ($p < 0.01$) in both years for dry weight, curcumin (%), total phenolic, and total flavonoids. However, irrigation levels were found to be statistically different in the study (Table 2). The fresh rhizome weight varied between 171.8-575.3 g $plant^{-1}$ in 2021 and 164.7-

826.7 g plant^{-1} in 2022. The highest rhizome weight was determined in the GC_1IL_1, while the minimum was determined in the GC_3IL_4 in the study. On the other hand, the dry rhizome weight varied between 30.9-136.3 g plant^{-1} in 2021 and 27.6-186.6 g plant^{-1} in 2022 (Table 4). Similarly, the highest dry rhizome weight was obtained from the GC_1IL_1 treatment, while the lowest dry rhizome weight was obtained from the GC_3IL_4 treatment in the study. The rhizome weight was relatively lower due to the reduction in irrigation water. The weight of the rhizome in 2022 is higher than in 2021 in the study. Similar findings were reported by Rathod et al. (2010), Mohamed et al. (2014), Anandaraj et al. (2014), Kaur & Brar (2016), Sandeep et al. (2017), Ravindra et al. (2020), Tripathi et al. (2021), and Somdutt et al. (2022), and who observed an increase in rhizome yield with higher irrigation levels in regions with different ecologies around the world.

Table 4. Means of fresh weight, dry weight, curcumin, total phenolic, and total flavonoid parameters determined in different growing conditions and irrigation levels.

Treatment	Years									
	2021					2022				
	FW	DW	C	TP	TF	FW	DW	C	TP	TF
Growing Conditions (GC)	114.02**	20.41**	0.21**	NS	0.58**	119.00*	27.46**	NS	NS	NS
GC_1	469.1 a	100.5 a	1.69 b	32.14	28.82 a	521.4 a	112.9 a	1.71	30.72	30.34
GC_2	249.6 b	45.9 b	2.15 a	34.70	32.14 a	329.7 b	66.6 b	1.57	32.16	34.40
GC_3	321.9 b	56.0 b	2.11 a	29.84	21.78 b	433.7 ab	83.3 b	1.50	23.48	22.62
Irrigation Level (IL)	131.66*	23.57**	0.24**	0.45**	0.67*	137.41**	31.71**	0.23**	NS	6.34*
IL_1	426.9 a	85.8 a	1.65 b	26.30 b	22.20 b	608.0 a	126.9 a	1.18 b	21.90	23.14 b
IL_2	398.9 a	74.4 a	1.84 b	30.22 b	26.15 b	505.3 ab	103.8 ab	1.65 a	27.36	27.80 b
IL_3	308.6 ab	66.5 ab	2.12 a	35.45 a	28.44 ab	380.0 b	79.5 b	1.71 a	31.22	29.92 ab
IL_4	253.1 b	43.1 b	2.34 a	37.00 a	33.42 a	219.7 c	40.3 c	1.84 a	34.50	35.66 a
GC×IL	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GC_1IL_1	575.3	136.3	1.23	21.20	19.93	826.7	186.6	1.28	21.32	20.40
GC_1IL_2	544.8	103.5	1.40	34.12	28.34	657.3	138.6	1.67	28.50	29.24
GC_1IL_3	403.8	102.5	2.03	35.61	30.92	369.3	79.0	1.90	36.41	33.72
GC_1IL_4	352.5	59.6	2.11	37.60	35.84	232.3	47.3	1.99	36.92	38.04
GC_2IL_1	294.7	52.1	1.79	31.73	28.77	443.3	88.5	1.11	24.30	29.92
GC_2IL_2	248.4	49.1	2.16	33.74	31.24	313.3	66.9	1.63	31.43	34.16
GC_2IL_3	220.3	43.6	2.23	36.35	31.86	300.0	65.2	1.75	33.32	33.84
GC_2IL_4	235.0	38.7	2.42	37.13	36.70	262.0	45.9	1.79	39.30	39.70
GC_3IL_1	410.7	69.0	1.91	25.92	18.00	554.0	105.5	1.14	20.20	19.10
GC_3IL_2	403.5	70.7	1.95	22.74	18.75	545.3	106.0	1.65	21.96	20.14
GC_3IL_3	301.5	53.3	2.10	34.32	22.44	470.7	94.2	1.48	24.18	22.35
GC_3IL_4	171.8	30.9	2.48	36.34	27.68	164.7	27.6	1.75	27.24	29.02

FW: Fresh weight (g), DW: Dry weight (g), Curcumin (%), TP: Total phenolic (mg GAE g^{-1}), TF: Total flavonoid (mg CE g^{-1})

GC_1: 25% Perlite t + 75% Cocopeat, GC_2:50% Peat + 50% Perlite, GC_3:25% Zeolite + 75% Peat, IL_1: Irrigated at 100%, IL_2: Irrigated at 75%, IL_3: Irrigated at 50%, and IL_4: Irrigated at 25%.

NS: not significant, *: significant at $p < 0.05$, **: significant at $p < 0.01$.

^{x} : Within each column, the levels containing the same letter form a group of means within which there are no statistically significant differences (95% confidence level).

As shown in Table 2, in the first year of the experiment, there was a significant difference ($p<0.01$) between the irrigation treatments. While curcumin varied between 1.65 % and 2.34 % in the first year of the study, in the second year the variation was between 1.18 % and 1.84 %. Depending on the irrigation treatments, the highest curcumin was obtained from the IL_4 irrigation treatment in 2021 and 2022 (Table 4). In the present study, water stress induced an increase in curcumin content. Raven et al. (2005) reported that abiotic stress can have similar effects on accumulating secondary metabolites. Prolonged water stress reduces key physiological traits and switches on defense mechanisms, resulting in higher production of secondary metabolites, including curcuminoids in our study. The highest curcumin amount was obtained as 2.48% from GC_3IL_4 treatment in the first year and 1.99% from GC_1IL_4 treatment in the second year, while the lowest curcumin was 1.23%% from GC_1IL_1 treatment in the first year and 1.11% from GC_2IL_1 treatment in the second year. It was detected that as the water stress decreased, the curcumin amount increased. There is a dilemma regarding the change in curcumin content, as some studies reported that curcumin content increased with increasing water stress. In contrast, others showed that curcumin content decreased with decreasing water stress. Mohamed et al. (2014) claimed that curcumin in dry rhizomes increased with weekly irrigation compared with bi-weekly and tri-weekly irrigation. Chintakovid et al. (2022) found that under full irrigation conditions in the greenhouse, curcumin content decreased by 35.0% compared to water stress conditions. On the contrary, Chungloo et al. (2024) found that the curcumin content of turmeric under well-watered conditions was the minimum (9.60 mg g^{-1} DW), which was significantly increased by 31.0% when exposed to water-deficit conditions (12.52 mg g^{-1} DW). Further research and validation under different water stress conditions is required to provide definitive data on the curcumin content of turmeric plants.

The content of total phenolics and total flavonoids obtained from the three growing conditions and four irrigation amounts used in the experiment, and the results of the analysis of variance of these yields, are presented in Table 2. For total phenolics and total flavonoids in 2021 and 2022, it was noticed that the interactions were not statistically different.

The total phenolic changed between 21.20-37.60 mg GAE g^{-1} dry weight in the first year and 20.20-39.30 mg GAE g^{-1} dry weight in the second year of the research while the total flavonoid changed between 18.00-36.70 mg CE g^{-1} dry weight in 2021 and 19.10-39.70 mg CE g^{-1} dry weight in 2022. The highest total phenolic was obtained as 37.00 mg GAE g^{-1} dry weight and 34.50 mg GAE g^{-1} dry weight from IL_4 treatment in 2021 and 2022 while the lowest total phenolic was 26.30 mg GAE g^{-1} dry weight and 21.90 mg GAE g^{-1} dry weight from IL_1 treatment in 2021 and 2022 in the study. In 2021 and 2022, the highest total phenolics were found in the IL_4 irrigation level, depending on the irrigation level (Table 4). On the other hand, the highest total phenolics were obtained from GC_2 in the first and second years of the study. Albergaria et al. (2020) reported that the widely accepted notion of a general increase in phenolic compounds in response to water shortage is incorrect, stating that, contrary to this notion, this complex mechanism is different in each plant species. Therefore, further studies are needed to fully explain the role of different irrigation levels and different growing conditions on the total phenolic content of turmeric.

Essential oil and components

The influence of different water amounts on the essential oil, ar-tumerone, alpha-tumerone, beta-tumerone), and alpha-zingiberene in turmeric is given in Table 5. The effect of irrigation water amounts was significant ($P < 0.01$) for essential oil, ar-tumerone, alpha-tumerone, beta-tumerone, and alpha-zingiberene in 2021 and 2022 (Table 2). Essential oil, ar-tumerone, alpha-tumerone, beta-tumerone and alpha-zingiberene content increased significantly when irrigation levels were reduced. It was found that growing conditions were not statistically different for beta-tumerone and alpha-zingiberene content in 2021 and 2022. The highest essential oil (5.94%-6.83%), ar-tumerone (51.5%-51.3%), alpha-tumerone (24.4%-19.7%), beta-tumerone (6.59%-665%), and alpha-zingiberene (5.12%-6.72%) content was obtained from IL_4 irrigation treatment in both of study years (Table 5). Essential oil compounds can either decrease or show no change in concentration when exposed to water stress (Albergaria et al., 2020), so the widely held belief that there is a widespread increase in essential oil compounds in response to water stress is mostly incorrect. Additionally, Jiang & Huang (2001) and Weidner et al. (2009) found either a decrease or an increase in the levels of oil compounds in response to water stress. Furthermore, the systematic review of the effect of water stress on the content of oil compounds of medicinal plants by Albergaria et al. (2020) found no widespread increase in oil compounds as response to water stress. Mohamed et al. (2014) reported that water stress leads to biochemical perturbations and may alter the way plants behave with respect to primary and secondary metabolite biosynthesis, that fats are essential for cell functioning, and that the plasma membrane may be the primary site of water stress damage. Chungloo et al. (2024) found that the bisdemethoxycurcumin and demethoxycurcumin content of turmeric plants under well-watered conditions was the minimum (5.23 and 5.43 mg g^{-1} DW), which was significantly increased when exposed to water-deficit conditions (7.16-7.38 mg g^{-1} DW). Results obtained from the current study recommend that increased water amount can limit specific components to increase secondary metabolites in confirmation with the findings of Battaieb et al. (2010), Gatabazi et al. (2022), El Sherif et al. (2022), Khattab et al. (2023) and Aydinsakir et al. (2024).

Table 5. Means of essential oil compounds determined in different growing conditions and irrigation levels.

Treatment	Years									
	2021					2022				
	EO	T	AT	BT	AZ	EO	T	AT	BT	AZ
Growing Conditions (GC)	0.31**	2.11*	1.60*	NS	NS	NS	NS	NS	NS	NS
GC_1	4.56 b	47.2 b	22.7 a	5.43	3.58	5.66	50.1	18.6	5.33	6.17
GC_2	6.31 a	50.3 a	21.1 ab	5.35	4.32	6.33	51.0	18.2	5.32	5.14
GC_3	4.85 b	49.9 a	20.3 b	4.92	4.22	5.79	48.4	17.7	4.71	6.02
Irrigation Level (IL)	0.35**	2.44**	1.85**	1.57*	0.73**	1.19*	3.85*	NS	1.25**	NS
IL_1	4.34 c	46.7 c	19.3 b	4.30 b	2.92 c	4.94 b	47.1 b	16.9	3.93 c	4.50
IL_2	5.04 b	48.9 bc	20.7 b	4.73 b	3.84 b	5.72 ab	49.9 ab	17.2	4.61 bc	5.51
IL_3	5.63 a	49.4 ab	21.1 b	5.32 ab	4.28 b	6.20 a	51.1 a	18.7	5.28 b	6.36
IL_4	5.94 a	51.5 a	24.4 a	6.59 a	5.12 a	6.83 a	51.3 a	19.7	6.65 a	6.72
GC×IL	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GC_1IL_1	3.87	42.8	20.7	5.09	2.37	5.08	45.0	17.6	3.84	5.07
GC_1IL_2	4.34	47.6	21.1	5.03	3.49	5.59	50.9	18.2	4.64	6.26
GC_1IL_3	4.58	48.3	22.7	5.38	4.10	5.89	51.7	19.1	5.17	6.41
GC_1IL_4	5.43	50.2	26.1	6.23	4.38	6.07	53.0	19.5	7.67	6.92
GC_2IL_1	5.15	48.8	19.6	3.88	3.40	4.83	49.4	17.0	3.74	3.07
GC_2IL_2	6.15	50.5	20.9	4.86	3.71	6.22	50.6	17.3	4.59	4.85
GC_2IL_3	6.94	50.8	20.4	5.98	4.23	6.50	53.1	18.5	5.70	6.22
GC_2IL_4	7.00	50.9	23.6	6.70	5.93	7.76	50.7	19.9	7.25	6.42
GC_3IL_1	4.01	48.4	17.4	3.92	2.99	4.92	46.9	16.0	4.21	5.36
GC_3IL_2	4.63	48.7	20.2	4.28	4.33	5.35	48.2	16.3	4.60	5.43
GC_3IL_3	5.37	49.2	20.1	4.62	4.51	6.23	49.0	18.6	4.98	6.45
GC_3IL_4	5.39	53.5	23.5	6.85	5.07	6.67	49.5	19.9	5.05	6.82

EO: Essential oil content (%), T: ar-tumerone (%), AT: alpha-tumerone (%), BT: beta-tumerone (%), AZ: alpha-zingiberene (%)

GC_1: 25% Perlite t + 75% Cocopeat, GC_2:50% Peat + 50% Perlite, GC_3:25% Zeolite + 75% Peat, IL_1: Irrigated at 100%, IL_2: Irrigated at 75%, IL_3: Irrigated at 50%, and IL_4: Irrigated at 25%.

NS: not significant, *: significant at $p < 0.05$, **: significant at $p < 0.01$.

^{x} : Within each column, the levels containing the same letter form a group of means within which there are no statistically significant differences (95% confidence level).

4. CONCLUSIONS

Several scientists have studied the water stress of turmeric in different countries. However, there is a lack of research on analyzing irrigation levels and growing conditions of turmeric crops in Türkiye. The present research determined the effects of irrigation water amounts and different growing conditions in turmeric cultivated in the greenhouse on yield, yield parameters, and essential oil. The data showed that deficit irrigation treatments significantly decreased rhizome dry and fresh weight, plant height, leaf length and width, tillers number, leaf area, and essential oil, but increased curcumin, total phenolic, total flavonoid, and essential oil compounds as compared to control irrigation treatments. In the research, the maximum rhizome fresh and dry weight was obtained from IL_1 treatments. Compared with the IL_1 water level, the mean curcumin content increases were 19, 26, and 34% and the total phenolic content increases were 16, 27, and 32% for IL_2, IL_3, and IL_4 treatments, respectively. Growing conditions GC_1 (covering 25% perlite + 75% cocopeat) indicated good crop growth and increased the fresh rhizome yield up to 73% and 33% compared to GC_2 (covering 50% peat + 50% perlite) and GC_3 (covering 25% zeolite + 75% peat). The combination of GC_1IL_1, also improved plant height, rhizome weight, and leaf area of turmeric. In conclusion, it can be argued that although water stress is an advantage for producing curcumin, essential oil, total phenolic compounds, and total flavonoids, it is a disadvantage for the yield of rhizomes and the morphological parameters. The data obtained from the current study can be used to select phenotypic traits for the development of drought-tolerant turmeric plants for breeders or to help producers achieve a higher yield per unit area under water stress conditions.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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