https://doi.org/10.17221/34/2024-HORTSCI

Determination of yield and biochemical characteristics of turmeric (*Curcuma longa* L.) grown in subtropical climate zone

*Fatma Uysal Bayar**

Bati Akdeniz Agricultural Research Institute, Medicinal Aromatic Plants Section, Antalya, Türkiye

**Corresponding author: uysal.fatma@tarimorman.gov.tr*

Citation: Uysal Bayar F. (2026): Determination of yield and biochemical characteristics of turmeric (*Curcuma longa* L.) grown in subtropical climate zone. Hort. Sci. (Prague), 53: 49–58.

Abstract: *Curcuma longa* L., known as turmeric, is a plant species belonging to the Zingiberaceae family. Turmeric is generally spread in Asian countries. It is used in many sectors, especially spices. It has been predicted that increasing climatic changes will affect the agricultural crop pattern. To provide an alternative crop for countries with sub-tropical climates, such as Turkey, the yield and quality values of turmeric grown under the greenhouse and shade net conditions were determined in the present study. Moreover, morphological traits such as plant height, tillering number, and leaf area were determined. The highest fresh yield (1 333.67 g/plant) was obtained under greenhouse conditions. Furthermore, the highest antioxidant value (3.01 IC50 mg/mg 2,2-diphenyl-1-picrylhydrazyl (DPPH)) was obtained under shade net conditions, while the highest total phenolic content (6.88 mg gallic acid equivalent (GAE)/g) was obtained under greenhouse conditions. Curcumin reached the highest level (1.79%) in greenhouse conditions. While the essential oil ratio varied between 5.22 and 7.32%, ar-turmerone, α-turmerone, and β-turmerone were determined as the main components in the essential oil. According to the results, turmeric can be grown in greenhouse conditions in subtropical regions.

Keywords: greenhouse; production; shade net; subtropic conditions

Turmeric, whose Latin name is *Curcuma longa* L., is one of the world's most valuable and important spices. It is also widely used as a colourant in the textile, food, and confectionery industries. Traditional medicine uses it as an anti-inflammatory, hepatoprotective, antitumor, and antiviral agent to heal wounds, prevent cancer, and relieve gastrointestinal and respiratory disorders (Nandakumar et al. 2022).

The main bioactive compounds in turmeric rhizome are curcuminoids, phenolic acids, and flavonoids. Curcumin, demethoxycurcumin, and bisdemethoxycurcumin constitute the active components called curcuminoids. Curcumin, a polyphenol, is the most active and non-toxic component of turmeric and has therapeutic properties (Ravindran 2007). These are the reasons why turmeric is important for health.

It is grown in the tropical regions of Asia, mainly in India, China, Indonesia, Jamaica, Peru, and Pakistan. It is grown both in combination with coconut and as a single crop. Traditionally cultivated turmeric has many local varieties and is known by village names (Nandakumar et al. 2022). Productivity varies by variety and region.

India, which has a distinct place in the national and international spice market, is the world's leading producer, consumer, and exporter of turmeric, with a global share of 78% and 60% in production and exports, respectively (Sravani et al. 2023). Major

https://doi.org/10.17221/34/2024-HORTSCI

importers of turmeric powder are the USA, UAE, Saudi Arabia, the UK, Australia, and Canada (Sasikumar 2019). Market proximity is important, and Turkey's proximity to the market provides a significant advantage over its competitors in the Far East.

Many researchers have conducted studies on climate change and revealed its impact on crops (Lionello et al. 2014; Chandio et al. 2020). Researchers who draw attention to the low yield of agricultural products emphasise the importance of creating new crop patterns. According to the estimated climate change analysis in Turkey, air temperature is expected to increase by 2–5 °C, and precipitation is expected to decrease in some regions (Lionello et al. 2014). Creating new cropping patterns and promoting technologies and innovations that can avoid environmentally and agriculturally sensitive climate fluctuations is essential to increase and sustain agricultural productivity. In Mediterranean countries like Turkey, especially in regions with sub-tropical climates, it is necessary to work on adapting tropical plants to turn increasing temperatures into an opportunity.

The main objective of the research was to determine the production conditions suitable for changing climatic conditions, to offer an alternative to the product pattern, and to reveal the potential for a more economical turmeric supply to the market. For this purpose, adaptation studies were carried out under shade net and greenhouse conditions. In addition to yield values, morphological measurements were performed. Furthermore, quality criteria such as antioxidant, phenolic, and flavonoid substances, curcumin content, essential oil content, and its components were determined. Many studies have been conducted on turmeric cultivation and its biochemical contents. However, no study has been found that addresses all of the topics. This is the first study to be conducted in Turkey.

MATERIAL AND METHODS

The study was conducted at the Bati Akdeniz Agricultural Research Institute between 2019 and 2020 in an unheated plastic greenhouse and a shaded area formed with a 75% shade net. The climatic data for the study years are given in Figures 1 and 2.

As plant material, 25–30 g rhizomes obtained from genotype 99-5 in the West Mediterranean

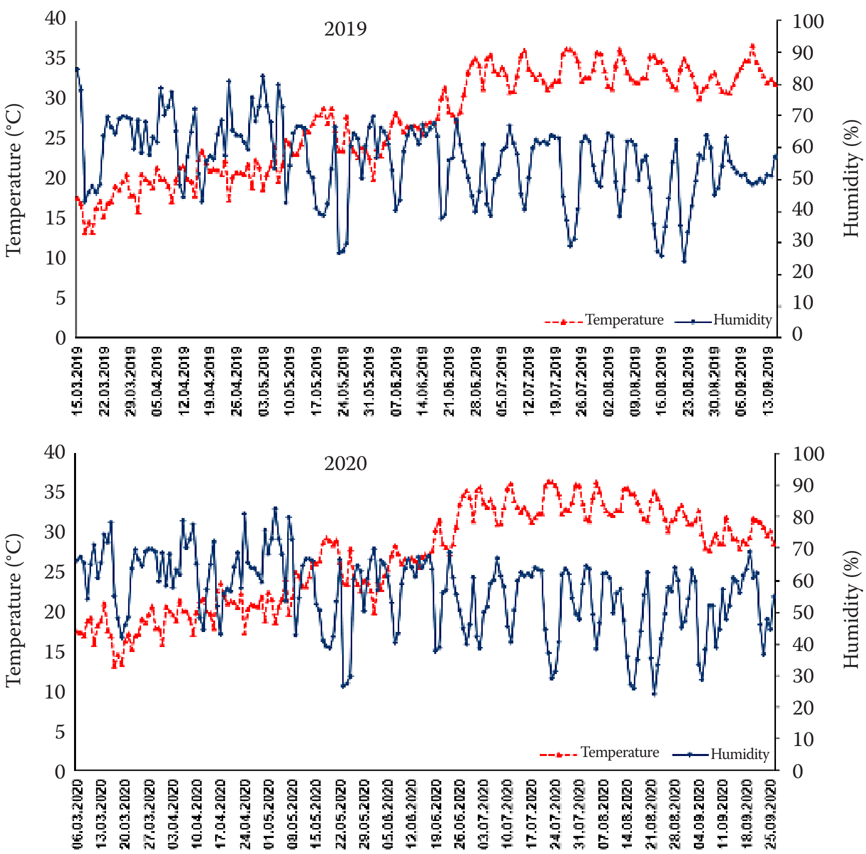

Figure 1. Average temperature and relative humidity measured in the greenhouse

https://doi.org/10.17221/34/2024-HORTSCI

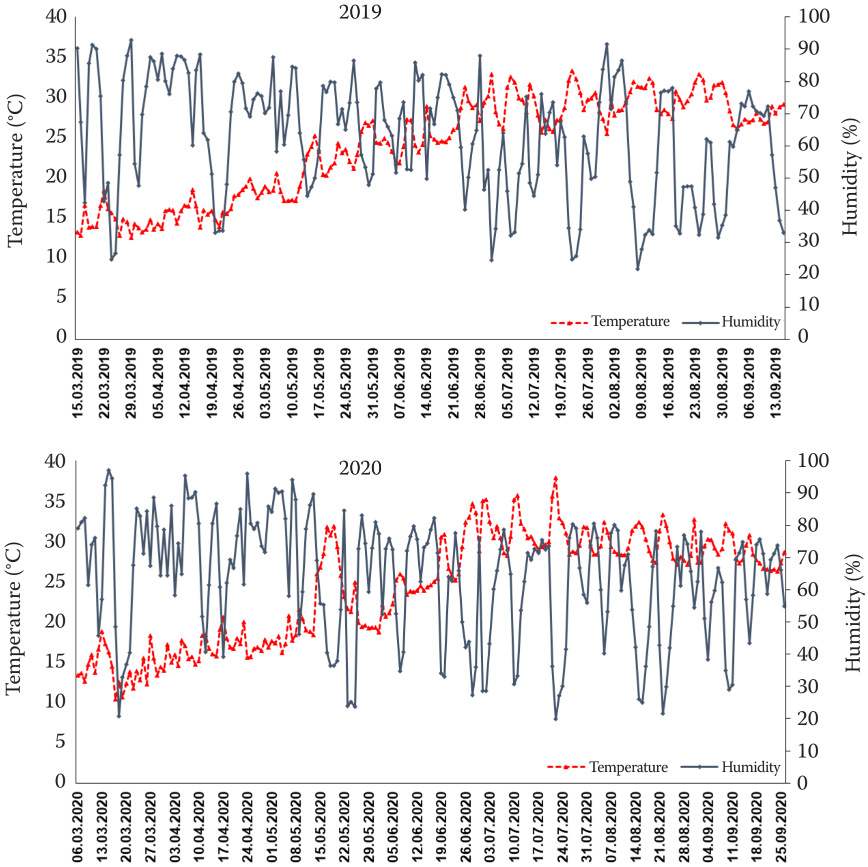

Figure 2. Average temperature and relative humidity measured in the shaded area

Agricultural Research Institute (BATEM) gene pool were used. Greenhouse and shade net cultivation was carried out in 25-litre pots using a (1 : 1) peat + perlite mixture. The experiment was established in three replications with ten pots and one seedling in each pot in both areas. Seedlings were planted in 1/3 full pots on February 15. The other parts of the pots were filled with a peat-perlite mixture prepared at three different times. The first addition was four months after planting, when the plants reached a certain size (60 cm), the second was five months after planting, and the third was seven months after planting (Heperly et al. 2004). The nutrient solution reported by Uysal Bayar et al. (2020) was used for fertilisation. Irrigation was performed with drippers with a flow rate of two litres per hour, three drippers per pot. Harvesting occurred approximately ten months after planting when 50% of the leaves had wilted. One month before harvesting, the tillering number and plant height were determined by measuring from the soil level to the top of the plant. The thickest of the tillers, 5 cm above the soil, was recorded as the tiller diameter. The leaf area was computed by multiplying the leaf length and width of the product with a conversion factor of 0.72 to determine the actual leaf area (Tripathi et al. 2021). Plant growth rate (cm/week) was calculated by dividing the measured height between two times by the time, according to Abdullah et al. (2018). The stages of the cultivation process are shown in Figure 3.

Fresh rhizome weight was measured upon harvest, and dry weight was determined by drying the rhizomes in a drying oven at 40 °C until they reached a constant weight. The dried rhizomes were pulverised by grinding at 10 000 rpm for a minute using the Grindomix GM 200 (Retsch, Germany). 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity of the sample extracts was determined by the method recommended by Cemeroğlu (2010). The analysis was performed in a spectrophotometer at a wavelength of 517 nm by using methanol as a blank solvent. The antioxidant value (IC50), which inhibits 50% of the DPPH radical, was calculated as mg/mg DPPH dry matter from the correct equation obtained from the % inhibition rate of DPPH radical.

https://doi.org/10.17221/34/2024-HORTSCI

The total phenolic content (TPC) of the samples was determined with Folin-Ciocalteu solution using the method proposed by Spanos and Wrolstad (1990) using a spectrophotometer (Shimadzu UV 1800, Japan) at a wavelength of 765 nm.

The total flavonoid content of the sample extracts was determined colourimetrically by the method proposed by Zhishen et al. (1999). Absorbance values were determined by reading in a spectrophotometer at a 510 nm wavelength.

To determine curcumin, extraction was made by revising the method of Paulucci et al. (2013). Accordingly, 2.5 g of dried and ground turmeric powder was weighed and transferred to 50 mL Falcon tubes. Afterwards, 15 mL of a 70% ethanol-water mixture was added. After mixing in a vortex device, shaking was made in a temperature-controlled shaker at room temperature for 12 hours. Curcumin amounts were determined by liquid chromatography (Agilent 1290)-Mass Spectrometry (6430 Triple Quadrupole) (LC-MS/MS) using a Zorbax RRHD Eclipse Plus C18 column (3 µm 2.1 × 100 mm) (Fischer et al. 2011). LC-MS/MS conditions:

Mobile phases:

A: methanol : water (5 : 95[v/v], 0.01% formic acid, and 5 µM ammonium formate);

B: methanol (0.01% formic acid and 5 µM ammonium formate);

Flow rate 0.30 mL/min.

Column temperature: 35 °C

Moving phase flow: gradient flow

0–3.00 min. 5% mobile phase B,

3.01– 8.00 min. 30% mobile phase B,

8.01–12.00 min. 95% mobile phase B,

12.01–15.00 min. 5% mobile phase B,

The essential oil ratio (%) was determined by the hydro distillation method in the Clevenger apparatus. Distillation was carried out for three hours by adding 200 mL of distilled water to the 20 g dry pulverised sample, and the essential oil ratio (mL/100 g dry sample, %) was calculated (TS EN ISO 6571 2011; Uysal Bayar, Cinar 2020).

Essential oil component analysis was performed by GC/GC-MS (gas chromatography (Agilent 7890A)-mass detector (Agilent 5975C)) using a capillary column (HP InnowaxCapillary; 60.0 m × 0.25 mm × 0.25 µm). The column temperature program was programmed as 60 °C (10 min), 60 °C to 220 °C at 4 °C/min and 220 °C (10 min). The results of WILEY and OIL ADAMS libraries were used to identify essential oil components. The percentages of the components obtained were determined using

Figure 3. Images from the study area

https://doi.org/10.17221/34/2024-HORTSCI

the FID detector, and the identification of the components was determined using the MS detector (Uysal Bayar, Çınar 2020). All samples were analysed in three replicates.

For statistical analysis, growth area (greenhouse, shade net), year (2019, 2020), and growth area-year interaction factors were considered, and analysis of variance was performed for morphology, yield, and biochemical characteristics. Furthermore, the SAS Ver. 9.0 statistical package program was used to analyse the data (SAS Institute Inc. 2002).

RESULTS AND DISCUSSION

The present study showed no difference between treatments and years regarding plant height, number of tillers, tiller diameter, and growth rate. While there was a statistical difference between the growing conditions in terms of the mean leaf length and leaf area, no difference was observed in the mean leaf width. There was a statistical difference between growing conditions in terms of fresh and dry yield (Table 4).

The yield potential of any plant is determined by plant growth characteristics (Gupta et al. 2015). In this context, morphological observations and measurements were made in the study. While the plant height obtained in the study was significantly higher than the findings (60.74–106.50 cm) of Harish et al. (2022), it was similar to the findings (100.21 cm) in the study conducted by Kifelew et al. (2018). Plant height was determined to be longer than that (46.68–101.47 cm) of Vithya et al. (2021), while other plant growth characteristics were similar. Man et al. (2021), on the other hand, stated plant growth characteristics to be higher (166.34 cm) (Figure 4).

The tillering number obtained in the greenhouse was about 40% higher than that obtained in the shade (Figure 4). The tillering number of turmeric grown in the greenhouse can be explained by the duration of light. Ravindran, Babu (2005) and Flores et al. (2021) reported that the tillering number increased with increasing light duration. In our study, the leaf area obtained in the greenhouse environment was about two times more than that (3160–6734 cm^2) of Harish et al. (2022) and ten times more than that (876.10–1 230.20 cm^2) of Tripathi et al. (2021). This difference is thought to be due to the suitability of the greenhouse conditions or insufficient irrigation and feeding, which were the subject of other studies.

Yield is the most important parameter in crop production. Many studies have been conducted on turmeric yield, and different results have been obtained. Generally, dry yield values are directly proportional to fresh yield values (Gupta et al. 2015; Bonacina et al. 2022; Harish et al. 2022). The dry yield values obtained in this study support the studies above. The yield values obtained under greenhouse conditions are considerably higher than the results (21.10 and 22.62 t/ha) of the studies conducted by Tripathi et al. (2021). The yield values obtained by Man et al. (2021) (299.57–474.38 g per plant) and Bonacina et al. (2022) (408.23–646.66 g per plant) were about half of the yield value obtained in the present study (Table 1). Moreover, the yield value obtained in the present study's shade is similar to that of Harish et al. (2022).

Fresh rhizome weight decreased by about 36% in the shade compared to greenhouse conditions (Table 1). In a temperature-controlled study, Chintakovid et al. (2022) reported that yield decreased by 32.96% in the treatment where the temperature was 25 °C. A previous study reported that a temperature of 30–35 °C would be ideal during the germination stage of turmeric tubers (Ishimine et al. 2004). The decrease in yield in the shade can be explained by the temperature being below the ideal temperature during the plant growth period (Figure 2).

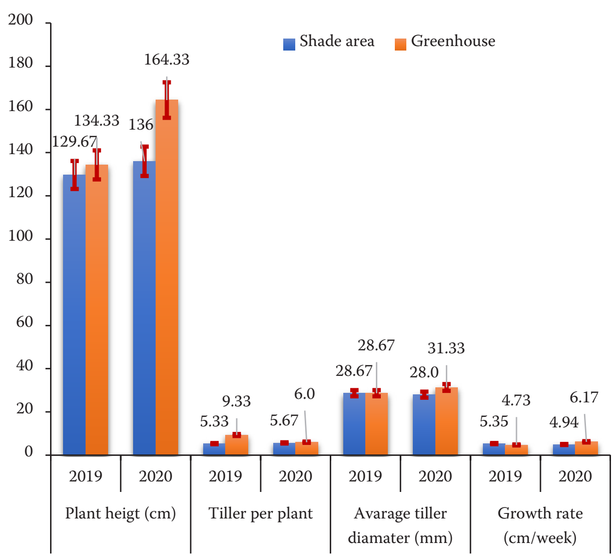

Figure 4. Plant height, tiller number, tiller diameter, and growth rate values

https://doi.org/10.17221/34/2024-HORTSCI

Table 1. Effect of different growing conditions on leaf length, leaf width, leaf area, fresh and dry rhizome weight

Characteristics	Leaf length (cm)		Leaf width (cm)		Leaf area (cm^2)		Fresh weight (g/plant)		Dry weight (g/plant)	
Year	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Shade net	45.53	48.29	14.14	14.12	10 683.00	10 378.05	736.00	644.67	148.63	125.53
Greenhouse	52.16	57.77	13.87	14.18	14 529.23	17 768.48	1 333.67	1 159.00	236.99	204.94

In the present study, all parameters, such as plant height, tiller number, tiller diameter, and leaf area, were generally higher in the greenhouse environment. This situation can be explained by greenhouses providing suitable plant conditions. On the contrary, environmental conditions in the shade are much more variable and force plants to adapt to survive. Yang et al. (2021) reported that plant height is a quantitative character controlled by many genes and is easily affected by environmental conditions. High wind speed in the outdoor environment can cause slight bending in plants, leading to height measurement changes (Ogwu 2020). Moreover, Ogwu (2020) and Yang et al. (2021) indicated that light intensity greatly affects plant height, tiller structure, and leaf size.

Turmeric is one of the most popular spices containing natural antioxidants (Lim et al. 2011).

In turmeric, quality values are as important as yield and morphological characteristics. The research has shown that there is an interaction between these parameters (Table S1 in Electronic Supplementary Material).

Table 5 shows a statistical difference between the growing environment and years in terms of the antioxidant and phenolic substances of turmeric grown under greenhouse and shade net conditions. It was also statistically revealed that there was an interaction between growing area and years. The findings of this study are in agreement with Tanvir et al. (2017) but lower than the results of the studies of Dutta and Neog (2016) (8.39–11.07 mg/mg) and Akter et al. (2019) (26.40–291.30 mg/mg) (Table 2). As reported by many studies, different factors affect secondary metabolites and antioxidant activity (Liu et al. 2016; Holopainen et al. 2018). The differences are due to genetic and environmental factors (Tanvir et al. 2017; Akter et al. 2019), seasonal variations (Hailemichael, Zakir 2021), growing conditions (Dutta, Neog 2016; Bonacina et al. 2022; Harish et al. 2022), postharvest treatments (Policegoudra, Aradhya 2007; Barbosa, Minguillan 2021), method of analysis (Akter et al. 2019), etc.

Plants are known to contain rich sources of phenolic compounds (Barbosa, Minguillan 2021). Turmeric is one of these plants. The average amount of phenolic matter obtained in the present study was similar to that of fresh turmeric in the study conducted by Barbosa, Minguillan (2021) but lower than that obtained from dried turmeric. While the findings obtained in the study support the study by Anwar et al. (2022), they are considerably lower than the findings obtained by Dutta and Neog (2016) (59.2–157.4 mg gallic acid equivalent (GAE)/g), Tanvir et al. (2017) (4.52–16.07 mg GAE/g), Akter et al. (2019) (37.90–157.4 mg GAE/g), and Alolga et al. (2022) (107.34–148.46 mg GAE/g) (Table 2). The high phenolic content in these studies can be explained by the fact that turmeric samples were obtained from their natural areas, i.e., tropical regions, or it can be explained by the difference in analysis methods.

Table 2. Effect of different growing conditions on antioxidant activity, total phenolic content, total flavonoid content, and curcumin content of *Curcuma longa* rhizomes

Characteristics	IC50 (mg/mg DPPH)		Total phenolic content (mg GAE/g)		Total flavonoid content (mg CE/g)		Curcumin (%)	
Year	2019	2020	2019	2020	2019	2020	2019	2020
Shade net	3.28	3.01	5.91	3.01	5.51	3.29	1.01	0.99
Greenhouse	6.16	3.28	6.10	6.88	5.49	5.62	1.05	1.79

IC50 – antioxidant value; DPPH – 2,2-diphenyl-1-picrylhydrazyl; GAE – gallic acid equivalent; CE – catechin equivalent

Table 3. Effect of different growing conditions on essential oil content and main components of essential oil of *Curcuma longa* rhizomes (in %)

Characteristics	Essential oil content		ar-turmerone		α-turmerone		β-turmerone (curlone)	
Year	2019	2020	2019	2020	2019	2020	2019	2020
Shade net	7.32	6.11	27.04	48.47	28.91	24.61	28.12	9.55
Greenhouse	6.67	5.22	27.99	50.10	30.19	23.35	24.51	8.56

Anwar et al. (2022) reported that turmeric may cause anti-arthritic activity, which may be due to the flavonoids in turmeric. In the same study, the total amount of flavonoids in turmeric was determined as 453.87 ± 0.72 quercetin equivalent (QE)/100 g. The flavonoid values obtained in this study are similar to those obtained in the present study.

The antioxidant activities of many plants are mainly attributed to phenolic content (Kalt et al. 1999). However, Policegoudra and Aradhya (2007) reported that the antioxidant activity of turmeric is independent of total phenolic content. Under greenhouse conditions, phenolic content increased while antioxidant activity was low, supporting the claim that the antioxidant activity of turmeric is independent of total phenolic matter. As reported in many studies, environmental factors affect secondary metabolites and antioxidant activity (Holopainen et al. 2018). The increase in antioxidant value in the shade can be explained by the fact that vitamins that affect the antioxidant value may increase in the shade, unlike phenolic substances. Yang et al. (2021) reached similar results in their studies.

Curcumin, an important metabolite of turmeric, is widely used as a food additive and a colouring agent. It also shows some therapeutic activities (Nisar et al. 2015). The curcumin ratios obtained in the present study are similar to those of Pal et al. (2020) in 45 genotypes. While the findings obtained were considerably higher than those of Alolga et al. (2022), they were lower than those of Tripathi et al. (2021) (4.76%) and Datta et al. (2022) (5.62%) (Table 2). These differences may be due to genotype differences (Pal et al. 2020) as well as differences in fertilization (Datta et al. 2022), irrigation (Tripathi et al. 2021), drying (Alolga et al. 2022), and analysis method (Sogi et al. 2010; Yang et al. 2020). The lack of light can explain the lower curcumin ratio in the shaded area. Harish et al. (2022) studied different photo-selective nets and stated that curcumin ratios changed according to relative light intensity.

Turmeric essential oil is among the internationally traded products (Madan 2016). Many studies have reported that turmeric essential oil has a strong antioxidant effect on cancer cells (Ji et al. 2004; Sahoo et al. 2019). The essential oil ratios obtained in this study were significantly higher than the results of Bonacina et al. (2022) (1.31 to 1.42%) and Carneiro et al. (2022) (1.68–3.02%), while similar to Hailemichael and Zakir (2021) (5.14%) (Table 3).

The component ratios of the oil are as important as the essential oil ratio in plants. Ray et al. (2022) reported that the dominant components

Table 4. Analysis of variance results for morphological and yield characteristics

Source of variation	*df*	Plant height (cm)	No. of tillers (pcs)	Tiller diameter (mm)	Leaf length	Leaf width	Leaf area (cm^2)	Growth rate (cm/week)	Fresh weight	Dry weight
					(cm)				(g/plant)	
Growing area	1	816.75	14.08	16.33	194.41*	0.04	2 347 322.549*	0.78	927 408.00**	211 10.08*
Year	1	990.08	6.75	0.33	52.50	0.06	250 565.7589	0.28	53 067.00	2 281.14
Growing area × year	1	420.08	10.08	3.00	6.12	0.08	165 823.2698	2.58	5 208.33	60.08
Error	8	245.75	3.25	10.42	17.58	0.29	136 686.2645	2.18	24 652.67	987.39

df – degree of freedom; *,**significant at the $P \leq 0.05$, 0.01 probability level

https://doi.org/10.17221/34/2024-HORTSCI

Table 5. Analysis of variance results for biochemical properties

Source of variation	*df*	IC50 (mg/mg DPPH)	Total flavonoid content (g CE/100 g)	Total phenolic content (g GAE/100 g)	Curcumin (%)	Essential oil content	ar-turmerone	α-turmerone	β-turmerone
						(%)			
Growing area	1	3.95*	4.03	12.71**	0.53**	1.78*	4.99	0.00	15.82
Year	1	3.95*	3.23	3.55**	0.39**	5.31*	1421.84*	92.98**	893.38**
Growing area × year	1	5.60*	4.14	9.88**	0.43**	0.04	0.33	4.84	5.18
Error	8	0.26	1.18	0.11	0.003	0.22	3.10	4.91	4.61

df – degree of freedom; IC50 – antioxidant value; DPPH – 2,2-diphenyl-1-picrylhydrazyl; CE – catechin equivalent; GAE – gallic acid equivalent; *,**significant at the $P \leq 0.05$, 0.01 probability level

of essential oils are ar-turmerone (28.00–38.81%), α-turmerone (17.56–27.03%), and β-turmerone (16.53–19.02%). The findings obtained are similar to the findings determined by Singh et al. (2010) and Carneiro et al. (2022) (Table 3). Many factors affect the content level and the components of essential oils of turmeric rhizomes. One of these factors is geographical location. Carneiro et al. (2022) reported large variations in the component ratios of turmeric cultivated outside the Amazon. In addition, it has been stated in these studies that ar-turmerone and β-turmerone are the main components of turmeric and have antioxidant, antidermatophytic, fungicidal, and insecticidal effects. Turmeric grown in subtropical regions such as Turkey can be emphasised, especially with these effects.

CONCLUSION

In conclusion, it can be concluded that greenhouse cultivation is more prominent in terms of yield and quality characteristics in the subtropical regions. In the future, different shade rates and different shade rates x greenhouse combination practices can be studied. According to the findings obtained in the present study, turmeric grown in the subtropical climate zone was determined to be above the average values in terms of yield compared to turmeric grown in the tropical zone, while it was below the average values in terms of some biochemical properties.

Although there is no loss of commercial value because the biochemical yield value obtained from the unit area does not decrease due to the high yield, developing early turmeric varieties for subtropical climatic regions with shorter vegetation periods, such as Turkey, and testing these varieties in these regions is recommended.

Acknowledgement: The author would like to thank the Turkish Ministry of Agriculture and Forestry, General Directorate of Agricultural Research and Policies, for supporting the study.

REFERENCES

Abdullah S., Kamaruddin N.Y., Harun A.R. (2018): The effect of gamma radiation on plant morphological characteristics of *Zingiber officinale* Roscoe. International Journal on Advanced Science, Engineering and Information Technology, 8: 2085–2091.

Akter J., Hossain M.A., Takara K., Islam M.Z., Hou D-X. (2019): Antioxidant activity of different species and varieties of turmeric (*Curcuma* spp): Isolation of active compounds. Comparative Biochemistry and Physiology Part C Toxicology & Pharmacology, 215: 9–17.

Alolga R.N., Osae R., Ibrahim T.S., Onoja V. Apaliya M.T., Kwaw E., Huang F. Q. (2022): Distinct metabolomes and quality characteristics of vacuum-assisted osmosonic-pretreated *Curcuma longa* L. rhizomes subjected to different drying methods. Industrial Crops and Products, 185: 115156.

Anwar S., Raut R., Kanwal B., Yahia E. A., Kumar, V. (2022): *In vitro* investigation of anti-inflammatory and antioxidant activities of *Curcuma Longa* rhizome methanol extract. International Journal of Creative Research Thoughts (IJCRT), 10: c559-81.

Barbosa G.B., Minguillan J.M.O. (2021): Antioxidant activity and total phenolic content of fresh and cured rhizomes of *Curcuma longa* and *Etlingera philippinensis.* International Food Research Journal, 28: 839–847.

https://doi.org/10.17221/34/2024-HORTSCI

Bonacina C., Monique R., Cruz S., Nascimento A.B., Barbosa L.N., Goncalves J.E., Gazim Z.C., Magalhaes H.M., Souza S.G.H. (2022): Salinity modulates growth, oxidative metabolism, and essential oil profile in *Curcuma longa* L. (Zingiberaceae) rhizomes. South African Journal of Botany, 146: 1–11.

Carneiro V.P.P., Pinc M.M., Cruz R.M.S., Gumy M.P., Biezus B.F., Alberton O. (2022): Essential oil chemotypes of turmeric (*Curcuma longa* L.) cultivated in four different farmers in Southwest of Paraná State-Brazil. Comunicata Scientiae, 14: e3830.

Cemeroğlu B. (2010): Gida Analizleri. Baski. Gida Teknolojisi Derneği Yayinlari No. 34, Ankara, Bizim Grup Basimevi. (in Turkish)

Chandio A.A., Jiang Y., Rehman A., Rauf A. (2020): Short and long-run impacts of climate change on agriculture: An empirical evidence from China. International Journal of Climate Change Strategies and Management, 12: 201–221.

Chintakovid N., Tisarum R., Samphumphuang T., Sotesaritkul T., Cha-Um S. (2022): Evaluation of curcuminoids, physiological adaptation, and growth of curcuma longa under water deficit and controlled temperature. Protoplasma, 259: 301–315.

Datta S., Sarkar A., Rai U (2022): Effect of nitrogen and potassium on yield and quality of turmeric under terai zone of West Bengal. Environment and Ecology, 40: 1757—1761.

Dutta S.C., Neog B. (2016): Accumulation of secondary metabolites in response to antioxidant activity of turmeric rhizomes co-inoculated with native arbuscular mycorrhizal fungi and plant growth promoting rhizobacteria. Scientia Horticulturae, 204: 179–184.

Flores S., Retana-Cordero M., Fisher P.R., Freyre R., Gómez C. (2021): Effect of photoperiod, propagative material, and production period on greenhouse-grown ginger and turmeric plants. HortScience, 56: 1476–1485.

Fischer R.A., Campbell A.J., Lord O.T., Shofner G.A., Dera P., Prakapenka V.B. (2011): Phase transition and metallization of FeO at high pressures and temperatures. Geophysical Research Letters, 38: 1–5.

Gupta A.K., Mishra R., Lal R.K. (2015): Genetic resources, diversity, characterization and utilization of agronomical traits in turmeric (*Curcuma longa* L.). Industrial Crops and Products, 77: 708–712.

Hailemichael G., Zakir M. (2021): Pre- and postharvest practices influencing yield and quality of turmeric (*Curcuma longa* L.) in Southwestern Ethiopia: A review. African Journal of Agricultural Research, 17: 1096–1105.

Harish B.S., Umesha K., Venugopalan R., Prasad, B.N.M. (2022): Photo-selective nets influence physiology, growth, yield and quality of turmeric (*Curcuma longa* L.). Industrial Crops and Products, 186: 115202

Hepperly P., Francis Z., Kai R., Arakawa C., Meisner M., Kratky B., Hamamoto K., ve Sato D. (2004): Producing bacterial wilt-free ginger in greenhouse culture. Soil and Crop Management, June 2004, SCM-8.

Holopainen J.K., Virjamo V., Ghimire R.P., Blande J.D., Julkunen-Tiitto R., Kivimäenpää M. (2018): Climate change effects on secondary compounds of forest trees in the northern hemisphere. Frontiers in Plant Science, 9: 1445.

Ishimine Y., Hossain M.A., Motomura K., Akamine H., Hirayama T. (2004): Effects of planting date on emergence, growth and yield of turmeric (*Curcuma longa* L.) in Okinawa Prefecture, Southern Japan. Japanese Journal of Tropical Agriculture, 48: 10–16.

Ji M., Choi J., Lee J., Lee Y. (2004): Induction of apoptosis by Ar-turmerone on various cell lines. International Journal of Molecular Medicine, 14: 253–256.

Kalt W., Forney C.H., Martin A., Prior R.L. (1999): Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. Journal of Agricultural and Food Chemistry, 47: 4638–4644.

Kifelew H., Bekele D., Yadesa L., Getu A., Getachew W., Hailemichael G., Mitiku H. (2018): Result of turmeric variety trial in Ethiopia. International Journal of Research Studies in Agricultural Sciences, 4: 34–38.

Lim H.S., Park S.H., Ghafoor K., Hwang S.Y., Park J. (2011): Quality and antioxidant properties of bread containing turmeric (*Curcuma longa* L.) cultivated in South Korea. Food Chemistry, 124: 1577–1582.

Lionello P., Congedi L., Reale M., Scarascia L., Tanzarella A. (2014): Sensitivity of typical Mediterranean crops to past and future evolution of seasonal temperature and precipitation in Apulia. Regional Environmental Change, 14: 2025–2038.

Liu W., Yin D., Li N., Hou X., Wang D., Li D. (2016): Influence of environmental factors on the active substance production and antioxidant activity in *Potentilla fruticosa* L. and its quality assessment. Scientific Reports, 6: 1–18.

Madan M.S. (2016): Production, Marketing, and Economics of Ginger. Ginger: The Genus Zingiber. Boca Raton, CRC Press.

Man S., Chakraborty S., Sarkar A., Roy S.K., Kundu A., Debnath M.K. (2021): Evaluation of some elite turmeric genotypes in Terai region of West Bengal. The Pharma Innovation Journal, 10: 884–890.

Nandakumar K., Vishnuvardhana F.B., Mohankumar S., Devappa V., Maruthiprasad B.N., Ramegowda G.K., Venkatesha J. (2022): Genetic variability of selected morphological traits in turmeric (*Curcuma longa* L.). The Pharma Innovation Journal, 11: 874–877.

https://doi.org/10.17221/34/2024-HORTSCI

Nisar T., Iqbal M., Raza A. (2015): Turmeric: A promising spice for phytochemical and antimicrobial activities. American-Eurasian Journal of Agricultural & Environmental Sciences, 15: 1278–1288.

Ogwu M.C. (2020): Value of *Amaranthus* [L.] Species in Nigeria. London, IntechOpen: 1–21.

Pal K., Chowdhury S., Kumar Dutta S., Chakraborty S., Chakraborty M., Kumar Pandit G., Dutta S., Kumar Paul P., Choudhury A., Majumderg B., Sahanaa N., Mandala S. (2020): Analysis of rhizome colour content, bioactive compound profiling and ex situ conservation of turmeric genotypes (*Curcuma longa* L.) from sub Himalayan terai region of India. Industrial Crops and Products, 150: 112401.

Paulucci V.P., Couto R.O., Teixeira C.C.C., Freitas L.A.P. (2013): Optimization of the extraction of curcumin from *Curcuma longa* rhizomes. Brazilian Journal of Pharmacognosy, 23: 94–100.

Policegoudra R.S., Aradhya S.M. (2007): Biochemical changes and antioxidant activity of mango ginger (*Curcuma amada* Roxb.) rhizomes during postharvest storage at different temperatures. Postharvest Biology and Technology, 46: 189–194.

Ravindran P.N. (2007): Turmeric-the golden spice of life. In: Turmeric, the Genus Curcuma. Boca Raton, CRC Press: 1–14.

Ravindran P.N., Babu K.N. (2005): Ginger: The genus Zingiber. Boca Raton, CRC Press.

Ray A., Mohanty S., Jena S., Sahoo A., Acharya L., Panda P.C., Sial P., Duraisamy P., Nayak S. (2022): Drying methods affects physicochemical characteristics, essential oil yield and volatile composition of turmeric (*Curcuma longa* L.). Journal of Applied Research on Medicinal and Aromatic Plants, 26: 100357.

Sahoo A., Kar B., Jena S., Dash B., Ray A., Sahoo S., Nayak S. (2019): Qualitative and quantitative evaluation of rhizome essential oil of eight different cultivars of *Curcuma longa* L. (turmeric). Journal of Essential Oil Bearing Plants, 22: 239–247.

Sasikumar B. (2019): Advances in adulteration and authenticity testing of turmeric (*Curcuma longa* L.). Journal of Spices and Aromatic Crops, 28: 96–105.

Singh G., Kapoor I.P.S., Singh P., De Heluani C.S., De Lampasona M.P., Catalan C.A.N. (2010): Comparative study of chemical composition and antioxidant activity of fresh and dry rhizomes of turmeric (*Curcuma longa* Linn.). Food and Chemical Toxicology, 48: 1026–1031.

Sogi D.S., Sharma S., Oberoi D.P.S., Wani I.A. (2010): Effect of extraction parameters on curcumin yield from turmeric. Journal of Food Science and Technology, 47: 300–304.

Spanos G.A., Wrolstad R.E. (1990): İnfluence of processing and storage on the phenolic com-position of Thompson seedless grape juice. Journal of Agricultural and Food Chemistry, 38: 1565–1571.

Sravani S., Prasad S.V., Praveena P.L.R.J. (2023): Problems Encountered by the turmeric farmers and suggestions to overcome the problems in marketing the produce in Kadapa District of Andhra Pradesh. Biological Forum an International Journal 15: 225–229.

Tanvir E.M., Hossen M.S., Hossain M.F., Afroz R., Gan S.H., Khalil M.I., Karim N. (2017): Antioxidant properties of popular turmeric (*Curcuma longa*) varieties from Bangladesh. Journal of Food Quality, 1: 8471785.

Tripathi S.K., Sharma B., Kumari P., Deb P., Ray R., Denis A.F. (2021): Evaluation of productivity, quality and economics of turmeric under diferent moisture regime and integrated nutrient management at eastern Indo-Gangetic plains. Agricultural Research, 10: 601–612.

TS EN ISO 6571 (2011): Spices, Condiments and Medicinal Plants – Determination of Essential Oil Content (Hydrodistillation Method). Bakanliklar, Turkish Standards İnstitute.

Uysal Bayar F., Cinar O. (2020): Yield and quality parameters of some cultivated *Origanum* spp. species. Derim, 37: 10–17.

Uysal Bayar F., Kaya A.S., Çinar O. (2020): The effects of different growing conditions on yield and quality parameters of ginger (*Zingiber officinale*). Mediterranean Agricultural Sciences, 34: 93–100.

Vithya K., Venkatesan K., Senthamizh Selvi B., Manonmani S., Kokiladevi E. (2021): Per se performance and diversity analysis in turmeric (*Curcuma longa* L.) genotypes for plant and rhizome yield characters. Electronic Journal of Plant Breeding, 12: 1314–1320.

Yang Q-Q., Cheng L-Z., Zhang T., Yaron S., Jiang H-X., Sui Z-Q., Corke H. (2020): Phenolic profiles, antioxidant, and antiproliferative activities of turmenic (*Curcuma longa*). Industrial Crops and Products, 152: 112561.

Yang Q., Lin G., Lv H., Wang C., Yang Y., Liao H. (2021): Environmental and genetic regulation of plant height in soybean. BMC Plant Biology, 21: 1–15.

Zhishen J., Mengcheng T., Jianming W. (1999): The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. Food Chemistry, 64: 555–559.

Received: February 20, 2024
Accepted: June 12, 2025
Published online: February 20, 2026