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Response of Different Substrates and Irrigation Water Levels on Yield and Oil Quality of Ginger Grown in Greenhouse

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ABSTRACT
Growing media and irrigation water levels are the most important factors affecting plant yield and quality throughout the world. The present research was conducted in a greenhouse located in the Batı Akdeniz Agricultural Research Institute between the 2019 and 2020 growing season. The study aims to determine the effects of different substrates and irrigation levels on yield and phenolic and essential oil compounds of ginger (*Zingiber officinale*) irrigated by means of a drip irrigation system. In order to investigate the effects of different substrates and irrigation levels on the physiological characteristics and yield of ginger, an experiment was conducted as factorial, in which the main factor was three substrates (S_1: 75% cocopeat + 25% perlite, S_2: 50% peat + 50% perlite, and S_3: 25% zeolite + 75% peat) and the sub factor was four irrigation levels (I_1:100% I_2: 75%, I_3: 50%, and I_4:25%) were applied experimental plots according to the daily solar radiation values reaching the greenhouse, with 3 replications. The evapotranspiration values ranged between 49.7-198.7 L plant^{-1} and 51.7-206.9 L plant^{-1} in the 2019 and 2020 years, respectively. Rhizome fresh weight values for I_1, I_2, I_3 and I_4 were determined as 134.8, 94.7, 71.2 and 31.1 g in 2019 and 164.5, 148.1, 95.1 and 74.9 g in 2020, respectively. Water deficit stress significantly ($P \leq 0.01$) increased the 6-gingerol, 6-shogaol, α-zingiberene, α-farnesene, and geranly-acetate contents while it decreased the β-sesquiphellandrene and β-bisabolene content. It was found that the essential oil yield of ginger decreased depending on the increasing irrigation water stress levels.

Keywords: Gingerol, Growing media, Solar radiation, Water deficit, *Zingiber officinale*

1. Introduction

Ginger (*Zingiber officinale*) is one of the most popular spices worldwide, and is widely used as both a spice and a medicinal herb. The plant, which is widely used in food, medicine, and beverage in the world, grows naturally in India, China, South East Asia, and Mexico (Hayden et al. 2004; Ghosh 2011; Nair 2013). The total cultivated area of ginger amounts to 385,172 ha and a production total of 4,081,374 tons worldwide (Malhotra et al. 2021). Ginger cultivation in Turkey is relatively new, where the spice is frequently used in food and in detox tea, with a total planting area of 200 ha (Uysal Bayar et al. 2021).

Ginger is usually consumed as young ginger or mature ginger. Ginger contains 80.9% moisture, 2.3% protein, 0.9% fat, 1.2% mineral, 2.4% fiber and 12.3% carbohydrates. The minerals found in ginger include iron, calcium, and phosphorus, while it also contains vitamins such as thiamine, riboflavin, niacin and vitamin C. Ginger also possesses several interesting bioactive constituents and health-promoting properties. 6-gingerol is a major pungent ingredient in ginger, also possesses potent anti-oxidant, anti-cancer, analgesic, anti-pyretic, anti-inflammatory, cytotoxic, anti-diabetic, anti-obesity, anti-nausea, anti-gastric and anti-proliferative activities (Puengphian & Sirichote 2008). The composition of ginger may vary depending on the species, variety, growing conditions, drying and storage conditions (Ghosh 2011).

Ginger is made up of 1-3% essential oil which contains several active ingredients. The main active ingredients in ginger oil are sesquiterpenes: bisabolene, zingiberene and zingerol. The phenolic compounds found in ginger are shogaol and gingerol components. The proportions of active ingredients and phenolic components vary according to the irrigation, nutrition, and cultural practices (Kemper 1999).

There are an increasing number of consumers of ginger products in the world. Water management is one of the major factors affecting ginger production in arid and semiarid regions. Deficit irrigation adversely affects many physical and chemical processes related to water use efficiency of ginger cultivation (irrigated via micro sprays), thus leading to a decrease in plant yield and quality (Meneghelli et al. 2020). Islam et al. (2015) studied the effects of two irrigation treatments (I_1: irrigation in a dry period, 7 days before planting and 60 days after planting and I_2: no irrigation) on ginger (irrigated by hose pipe which has 2.5 cm diameter). They found that the highest weight of rhizome (268 g plant^{-1}) was obtained from I_1 irrigation treatments. Kumar et al. (2018) reported that ginger crops demand a large amount of irrigation water, requiring continuous irrigation throughout the growing periods. Gatabazi et al. (2019) investigated the effects of different irrigation water levels (T_1: 2025% maximum allowable depletion, T_2: 40–45% maximum allowable depletion, T_3: 60–65% maximum allowable depletion, and T_4: 80–85% maximum allowable depletion) on the yield and quality of ginger and found that water use (WU) ranged between 219 and 509 mm in greenhouse conditions. Meneghelli et al. (2020), in their study in Brazil, determined five irrigation depths (50%, 75%, 100%, 125% and 150% of crop evapotranspiration) on ginger and noted that total water use ranged between 919 and 1564 mm in open field conditions. Mohd and Sembok (2020) investigated three irrigation frequencies (WF_2 = two times a day applications, WF_4 = four times a day applications and WF_6 = six times a day applications) and three volumes of irrigation water (A_1 = 300 mL, A_2 = 600 mL and A_3 = 1200 mL) on yield and quality of ginger in soilless culture (100% of coir dusts) conditions. They reported that a combination of 6 times per day of irrigation frequency and 1200 mL irrigation water gave the best ginger plant growth performance and rhizomes weight in the soilless culture system.

On the other hand, the soilless culture system is the most intensive production method in agriculture. Soilless culture system can result in higher yields even under a limited and adverse growing environment. Significant factors persuading plant growth in soilless culture systems are water availability, nutrient content, moisture and soil aeration (Tüzel et al. 2019). Ravindran et al. (2004) argued that ginger growth improved under constant elevated moisture root and water availability to the plant in soilless culture. Yaseer Suhaimi et al. (2012) evaluated five combinations of substrates (100% coir dust; 100% burnt paddy husks; 70% coir dust + 30% burnt paddy husks; 30% coir dust + 70% burnt paddy husks; and 50% coir dust + 50% burnt paddy husks) on ginger and reported that the highest shoot height, shoot fresh weight, and rhizome weight were obtained plants grown in 100% coir dust. Supriya et al. (2020) studied three different substrates (cocopeat – 100%, cocopeat + perlite – 75:25 and cocopeat + sand – 75:25) on ginger and determined that the highest plant height, number of leaves, number of tillers, leaf area, and fresh rhizome weight per plant were recorded in a cocopeat + sand (75:25) combination.

Gatabazi et al. (2019) note there is limited information available on the response of ginger species that are subjected to varying water stress regimes. Information regarding the plant's response to water stress regimes and drought tolerance mechanisms can help to devise appropriate irrigation management strategies and be useful in breeding programs for the selection of genotypes that can withstand extreme conditions. Research concerning the effects of different irrigation water levels and substrates on son ginger have not been found in Turkey. For this reason, the aims of this study were (i) to evaluate different irrigation levels of ginger under greenhouse conditions (ii) to examine the effects of different growing media on ginger yield and (iii) to determine phenolic compounds, essential oil, and oil components of ginger under greenhouse conditions.

2. Material and Methods

2.1. Experimental area and climatic conditions

The study was conducted in a greenhouse located at the Batı Akdeniz Agricultural Research Institute, Antalya, Turkey in 2019-2020. The research area was located at a latitude of 36 56' N and a longitude of 30 53' E, and an altitude of 28 m. The average temperature and relative humidity inside the greenhouse for the study period are presented in Figure 1. The temperature and relative humidity ranged between 13.2-36.8 °C and 24.2-84.7% in 2019, respectively. In 2020, temperature and relative humidity ranged between 13.5-36.2 °C and 24.8-82.5%, respectively.

2.2. Treatments and experimental design

Three different substrates consisted of volumetric mixtures of cocopeat (C) and perlite (P) (S_1: 75% C + 25% P), peat (Pe) and perlite (S_2:50% Pe + 50% P), and zeolite (Z) and peat (S_3:25% Z + 75% Pe) and four irrigation levels (I_1:100%, I_2: 75%, I_3: 50%, and I_4:25%) were used in the study. Some properties of the different substrates used in study are given in Table 1. Different substrates formed by main plots were designed according to the randomized block design whereas the irrigation levels were designed as sub-plots. Thus, 4×3 split plots were applied and each treatment was replicated three times in the experiment (Figure 2).

2.3. Planting and growing conditions

Ginger rhizome was planted on 15 March 2019 and 6 March 2020. Each of the rhizomes was cut into smaller pieces of about 3-4 cm long and 35-45 g in weight before planting. The rhizomes were planted in 2.43 m^3 polypropylene bags (12.0 m long × 0.45 m wide × 0.45 m deep) with one row (0.45 x 0.45 m spacing, 5 plants m^{-2}) and a distance between the adjacent polypropylene bags of 50 cm. The polypropylene bags were filled with three different substrates. Each polypropylene bag contained 27 plants. The polypropylene bags were placed in gutters for the collection of drainage water.

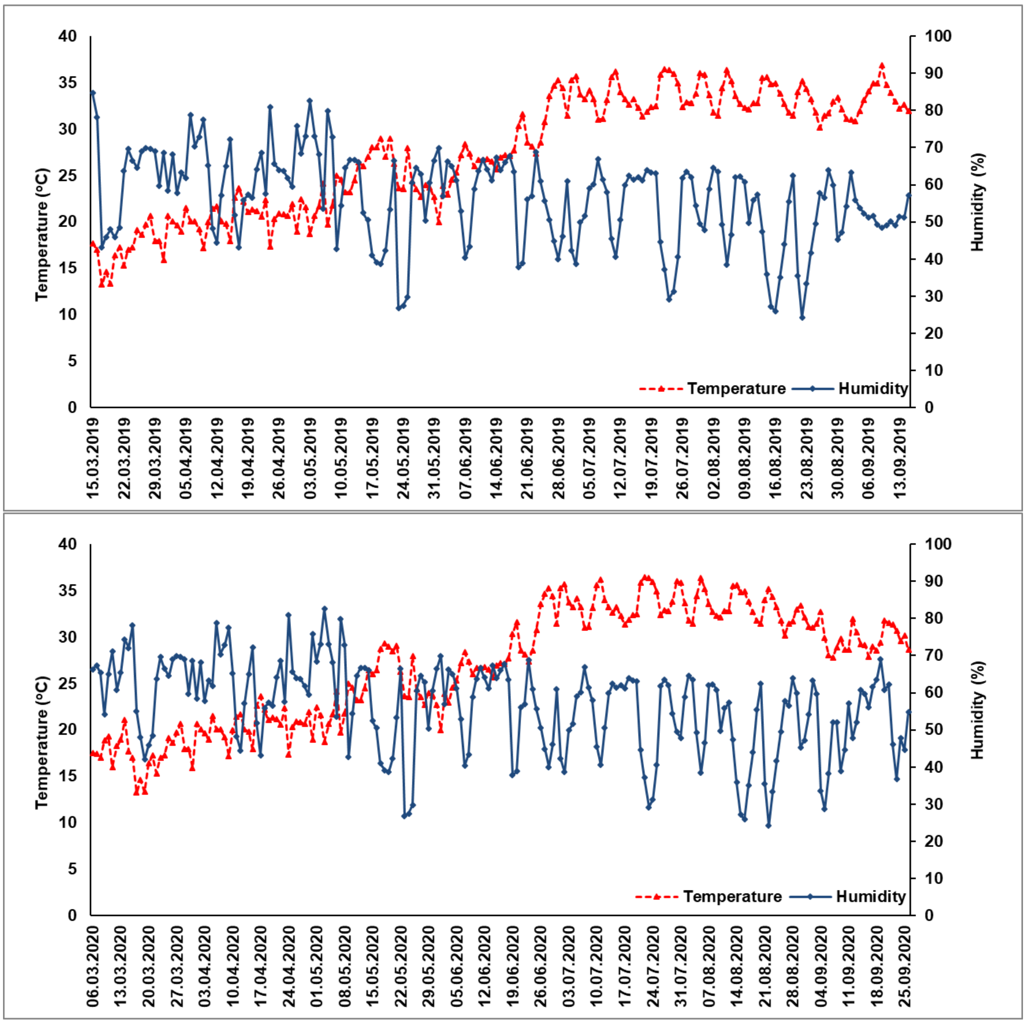


Figure 1- Average temperature and relative humidity measured inside the greenhouse

Table 1- Some properties of different substrates used in the study

Properties	S_1	S_2	S_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

S_1: 75% cocopeat + 25% perlite, S_2: 50% peat + 50% perlite, and S_3: 25% zeolite + 75% peat)

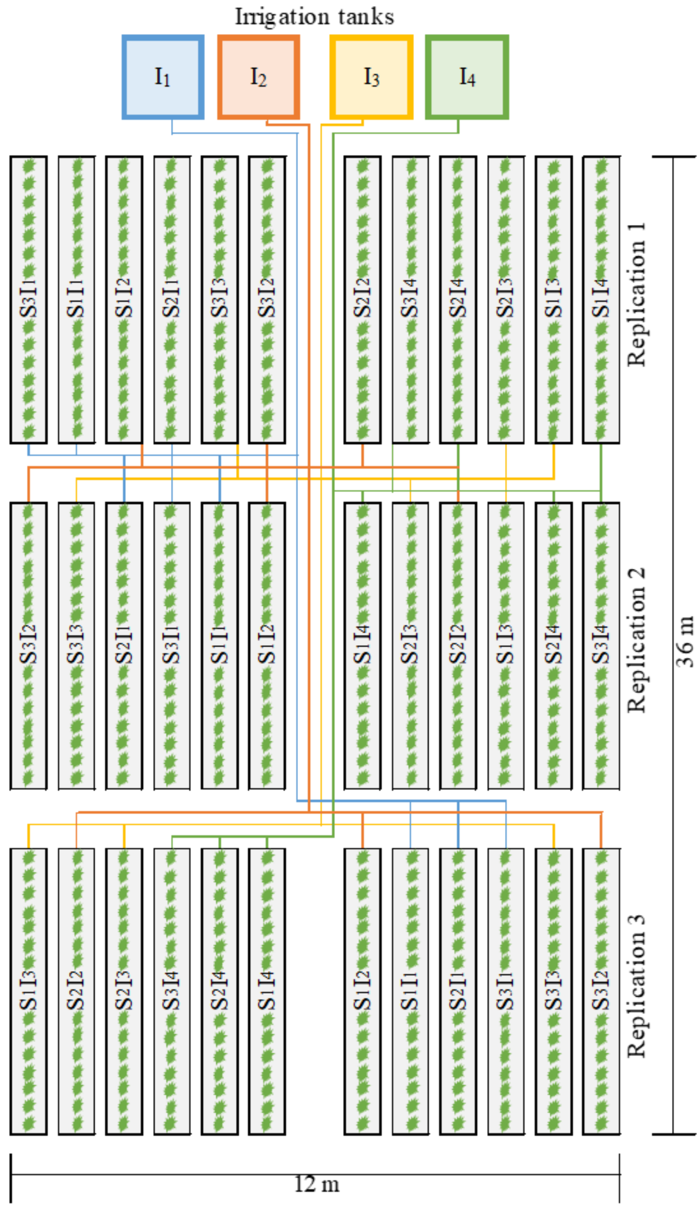


Figure 2- Experimental design used in the study S_1: 75% cocopeat + 25% perlite, S_2: 50% peat + 50% perlite, and S_3: 25% zeolite + 75% peat), I_1: Irrigated at 100%, I_2: Irrigated at 75%, I_3: Irrigated at 50%, and I_4: Irrigated at 25%

2.4. Nutrient management and irrigation

The plant nutrient solution recommended for ginger was 119 mg L^{-1} N, 83 mg L^{-1} P, 163 mg L^{-1} K, 193 mg L^{-1} Ca, 48 mg L^{-1} Mg, 6 mg L^{-1} Fe, 0.9 mg L^{-1} Mn, 0.3 mg L^{-1} B, 0.08 mg L^{-1} Zn, 0.06 mg L^{-1} Cu and 0.04 mg L^{-1} Mo (Hayden et al. 2004). The prepared stock nutrient solutions were used in irrigation practices for a balanced nutritional level in each treatment. Each irrigation level was provided with a tank of nutrient solution (1000 L) and a pump. The solution pH in each irrigation tank was arranged between 5.5-6.0 by the addition of nitric acid. All treatments were irrigated at the same time by a drip irrigation system having an in-line dripper discharging 1.6 L h^{-1} at a pressure of 0.1 MPa. The irrigation frequency was based on solar radiation achieved in greenhouse. The amount of water applied was calculated to meet the solar radiation. The irrigation scheduling was automatically implemented by a digital timer. A radiation-based evapotranspiration method was used to determine the applied irrigation water. For this purpose, a solar radiation sensor, placed in the greenhouse was used to apply the four irrigation rates 25% (I_4), 50% (I_3), 75% (I_2), and 100% (I_1) times the standard rate. The applied irrigation water (L) was determined using the following equation (Guyot 1998).

$$I = \frac{R_i}{\lambda} \times A \tag{1}$$

Where; I is the applied irrigation water (L), R_i is the incoming solar radiation inside the greenhouse (MJ m^{-2} day^{-1}), $\boldsymbol{\lambda}$ is the latent heat of water vaporization (MJ kg^{-1}), and A is the area of the polypropylene bags (m^2).
Plant water consumption (L $plant^{-1}$) was calculated using the following equation.

$$PWC = \frac{I-D}{PN} \tag{2}$$

Where; PWC is the plant water consumption (L plant^{-1}), I is the applied water (L), D is the drainage water (L) and PN is the plant number per polypropylene bags.

2.5. Harvesting and measurements

The harvest was performed when the leaves turned yellow and started to dry 50%. Twenty plants were harvested from each plot on September 15, 2019 and September 26, 2020. The fresh rhizome weight was measured in precision digital scale (0.1 g accuracy) for each treatment. Plant height was measured via ruler and the results given in terms of cm. The number of brunch per plant was counted one by one from selected 20 ginger samples.

2.6. Determination phenolic and essential oil compounds

The rhizomes of the ginger plants were dried and grinded before extraction. The rhizomes were dried in an air-circulated (7.272 m^3/hr) drying oven (Venticell-404 Standard, MMM group, Germany) at 40 °C until the humidity level was approximately 10%. After drying procedure, the rhizomes were ground. The grinding was realized at grinder (Retsch Grindomix GM 200) at 10.000 rpm during 1 minute.

The extraction of the phenolic compounds was realized using rhizome powders. The phenolic compounds of the powders were extracted using a methanol-water mixture (80:20). The extraction was made in an orbital shaker (Heidolph Unimax 2010) over a period of 1 hour. After extraction, the extracts were centrifuged at 5000 rpm for a total of 5 minutes. Later, the liquid phase was taken. The methanol-water mixture was added to the residual part and the same procedures were repeated 3 times. After this procedure, the extracts were taken to the 50 mL volumetric flask and it was diluted to the volume of the volumetric flask (Cemeroğlu 2010). In this part of the study, 6-gingerol and 6-shogaol contents of the rhizomes were determined. The compounds were detected in Liquid Chromatography (Agilent 1290)-Mass Sepctrometry (6430 Triple Quadropole) (LC-MS/MS) device with Zorbax RRHD Eclipse Plus C18 column (3 µm 2.1x100 mm) by using the method developed by Fischer et al. (2011). The calibration solutions of the compounds were prepared, firstly. The MS parameters (polarity, fragmentor voltage, product ions, collision energies) were determined. The calibration curve was plotted using calibration solutions and MS parameters. The quantitative contents of the compounds were calculated using calibration curves.

Essential oil extractions of the rhizome powders were realized at Clevenger apparatus (Isotex, 98-IV-B). The rhizome powders (20 g) were placed into the Clevenger apparatus and 200 mL of deionized water was added. The hydrodistillation was made during 2 hours. The essential oil content was calculated as (v/w, %) (Anonymous 2011). The essential oils were diluted with hexane as 1:100. The essential oil components were determined using Gas chromatography (Agilent 7890A)-mass detector (Agilent 5975C)/flame ionization detector (GC-MS/FID) device with capillary column (HP Innowax Capillary; 60.0 m x 0.25 mm x 0.25 µm). Helium was used as carrier gas with 0.8 mL/min flow rate, and the samples were injected into the device as 1 µL with 40:1 split rate. The injection block temperature was 250 °C, column temperature programme was adjusted as 60 °C (10 minute), from 60 °C to 220 °C with 4 °C/minute increasing rate and 220 °C (10 minute). The scanning range was 35-450 atomic mass unit and 70 eV was used as electron bombardment ionization, WILEY7 and OIL ADAMS libraries data were used in identification of the essential oil components. The components percentage ratios were determined using a FID detector and the identification of the components was made using an MS detector (Özek et al. 2010).

2.7. Statistical analyses

The experiment was carried out in a randomized block design with three replications in 36 experimental plots. During the experiment, the rhizome weight (g plant^{-1}), plant height (cm), number of branch (per plant), plant water consumption (L plant^{-1}), oil content (%), phenolic and essential oil compounds were determined. The collected data were subjected to the analysis of variance (ANOVA) using SPSS Statistics Base v23 (SPSS Inc., Chicago, IL, USA), and significant differences between means were compared through an LSD test ($P<0.05$) (Dean et al. 2017).

3. Results and Discussion

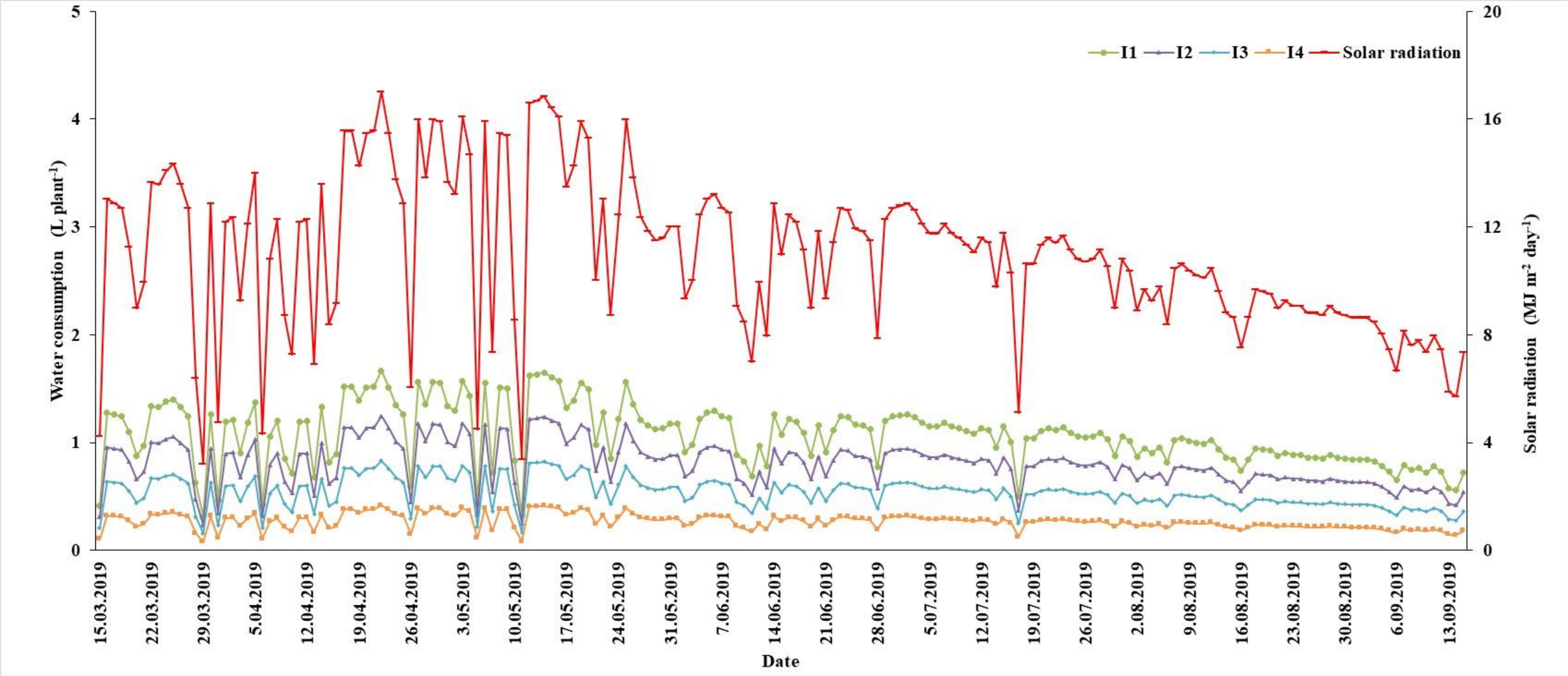
3.1. Solar radiation and plant water consumption

Daily solar radiation and plant water consumption are given in Figure 3. The daily solar radiation ranged from 4.32 to 17.02 MJ m^{-2} day^{-1} and 1.98 to 16.33 MJ m^{-2} day^{-1} in the 2019 and 2020 growing seasons, respectively. The highest solar radiation was measured in 22 April 2019 and 13 April 2020. Plant water consumption varied between 49.7-198.7 L plant^{-1} (248-994 mm) and 51.7-206.9 L plant^{-1} (258-1034 mm) in 2019 and 2020 growing season, respectively. Kandiannan et al. (1996) noted that the water requirement of ginger has been estimated by the Queensland Irrigation and Water Supply Commission to be between 1320-1520 mm during a complete crop cycle. Gatabaziet al. (2019) found that ginger is highly sensitive to water stress and deficit irrigation levels effect on yield and quality (plant height, stems per plant, number of leaves, leaf area index) of ginger. They determined that the total water consumption of ginger varied between 219 and 549 mm (31.8 and 13.7 L plant^{-1}) in open field conditions. Meneghelli et al. (2020) reported that the total water depth applied in the range of 1100–1200 mm favors the development of ginger plants, providing the highest yields of total and export rhizomes, the greatest average mass of export quality rhizome and lowest production of small rhizomes.

Table 2- Effects of different substrates and irrigation levels on yield and quality parameters

Treatments	*Years*							
	2019				*2020*			
	RW	*PH*	*SN*	*EO*	*RW*	*PH*	*SN*	*EO*
S_1	48.6 c^x	67.7 b	2.9 c	0.8 c	91.2	71.2	5.3	0.9 b
S_2	85.9 b	71.4 a	4.0 b	0.9 b	128.0	71.3	5.7	0.9 b
S_3	114.4 a	72.7 a	4.4 a	1.0 a	142.7	74.5	6.1	1.0 a
Substrates (S)	**	*	**	**	NS	NS	NS	**
LSD (0.05)	4.35	3.44	0.20	0.08				0.09
I_1	134.8 a	79.7 a	5.7 a	1.1 a	164.5 a	77.1	7.1 a	1.2 a
I_2	94.7 b	74.2 b	3.6 b	1.0 ab	148.1 a	75.5	6.4 b	1.0 b
I_3	71.2 c	66.5 c	3.3 c	0.8 b	95.1 b	73.2	5.1 c	0.8 c
I_4	31.1 d	62.1 d	2.4 d	0.7 c	74.9 b	63.5	4.1 c	0.6 d
Irrigations (I)	**	**	**	**	**	NS	**	**
LSD (0.05)	5.02	3.97	0.23	0.09	50.84		1.86	0.12
S_1I_1	79.4 d	69.6 de	3.4 cd	1.0	132.4	64.5	7.0	1.1
S_1I_2	45.6 e	68.6 ef	3.4 cd	0.9	124.6	67.4	5.7	0.8
S_1I_3	40.4 ef	67.4 ef	2.8 ef	0.7	74.3	79.3	5.0	0.8
S_1I_4	29.0 g	65.4 eg	1.8 g	0.6	33.6	73.4	3.7	0.7
S_2I_1	137.9 b	82.4 ab	6.6 a	1.1	166.4	82.8	7.0	1.0
S_2I_2	93.8 c	78.6 bc	3.4 cd	1.0	148.7	78.5	6.7	1.0
S_2I_3	81.0 d	66.1 ef	3.2 de	0.9	104.7	72.8	5.0	1.0
S_2I_4	30.0 g	58.5 g	2.6 f	0.7	92.1	51.0	4.0	0.9
S_3I_1	187.1 a	87.0 a	7.0 a	1.2	194.8	83.9	7.3	1.0
S_3I_2	144.6 b	75.5 cd	4.0 b	1.0	171.0	80.6	7.0	0.9
S_3I_3	92.3 c	66.0 ef	3.8 bc	0.9	106.2	67.3	5.3	0.9
S_3I_4	33.6 fg	62.5 fg	2.8 ef	0.7	98.9	66.0	4.7	0.8
S×I	**	**	**	NS	NS	NS	NS	NS
LSD (0.05)	8.70	6.88	0.40					

RW: Rhizome weight (g plant^{-1}); PH: Plant height (cm); SN: Stem number (number plant^{-1}); EO: Essential oil (%); S_1: 75% cocopeat + 25% perlite, S_2: 50% peat + 50% perlite, and S_3: 25% zeolite + 75% peat); I_1: Irrigated at 100%; I_2: Irrigated at 75%; I_3: Irrigated at 50%, and I_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)


I1
I2
I3
I4
Solar radiation
Water consumption (L plant⁻¹)
Solar radiation (MJ m⁻² day⁻¹)
Date
15.03.2019
22.03.2019
29.03.2019
5.04.2019
12.04.2019
19.04.2019
26.04.2019
3.05.2019
10.05.2019
17.05.2019
24.05.2019
31.05.2019
7.06.2019
14.06.2019
21.06.2019
28.06.2019
5.07.2019
12.07.2019
19.07.2019
26.07.2019
2.08.2019
9.08.2019
16.08.2019
23.08.2019
30.08.2019
6.09.2019
13.09.2019

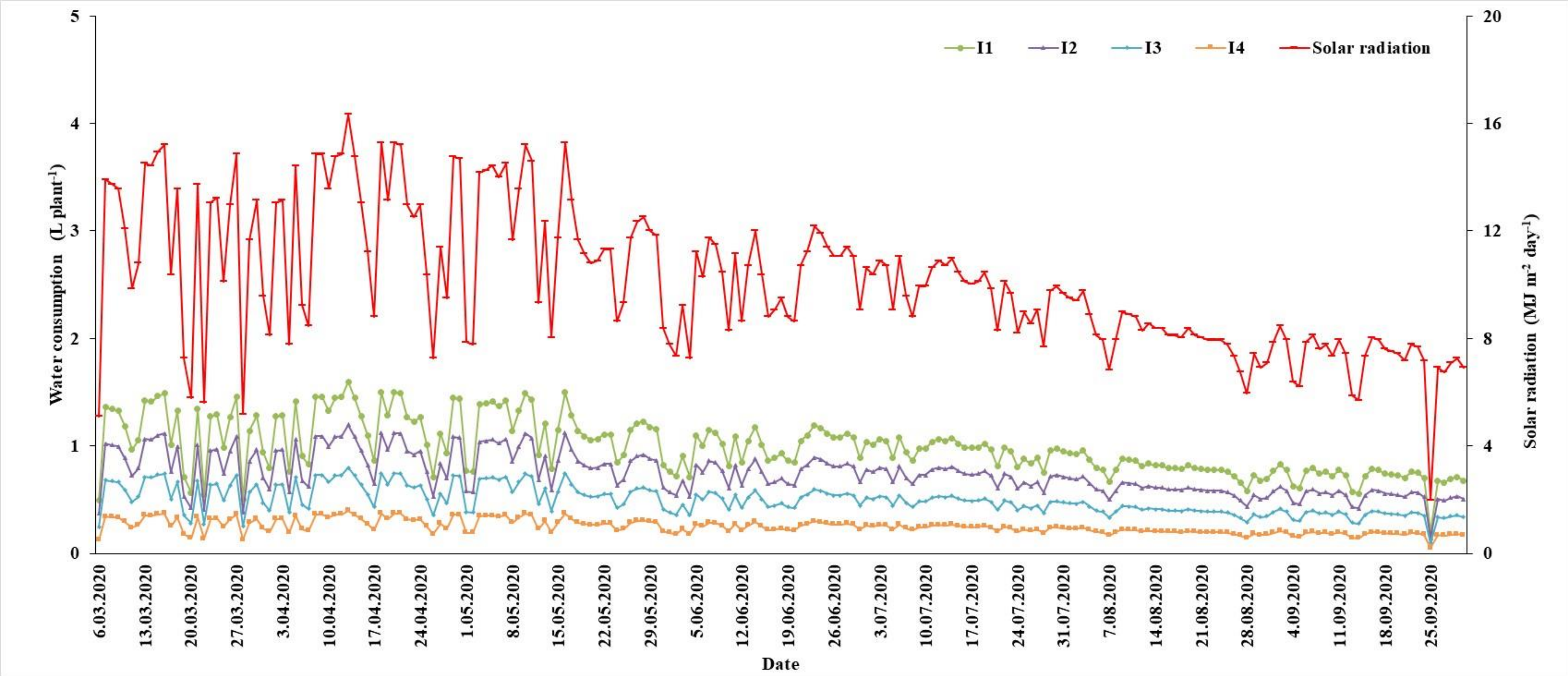


Figure 3- Daily solar radiation and cumulative water consumption (I_1: Irrigated at 100%, I_2: Irrigated at 75%, I_3: Irrigated at 50%, and I_4: Irrigated at 25%)

3.2. Yield, quality parameters, and essential oil

The average rhizome weight obtained from the different substrates and irrigation levels taken in the experiment and the variance analysis results of these yields are given in Table 2.

It was found that interactions were statistically different (P<0.01) for rhizome weight, plant height, and stem number in 2019, with the exception of essential oil, although no difference was found in 2020 (Table 2). The rhizome weight changed between 29.0-187.1 g plant^{-1} in the first year and 33.6-194.8 g plant^{-1} in the second year of the study. The highest rhizome weight was obtained as 187.1 and 194.8 g plant^{-1} from S_3I_1 treatment while the lowest rhizome weight was 29.0 and 33.6 g plant^{-1} from S_1I_4 treatment in the study. The reduction in the quantity of irrigation water resulted in a relatively lower rhizome weight. Rhizome weights in the second year are higher than in the first year. Temperature is one of the most important climatic factors for the development of ginger, which is a tropical plant. In the second year of the study, higher temperatures (Figure 1) from the planting date (first 15 days) compared to the first year may be the reason for the increase in rhizome weight. Beardsell et al. (1979) stated that sufficient water in a substrate is crucial for plant growth and development. Prasad et al. (2008) reported that deficit irrigation affects plant growth stages. They also stated that besides physiological reactions, plants underwent morphological changes, vegetative growth was reduced and the development of plant reproductive organs was inhibited under water stress. As can be seen, in both years of the experiment, as the stress of irrigation water increased, the rhizome weight per plant decreased. Baloyi (2004) reported the rhizome weight of wild ginger as 161.5, 121.1, 163.8, 178.0, and 76.5 g under 0.25 L day^{-1}, 1 L day^{-1}, 2 L day^{-1}, 2 L 2nd day^{-1}, and 2 L week^{-1}, respectively. Manjunatha (2010) determined the rhizome weight as 123.3, 165.0 and 230.7 g under 12, 18 and 24 L m^{-2} day^{-1}, respectively. Yaseer Suhaimi et al. (2012) obtained the highest rhizome weight from plants grown in 100% cocopeat medium with 1340 g, while the lowest rhizome weight was obtained from 30% cocopeat + 70% burnt rice hull with 1090 g. Islam et al. (2015) determined the rhizome weight as 268.07 g and 60.80 g, respectively, under irrigated and non-irrigated conditions. Gatabazi et al. (2019) determined the rhizome weight as 250 and 100 g plant^{-1}, under fully irrigated and 80% water constraint conditions, respectively. Meneghelli et al. (2020) determined the rhizome weight as 316 g plant^{-1} under control conditions, and determined the rhizome weight as 263 g plant^{-1} under 50% water constraint conditions. Similar results were found by Mishra & Mishra (1982) and Ghosh (1996).

According to Table 2, deficit irrigation treatments showed significant difference (P<0.01) for plant height in the first year of the experiment. While in the first year of the study, the plant height changed between 58.5 and 87.0 cm, in the second year, it ranged from 51.0 to 83.9 cm. Depending on the irrigation levels, the highest plant height was obtained from the I_1 irrigation level in the first and second year of the study. The highest plant was obtained as 87.0 and 83.9 cm from S_3I_1 treatment while the lowest plant was 58.5 and 51.0 cm from S_1I_4 treatment in the study. Plant height is a good indicator for determining the effect of water stress on the plant and is among the most important parameters affecting the weight. It was observed that as the irrigation level decreased, plant height values also decreased. Water stress, which is one of the abiotic stress sources, causes an increase in the osmotic pressure in the plant root zone and in this case makes it difficult for the plant roots to take water and plant nutrients (Sonneveld et al. 1999). The vegetative growth of the plant is limited as a result of the decrease in water intake. Plant height of ginger varied from Baloyi (2004) and Manjunatha (2010) determined plant height varied from 49.9 to 59.8 cm and 51.3 to 58.2 cm, respectively. Islam et al. (2015) found that plant height was significantly affected by irrigation and that the plant height was 60.5 cm in non-irrigated conditions and 71.6 cm in irrigation conditions. Similarly, Gatabazi et al. (2019) determined the plant height as 68 and 42 cm under full irrigation and water stress conditions, respectively. Yaseer Suhaimi et al. (2012) obtained the tallest plants from plants grown in a 100% cocopeat with 123 cm, while the shortest plant length was 105 cm and those grown in a mixture of 30% cocopeat + 70% burnt paddy husks. Other studies reported that deficit irrigation shortened plant height in ginger (Pawar 1990; Ghosh 1996; Chandra et al. 2001).

The stem number obtained from the study is given in Table 2. In the first year of the experiment, the effect of substrates, irrigation level, and substrates–irrigation levels interaction on the stem number was statistically significant. Examining the stem number with respect to irrigation level in the first year, the highest stem number was obtained from I_1 (4.4), while the lowest stem number was from I_1 (2.9). In the second year of the experiment, the effects of substrates and substrates-irrigation levels on stem number were not statistically significant; while the effect of irrigation level on stem number was statistically significant. The highest stem number was found in I_1 (7.1), while the lowest stem number was in I_4 (4.1). In substrates–irrigation levels interaction, the highest stem number was obtained from S_3I_1 treatments. Reducing the amount of irrigation water negatively affects plant growth by reducing the moisture content in the substrates and thus restricting the water uptake through plant roots. At the same time, water stress decreases plant growth by causing a decrease in photosynthesis rate and a decrease in cellular expansion. Mokgehle et al. (2017) stated that irrigation water plays an important role in the physiological processes of plants and that well-watered ginger easily maintains its normal physiological functions. Gatabazi et al. (2019) stated that the first sign of water stress usually causes a decrease in cell swelling, thus causing a decrease in cell growth, especially thinning of the stem and leaf number. The same researchers found that the number of stem was 8.8 and 5.6 under fully irrigated and 80% water constraint conditions, respectively.

The essential oil obtained from the different substrates and irrigation levels taken in the experiment and the variance analysis results of these yields are given in Table 2. It was found that interactions were not statistically different for the essential oil in 2019 and 2020. The essential oil changed between 0.6-1.2% in the first year and 0.7-1.1% in the second year of the study. The highest essential oil was obtained as 1.2% from the S_3I_1 treatment while the lowest essential oil was 0.6% from the S_1I_4 treatment. Depending on the irrigation levels, the highest essential oil was obtained from the I1 irrigation level in the first and second year of the study. The highest essential oil was obtained from the S3 substrate in the first and second year of the study. A reduction in the quantity of irrigation water resulted in a relatively lower essential oil content in our study. There is a dilemma about the change in essential oil content as some of the studies reporting that essential oil content t increases with an increase in water stress whereas others show essential oil contents decrease as the water stress decreases. Lawrence (1984) argued that decreased irrigation water amount increased the essential oil content whereas Kumar et al. (2018) reported that irrigation water deficiency has reduced the essential oil yield.

3.3. Phenolic and essential oil compounds

The influence of irrigation levels on phenolic and essential oil compounds in ginger is given in Table 3. Two phenolic and twenty-two essential oil compounds were positively identified after analysis via liquid and gas chromatography, respectively. Five essential oil compounds of more than 2% in abundance level are given Table 3. The effect of irrigation treatments was significant ($P<0.01$) for all phenolic and essential oil compounds in 2019 and 2020. In 2019, the highest 6-gingerol (9.03 mg g^{-1}), 6-shogaol (1.48 mg g^{-1}), α-zingiberene (36.98%), α-farnesene (6.82%) and geranly-acetate (7.27%) content was obtained from the I_4 irrigation treatment; β-sesquiphellandrene (24.72%) and β-bisabolene (8.44%) content from I_1 irrigation treatment. In 2020, the highest 6-gingerol (6.16 mg g^{-1}), 6-shogaol (1.39 mg g^{-1}), α-zingiberene (32.24%), α-farnesene (5.06%) and geranly-acetate (8.68%) content was obtained from the I_4 irrigation treatment; β-sesquiphellandrene (22.34%) and β-bisabolene (7.72%) content from the I_1 irrigation treatment. 6-gingerol and 6-shogaol are the most pungent phenolic compounds of ginger and have potent antioxidant activity and health promoting properties. Decreasing the irrigation levels also resulted in a significant increase in 6-gingerol and 6-shogaol content. It was found that the substrates were not statistically different for 6-gingerol and 6-shogaol content in 2020. Ginger cultivated in the S_1 media showed a slightly higher 6-gingerol content. The widely accepted idea there is a widespread increase in phenolic compounds in response to water stress is most often incorrect, since phenolic compounds may experience either a decrease or no changes in concentration when subjected to water stress (Albergaria et al. 2020). Sharizan et al. (2014) and Yaseer Suhaimi et al. (2018) suggested that secondary metabolites, such as 6-gingerol and 6-shogaol content and accumulation, were not affected by the substrates.

Gatabazi et al. (2022) found that water stress may help to improve the phenolic content for ginger species. The total phenolic content was lower in the full irrigation treatments in the study. The decrease in the total phenolic content under full irrigation treatments conditions observed in the current study aligns with previous findings that suggest that increased irrigation can limit specific components to improve secondary metabolites (Battaieb et al. 2010; Gatabazi et al. 2022). On the other hand, Jiang & Huang (2001) and Weidner et al. (2009) determined water stress either decreases or increases the content of phenolic and oil compounds. Additionally, Albergaria et al. (2020) carried out a systematic review on the effect of water stress on the contents of total phenolic and oil compounds in medicinal plants, concluding that that the acceptance that there is a widespread increase in phenolic and oil compounds in response to water stress is most often incorrect.

4. Conclusions

This study analyzed the effects of deficit irrigation levels and different substrates in ginger grown in greenhouse on yield, quality parameters. The effects of different irrigation levels on rhizome weight, plant height, stem number, essential oil, phenolic and essential oil compounds were found to be statistically significant. The maximum rhizome weight was obtained from I_1 treatments. The phenolic and essential oil compounds content increased as the amount of water deficiency increased, whereas β-sesquiphellandrene and β-bisabolene content decreased as the amount of water deficiency increased. Compared with the I_1 irrigation treatment, the mean relative rhizome weight decreases were 19, 45, and 65% and the essential oil content decreases were 13, 20, and 43% for I_2, I_3, and I_4 treatments, respectively. However, water deficit treatments caused an increase in the phenolic content (6-gingerol and 6-shogaol) in ginger. Substrate S_3 (containing 25% zeolite + 75% peat) showed good growth and increased the rhizome yield up to 46% and 17% compared to S_1 (containing 75% cocopeat + 25% perlite) and S_2 (containing 50% peat + 50% perlite). It can be concluded that the best performance in terms of ginger yield was obtained in S_3 substrate with I_1 irrigation treatments in soilless culture system.

Table 3- Effects of different substrates and irrigation levels on phenolic and essential oil compounds

Treatments	*2019*							*2020*						
	Phenolic compounds		*Essential oil compounds*					*Phenolic compounds*		*Essential oil compounds*				
	6-gingerol ($mg\ g^{-1}$)	*6-shogaol ($mg\ g^{-1}$)*	*A-zingiberene (%)*	*β-sesquiphellandrene (%)*	*β-bisabolene (%)*	*α-farnesene (%)*	*geranly-acetate (%)*	*6-gingerol ($mg\ g^{-1}$)*	*6-shogaol ($mg\ g^{-1}$)*	*α-zingiberene (%)*	*β-sesquiphellandrene (%)*	*β-bisabolene (%)*	*α-farnesene (%)*	*geranly-acetate (%)*
S_1	7.50 a[x]	1.15 b	34.77 a	21.92 b	7.72	6.62 b	5.02 b	5.44 a	1.19	31.10	20.74	6.84 b	4.57	7.78 a
S_2	6.82 c	1.13 b	32.78 b	21.54 c	7.60	6.40 c	5.84 a	5.26 b	1.09	30.20	20.72	7.26 a	4.42	7.16 a
S_3	7.13 b	1.31 a	33.59 b	22.76 a	7.62	6.82 a	4.82 c	5.11 c	1.15	30.30	21.44	7.32 a	4.84	6.04 b
Substrates (S)	**	**	**	**	NS	**	**	NS	NS	NS	NS	*	NS	**
I_1	5.65 d	0.99 d	30.49 d	24.72 a	8.44 a	6.58 b	3.72 d	4.35 d	0.87 b	29.22 b	22.34 a	7.72 a	4.16 c	5.20 d
I_2	6.22 c	1.07 c	32.82 c	22.55 b	7.63 b	6.62 b	4.70 c	5.12 c	0.96 b	29.64 b	21.93 a	7.35 a	4.56 b	6.04 c
I_3	7.71 b	1.24 b	34.56 b	21.20 c	7.32 b	6.74 a	5.14 b	5.45 b	1.36 a	31.02 a	20.44 b	7.02 b	4.73 ab	7.28 b
I_4	9.03 a	1.48 a	36.98 a	19.82 d	7.28 b	6.82 a	7.27 a	6.16 a	1.39 a	32.24 a	19.12 c	6.52 c	5.06 a	8.68 a
Irrigations (I)	**	**	**	**	**	**	**	**	**	**	**	**	**	**
S_1I_1	6.59 g	1.00 gh	30.82 fg	23.49 c	8.06	7.16 ab	3.98 h	4.35 i	0.97 e	28.98	22.91	7.30	3.98	5.04
S_1I_2	6.70 fg	1.10 e	34.74 cd	22.35 d	7.71	6.83 cd	4.86 f	4.71 g	1.06 de	29.89	22.54	7.09	4.46	6.43
S_1I_3	7.92 d	1.11 de	35.78 bc	21.43 e	7.19	6.41 e	4.95 f	5.29 e	1.38 ac	32.23	18.58	6.66	4.60	7.51
S_1I_4	8.81 b	1.41 b	37.75 a	20.30 f	7.84	6.19 ef	6.34 c	6.08 b	1.35bc	33.16	18.96	6.20	4.97	9.63
S_2I_1	5.23 h	1.00 gh	29.04 g	24.85 b	8.80	5.99 f	4.15 h	4.31 i	0.90 ef	29.55	21.50	7.72	3.96	5.95
S_2I_2	6.81 ef	1.03 fg	31.56 ef	21.35 e	7.36	6.09 f	5.64 e	5.23 f	0.94 e	29.24	21.20	7.34	4.30	6.09
S_2I_3	6.90 e	1.17 d	33.07 de	20.25 f	7.13	6.73 d	6.03 d	5.42 d	1.23 cd	30.04	21.10	7.15	4.48	7.63
S_2I_4	8.33 c	1.29 c	37.43 ab	19.60 g	7.00	6.92 bd	7.19 b	6.09 b	1.28 bc	31.90	18.88	6.70	4.92	8.67
S_3I_1	5.11 h	0.95 h	31.60 ef	25.80 a	8.47	6.22 ef	2.94 l	4.40 h	0.75 f	29.00	22.43	8.07	4.22	4.51
S_3I_2	5.15 h	1.08 ef	32.15 ef	23.68 c	7.63	6.76 cd	3.65 i	5.41 d	0.88 ef	29.73	21.85	7.35	4.70	5.56
S_3I_3	8.32 c	1.45 b	34.83 cd	21.93 d	7.51	6.98 bc	4.45 h	5.63 c	1.45 ab	30.86	21.64	7.22	5.06	6.40
S_3I_4	9.94 a	1.73 a	35.77 bc	19.48 g	6.75	7.39 a	8.00 a	6.30 a	1.53 a	31.62	19.50	6.54	5.16	7.56
S×I	**	**	*	**	NS	**	**	**	*	NS	NS	NS	NS	**

S_1: 75% cocopeat + 25% perlite, S_2: 50% peat + 50% perlite, and S_3: 25% zeolite + 75% peat); I_1: Irrigated at 100%; I_2: Irrigated at 75%; I_3: Irrigated at 50%, and I_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)

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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