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THE EFFECTS OF HIGH TEMPERATURE AND LOW HUMIDITY ON CROP WATER STRESS INDEX OF SEED PUMPKIN PLANTS (*Cucurbita pepo* L.) IN SEMI-ARID CLIMATE CONDITIONS

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ABSTRACT

This study aimed to evaluate the effects of high temperature and low humidity on the crop water stress index (CWSI) of seed pumpkin plants grown under semi-arid climate conditions to determine the optimum irrigation time. This research unveils the critical impact of high temperature and low humidity on seed pumpkin growth, emphasizing the vital role of the CWSI in optimizing irrigation strategies and seed yield. Moreover, the relationship between CWSI, physiological parameters, and seed yield of the pumpkin was investigated. The mean CWSI values in the I70 (0.40) and I35 (0.56) treatments were 42% and 100% higher, respectively than those in the full irrigation (I100) treatment (0.28). While the I70 treatment showed manageable water stress with minimal impact, the I35 treatment experienced severe stress, significantly reducing crop growth and yield. The mean seed yield (SY) in the I70 treatment increased to 1245.2 kg ha^{-1} compared to I35 (903.3 kg ha^{-1}) but remained lower than I100 (1339.3 kg ha^{-1}). The CWSI had negative correlations ($p \leq 0.01$) with seed yield, chlorophyll content, and leaf area index, while it had positive correlations with water use efficiency and irrigation water use efficiency ($p \leq 0.01$). This study showed that pumpkins could be grown successfully at 30% water deficit conditions, and a water deficit higher than 30% may cause a significant seed yield loss in semi-arid climate conditions. In addition, the results highlight the importance of optimal irrigation and CWSI monitoring for informed irrigation decisions and sustainable agricultural practices. Therefore, moderate water deficit (I70) can be adopted in pumpkin cultivation as an alternative to full irrigation.

Key words: chlorophyll, CSWI, yield, irrigation time, Turkey

INTRODUCTION

Drought, characterized by irregular precipitation and reduced water availability, profoundly impacts agricultural production [Chartzoulakis and Bertaki 2015]. As studies on drought occurrence proliferate, there is a growing need to analyze and comprehend its nuances. Addressing this, researchers underscore the urgency of developing drought prevention and mitigation plans, necessitating the immediate implementation of effective water resources management [Rolbiecki et al. 2022]. In irrigated agriculture, wa-

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ter application stores sufficient water within the crop root zone during the vegetation period. Prioritizing appropriate irrigation methods and schedules, including timing and quantity, is crucial before initiating water application [Kayam et al. 2000]. Designing effective irrigation plans hinges on accurately estimating plants' water needs, often achieved through calculating reference evapotranspiration and utilizing suitable crop coefficients [Rolbiecki et al. 2023]. Widely adopted in assessing water stress, the crop water stress index (CWSI) plays a pivotal role in determining the water status of crops [Kirnak et al. 2019]. Calculated based on two baselines, the lower limit (LL) and upper limit (UL), CWSI considers the temperature difference between canopy (Tc) and air (Ta) and the relationship with vapor pressure deficit (VPD) [Gençoğlan and Yazar 1999]. CWSI values range between 0 and 1.0 when reference points are LL and UL baselines [Anda 2009]. However, while CWSI aids in determining the appropriate irrigation time, it falls short in estimating the required irrigation volume [Nielsen 1990]. Traditional parameters such as soil moisture, meteorological data, and observation of changes in plant growth remain crucial in irrigation planning, aiming to maintain optimal soil moisture levels and minimize yield stress during the growing season [Seymen et al. 2019]. This research explores the effects of high temperature and low humidity on the CWSI of seed pumpkin plants under semi-arid climate conditions to ascertain optimal irrigation timing. Additionally, the study investigates the relationship between CWSI, physiological parameters, and seed yield of the pumpkin *Cucurbita pepo* (L.). Considering the detrimental effects of high temperature and low humidity on seed pumpkin growth observed in semi-arid climates, it was hypothesized that manipulating irrigation levels, specifically implementing moderate water deficit conditions (I70), will positively influence the crop water stress index. However, exceeding this deficit level (beyond 30%) will result in significant yield losses due to severe water stress reflected in higher CWSI values. It is predicted that this strategic adjustment in irrigation will lead to an optimized seed yield, establishing a balance between water conservation and crop productivity. By exploring this hypothesis, it was intended to provide valuable insights into sustainable pumpkin cultivation practices under challenging environmental conditions.

MATERIALS AND METHODS

Study area. The experiment was carried out during the pumpkin (*Cucurbita pepo* L.) called "framed seed" growing seasons of 2016 at the research fields of the Agricultural Faculty at Siirt University, Turkey. The study area is located between 37°58'13" N and 41°50'51" E latitudes, and the altitude of the experimental field was 581 m. Hot and dry air masses dominate in the summer months. The temperature during the daytime in summer exceeds 40°C, and the mean air temperature in the study area is 26°C. The temperature does not fall below 2.7°C. The minimum and maximum long-term mean relative humidity were recorded in January (70.2%) and August (26.9%), respectively [GDM 2022].

Soil characteristics. Table 1 shows the results of soil and irrigation water analyses. Clay particles dominated the soil texture in the experimental field. The EC of irrigation water was 0.34 dS $m^{-1,}$ and pH was 7.21 (C_2S_1 class), indicating high-quality irrigation water.

Details of the field experiment. The pumpkin seed used in the trial is a local variety known as "Nevşehir pumpkin seed". This variety is characterized by its more oval and broader seed type and is widely cultivated in Turkey under irrigated conditions. The "Nevşehir pumpkin seed" plant is not tolerant to excessive heat and drought stress. The optimal temperature is 20–25°C, and climatic fluctuations during the cultivation period can slow development. The plant thrives in well-lit conditions but is susceptible to spreading fungal diseases in prolonged drought or excessive humidity (Nevşehir Commodity Exchange 2024). The field experiment design was completely randomized blocks with three replications. The pumpkin seeds were sown on June 7 using a pneumatic seeder. The inter-row spacing was 70 cm. The length of the rows was 5 m, and the total size of each plot was 14.0 m^{-2}. The experiment, lasting a total of 124 days, was concluded on October 11. Two rows in the middle were harvested, each containing seven plants per row, resulting in 14 plants analyzed in each plot.

Plant nutrients needed for pumpkin plants were applied considering crop needs and the results of soil analyses. Half of the nitrogen fertilizer (60 kg ha^{-1}) and all phosphorus and potassium (150 kg P ha^{-1} and 120 kg K ha^{-1}) were applied during sowing. Di ammo-

Table 1. The physical and chemical properties of the soil and the characteristics of the irrigation water used in the experiment

Soil depth (cm)	Sand (%)	Clay (%)	Silt (%)	Organic matter (%)	Lime (%)	pH	EC (dSm^{-1})	P ($kg \cdot ha^{-1}$)	K ($kg \cdot ha^{-1}$)	Texture class	Bulk density ($g \cdot cm^{-3}$)	Field capacity (%)	Wilting point (%)
0–30	20.9	57.1	22.0	1.33	27.5	7.03	0.87	19.43	1654	clay	1.43	31.42	21.70
30–60	28.9	55.1	16.0	1.22	30.5	7.47	1.08	14.21	1420	clay	1.41	33.83	22.01
60–90	28.7	57.3	14.0	0.84	36.6	7.67	1.21	8.61	1540	clay	1.40	30.52	22.91

characteristics of irrigation water

pH	EC ($dS \cdot m^{-1)}$)	Ca^{2+} ($me \cdot L^{-1}$)	Mg^{2+} ($me \cdot L^{-1}$)	Na^{+} ($me \cdot L^{-1}$)	K^{+} ($me \cdot L^{-1}$)	CO_3^{2-} ($me \cdot L^{-1}$)	HCO_3^{-} ($me \cdot L^{-1}$)	Cl^{-} ($me \cdot L^{-1}$)	SO_4^{2-} ($me \cdot L^{-1}$)	SAR	Class
7.21	0.34	40.08	14.60	14.70	0.85	0.00	153.00	24.81	35.83	0.50	C_2S_1

EC – electrical conductivity, SAR – sodium adsorption ratio

nium phosphate (18% N, 46% P_2O_5) and potassium nitrate (13% N and 44% K_2O) were used as the sources of fertilizers in sowing. The rest of the nitrogen as ammonium sulfate (21% N) was manually applied during the throat filling when the heights of pumpkin plants reached 12 cm.

Irrigation treatments. The irrigation treatments used in the experiment were complete irrigation (I100), 70% (I70) of complete irrigation, and 35% (I35) of complete irrigation. In complete irrigation (I100) treatment, water was applied to bring the moisture content to 90 cm depth, the field capacity moisture content. Therefore, the field capacity moisture content was accepted as complete irrigation (I100) or control treatment. The drip irrigation system was used to apply water in irrigation treatments. The irrigation system was activated once every 7 days for 8 hours between 6–10 a.m. and 4–8 p.m. on the same day. Furthermore, the gravimetric method was applied before each irrigation to estimate the moisture content of the soil profile (0–90 cm). The irrigation was activated when 40% of the available moisture content within 90 cm soil depth was depleted.

The drip irrigation system used rigid PE pipes. Each plot consisted of 4 pumpkin rows separated by a distance of 70 cm, and each line (5 m in length) had a lateral pipeline. The infiltration rate of experimental soils was prolonged (7 mm h^{-1}) due to the high clay content (Tab. 1); therefore, the flow rate of drippers was set to 4 L h^{-1} with 1 atm operation pressure. The drippers on each lateral were placed at 33 cm spacings.

$$d = Pw \times As \times D/10 \tag{1}$$

where d is soil water content in depth (mm), Pw is soil water content (%) in each soil layer, As is soil bulk density (g cm^{-3}), and D is the depth of each soil layer (cm).

The amount of water calculated for each soil layer was summed to determine total water (dT) in 90 cm depth, as shown in the equation:

$$dT = d(0\text{–}30) + d(30\text{–}60) + d(60\text{–}90) \tag{2}$$

The amount of water used in each plot was calculated by multiplying total water, plot size, deficit percentage (1.00–0.70–0.35), and percentage of plant cover using the equation:

$$V = dT \times A \times Uma \times P \tag{3}$$

where V is the amount of water (liter) consumed, A is each experimental plot size (m^2), Uma is percent deficiency (%), and P is the percentage of canopy cover (%).

The P was calculated using the crown width to the row spacing ratio. The P value was considered 0.30 from the beginning to 80% of plant coverage. The P was set as 0.8 after this period. Rashid et al. [2005] developed the water balance equation to calculate crop water consumption.

$$ETa = P + I - Rf \pm \Delta S \tag{4}$$

where ETa is evapotranspiration (mm), P is precipitation (mm), I is irrigation water (mm), Rf is runoff (mm), and ±ΔS is changes of soil moisture (mm) in a root zone or the difference in water deficit between the beginning and end of a growing season.

The flow rate of drippers in the drip irrigation system was lower than the water infiltration rate into the soil. Therefore, no surface runoff occurred during the irrigation treatments. Similarly, water was applied to complete soil moisture in the root zone up to field capacity; therefore, water was assumed to be infiltrated within the root zone, and no leaching occurred. The Rf value was used as zero since no runoff and deep infiltration occurred in the experiment [Idso 1982]. Moreover, there was no precipitation during the growing season.

Data collection. The empirical method proposed by Idso et al. [1981] was used to calculate CWSI:

$$\mathrm{CWSI} = \frac{(\mathrm{Tc}-\mathrm{Ta})-\mathrm{LL}}{\mathrm{UL}-\mathrm{LL}} \quad (5)$$

where CWSI is the plant water stress index, Tc denotes the crown temperature (°C), Ta denotes the air temperature (°C), LL denotes the lower limit for stress-free water conditions, and UL denotes the upper limit for values at which the plants are not under stress.

The LL was calculated using the regression analysis in the equation below, the difference between T_C and Ta, and the vapor pressure deficit (VPD, kPa) [Howell et al. 1992].

$$\mathrm{Tc}-\mathrm{Ta}=\mathrm{a}-\mathrm{b} \times \mathrm{VPD} \quad (6)$$

where a denotes the cross-sectional temperature of the line (°C), and b denotes the slope of the line (°C kPa^{-1}). The vapor pressure deficit was estimated using the basic psychrometry equations described by Howell et al. [1992].

$$e_w = 0.61078 \exp\left[\frac{17.27\,\mathrm{Tw}}{237.3 + \mathrm{Tw}}\right] \quad (7)$$

$$e_a = e_{w-[(\mathrm{AP})(T_a - T_W)]} \quad (8)$$

where ew is saturated vapor pressure (kPa) at wet thermometer temperature, ea is actual vapor pressure Ta air temperature (kPa), Tw is the wet thermometer temperature (°C), A is the psychrometric constant (°C kPa^{-1}) and P is barometric pressure (kPa).

The following equation was used to calculate the psychometric constant:

$$\mathrm{A} = [0.00066(1 + 0.00115\,T_w)] \quad (9)$$

The saturated vapor pressure (kPa) was calculated the following equation:

$$P\,(T_a) = 0.61078 \exp\left[\frac{17.27\,\mathrm{Tw}}{237.3 + \mathrm{Tw}}\right] \quad (10)$$

In the equation, P (Ta) is the saturated vapor pressure at dry thermometer temperature (Ta), and Tw is in degrees Celsius (°C). The vapor pressure deficit (VPD) was calculated by subtracting the saturated vapor pressure at the dry thermometer temperature (P(Ta)) from the actual vapor pressure (P) at the same temperature.

$$\mathrm{VPD} = [(P\,(T_a) - P)] \quad (11)$$

The upper limit (UL) for plants experiencing complete water scarcity was calculated using the equations proposed by Idso [1982]:

$$\mathrm{Tc} - \mathrm{Ta} = a - b \times \mathrm{VPG} \quad (12)$$

$$\mathrm{VPG} = [(P\,(T_a) - P \times (T_a + a))] \quad (13)$$

where *a* and *b* are the regression coefficients for LL, and VPG is the negative atmospheric vapor pressure slope required to achieve a zero crown-air vapor pressure slope in these equations.

The water use efficiency (WUE) was estimated using the equation:

$$\mathrm{WUE} = \mathrm{GY} / \mathrm{Eta} \quad (14)$$

where WUE is water use efficiency (kg da^{-1}, mm), GY is seed yield (kg da^{-1}), and ETa is evapotranspiration (mm).

A portable chlorophyll meter (Minolta SPAD-502, Osaka, Japan) was used to measure chlorophyll content (CC, SPAD). The leaf area index (LAI) was determined using an LI-COR LAI-2000 sensor and plotter [Papanikolaou and Sakellariou-Makrantonaki 2020].

Methods of soil and water analysis. Particle size distribution of experimental soil was determined by the hydrometer method using disturbed samples [Gee

and Bauder 1986]. Furthermore, using Blake and Hartge's [1986] core method, bulk density was identified using undisturbed soil samples. Organic matter of soil was analyzed using the Walkley and Black method [Nelson and Sommer 1982]. Soil pH and EC values were measured in a 1 : 2.5 soil water mixture [Rhoades 1982]. The lime content of the soil sample was determined using the calcimeter method [Allison and Moodie 1965]. Field capacity (–1/3 bar) and permanent wilting point (–15 bar) moisture contents were determined in a pressure plate [Klute 1986]. The soil's sodium adsorption ratio (SAR) was identified using the method described by Soil Survey Staff [1996]. Plant-available phosphorus content was analyzed using sodium bicarbonate method [Olsen 1954]. Moreover, the ammonium extraction method determined the soil's exchangeable potassium content [Bouazzama et al. 2012].
The chemical properties of irrigation water (electrical conductivity (EC), pH anion, and cation contents) were determined using the methods described by Tuzuner [1990].

Statistical analysis. The effects of irrigation treatments on yield and other parameters were assessed by variance analysis (ANOVA). When ANOVA indicated a significant difference between the irrigation treatments, the least significant difference test (LSD at 0.05 probability level) was used to assess the differences among the means. Statistical analyses were conducted using SPSS statistical software version 21.0.

RESULTS AND DISCUSSION

Crop water consumption. The average amount of water used in I100 and I35 applications was 573.30 and 200.2 mm, respectively. The mean ETa value in the I100 and I35 irrigation treatments was 624 and 254.5 mm, respectively (Tab. 2).

Water use efficiency. The WUE is a commonly used parameter to provide information on the seed yield obtained per unit of Eta. The highest mean WUE value (0.36 kg da^{-1} mm) was calculated for I100, while the lowest value (0.22 kg da^{-1} mm) was for I35 irrigation treatment. The WUE difference between complete and moderate irrigation treatments was minimal. High values of WUE in the I100 treatment indicate an increased water consumption of pumpkin plants. The difference in WUE between I100 and I70 treatments was slight, and this result is probably related to the study area's climate and the water level applied in the deficit treatment. The variation of WUE values between the treatments is consistent with Kirnak et al. [2019]. The researchers reported that the WUE values in 2015 and 2016 varied between 0.18 and 0.30 kg m^{-3} and 0.55–0.89 kg m^{-3}.

Lower limit and upper limit. The LL was used to show the potential transpiration status of pumpkin plants, and the UL indicated high water stress conditions (Fig. 1a). The LL equation showed a positive water vapor flow toward the atmosphere throughout the growing season of the pumpkin population. Like

Table 2. The parameters of the pumpkin population determined in the experiments

IT	SY (kg ha^{-1})	CWSI	CC (SPAD)	WUE (kg da^{-1})	Eta (mm)	IW (mm)	IWUE	LAI
I_{100}	1339.3a	0.28c	45.00a	0.36a	624.0a	573.3a	0.45a	1.39a
I_{70}	1245.2a	0.40b	42.00b	0.28b	449.8b	400.0b	0.31b	1.34b
I_{35}	903.3b	0.56a	39.00c	0.22c	254.5c	200.2c	0.23c	1.30c
Mean	1162.7	0.41	42.00	0.28	441.5	391.4	0.33	1.34
CV (%)	16.5	28.6	6.1	21.2	34.4	38.9	27.6	2.89
LSD (*0.05*)	103.5**	0.086**	1.99**	0.035**	8.444**	17.51**	0.042**	0.31**

I_{100} – complete irrigation, I_{70} – moderate water deficit, I_{35} – severe water deficit, SY – pumpkin seed yield (kg ha^{-1}), CWSI – crop water stress index, CC: chlorophyll content (SPAD), IW – irrigation water (mm), Eta – crop water consumption (mm), WUE – water use efficiency (kg da^{-1}, mm), IWUE – irrigation water use efficiency; LAI – leaf area index; IT – irrigation treatment. Means followed by different letters are significantly different from each other $p < 0.05$.
** – the difference in mean values is important at $p < 0.01$, CV – coefficient of variation

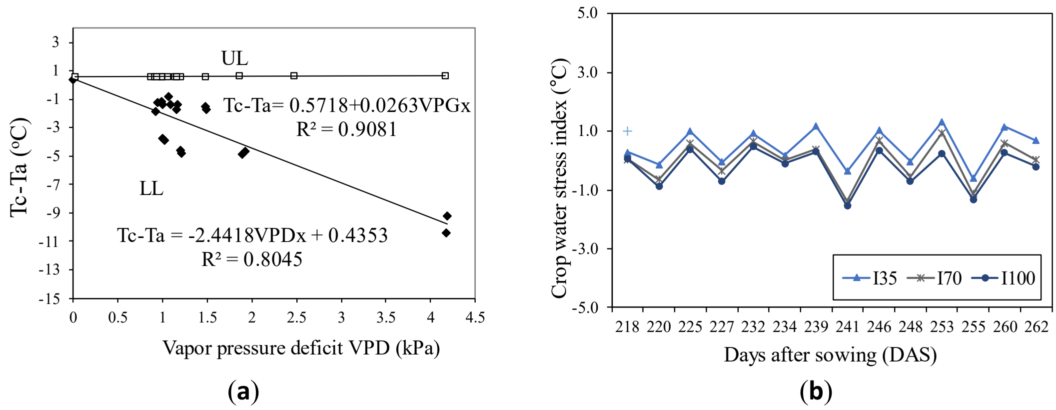

Fig. 1. a) LL and UL relationship graph of pumpkin population plant; LL – lower limit for plants with no water stress, UL – upper limit for plants at the highest water stress; b) CWSI in different irrigation treatments

these findings, Idso [1981] also reported a positive water vapor flow from leaves to the atmosphere. The UL equation determined in the study was:

$$Tc - Ta = 0.5718 + 0.0263\ VPGx\ (R^2 = 0.9081^{**})\quad (15)$$

The low slope of the UL equation shows that the difference in Tc and Ta at UL was 0.5718°C. The results agree with Bouazzama et al. [2012] and Kirnak et al. [2019]. Negative CWSI values were obtained when the values were less than the LL line (Fig. 1b).

The upper limit (UL) temperature for pumpkin growth was recorded as 0.57°C. The pumpkin seed yield at the CWSI threshold value of 0.40 was decreased. Therefore, 0.40 CWSI was considered the threshold for yield decrease in pumpkin production.

Crop water stress index. The CWSI values for irrigation applications mostly ranged between 0 and 1, while negative CWSI values were also recorded in the experiment. The negative CWSI values were obtained when measurement values were below the LL line. The highest (0.56) and lowest (0.28) CWSI values for pumpkin plants were obtained for I35 and I100 irrigation treatments, respectively (Tab. 2). The changes in daily CWSI values during the pumpkin growing season are shown in Figure 1b.

The mean CWSI values in the I70 (0.40) and I35 (0.56) treatments were 42 and 100% higher than the CWSI values recorded in the I100 treatment (Tab. 2). The findings showed that the increase in CWSI values caused a significant increase in water stress. The CWSI values in the I100 irrigation application during the growing season were between 0.25 and 0.31, and the CWSI values in the I35 application were between 0.49 and 0.61. In the I70 treatment, the CWSI value was moderately increased, suggesting moderate water stress that might have slightly impacted crop growth and yield. However, the I35 treatment exhibited an extremely high CWSI value, indicating severe water stress that caused significant reductions in crop growth and yield (Tab. 2). Therefore, it is crucial to maintain optimal irrigation levels to avoid water stress and ensure optimal crop performance. By monitoring CWSI values, farmers can make informed irrigation decisions to prevent yield losses and ensure the sustainability of their agricultural practices. Sarker et al. [2019] reported that plants with no irrigation treatments faced severe water stress and dried. The CWSI values start decreasing 4 to 5 days after the irrigation, and the increase in CWSI values indicates experiencing plant-to-water stress and decreasing soil water content [Ödemış and Baştug 2019]. Moreover, significant yield losses occur at high CWSI values [Wang et al. 2020].

Plants do not experience water stress when CWSI values are ≥0.2 [Fattahi et al. 2018]. In parallel with these values, Gençoğlan and Yazar [1999] reported the threshold values obtained from infrared and porometer readings of CWSI as 0.19 and 0.26. However, the threshold values for CWSI reported by Kirnak et al. [2019] differed slightly. The differences in CWSI values obtained in previous studies may be attributed to the differences in tolerances of various crops to soil moisture deficit conditions.

Yield response factor. The results recorded for Ky are given in Figure 2. Ky is an essential parameter in preparing an efficient irrigation plan and assessing the effect of water deficit on pumpkin population seed yield. The Ky value of the pumpkin population seed yield obtained in this study was 0.69. The Ky values reported by Kara and Sahin [2021] were 0.55 and 1.41, respectively. The Ky value obtained in this study can be used to optimize the water use efficiency of pumpkin plants cultivated using a drip irrigation system in semi-arid climate conditions.

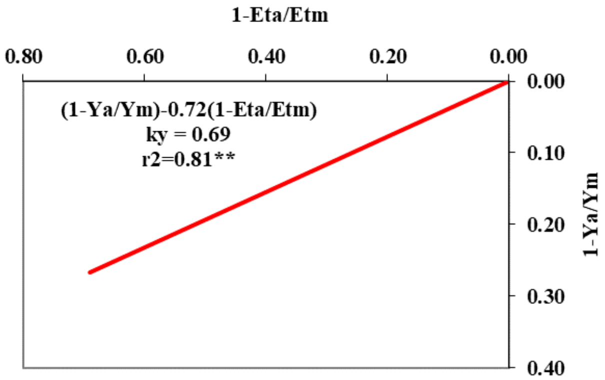

Fig. 2. The yield response factor (Ky)

Leaf area index. The LAI of pumpkin plants significantly increased with increasing irrigation water applied (Tab. 2). The average LAI values obtained under water deficit treatments were generally smaller than the average LAI value obtained in complete irrigation treatment. The highest (1.39) and the lowest LAI (1.30) values were recorded in the I100 and I35 irrigation treatments (Tab. 2). The LAI value in the I70 treatment (1.34) was between I100 and I35 treatments. The mean LAI values in the I70 and I35 treatments were 3.59 and 6.47% lower than the average LAI value of the I100 treatment. This positive correlation between LAI and irrigation can be attributed to enhanced leaf expansion due to improved water availability and nutrient uptake. Adequate water supply promotes photosynthesis and plant growth, potentially leading to higher yields. Therefore, maintaining optimal irrigation levels is crucial for maximizing pumpkin leaf area and, potentially, fruit production. Similar to our findings, Kirnak et al. [2019] reported that the increase in water stress caused a decrease in the LAI of pumpkin population plants. Low LAI under deficit irrigation conditions was attributed to the disruption of photosynthesis [Wang et al. 2011].

Chlorophyll content. The highest (45.00) and the lowest (39.00 SPAD) CC values were measured in I100 and I35 irrigation treatments (Tab. 2). The CC value in the I70 treatment (42.00 SPAD) was higher than the CC in I35 and lower than that in the I100 treatment. The mean CC values in the I70 (42) and I35 (39) treatments were 6.67% and 13.33% lower than the mean CC value recorded in the I100 (45) treatment. The leaf area index and CC are closely linked physiological parameters, exhibiting a strong positive correlation due to their shared roles in photosynthesis. However, this relationship is sensitive to water stress. Under water deficit conditions, limited nutrient transport from roots to leaves restricts chlorophyll production and slows leaf expansion, significantly decreasing LAI and CC [Papanikolaou and Sakellariou-Makrantonaki 2020]. Decreased canopy greenness and photosynthetic potential can significantly impact plant growth and productivity.

Seed yield. The highest (1339.30 kg ha^{-1}) and the lowest SY (903.10 kg ha^{-1}) were recorded in full irrigation and severe water deficit irrigation treatments (Tab. 2).

The overall mean seed yield (SY) value was 1162.7 kg ha^{-1}. In the I70 treatment, the mean SY was higher at 1245.2 kg ha^{-1} compared to the SY recorded in the I35 treatment, which was 903.3 kg ha^{-1}. However, it was lower than the SY in the I100 treatment, which was 1339.3 kg ha^{-1}. The decrease ratio in SY from I100 to I70 was 7.2%, while the increase in SY from I35 to I70 was 37.7%. The SY values of the pumpkin population had a statistically significant positive correlation with CC. In contrast, CWSI, WUE, and IWUE values negatively correlated with the pumpkin population's SY. The negative correlation revealed that the increase in CWSI caused a significant yield loss. Similar to our findings, Kirnak et al. [2019] reported a significant decrease in pumpkin population plant seed yield with increased CWSI values. Water deficit during the tasseling period adversely affects fertilization and seed yield of corn plants. The outcomes of this research align with Kirnak et al.'s [2019] findings.

Table 3. The correlation coefficients between seed yield and other parameters

	SY	CWSI	CC	WUE	IWUE	LAI
SY	1	–	–	–	–	–
CWSI	–0,883**	1	–	–	–	–
CC	0,911**	–0,866**	1	–	–	–
WUE	–0,874**	0,962**	–0,894**	1	–	–
IWUE	–0,907**	0,966**	–0,901**	0,996**	1	–
LAI	0,930**	–0,896**	0,907**	–0,854**	–0,865**	1

SY – seed yield, CWSI – crop water stress index, CC – chlorophyll content, WUE – water use efficiency, IWUE – irrigation water use efficiency, LAI – leaf area index, ** – the correlation is significant at 0.01 level of probability

The relationships between parameters. The results of the correlation analysis are given in Table 3. Statistically significant ($p \leq 0.01$) relationships were recorded between the characteristics examined in this study. The CWSI had a significant ($p \leq 0.01$) negative correlation with all the parameters except WUE and IWUE (Tab. 3). The correlation coefficient for SY was –0.883, CC was –0.866, and LAI was –0.896.

The relationship between CWSI values and the leaf area index photosynthetic activity has been reported in other studies [Ru et al. 2020]. Orta et al. [2003] indicated that CWSI for watermelon increased with increased soil water deficit. A significantly high negative correlation between the seed yield of the pumpkin population and the CWSI value obtained in this study reveals that the CWSI is a good indicator of seed yield to available water. The negative correlations indicated that an increase in CWSI value causes a significant decrease in SY, CC, and LAI values. Therefore, Irmak et al. [2000] recommended using CWSI as an efficient tool to monitor and quantify the water stress for corn in a Mediterranean climate. A significantly high correlation between the CWSI value and surface soil moisture content may provide information to evaluate the water status of plants [Ru et al. 2020]. Similar to our results, Ru et al. [2020] showed that the CWSI value increased with the decrease in irrigation water used. The SY of pumpkin population plants had a significant positive correlation with CC (r = 0.911**), WUE (r = 0.730**), CC (r = 0.978**), and LAI (r = 0.930**). The positive correlation indicated that the increase in CC and LAI causes a significant increase in the SY of pumpkin population plants. Similar to these findings, Al-Ghzawi et al. [2018] reported that SPAD and WUE values were significantly higher under high soil moisture content, and both SPAD and WUE had a high positive correlation with the grain yield of wheat grown in dry regions of Jordan. The researchers further recommended using SPAD as a selection parameter in breeding programs to develop high-yielding genotypes under drought and heat stress conditions. The WUE values had a significant negative correlation with the IWUE values. The WUE values significantly negatively correlated with SY (r = –0.874**) and IWUE (r = –0.907**). The negative correlations indicated that the increase in WUE value significantly decreases the SY, CC, and LAI of pumpkin population plants. The findings are consistent with the findings of Cheng et al. [2021].

One limitation lies in the scope of the study. This study focused on a single pumpkin population, location, and season. Future research needs to explore diverse varieties, climates, and growing seasons to confirm the reliability of the CWSI threshold across broader contexts. Additionally, this study solely assessed seed yield, while investigating other yield components like fruit size and quality could provide a more complete picture of the impact of water stress.

Despite these limitations, this work provides a valuable step toward sustainable pumpkin cultivation in water-scarce regions. Future research addressing limitations can refine irrigation strategies and optimize water use efficiency for various pumpkin varieties and environmental conditions.

CONCLUSIONS

The findings from this study highlight the theoretical benefits for researchers and growers in the field. Identifying the CWSI threshold value of 0.40 for irrigating pumpkin population plants in semi-arid conditions, preventing yield losses, is a crucial insight. The study indicates that maintaining this threshold value is essential to avoid significant decreases in plant growth and seed yield. Additionally, the research suggests that implementing a water deficit of up to 30% compared to full irrigation (I100) in pumpkin cultivation under semi-arid climates can result in substantial water savings. However, exceeding a 30% water deficit may lead to a considerable decline in pumpkin seed yield.

Furthermore, the study introduces the concept that the I70 treatment could be a viable alternative to the I100 in highly water-stressed locations. The similarity in CWSI values and seed yields between I100 and I70 treatments, with only a 7% decrease in seed yield at I70, suggests the potential feasibility of this alternative irrigation approach. These theoretical insights are particularly significant for better water management and conservation on a global scale. The findings propose I70 irrigation as a promising alternative in regions facing limited water resources.

It is important to note that the specific pumpkin variety and climatic and environmental conditions may influence yields differently under water-scarce circumstances.

Future research should explore the application of CWSI thresholds in precision agriculture and refine irrigation strategies for diverse pumpkin varieties and climatic conditions to maximize water savings and yield potential in semi-arid regions. It will enable water-scarce regions to embrace sustainable pumpkin cultivation with optimized water use and broader environmental benefits.

While this study provides valuable insights into optimal irrigation strategies for pumpkin cultivation in semi-arid regions, it is essential to acknowledge some limitations. First, the findings are limited to a single pumpkin population, season, and location. It restricts their applicability to other varieties, climates, and growing seasons. Additionally, the short-term nature of the study leaves open the question of how these findings translate to the long-term. Furthermore, focusing solely on seed yield omits other crucial aspects like fruit quality and environmental impacts, requiring future research to address these gaps. Finally, while CWSI emerges as a critical indicator, other factors like soil properties and pest pressure could also influence yield and water use efficiency, needing further investigation.

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