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**ARAŞTIRMA MAKALESİ** **RESEARCH ARTICLE**

# Quantifying photosynthetic properties of drought-resistant and sensitive cotton varieties grown in Eastern Mediterranean conditions

Doğu Akdeniz koşullarında yetiştirilen kuraklığa dayanıklı ve hassas pamuk çeşitlerinin fotosentetik özelliklerin belirlenmesi

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Ö Z E T / A B S T R A C T

***Aims***: This study aimed to investigate the effects of different irrigation water levels on evapotranspiration, water use efficiency, stomatal conductance, photosynthesis rates and yields in 14 drought-sensitive and resistant cotton varieties.
***Methods and Results***: The trial was carried out according to the random blocks experimental design pattern. The experimental study was conducted on ST 506, ST468, BA525, BA119, FLASH, SIOKRA L-22, TAM SPHINX, TAM 94L-25, PIMA S-7, TAMCOT-22, TAMCOT SP 21 S, TAMCOT SP 23, TAMCOT CAMD-ES and AKSEL cultivars. Evapotranspiration, water use efficiency, stomatal conductance, transpiration and photosynthesis rates and yields of the mentioned cultivars were determined. Photosynthesis rate, transpiration rate and stomatal conductance were measured only at the levels of full irrigation ($I_{100}$) and 25% of the full irrigation ($I_{25}$).
***Conclusions***: The total numbers of irrigation done in the first and second years were four and six, respectively. The amount of irrigation water applied varied between 270 and 480 mm in the first year, and 298 and 520 mm in the second year. Yield and evapotranspiration increased depending on the amount of irrigation water applied. The highest and lowest yields were determined as 358 kg da$^{-1}$ in Aksel cultivar and 555 kg da$^{-1}$ in BA525 variety, respectively. On average, the photosynthesis rate was measured as 12,616 µmol m$^{-2}$ s$^{-1}$ for $I_{100}$, and 7.549 µmol m$^{-2}$ s$^{-1}$ for $I_{25}$. As the stomatal conductance increased, the yield also increased (0.093 mol m$^{-2}$ s$^{-1}$ for $I_{25}$ and 0.182 mol m$^{-2}$ s$^{-1}$ for $I_{100}$). Transpiration rate was determined as 2.947 mmol m$^{-2}$ s$^{-1}$ for $I_{25}$ and 3.919 mmol m$^{-2}$ s$^{-1}$ for $I_{100}$. The varieties did not significantly differ in terms of water stress. Aksel cultivar is drought-sensitive, whereas the others are drought-resistant varieties.
***Significance and Impact of the Study***: The research revealed the physiological characteristics, plant water consumption and water use efficiency of 14 different cotton varieties widely grown in eastern Mediterranean conditions. And also, when the relationship of the mentioned parameters with yield was examined, the relationship between stomatal conductance and yield was found lower than the one between transpiration and photosynthesis rates.

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## INTRODUCTION

Drought is the stress factor that limits the growth, development and productivity of the plants the most. The response of plants to drought varies depending on plant species and cultivars, plant age, growth and development periods, drought period, and drought severity. Plants try to protect themselves against the harmful effects of stress by morphological, biochemical and physiological ways. The most important of these physiological features are stomatal conductance, leaf temperature (Jones, 1999), photosynthetic capacity (Lawlor and Cornic, 2002), phenological periods (Slafer et al., 2005; Richards, 2006), and leaf area (Walter and Shurr, 2005). There exists no single response parameter that correlates well with yield under arid conditions. Drought and osmotic stress caused by water deficiency also adversely affect chlorophyll content, which is considered the beginning of the protective mechanism in the morphology, water content, and the plant (Jackson et al., 1996). Kerepesi and Galiba (2000) stated that drought-resistant varieties accumulated more dry matter (biomass) in their leaves than the sensitive ones. The decrease in the number and area of leaves is directed to reduce the decrease in the amount of water lost by transpiration, while the changes in the roots are directed to absorb (suction) water from the soil with a higher force. In the drought stress, the root development first accelerates, and the ratio of root to stem increases. As a result of the slowed photosynthesis, the development weakens during the seedling period. Leaf growth slows down even in a short drought period. Drought causes leaves to be covered with frequent hairs in some plants. The hair reduces the transpiration rate by lowering the temperature of the underlying cells by 1–2°C. In addition, the waxy (cuticle) layer formed on the leaf reflects the rays of the sun and reduces the effect of the temperature, thus reducing the transpiration rate (Goksoy and Turan, 1991).

Stomatal conductance/resistance is the parameter most affected by water stress. The importance of stomata in plant physiology is due to the gas exchange between the intercellular space of the leaf and the atmosphere and to enable the water vapor output. Gas exchange is very sensitive to drought stress (Kerepesi and Galiba, 2000). It is generally accepted that the decrease in $CO_2$ use in the moderate drought stress is related to stoma closure (Mansfield and Davies, 1981). However, if the drought time is prolonged, this time, the decrease in photosynthesis is not caused by stomatal closure, but by the membrane damage in mesophile cells, a decrease in chlorophyll content, and the deterioration in the transport and synthesis of assimilation products. The amount of the decrease in photosynthesis varies depending on the severity and period of drought stress, plant species and variety, development period, aging of leaves, oxidation of chloroplasts, and changes in the structure of proteins and pigments (Passioura et al., 1993).

The following two mechanisms have developed in drought stress that control the closure of the stomata: hormonal and ion controls. In plants exposed to drought stress, the amount of abscisic acid (ABA) increases in stoma cells, as a result of which water-insoluble starch forms and potassium ion decreases. Thus, stomata cells, whose osmotic pressure decreases, close by losing their turgor. This mechanism is considered to be the hormonal control. The amount of potassium ion in the stoma cells also has an effect on stoma movements. While the plant is in turgor state, potassium ions are taken from the cells adjacent to the stomata cells. Thus, stomata with increased osmotic pressure are opened. When the turgor ends in the plant, the potassium ions in the stoma cells pass back to the adjacent cells, and in this way, the stoma cells, whose osmotic pressure decreases, lose their turgor and close. This mechanism is called the ion control (Lang et al., 1994).

Loka and Oosterhuis (2014) suggested that the period of flowering in cotton was the most sensitive period against water stress, but the metabolism in this period was not fully understood. They created a sufficient (optimum) water stress at the flowering period and 50% of this level using Hoogland solution in the growth chamber in 2008 and 2009. They stated that leaf stomatal conductance, photosynthesis and respiration rates were significantly reduced under the stress conditions. Cotton flowers were found to be significantly resistant to changes in plant water content. Water stress during flowering also significantly reduced the rate of leaf gas exchange.

In the cotton plant, the nutrition process needs the appropriate amount of water for growth, metabolic functions and the movement of nutrients. Therefore, drought stress and irrigation strongly affect fertilizer effectiveness and ultimately development and yield. The drought resistance of the cotton plant is higher than that of sorghum, sunflower, corn and soybean due to different mechanisms such as different fruit casting feature, osmotic compatibility, and root development. Drought reduces growth such as leaf shrinkage, root structure, and plant height as well as yield such as increased fruit falls, cocoon size, and less crop. As the plant effectively cools itself with evaporative water loss from the leaves in dry conditions, the leaf temperature is a few degrees lower than the air temperature. This significantly increases the effects of high temperature in dry conditions (Oosterhuis, 2001).

Water stress is one of the important factors that negatively affect the growth and yield of the cotton plant, which is a water-loving plant in the growing process. As with all the plants, cotton has different genetic structures in terms of resistance to drought (Cook and El-Zik, 1993; Gomathinayagam et al., 1988; Lacape et al., 1998). With its deep and dense root system, Cotton also has physiological mechanisms that can adapt to semi-arid areas such as pouring flowers and cocoons under stress (Ray et al., 1974).

The effects of water stress on yield depend on the duration and severity of the drought. Decreasing photosynthesis due to stress reduces the leaf size and number and slows down the plant growth rate. In cotton, the period from carding to the period when the first flower is seen is the most important development period that affects the yield elements. The most susceptible period to drought is flowering (beginning of carding and flowering) period. The water stress that will occur in this period causes huge reductions in efficiency (Krieg, 1997).

Mc Michael and Hesketh (1982) stated that the net photosynthesis rate decreased linearly to a threshold value of -20 to -22 bar and reached the lowest level at -36 bar. Stoma resistance decreased at -20 to -25 bar on the upper surface of the leaf, which is sensitive to stress, and -25 to -30 bar on the lower surface of the leaf. It was determined that the stomata closed when the plant water potential reached -25 to -30 bar.

Turner et al. (1986) reported that as the lack of water in the soil increased, the leaves adapted to the full turgor state at 0.5-0.6 MPa, while the photosynthesis rate and stomatal conductance decreased continuously when the leaf water potential was between -1.9 MPa and -3.5 MPa. Leaf development was more sensitive to water deficiencies in leaf and soil than photosynthesis rate. As a result of the lack of soil water that decreases the rate of photosynthesis, the fruit capacity that the plant can carry also decreased (Turner et al., 1986).

Ullah et al. (2008) quantified photosynthesis rate, stomatal conductance, transpiration rate, and productivity characteristics to evaluate the drought tolerance of 32 cotton varieties under limited and full irrigation conditions. The yield and biological productivity of all the cultivars were reported to decrease except for two varieties under the limited water conditions, while the CIM-1100 and RH-510 varieties showed very high resistance to drought, with the significant genotypic variations against gas exchange among the cotton varieties. In the study, a significant positive relationship was determined between transpiration and stomatal conductance at $p < 0.01$. In the limited water conditions, stomatal effects played an important role in the realization of photosynthesis rate, with the significant relationship between photosynthesis and stomatal conductance at $p < 0.01$.

This study aimed to determine the effects of water stress on 14 cotton varieties created according to the different levels of evaporation amount measured in class A pan. The effects of the resulting stress, as well as the changes in photosynthesis rate, transpiration rate, stomatal conductance, and water use efficiency were determined.

## MATERIALS and METHODS

### *Description of study area*

The experiment was carried out in the research station of ProGen Tohum A.Ş in Antakya/Hatay in Amik Plain. Physical and chemical properties related to the trial area are given in Table 1.

Table 1. Soil Properties in the Study Area

| Depth (cm) | Texture class | pH | $EC_e$ (µmhos $cm^{-1}$) | $CaCO_3$ (%) | N (%) | OM (%) | FC (% Pw) | PWP (% Pw) | As (g $cm^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|
| 0-30 | SiCL | 7.55 | 1124 | 2.265 | 1.42 | 0.33 | 21.3 | 13.4 | 1.66 |
| 30-60 | SiCL | 7.62 | 560 | 0.680 | 1.65 | 0.34 | 24.1 | 14.2 | 1.67 |
| 60-90 | SiCL | 7.80 | 429 | 0.905 | 2.01 | 0.38 | 25 | 14.5 | 1.53 |
| 90-120 | SiCL | 7.65 | 400 | 0.300 | 2.12 | 0.37 | 25.2 | 14.7 | 1.47 |

ECe: electrical conductance of soil solution extract; OM: organic matter; FC: field capacity; PWP: permanent wilting point; As: bulk density

### *Climate regime*

In the province of Hatay, in the Mediterranean climate zone, winters are mild and rainy, while summers are hot and dry. Most of the rainfall is out of the growing season of cotton. According to the long-term average climate data, the mean annual temperature and relative humidity were 19.95 (8.2-29.1) and 53% (45-60%), respectively, while the total rainfall was between 650 and 1000 mm.

***Properties of Cotton Genotyping***

In this study, genotypes which are widely grown in the country, and drought resistant genotypes that have been proved by the scientific studies were adopted. These varieties also differ in terms of ginning efficiency and earliness. In the study, drought-resistant, ST 506 ST468, BA525, BA119, FLASH, SİOKRA L-22, FULL SPHINX, FULL 94L-25, PIMA S-7, TAMCOT-22, TAMCOT SP 21 S, TAMCOT SP 23, TAMCOT CAMD-ES and drought-sensitive AKSEL varieties were used.

***Experimental design and treatments***

In calculating the irrigation water applied to the plots, open water surface evaporation was used. The treatments were irrigated when cumulative amount of evaporation measured in class A pan reached 80-90 mm so that the stress level was approximately the same. The amount of irrigation water to be applied to the plots was determined by multiplying cumulative amount of pan evaporation with different Kcp (Kcp = Kc x Kp) coefficients (0.25-S25, 0.50-S50, 0.75-S75, 1.0-S100, 1.25-S125) (Eq. 1).

$$V = A \times Eo \times Kcp \times P \quad \text{Eq. (1)}$$

Where;
V: irrigation water (l)
A: plot area (m²)
Kcp: Crop-Pan coefficient
P: percentage of cover (%)
Eo: open water surface evaporation amount (mm).

Cover percentage was measured and monitored before each irrigation. Kp values were taken as 0.85 due to the climatic conditions of the region and the location of the evaporation pan. Kc values were taken for full irrigation (Kcp: 1.0 –Kcp:0.25) to vary between 0.30-1.17 (Doorenbos and Kassam, 1986). Since a drip irrigation system was used, irrigation efficiency was taken as 0.95 for each irrigation (Yıldırım, 2008). Crown width measurements were measured from plants labeled on the row before each irrigation.

During the study, a drip irrigation system with a flow rate of 1.6 L $h^{-1}$ at 40 cm was used. The laterals are placed in two rows. Pressure measurements were made at the beginning and end of the lateral, while the head losses were continuously monitored to remain within the desired limits. Also, at the time of irrigation, the flow rate measurements of the drippers marked earlier, at the beginning, in the middle and at the end of each running lateral were made to test whether or not the drippers delivered the desired flow rate.

***Evapotranspiration***

In the irrigation treatments, the water balance equation given below was used to determine the water consumption of plants (James, 1988).

$$ET = I + P + Cr - Dp - Rf \pm \Delta s \quad \text{Eq. (2)}$$

Where;
ET = Evapotranspiration (mm)
I = irrigation water (mm)
P = rainfall amount (mm)
Cr = capillary rise (mm)
Dp = deep percolation loss (mm)
Rf = runoff loss (mm)
Δs = water content change in soil profile (mm).
According to the use of the drip irrigation system, the value of Rf was assumed as 0.

***Water Use Efficiency (WUE)***

One of the criteria used to compare the irrigation levels and varieties is water use efficiency (WUE). Water use efficiency is defined as the amount of water used in dry matter production. The equation proposed by Howell et al. (1990) was used in the study.

$$WUE = 100 \times \left( \frac{Ey}{Et} \right) \quad \text{Eq. (3)}$$

Where;
Ey = economic yield (kg)
Et = evapotranspiration (m³).
In the calculations, instead of economic efficiency, the mass yield obtained directly from the unit area is used.

***Stomatal Conductance and Chlorophyll Measurements***

To measure the response of the plants to all the irrigation levels in the experiment, stomatal conductance (mmol $m^{-2}$ $s^{-1}$) was measured using a porometer of AP4 Delta-T, Cambridge, UK for the $I_{100}$ and $I_{25}$ irrigation levels between 10:00 and 14:00. The measurements were based on the three replications at each irrigation level and two leaves in each replication. Chlorophyll values were measured and expressed in µmol $m^{-2}$ with three replications for all the irrigation levels and two leaves per replications with the SPAD-512 color meter.

***Measurements of Photosynthesis and Transpiration Rates***

Using a LI-6400XTR (Li-Cor, Lincoln, NE) type portable gas analyzer, the different plants were measured at the different levels of development, on a single leaf in the 1st position closest to the main body in each plot for the $I_{100}$ and $I_{25}$ irrigation levels. Measurements were continued regularly between 10:00 and 14:00 (before and after irrigation) when the photosynthetic photon flow (PPF) > 1800 mmol $m^{-2}$ $s^{-1}$.

***Cotton Yield***

The total mass yield per decare was calculated as a result of manually collecting and weighing separately based on the remaining area that excluded 1 m area from each parcel beginning and end as the edge effects. The data obtained were subjected to variance analysis using SPSS 14.0. The averages were compared with Duncan test (Bek and Efe, 1988).

## RESULTS and DISCUSSION

***Irrigation patterns***

In the first and second years, seven and eight irrigations were performed, respectively. The first year irrigations were started on July 6, 2010, and the second year on July 8, 2011. Irrigation intervals changed between 6-7 days in the first year and 5-7 days in the second year. In the first and second years, irrigation water was applied in 400 and 450 mm, respectively. Irrigation water quantities were made according to the Pan evaporation method. Evaporation amounts approximately at the same level were taken as the basis in order to ensure no difference in the stress levels among the treatments. An average of 425 mm of irrigation water was applied to the treatments of full irrigation ($I_{100}$) in both periods (Table 2).

Table 2. Results for water and yield variables

| Variety | Irrigation ($I_{100}$) | Evapotranspiration (mm) | Yield kg $da^{-1}$ | IWUE kg $m^{-3}$ | WUE kg $m^{-3}$ |
|---|---|---|---|---|---|
| AKSEL | 425 | 512 | 358 | 0.84 | 0.70 |
| ST 506 | 425 | 558 | 442 | 1.04 | 0.79 |
| ST468 | 425 | 596 | 448 | 1.05 | 0.75 |
| BA525 | 425 | 493 | 555 | 1.30 | 1.13 |
| BA119 | 425 | 478 | 512 | 1.20 | 1.07 |
| FLASH | 425 | 515 | 515 | 1.21 | 1.00 |
| SİOKRA L-22 | 425 | 444 | 498 | 1.17 | 1.12 |
| TAM SPHINX | 425 | 458 | 478 | 1.12 | 1.04 |
| TAM 94L-25 | 425 | 465 | 495 | 1.16 | 1.06 |
| PIMA S-7 | 425 | 496 | 478 | 1.12 | 0.96 |
| TAMCOT-22 | 425 | 512 | 488 | 1.14 | 0.95 |
| TAMCOT SP 21 S | 425 | 501 | 500 | 1.17 | 1.00 |
| TAMCOT SP 23 | 425 | 502 | 501 | 1.18 | 1.00 |
| TAMCOT CAMD-ES | 425 | 481 | 476 | 1.12 | 0.99 |

Irrigation water was applied using the treatment ratios to the subjects. A minimum of water (mm) was applied using the treatment of $I_{25}$ (75% of full irrigation) in both years. Irrigation water levels reached their highest in July and August. Irrigation water applied to the plant at the beginning and end of the irrigation season decreased.

***Evapotranspiration***

Evapotranspiration (Et) varied by variety (Table 2) probably due to the amount and number of irrigation water applied in the irrigation season, and the soil water content as a result of the winter rainfall, and the differences in the weather conditions. In both years, the highest Et was determined in Carisma variety. Evapotranspration varied between the varieties ($p < 0.05$). The lowest Et was determined in the Siokra variety. The fact that the Siokra variety has a narrow and thin structure in terms of leaf structure and less leaf area when compared to the other varieties was evaluated as the contributing factor to its low water consumption. The increased amount of irrigation water increased the Et by all the varieties.

***Water Use Efficiency***

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) are the concepts used to express the effectiveness of 1 mm of water in the biomass production. Both WUE and IWUE differed among the varieties. The lowest WUE and IWUE were determined in the the Aksel variety, sensitive to drought (Table 2). The highest IWUE and WUE belonged to the BA525 variety (1.30 kg $m^{-3}$, 1.13 kg $m^{-3}$). The Aksel, ST506 and ST468 varieties generally had the low IWUE values. All the IWUE values except for Aksel were found to be greater than 1. Among the cotton cultivars grown regionally, the BA525 variety can be preferred due to its high performance in water use efficiency.

***Yield***

Yields changed depending on the irrigation treatments of the experiment. The yields for the 25% water constraint appeared more economically important than those for the full irrigation ($I_{100}$). The effect of the water stress changed depending on the varieties. The highest response to the water stress was seen with $I_{25}$ (75% of full irrigation) (Table 3).

Table 3. Mean yields depending on the irrigation treatments

| Variety | Yield kg $da^{-1}$ | | | | |
|---|---|---|---|---|---|
| | $I_{25}$ | $I_{50}$ | $I_{75}$ | $I_{100}$ | $I_{125}$ |
| AKSEL | 87 | 176 | 300 | 358 | 383 |
| ST 506 | 118 | 236 | 436 | 442 | 486 |
| ST468 | 115 | 224 | 426 | 448 | 493 |
| BA525 | 148 | 312 | 512 | 555 | 568 |
| BA119 | 132 | 256 | 489 | 512 | 528 |
| FLASH | 123 | 257 | 482 | 515 | 568 |
| SİOKRA L-22 | 136 | 225 | 371 | 498 | 500 |
| TAM SPHINX | 127 | 218 | 453 | 478 | 515 |
| TAM 94L-25 | 122 | 256 | 473 | 495 | 540 |
| PIMA S-7 | 139 | 249 | 448 | 478 | 510 |
| TAMCOT-22 | 112 | 237 | 467 | 488 | 500 |
| TAMCOT SP 21 S | 135 | 222 | 472 | 500 | 520 |
| TAMCOT SP 23 | 137 | 233 | 476 | 501 | 521 |
| TAMCOT CAMD-ES | 116 | 228 | 458 | 476 | 515 |

The yields varied between 87 and 148 kg $da^{-1}$ with $I_{25}$, 176 and 312 kg $da^{-1}$ with $I_{50}$, 300 and 512 kg $da^{-1}$ with $I_{75}$, 358 and 555 kg $da^{-1}$ with $I_{100}$ 383 and 568 kg $da^{-1}$ with $I_{125}$. The lowest yield value seen in the Aksel variety with all the irrigation treatments stemmed from its susceptibility to drought. The varieties, the irrigation levels, and the irrigation level-by-variety interaction were significant at $p < 0.05$.

***Chlorophyll (SPAD value)***

Chlorophyll values are an important parameter in the evaluation of the response of the plant under the abiotic stress conditions. Stressed plants show their reactions especially thanks to the color changes occurring on the leaf surfaces that can be measured using a tool called SPAD. Chlorophyll values in the measurements made during the trial showed differences depending on both cultivars and irrigation levels (Table 4).

The chlorophyll values increased as the irrigation levels increased. The highest chlorophyll values among all the varieties were obtained from the highest irrigation level. The TAMCOT-22 variety was the one in which the highest chlorophyll value was measured. The lowest chlorophyll value was determined in the Aksel variety for the $I_{100}$. Towards the end of the time period, the chlorophyll values started to decrease in all the varieties and irrigation levels. The highest values were generally determined during the flowering period. The signs of aging caused by stress caused the chlorophyll values to decrease as all the varieties approached the harvest period. On average, the chlorophyll values changed as a function of the irrigation levels: 48.108 with $I_{100}$, 48.425 with $I_{75}$, 44.994 with $I_{50}$, and 40.735 µmol $m^{-2}$ with $I_{25}$. The chlorophyll values differed with the variety and irrigation ($p < 0.001$), and their interaction term ($p < 0.01$) (Table 5). Based on the Duncan test, the seven groups were formed. While the BA119 and Flash varieties were together, FULL SPHINX was in the last group. When the irrigation levels were evaluated together, the $I_{100}$, $I_{75}$ and $I_0$ irrigation levels constituted a group, while $I_{25}$ and $I_{50}$ were another group.

Table 4. Chlorophyll properties depending on the irrigations and varieties

| Variety | Irrigation | | | | |
|---|---|---|---|---|---|
| | $I_0$ | $I_{25}$ | $I_{50}$ | $I_{75}$ | $I_{100}$ |
| AKSEL | 42.17 | 46.97 | 48.90 | 48.03 | 47.35 |
| ST 506 | 41.23 | 46.44 | 48.41 | 47.24 | 49.93 |
| ST468 | 39.40 | 43.93 | 46.26 | 46.03 | 47.33 |
| BA525 | 39.48 | 45.72 | 51.63 | 49.154 | 50.01 |
| BA119 | 37.97 | 40.66 | 45.51 | 46.35 | 51.18 |
| FLASH | 37.70 | 40.87 | 46.58 | 46.96 | 48.91 |
| SİOKRA L-22 | 37.70 | 40.87 | 46.58 | 46.96 | 48.91 |
| TAM SPHINX | 39.22 | 45.80 | 49.04 | 47.95 | 44.90 |
| TAM 94L-25 | 45.00 | 47.10 | 50.49 | 49.74 | 51.33 |
| PIMA S-7 | 42.21 | 47.49 | 50.26 | 48.73 | 51.40 |
| TAMCOT-22 | 41.67 | 45.59 | 48.51 | 49.30 | 53.00 |
| TAMCOT SP 21 S | 42.00 | 45.34 | 47.94 | 49.35 | 50.70 |
| TAMCOT SP 23 | 40.75 | 46.80 | 48.65 | 48.78 | 52.65 |
| TAMCOT CAMD-ES | 40.86 | 45.32 | 47.70 | 47.58 | 50.12 |

Table 5. Analysis of variance results for chlorophyll variables

| Source | KT | Sd | KO | F |
|---|---|---|---|---|
| Variety (Ç) | 2519.439 | 13 | 193.803 | $8.737^{***}$ |
| Irrıgation (Sd) | 15487.954 | 4 | 3871.989 | $174.556^{***}$ |
| Ç x Sd | 1854.334 | 52 | 35.660 | $1.608^{**}$ |
| Error | 51846.249 | 1491 | | |

***Photosynthesis rate, Stomatal Conductance and Transpiration Rate***

In order to determine the effects of the water stress on the plant physiology, photosynthesis rate, transpiration rate and stomatal conductance values were measured in all the varieties at the irrigation levels of $I_{25}$ and $I_{100}$. The high and low levels of stress in $I_{25}$ and in $I_{100}$ was effective in the evident emergence of the physiological differences among the varieties (Table 6). However, the difference among the varieties was not significant ($p > 0.05$). This situation revealed no difference in the physiological response among the varieties under the same conditions. The difference in the stress levels caused the significant differences in photosynthesis rate, transpiration rate, and stomatal conductance ($p < 0.01$). On average, when the difference between the $I_{25}$ and $I_{100}$ irrigation levels, and standard errors were considered, the photosynthesis rate was determined as 7.549 µmol $m^{-2}$ $s^{-1}$ with $I_{25}$ and 12.616 µmol $m^{-2}$ $s^{-1}$ with $I_{100}$.

Table 6. Analysis of variance results for photosynthesis and transpiration rates, and stomatal conductance

| Variation source | Sd | Pn (µmol $m^{-2}s^{-1}$) | | | Tr (mmol $m^{-2}s^{-1}$) | | | Sc (mol $m^{-2}s^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | KT | KO | F | KT | KO | F | KT | KO | F |
| Variety (Ç) | 13 | 479.46 | 36.88 | 1.266 | 19.75 | 1.52 | 0.72 | 0.164 | 0.01 | 1.06 |
| Irrigation (Sd) | 1 | 3107.34 | 3107.34 | $106.67^{**}$ | 114.66 | 114.66 | $54.22^{**}$ | 0.948 | 0.94 | $79.99^{**}$ |
| Ç * Sd | 13 | 522.03 | 40.15 | 1.38 | 13.57 | 1.05 | 0.49 | 0.155 | 0.01 | 1.007 |
| Error | 510 | 18385.23 | | | 1178.34 | | | 7.044 | | |

SS: Sum of square, SM: Mean square, df: Degree of Freedom, F: Significant degree

Although there was a four-fold difference between the irrigation levels, a 1.67-fold difference was determined in the photosynthesis rate. The difference was at a lower level in the transpiration rate and stomatal conductance. The transpiration rate was measured as 2.947 mmol $m^{-2}$ $s^{-1}$ with $I_{25}$ and 3.919 mmol $m^{-2}$ $s^{-1}$ with $I_{100}$. The transpiration rate was 1.33 times higher with $I_{100}$ than $I_{25}$. A similar situation was observed in the mean stomatal conductance. The stomatal conductance was 0.093 moles m$^{-2}$ s$^{-1}$ with $I_{25}$ and 0.182 moles m$^{-2}$ s$^{-1}$ with $I_{100}$. A 1.96-fold difference was estimated among the treatments.

Table 7. Mean photosynthesis and transpiration rates and stomatal conductance

| Variety | Irrigation level | Photosynthesis µmol m$^{-2}$s$^{-1}$ | | Stomatal conductance mol m$^{-2}$s$^{-1}$ | | Transpiration rate mmol m$^{-2}$s$^{-1}$ | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| AKSEL | $I_{25}$ | 8.31 | 3.22 | 0.08 | 0.03 | 2.98 | 0.86 |
| | $I_{100}$ | 13.41 | 6.67 | 0.18 | 0.12 | 3.88 | 1.13 |
| | Mean | 11.17 | 5.95 | 0.14 | 0.11 | 3.48 | 1.10 |
| ST 506 | $I_{25}$ | 7.59 | 5.20 | 0.10 | 0.09 | 2.65 | 1.44 |
| | $I_{100}$ | 15.93 | 5.26 | 0.23 | 0.13 | 4.37 | 1.26 |
| | Mean | 12.42 | 6.64 | 0.17 | 0.13 | 3.65 | 1.57 |
| ST468 | $I_{25}$ | 4.93 | 2.57 | 0.06 | 0.02 | 3.31 | 4.52 |
| | $I_{100}$ | 14.52 | 3.91 | 0.19 | 0.07 | 4.16 | 1.27 |
| | Mean | 10.63 | 5.85 | 0.14 | 0.09 | 3.82 | 3.01 |
| BA525 | $I_{25}$ | 7.21 | 5.59 | 0.08 | 0.05 | 2.77 | 1.26 |
| | $I_{100}$ | 11.54 | 5.16 | 0.13 | 0.08 | 3.58 | 1.28 |
| | Mean | 9.79 | 5.69 | 0.11 | 0.07 | 3.25 | 1.32 |
| BA119 | $I_{25}$ | 5.27 | 3.04 | 0.05 | 0.02 | 2.31 | 0.85 |
| | $I_{100}$ | 11.00 | 6.41 | 0.16 | 0.13 | 3.70 | 1.34 |
| | Mean | 8.68 | 5.97 | 0.12 | 0.12 | 3.14 | 1.34 |
| FLASH | $I_{25}$ | 7.83 | 3.96 | 0.08 | 0.05 | 2.98 | 1.22 |
| | $I_{100}$ | 12.87 | 5.19 | 0.25 | 0.21 | 4.35 | 0.97 |
| | Mean | 10.83 | 5.30 | 0.18 | 0.18 | 3.79 | 1.26 |
| SİOKRA L-22 | $I_{25}$ | 7.25 | 4.98 | 0.09 | 0.08 | 2.91 | 1.34 |
| | $I_{100}$ | 11.84 | 5.60 | 0.17 | 0.11 | 3.95 | 1.32 |
| | Mean | 9.98 | 5.76 | 0.14 | 0.10 | 3.53 | 1.41 |
| TAM SPHINX | $I_{25}$ | 8.04 | 3.58 | 0.08 | 0.05 | 3.00 | 0.96 |
| | $I_{100}$ | 13.04 | 6.07 | 0.16 | 0.09 | 3.80 | 1.14 |
| | Mean | 11.07 | 5.73 | 0.13 | 0.08 | 3.48 | 1.13 |
| TAM 94L-25 | $I_{25}$ | 8.64 | 5.35 | 0.09 | 0.07 | 3.11 | 1.35 |
| | $I_{100}$ | 13.97 | 6.45 | 0.17 | 0.10 | 3.79 | 1.14 |
| | Mean | 11.75 | 6.50 | 0.14 | 0.09 | 3.52 | 1.25 |
| PIMA S-7 | $I_{25}$ | 6.25 | 3.87 | 0.12 | 0.15 | 3.07 | 1.51 |
| | $I_{100}$ | 12.91 | 7.71 | 0.20 | 0.13 | 4.09 | 1.42 |
| | Mean | 10.21 | 7.17 | 0.17 | 0.14 | 3.68 | 1.52 |
| TAMCOT-22 | $I_{25}$ | 9.0 | 5.25 | 0.11 | 0.08 | 3.23 | 1.59 |
| | $I_{100}$ | 13.23 | 5.34 | 0.17 | 0.09 | 4.08 | 1.12 |
| | Mean | 11.73 | 5.62 | 0.15 | 0.09 | 3.78 | 1.35 |
| TAMCOT SP 21 S | $I_{25}$ | 8.70 | 4.38 | 0.10 | 0.08 | 3.18 | 1.09 |
| | $I_{100}$ | 10.32 | 6.16 | 0.14 | 0.08 | 3.49 | 1.08 |
| | Mean | 9.75 | 5.58 | 0.13 | 0.08 | 3.38 | 1.08 |
| TAMCOT SP 23 | $I_{25}$ | 7.92 | 6.10 | 0.10 | 0.10 | 2.75 | 1.47 |
| | $I_{100}$ | 9.47 | 5.53 | 0.14 | 0.09 | 3.53 | 1.36 |
| | Mean | 8.94 | 5.69 | 0.13 | 0.10 | 3.26 | 1.43 |
| TAMCOT CAMD-ES | $I_{25}$ | 8.67 | 5.44 | 0.09 | 0.06 | 2.96 | 1.42 |
| | $I_{100}$ | 12.5 | 5.99 | 0.19 | 0.17 | 4.03 | 1.40 |
| | Mean | 11.12 | 6.01 | 0.15 | 0.14 | 3.65 | 1.48 |

Stomatal conductance, the first step in the realization of photosynthesis, is a physiologically important measure. In order to maintain the internal water condition of the plant under the water stress conditions, it is decisive for the effectiveness of the other parameters to close the stomata first. However, when the relationships of these parameters with yield were considered, stomatal conductance had a lower correlation than did the rates of transpiration and photosynthesis. When the difference among the varieties was considered, the one with the highest photosynthesis rate was determined as ST 506 (15.93 µmol $m^{-2}$ $s^{-1}$) with $I_{100}$ (Table 7). The lowest value was measured as 4.93 µmol $m^{-2}$ $s^{-1}$ with $I_{25}$ for ST468. The highest value of stomatal conductance was measured for Flash (0.25 mmol $m^{-2}$ $s^{-1}$), The transpiration rate was highest in both ST506 (4.38 mmol $m^{-2}$ $s^{-1}$) and Flash (4.35 mmol $m^{-2}$ $s^{-1}$).

## CONCLUSIONS

The BA525 variety came to the forefront in terms of its widespread cultivation and yield characteristics among the varieties. The Aksel variety is the most susceptible to drought. When the current and future climate data are considered, this variety was not suitable for the region. 25-40% water shortage can be achieved in almost all the varieties in the drought conditions. When the chlorophyll and stomatal conductance values were related to the yield values, the highest correlation values were obtained for the chlorophyll values. The physiological drivers of stomatal conductance and chlorophyll content exerted the highest impact on the yield. These variables can be monitored to quantify the impact of the water stress conditions on the yields.

## ÖZET

***Amaç***: Bu araştırma 14 farklı pamuk çeşidinde, kuraklığa dayanıklı ve hassas çeşitler esas alınarak, farklı sulama suyu düzeylerinin, bitki su tüketimi, su kullanım etkinliği, stoma iletkenliği, fotosentez hızları ve verim değerleri üzerine etkilerinin incelenmesi amacıyla yapılmıştır.

***Yöntem ve Bulgular***: Araştırma, ST 506, ST468, BA525, BA119, FLASH, SIOKRA L-22, TAM SPHINX, TAM 94L-25, PIMA S-7, TAMCOT-22, TAMCOT SP 21 S, TAMCOT SP 23, TAMCOT CAMD-ES ve AKSEL çeşitlerinde yürütülmüştür. Aksel çeşidi kuraklığa hassas diğer çeşitler kuraklığa dayanıklı çeşitlerdir.. Deneme tesadüf bloklarında deneme desenine göre yürütülmüştür. Araştırmada söz konusu çeşitlerin bitki su tüketimi, su kullanım etkinliği, stoma iletkenliği, fotosentez hızları ve verim değerleri belirlenmiştir. Fotosentez hızı, transpirasyon hızı ve stoma iletkenliği sadece tam sulama ($I_{100}$) ve elverişli kapasitenin %25'i düzeyinde ($I_{25}$) ölçülmüştür. Araştırmada çeşitler arasında su stresinin etkisinin önemli olmadığı belirlenmiştir.

***Genel Yorum***: Sonuç olarak, ilk yıl 4, ikinci yıl toplam 6 sulama yapılmıştır. Uygulanan sulama suyu miktarı ilk yıl 270-480 mm, ikinci yıl 298-520 mm arasında değişmiştir. Verim ve bitki su tüketimi uygulanan sulama suyu miktarına bağlı olarak artmıştır. En yüksek ve en düşük verim sırasıyla BA525 çeşidinde (555 kg $da^{-1}$) Aksel çeşidinde 358 kg $da^{-1}$ olarak belirlenmiştir. Ortalama olarak fotosentez hızı $I_{100}$ konusunda 12.616 µmol $m^{-2}s^{-1}$, $I_{25}$ konusunda 7.549 µmol $m^{-2}$ $s^{-1}$ olarak ölçülmüştür. Stoma iletkenliği arttıkça verim değerleri de artmıştır ($I_{25}$ konusunda 0.093 mol $m^{-2}s^{-1}$ $I_{100}$ konusunda 0.182 mol $m^{-2}s^{-1}$). Transpirasyon hızı $I_{25}$ konusunda 2.947 mmol $m^{-2}s^{-1}$ $I_{100}$ konusunda 3.919 mmol $m^{-2}s^{-1}$ olarak belirlenmiştir. Bununla birlikte anılan parametrelerin verim ile ilişkileri incelendiğinde stoma iletkenliğinin verim ile ilişkisi transpirasyon hızı ve fotosentez hızından daha düşük saptanmıştır.

***Çalışmanın Önemi ve Etkisi***: Araştırma Doğu Akdeniz Bölgesinde yaygın olarak yetiştirilen 14 pamuk çeşidinde su kullanım etkinliği, bitki su tüketimi ve fizyolojik özelliklerini ortaya çıkarmıştır. Ayrıca belirtilen fizyolojik özellikler ile verim arasındaki ilişkiler irdelendiğinde verim ve stoma iletkenliği arasındaki ilişkinin, transpirasyon ve fotosentez hızının ile verim arasındaki ilişkisinden daha düşük olduğu saptanmıştır.

***Anahtar Kelimeler***: Pamuk, Stoma iletkenliği, Transpirasyon hızı, Fotosentez hızı

## CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## AUTHOR'S CONTRIBUTIONS

The contribution of the authors is equal.

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