Morpho-physiological effects of environmental stress on yield and quality of sweet corn varieties (Zea *mays* (L.) var. *saccharata*) (#61345)

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Morpho-physiological effects of environmental stress on yield and quality of sweet corn varieties (Zea *mays* (L.) ~~var. *saccharata*~~)

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Morpho-physiological effects of environmental stress on yield and quality of sweet corn varieties (Zea *mays* (L.) var. *saccharata*)

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Abstract

Morpho-physiological effects of environmental stress on yield, yield components and quality of some sweet corn varieties were determined in field studies conducted in Southeastern Anatolia Region of Turkey during 2019 and 2020 growing seasons. Mean values of pollen fertility rate (PFR, %), total soluble solids (TSS, ^{0}Brix), abscisic acid (ABA, nmol/g^{-1} DW), ear length (EL, cm), plant height (PH, cm), number of grains per cob (CGN, grain) and fresh cob yield (FCY, t ha^{-1}) were significantly different between years and sweet corn varieties. The PFR, TSS, ABA, EL, PH, CGN and FCY ranged from 40.29-67.65%, 13.24-20.09 ^{0}brix, 7.74-21.04 nmol/g^{-1}DW, 9.69-15.98 cm, 97.80-171.34 cm, 289.15-420.33 grain and 4.15-10.23 t ha^{-1}, respectively. The FCY, yield components and PFR values in the second year that had a higher temperature and lower relative humidity were lower compared to the first year of the experiment, while ABA and TSS values were higher in the second year. The results revealed that the PFR physiological parameter and ABA hormone in the plants provide important information about stress level and stress tolerance level of the cultivars, respectively.

Key words: sweet corn, heat stress, pollen fertility, abscisic acid

INTRODUCTION

Sweet corn which is ~~a~~ ~~sub-species~~ of maize produced in large areas, ~~is known as "*Zea mays L. var saccharata Sturt.*" within the family of cereals (Graminea).~~ Smaller plant habitus and chemical composition of the grains are the distinguishing features of sweet corn from other corn types. The 'su', ~~'sh-2', 'se' genes (sugary gene)~~ of sweet corn varieties ~~prevent~~ the conversion of sucrose which is carried to the endosperm, to starch, and ensures that the grains have a high sugar content. The ratio of fat and protein is higher than other ~~subspecies~~ due to the larger embryo of sweet corn (*Szymanek, 2009*).

Sweet corn is consumed before or after processing throughout the world. Unique taste, pleasant flavor and sweetness attracts the attentions of consumers. Sweet corn is also important for human nutriition due to positive contribution to health. High water (72.7%) and total solids (27.3%) contents of sweet corn kernels significantly contribute to the nutritional value. Solid part is composed of hydrocarbons (81%), proteins (13%), lipids (3.5%) and others (2.5%). ~~Starch is the dominant hydrocarbon component~~ (*Szymanek, 2012*). Calorie content of sweet corn kernel is moderate compared to the other vegetables. The nutritional quality of sweet corn is related to the dietary fiber, various vitamins and antioxidants contents in addition to a sufficient mineral contents. In addition, rich lutein, zeaxanthin and other carotenoids contents of sweet corn also attracts the consumers (*Szymanek, 2012*).

The sweet corn cultivation area in the world is about 1.6 million ha^{1}with approximately 20 million tons production and average yield of 13.029 t ha^{-1} (*Anonymous, 2020*). Contracted farming model is widely applied for the production of sweet corn especially in Aegean, Marmara and the western part of Turkey; however, domestic production is not adequate to meet the demand of the country. Therefore, frozen-canned sweet corn import of Turkey in 2018 was approximately 7000 tons, which corresponds to approximately $ 9 million tons, while sweet corn export is $ 0.85 million tons (*Anonymous, 2018*).

Sweet corn production which is mainly carried out in the western regions of Turkey, should be spread to the rest of the country in order to prevent sweet corn import and economic losses. The study was carried out in the southern Turkey, which meets about 17 % of dent corn production and is dominated by the high temperatures and dry weather conditions. Previous studies indicated that sweet corn is highly susceptible to environmental stress conditions than other corn subspecies (*Ordóñez et al., 2015*). The adaptation of varieties to the ecological conditions of a region is important in selection of sweet corn varieties. Absisic acid (ABA) is an important plant regulating hormone used to determine the tolerance of sweet corn plant to stress conditions, while, pollen vitality ratio also provides important clues about the stress levels of sweet corn plants.

High day and night time temperatures due to climate change threatens global agricultural production (*Khaliq et al., 2019*). Several plant physiological and metabolic processes are adversely affected by heat stress, therefore it was reported an important constraint to plant growth and crop productivity (*Allakhverdiev et al., 2008*). The responses of plants to abiotic stress factors change depending phytohormones, which are modulate the physiological and molecular responses of plants to survive under abiotic stress conditions (*Fahad et al., 2015*). The abscisic acid (ABA), a stress hormone, is very active in plant mechanism to abiotic stressors such as heat stress (*Islam et al., 2018*). The ABA concentration was reported to induce heat tolerance in corn (*Islam et al., 2018*). Under heat and dry weather conditions, lack of ABA in corn plants increases water loss from stomata, therefore plants display heat stress-sensitive phenotypes (*Du et al., 2013*). Heat stress tolerance of mutants defective in ABA signaling (abi1-1) or lack of ABA biosynthesis (aba1-1) is reported very low (*Suzuki et al., 2016*). Similarly, Zandalinas et al. (2016) reported that ABA reduces the damage in sweet corn plants caused by heat stress.

Environmental factors which have adverse effects on plant growth and survival are known as abiotic stresses. The abiotic stress factors negatively affect the development of a plant, which adapted to any environment and grows smoothly (*Abiko et al., 2005*). Pollen viability is affected abiotic and biotic stresses. The environmental factors such as fertility of soils, available water content, soil and air temperatures and relative humidity have significant effects on pollen production ability of plants; thus, affect the size and number of seeds produced. Pollens have 60% water content by weight; therefore, are sensitive to environmental conditions that may cause a decrease in water content up to 30% (*Firon, Nepi & Pacini, 2012*). Therefore, environmental stress affects plant growth, and even more drastically male reproductive development and causes sterile pollens (*Begcy et al., 2019*). The exposure of heat stress during micro gametogenesis cause abortion of microspores and sterility of males (*Rieu, Twell & Firon, 2017; Begcy & Dresselhaus, 2018*). Alghabari et al. (2014) indicated that increased temperatures during the microspore stage of sweet corn pollen reduced corn cob fertility by affecting endogenous levels of ABA. Exposure of 35°C light and 25°C dark stress for 48 h specifically at pollination stage negatively affects gas exchange and chlorophyll content in addition to pollen fertility (*Sunoj et al., 2017*). Heat stress and low relative moisture humidity reduce pollen viability; thus they can be used to distinguish crop genotypes against various infield stresses (*Razzaq et al., 2019*). The seed yield is affected by the supra-optimal temperatures. Supra-optimal temperature, when especially greater than or equal to 32 °C decreases the viability of pollen~~s~~, retention of pollen~~s~~ in the anthers and germination of pollen~~s~~ in various sweet corn varieties (*Razzaq et al., 2017*). High temperature during silking, pollination and grain filling profoundly ~~e~~ffects pollen shedding and viability of sweet corn. Therefore, pollen viability and filled grains or number of grains under stress conditions such as heat stress ~~have a~~ positive correlat~~ion~~ (*Kalyar et al., 2013*). The sugar content in kernels of sweet corn ~~is used to determine~~ the quality of sweet corn (*Szymanek, Tana´s & Kassar, 2015*), and ~~the~~ varieties, climate conditions and harvest time have significant effec~~t~~ on sugar content of kernels (*Abadi & Sugiharto, 2019*). The eating quality of final product for sweet corn is directly related to tenderness of sweet corn genotypes with a higher sugar and lower starch contents and an increased aroma (*Ibrahim & Ghada 2019*). The sugar content of fresh kernels in most of ~~the~~ sweet corn varieties was reported higher compared to the frozen and canned grains (*Alan et al., 2014*). The optimum temperature for maize flowering occurrs between 29 and 37.3 °C (*Sánchez et al., 2014*). Although the effect of temperature stress on number of grains in pre-tasseling period is not clear, high temperature in tasseling-silking interval leads to significant yield reduction (*Lizasoa et al., 2018*). This study was conducted to investigate the morpho-physiological aspects of yield, yield components and quality characteristics of sweet corn varieties under environmental stress conditions such as high temperature and low relative humidity.

MATERIAL & METHODS

The study was conducted between June and November during the second crop corn season in the research fields of South Eastern Project Agricultural Research Institute in 2019 and 2020. The experimental field is located between 36° 44′ 10″ N latitudes and 38° 50′ 20″E longitudes (*Figure 1*).

INSERT FIGURE 1

The study area is located in a semi-arid climate zone with high temperatures and low relative humidity in summers and cold in winters. Higher temperature and lower relative humidity conditions prevailed in the second year of the study (2020) compared to the first year (2019). The highest temperature recorded in June, July, August and September for both 2019 and 2020 were over 40 ºC and relative humidity was less than 40% (*Table 1*).

INSERT TABLE 1

The average temperature during the 12-day top tasseling period in both years was over 40 ºC. Daily average temperature values in both years are shown in *Figure 2*.

INSERT FIGURE 2

Soils of the experimental site have clayey texture, pH varies from 7.96 to 8.00 and electrical conductivity is between 1.05 and 1.40 dS/m which indicates no salinity problem Lime content is between 29.2 and 32.3% and increases with soil depth. Plant available phosphorus and organic matter content of soils was between 10.7-28.8 kg/ha^{-1} and 0.73 - 1.24%, respectively.

The experiment was conducted at the second week of June in both 2019 and 2020. Experimental lay out was randomized blocks with three replicates. Eight candidates and two control sweet corn varieties classified as moderate maturity (FAO 650-700) classes were used in the study. Sweet corn seeds were sowed in 70 cm interrow and 18 cm intrarow spacing. Each plot had 4 rows with 5 m length. Fertilizer was applied in the seedbeds at rate of 400 kg ha^{-1} in the form of diammonium phosphate (18N-46P_2O_5-0$K_2$0) during planting and the rest of the nitrogen (400 kg N ha^{-1}) was applied in the form of urea (46 % N into two equal parts in the second and thirteenth weeks of planting (*Seydosoglu & Cengiz, 2020*). Sprinkler irrigation method was used after planting to ensure a homogeneous seed germination. Furrow irrigation method was applied in subsequent irrigations. The amount and number of irrigation during vegetation period varied depending on climate and water demand of plants. In the first year of the study, 600 mm of water was given in 5 irrigations, while in the second year 670 mm of water was given in 6 irrigations. Fresh cobs were harvested between 17 and 25 September in both years of the trial. Harvest time of varieties varied between 80 and 90 days. Fresh cobs were harvested when the grain moisture content was between 70 and 75 %.

Analytical procedures

Ten fresh cobs were collected from experiental plots, and the husks were peeled to determine the number of grains per cob (CGN, number), ear length (EL, cm), and fresh ear yield (FEY, t ha^{-1}) (*Ibrahim & Ghada, 2019*). Sweet corn kernels were squeezed out, and total soluble solids (TSS) content in sweet corn kernel juice was determined using a hand refractrometer (0-32°Brix). The TSS value of each cob was recorded and the TSS value representing the sweet corn variety was determined by calculating the mean values (*Alan et al., 2014*). Three top tassels of each sweet corn variety were collected from each plot between 10:^{00} and 14:^{00} during top tasseling development period when pollens start to scatter, and the samples were quickly transported to the laboratory by cold chain. The pollens brought to the laboratory was placed on a glass lamella using a fine-tipped brush. A drop of 1% TTC (2.3.5 Triphenyl Tetrazolium Chloride) liquid, which contained 0.2 g TTC and 12 g sucrose dissolved in 20 mL distilled water, was dropped on pollen samples, and the pollens were dyed within 2 to 3 hours. Pollen grains were counted under a light microscope to determine the viability rate of the dyed pollens. Pollen grains not dyed with TTC (dark red or brown color) were considered not viable, while pollen grains dyed with orange or bright red color were evaluated as viable (*Sulusoglu & Cavusoglu, 2014*).

In the post-tassel emergence period, 10 flag leaves were sampled randomly in each plot. One hundred mg leaf sample was weighed and wrapped in aluminum foil and transported to the laboratory at -198 °C in a nitrogen tank. Leaf samples were stored in a refrigerator at -20 °C. The ABA level of leaf samples were determined by reading the absorbance values at 450 nm using *Enzyme-Linked Immuno Sorbent Assay* (ELISA) method (*Cabot, Poschenrieder & Barcelo, 1986*) (*Figure 3*).

INSERT FIGURE 3

The experiments were carried out in a randomized complete block design with three replications. Statistical analysis was performed using JUMP (Version 13.2.0) Statistical software. The mean values for the varieties were compared using the LSD test at $p \leq 0.05$ probability level. Correlation test was performed between all traits determined in the study (*Ucak et al., 2016*).

RESULTS

The PFR and ABA parameters were significantly different ($P \leq 0.01$) between years and cultivars. The difference in TSS parameter was very significant ($P \leq 0.01$) between sweet corn varieties, while it was significant ($P \leq 0.05$) between the years (*Table 2*).

INSERT TABLE 2

The PFR parameter is one of the most important abiotic stress indicators for sweet corn varieties. The highest mean PFR value was obtained from Control-2 (67.65%) sweet corn variety, while the lowest PFR value was obtained from ŞADA-18.2 (40.29%) variety. The mean PFR in the first year was 55.80%, while the mean PFR in the second year was 50.28%. High temperature and low relative humidity values in the study area caused approximately 30-50% decrease in PFR values of sweet corn varieties. Daily average temperatures above 40 ^{0}C especially during 12-day of tasseling period negatively affected the pollen fertility. The results of correlation test indicated that the increase in PFR caused an increase in ABA level and yield components such as FCY, PH, EL and CGN. Similar to our findings, Patel & Mankad (2014) reported a significant correlation between high cob yield and pollen fertility of sweet corn varieties. Consistent with our findings, Lizasoa et al. (2018) observed a 42% decrease in grain weight per plant and 32% in pollen viability with the increases in day/night temperatures from 25/15 to 35/15 ◦C during anthesis-silking interval period.

Contrary to the yield and yield components, the TSS values in the grains of sweet corn varieties were higher in the second year when warmer and dry weather conditions prevailed compared to the first year of the experiment. The highest TSS value (20.09 ^{o}brix) was recorded from the SADA-18.7 variety, and the lowest TSS value (13.24 ^{o}brix) was obtained from the Control-1 variety. The ^{O}brix values of most sweet corn varieties were higher than the mean value of the experiment. The results reveal that plants cannot absorb the water lost through evapotranspiration through the roots, and they expose to stress. Insufficient water content at cellular level in plants caused an increase in the dry matter ratio, in other words TSS values. High TSS values in sweet corn varieties are desired, but not yield losses. The TSS parameter had a negative correlation with PFR, FCY and yield components, while the TSS had a positive correlation with ABA. Environmental stress causes decrease in yield and yield components, while increase in TSS values. The changes in TSS values of sweet corn varieties may attributed to the genetic structure and environmental conditions such as temperature, sowing time and harvest time. Similar to our findings, Ibrahim and Ghada (2019) reported that TSS contents of sweet corn hybrids ranged from 12.10 to 17.43 ^{o}Brix. Alan et al. (2014) recorded higher TSS values (16.3 to 27.4 ^{o}Brix) in kernels of seven sweet corn varieties. The results of Subaedah et al. (2021), which reported that the TSS values of sweet corn varieties varied between 20.8-22.8 ^{o}Brix under Indonesian conditions, are substantially similar to those obtained in this study. The researchers associated the changes in TSS values to the differences in climate and variety.

The ABA level recorded in ŞADA-18.8 sweet corn candidate variety (21.04 nmol/g^{-1} DW) was higher than control and other varieties. Sweet corn varieties produced ABA hormone in both years of the study. The differences in environmental conditions (temperature and relative humidity) between years have also caused the differences in ABA levels. The results revealed that the amount of ABA hormone produced by sweet corn varieties varies depending on environmental stress conditions and genetic characteristics of the varieties. Positive correlation between ABA hormone and all other parameters indicates that the increase in ABA hormone causes an increase in FCY, yield components, PFR and TSS values of the sweet corn varieties. The results indicated that ABA hormone is an important selection criterion of sweet corn varieties or lines that are tolerant to environmental stress conditions. Similar to our findings, the importance of ABA as a phytohormone involved in heat stress response and tolerance has been reported by *Wasilewska et al. (2008)* and *Haizhen et al. (2018*). In addition, *Xu et al. (2013*) indicated that ABA accumulates under stress stess conditions. The positive correlation between ABA and yield components indicates that the ABA hormone produced by plants promoted both lateral shoot and lateral root development; therefore, plants with strong roots and shoots grown healthier. The findings of Opitz et al. (2016) and Seeve et al. (2017) who reported that severe environmental stress inhibited both root and shoot growth but ABA promoted the formation of lateral roots and shoot, are in accordance with our conclusion.

The ear length (EL) and plant height (PH) values in 2019 and 2020 were statistically significant at P≤0.01 level, while the difference between years was significant ~~only~~ at P≤0.05 level (*Table 3*).

INSERT TABLE 3

The EL and PH parameters are important agronomic traits which may have direct or indirect relationship with fresh cob yield (FCY). The highest EL value was measured in ŞADA-18.7 (14.28 cm) candidate variety and Control-1 and control-2 varieties were placed in the same statistical group with ŞADA-18.7. The lowest EL values was recorded in ŞADA-18.1 (6.76 cm). Lower EL values in the second year can be attributed to the higher temperature and lower relative humidity values in the second year. The mean PH value of sweet corn varieties in the second year was 122.78 cm, while it was 141.69 cm in the first year. Similar to the EL parameter, PH values were also affected by differences in temperature and relative humidity between years. The highest PH value was recorded in Control-2 cultivar (171.34 cm), while the shortest PH value was measured in ŞADA-18.2 cultivar (97.80 cm).
The differences in number of grains per cob (CGN) and FCY in both years of the experiment were statistically significant at P≤0.01 level, and the differences between years were significant at P≤0.05 level Statistical groups of varieties and years in terms of CGN and FCY parameters and level of significance were given in *Table 4*.

INSERT TABLE 4

The CGN parameter is an important yield component and is directly related to the yield. Similar to the other yield components, the CGN parameter was negatively affected by the extreme temperature and relative humidity values. The mean CGN value of sweet corn varieties in 2020 was 323.05 grains, when environmental stress conditions were dominant, the CGN was 359.38

grains in 2019. The highest CGN value during the experiment was obtained from ŞADA-18.7 (420.33 grains), while the lowest CGN value was recorded in ŞADA-18.2 (289.15 grains) sweet corn variety. The results of yield components were in agreement with the results of FCY parameter. The highest FCY value was obtained in ŞADA-18.7 (10.23 t ha^{-1}) candidate variety, and the lowest FCY value was recorded in ŞADA-18.2 (4.15 t ha^{-1}) variety. The FCY values recorded in ŞADA-18.8, ŞADA-18.3 and ŞADA-18.7 candidate varieties were higher than the mean values of the experiment. The FCY value obtained in ŞADA-18.7 variety was higher than the control varieties. Some parameters measured in the study were significantly different between years. Daily average temperatures during the tasseling period were above 40 °C, which decreased the pollen viability ratios by almost half. Low relative humidity ratios in the same period also had an impact on the decrease in pollen viability. The ABA and TSS values in 2020 were higher, while the FCY values were lower, due to higher temperature and lower relative humidity compared to the first year of the experiment. The mean values of PFR ABA, TSS and FCY in both years were shown in *Figure 4*.

INSERT FIGURE 4

The images of normal and abnormal pollens were recorded during pollen examination under the light microscope. The light red and bright colored pollens in the image A are alive, while the mat and black pollens in the image B are not alive. Pollen images of ŞADA-18.7 sweet corn variety examined under light microscope are given in *Figure 5*.

INSERT FIGURE 5

Correlations

All parameters of sweet corn varieties determined were subjected to correlation test. The results of correlation test including correlation coefficients ad level of significance was given in ***Table 5***. ~~Significant positive correlations were recorded between EL and PH (r=0.8162, p<0.01), CGN and PH (r=0.8292, p<0.01), CGN and EL (r=0.7154, p<0.01), FCY and PH (r=0.8577, p<0.01), FCY and EL (r=0.8666, p<0.01), FCY and CGN (r=0.8434, p<0.01), PFR and PH (r=0.9128, p<0.01), PFR and EL (r=0.7664, p<0.01), PFR and CGN (r=0.7796, p<0.01), PFR and FCY (r=0.7691, p<0.01), ABA and PH (r=0.4701, p<0.01), ABA and EL (r=0.2579, p<0.05), ABA and CGN (r=0.3627, p<0.01), ABA and FCY (r=0.2888, p<0.05), ABA and PFR (r=0.5285, p<0.01). In contrast, TSS and EL (r=-0.3503, p<0.01) and TSS and FCY (r=-0.2775, p<0.05) had a significant negative correlations.~~

INSERT TABLE 5

DISCUSSION

Agronomic traits such as PH and EL are important parameters that provide information on FCY. Taller sweet corn plants have a higher number of leaves. Plants with higher number of leaves ~~make more~~ photosynthesi~~s~~, which causes an increase in EL and FCY values. Similar to the FCY and CGN, the PH and EL values decreased in the second year when environmental stress conditions were more dominant. The highest correlation coefficients of the experiment were obtained between PH and FCY, CGN and EL. The sweet corn varieties with ~~high plant heights~~

had high FCY, EL and CGN values. Positive correlation between PH and PFR and ABA indicated that sweet corn varieties with a good PH had high PFR and ABA values. The characteristics of a variety and climate have significant impact on plant heights of sweet corn (*Subaedah, Edy & Mariana, 2021*). The results suggested that vegetative stages of some plants were completed very fast, and thus healthy leaves could not be developed and healthy plant height did not occur. The plant heights recorded in this study are in harmony with the plant heights (130.83-171.67 cm) of Subaedah et al. (2021), while they were lower than the plant heights (170.8-197.8 cm) reported by Ibrahim & Ghada (2019). Similar to the PH, EL parameter is a directly related yield component with FCY, PFR and CGN. The results indicated that EL values of the varieties with high pollen viability rates were also high, therefore the FCY value was also higher. The EL parameter had a negative correlation with TSS, while the EL had significantly positive correlations with other traits The FCY values of sweet corn varieties, which have a long cob size were also high. The EL values recorded are compatible with the findings of Kara (2011), while they are lower than the EL values reported by Ibrahim & Ghada (2019) (16.2-21.4 cm). Genetic characteristics of the varieties and environmental stress conditions of the study played a determinant role in the EL values measured. Short cob sizes can be attributed to the decrease in photosynthesis under stress conditions such as temperature and low relative humidity and insufficient production of nutrients in the leaves.

Positive correlation between CGN and PFR parameters in sweet corn varieties indicated that the CGN is an important parameter to assess the impacts of environmental factors on sweet corn. The results showed that the fertilization rates of sweet corn varieties were high when viable pollen numbers in the grains were high, and in that case, the number of grains formed on a cob were higher. The CGN and EL, PH, FCY and PFR parameters were highly correlated and a moderate positive correlation was recorded between CGN and ABA. The results revealed that PFR values, which are important physiological parameters, coincided with the CGN values of sweet corn varieties. Similar to our findings, Lizasoa et al. (2018) reported that the number of grains per cob in sweet corn varieties had a high correlation with yield and yield components. The researchers showed that yield and yield components were decreased under high temperature conditions. Sweet corn varieties grown in the experimental area where environmental stress conditions prevail presented a good performance in terms of FCY. The responses of sweet corn varieties to environmental stress conditions and genetic characteristics of the varieties can be related to the good performance. The values of physiological parameters such as PFR and ABA determined in this study are compatible with the FCY values. Significant positive correlations were obtained between FCY and yield components such as PH, EL and CGN and physiological parameter such as PFR. Moderate positive correlation was recorded between FCY and ABA, while a negative correlation was obtained between FCY and TSS. Morphological and physiological parameters of ŞADA-18.7 candidate sweet corn variety were better compared to the other varieties, and the highest yield of the experiment was obtained from ŞADA-18.7 candidate variety. The differences in the yield of the tested sweet corn varieties was related to the differences in genetic potentials. Subaedah et al. (2021) also indicated that the variety and the climate conditions of the exponential field have significant impact on growth and yield of sweet corn varieties. The high yield of sweet corn varieties was supported by the number of grains per cob, as well as the ear length. Therefore, higher number of grains per cob and a longer cob size cause to obtain higher yield per unit area (*Khan, Khan & Afzal, 2017*). Ilker (2011) also indicated that the fresh cob yield value was positively correlated with the yield components. The findings are consistent with the results obtained by Ahmad et al. (2015) who showed that fresh ear yields of sweet corn had a significant positive correlation with CGN, PH, EL and yield components.

CONCLUSIONS

The results of the study indicated that pollen fertility is an important index of environmental stress. The PFR parameter has come to the fore as an important and practically usable selection criterion to determine the most suitable varieties under stress conditions. The ABA hormone has a significant role in regulating the tolerance level of plants to temperature stress conditions. The ABA hormone protects the plants against heat stress at the cellular level, in addition, the ABA hormone positively contributes to the yield components, especially FCY and PFR values. The ABA hormone level will provide important clues about the tolerance level and yield of the sweet corn varieties in breeding programs to be carried out under abiotic or biotic stress conditions in the future, or in adaptation studies to determine the appropriate variety for all regions in the world. In long-term breeding and adaptation programs, the ABA hormone level of sweet corn lines and varieties included in breeding programs should be determined to save time and labor. The results concluded that physiological parameters such as ABA and PFR will save time and labor in breeding programs and variety adaptation experiments carried out with multiple materials in areas with environmental stress such as high temperature and low relative humidity.

ADDITIONAL INFORMATION AND DECLARATIONS

Funding

This study was supported by General Directorate of Agricultural Research and Policies affiliated to Republic of Turkey Ministry of Agriculture and Forestry. This study was a part of the national corn breeding program.

Competing Interests

The authors declare there are no competing interests.

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Table 1(on next page)

Table 1: Important climatic values of the trial location.

Table 1:

Important climatic values of the trial location.

	Mean temperatures (°C)		**The highest temperatures (°C)**		**The lowest temperatures (°C)**		**Mean humidity (%)**		**Total precipitation (mm/m^{-2})**	
Months	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
May	31.0	32.2	38.8	40.0	15.8	14.6	42.3	45.9	10.2	0.2
June	36.5	37.9	41.6	44.2	18.9	21.4	34.4	33.9	0.8	0.0
July	38.9	41.6	42.2	44.7	21.9	24.1	35.7	31.1	0.2	0.0
August	39.7	40.1	42.8	45.4	22.7	22.0	38.9	36.2	1.2	0.0
September	35.5	38.3	38.6	43.4	17.7	19.7	40.0	42.3	0.0	0.2
October	30.7	32.2	34.6	37.0	12.9	14.9	50.6	39.5	12.8	0.0
November	22.6	24.1	26.5	28.1	6.9	10.9	47.2	43.3	2.6	0.0
Average	33.6	35.2	37.9	40.4	16.7	18.2	41.3	38.9	27.8	0.4

Table 2(on next page)

Table 2: Pollen fertility and total soluble solids and absisic acid of sweet corn varieties in 2019 and 2020.

Table 2:

Pollen fertility and total soluble solids and absisic acid of sweet corn varieties in 2019 and 2020.

Varieties	Pollen fertility rate (%)			Total soluble solids (^{0}brix)			Absisic acid (nmol/g^{-1} DW)		
	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
ȘADA-18.1	44.33 f	38.48 h	41.41 gh	17.32 abc	18.51 cd	17.92 bc	8.04 f	12.11 ef	10.08 g
ȘADA-18.2	45.51 ef	35.07 h	40.29 h	17.70 ab	20.15 bc	18.93 ab	5.67 f	9.81 f	7.74 h
ȘADA-18.3	58.14 bc	55.22 cd	56.68 d	12.63 f	15.24 de	13.94 e	15.44 bcd	18.40 bc	16.92 cd
ȘADA-18.4	46.22 ef	42.37 g	44.29 g	16.29 bcd	19.66 bc	17.98 bc	11.67 e	14.26 de	12.96 f
ȘADA-18.5	53.89cd	50.66 e	52.28 e	14.59 cdef	19.88 bc	17.24 bc	14.77 bcd	17.15 bcd	15.96 de
ȘADA-18.6	50.41 de	46.70 f	48.56 f	14.41 def	18.33 cd	16.37 cd	12.79 de	15.78 cd	14.28 ef
ȘADA-18.7	61.44 b	58.55 bc	60.00 c	15.70 bcde	24.47 a	20.09 a	14.33 cde	24.11a	19.22 ab
ȘADA-18.8	57.36 bc	52.93de	55.15 de	13.37 ef	16.15 de	14.76 de	19.42 a	22.67 a	21.04 a
Control-1	68.85 a	59.37 b	64.11 b	11.91 f	14.56 e	13.24 e	17.14 ab	19.59 b	18.37 bc
Control-2	71.81 a	63.48 a	67.65a	19.45 a	22.34ab	20.90 a	16.82 abc	17.34 bc	17.08 cd
Mean**	55.80 a	50.28 b	53.04	15.34 b	18.93 a	17.13	13.61 b	17.12 a	15.37
CV (%)	5.34	4.17	5.07	10.90	10.34	10.35	11.67	10.41	11.03
LSD (0.05)	5.11**	3.59**	3.15**	2.87**	3.36**	2.07**	2.72**	3.06**	1.98**
Mean LSD		3.39**			2.86*			1.36**	

$^{+}$)The means indicated with the same letter in the same column are not significantly different according to the JUMP test at P≤0.05, $^{++}$) The means indicated with the same capital letter in the same row are not significantly different at P≤0.05

$^{+++}$) The means of different year-varieties combinations with the same lower case letters are not significantly different according to the JUMP test at P≤0.05

Table 3(on next page)

Table 3: Agronomic traits performance of sweet corn varieties in 2019 and 2020.

Table 3:

Agronomic traits performance of sweet corn varieties in 2019 and 2020.

Varieties	Ear length (cm)			Plant height (cm)		
	2019	**2020**	**Mean**	**2019**	**2020**	**Mean**
ŞADA-18.1	12.62 ef	6.76 e	9.69 e	107.90 h	93.33 gh	100.62 h
ŞADA-18.2	12.15 f	9.20 d	10.68 de	111.90 gh	83.70 h	97.80 h
ŞADA-18.3	15.21 bc	11.87 bc	13.54 b	152.79 cd	138.30 bc	145.54 cd
ŞADA-18.4	13.36 def	7.98 de	10.67 de	121.90 fg	103.63 fg	112.77 g
ŞADA-18.5	14.22 cd	10.09 cd	12.15 c	129.57 ef	114.48 ef	122.02 fg
ŞADA-18.6	13.77 cde	8.65 de	11.21 cd	136.90 e	120.78 de	128.84 ef
ŞADA-18.7	17.69 a	14.28 a	15.98 a	168.56 b	148.52 ab	158.54 b
ŞADA-18.8	14.68 cd	12.72 ab	13.70 b	141.90 de	129.41 cd	135.65 de
Control-1	17.16 a	13.79 ab	15.48 a	158.56 bc	139.85 bc	149.21 bc
Control-2	16.55 ab	13.76 ab	15.16 a	186.90 a	155.78 a	171.34 a
Mean**	14.74 a	10.91 b	12.82	141.69 a	122.78 b	132.24
CV (%)	5.96	12.47	9.00	5.53	5.99	6.78
LSD (0.05)	1.51**	2.33**	1.35**	13.45**	12.61**	10.49**
Mean LSD		2.67*			12.01*	

[+])The means indicated with the same letter in the same column are not significantly different according to the JUMP test at P≤0.05, [++]) The means indicated with the same capital letter in the same row are not significantly different at P≤0.05

[+++]) The means of different year-varieties combinations with the same lower case letters are not significantly different according to the JUMP test at P≤0.05

Table 4(on next page)

Table 4: A number of grains/per cob and fresh cob yield of sweet corn varieties in 2019 and 2020.

Table 4:

A number of grains/per cob and fresh cob yield of sweet corn varieties in 2019 and 2020.

Varieties	A number of grains/per cob (grain)			Fresh cob yield (t ha^{-1})		
	2019	**2020**	**Mean**	**2019**	**2020**	**Mean**
ŞADA-18.1	299.07 g	295.00 bcd	297.04 e	6.64 ef	4.13 ef	5.38 fg
ŞADA-18.2	312.52 fg	265.78 d	289.15 e	5.49 f	2.82 f	4.15 g
ŞADA-18.3	367.07 bc	314.78 bcd	340.93 bc	9.40 bc	6.86 c	8.13 cd
ŞADA-18.4	328.25 ef	322.63 b	325.44 cd	7.39 def	5.20 de	6.29 ef
ŞADA-18.5	354.22 cd	301.29 bcd	327.76 cd	8.26 cde	4.92 de	6.59 ef
ŞADA-18.6	339.44 de	271.23 cd	305.33 de	7.66 cde	3.46 f	5.56 f
ŞADA-18.7	428.37 a	412.29 a	420.33 a	11.34 a	9.11 a	10.23 a
ŞADA-18.8	353.59 cd	317.30 bc	335.44 bc	8.63 bcd	5.99 cd	7.31 de
Control-1	378.11 b	337.41 b	357.76 b	10.21 ab	7.13 bc	8.67 bc
Control-2	433.15 a	392.78 a	412.97 a	10.49 ab	8.55 ab	9.52 ab
Mean**	359.38 a	323.05 b	341.21	8.55 a	5.82 b	7.18
CV (%)	3.17	8.85	6.58	12.95	14.55	15.17
LSD (0.05)	19.53**	49.07**	26.25**	1.90**	1.45**	1.27**
Mean LSD	35.98*			2.83*		

[+])The means indicated with the same letter in the same column are not significantly different according to the JUMP test at P≤0.05, [++]) The means indicated with the same capital letter in the same row are not significantly different at P≤0.05

[+++]) The means of different year-varieties combinations with the same lower case letters are not significantly different according to the JUMP test at P≤0.05

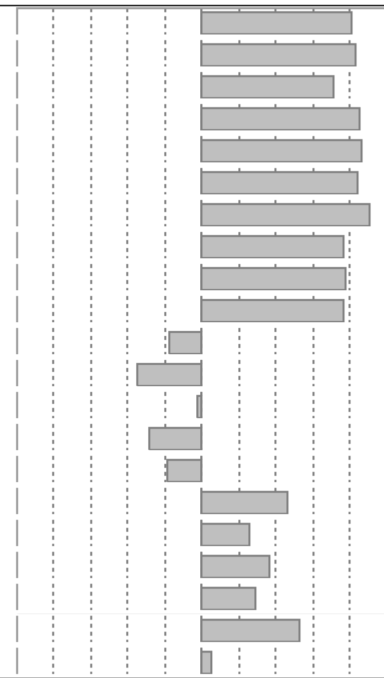
Table 5(on next page)

Table 5: Correlation coefficients and significance levels of yield components and grain yield and physiological parametre.

Table 5:

Correlation coefficients and significance levels of yield components and grain yield and physiological parametre.

Traits	Traits	Correlation coefficients (r)	Count	The lowest coefficients (95%)	The highest coefficients (95%)	Significance levels (p)	Correlation levels
EL	PH	0.8162	60	0.7092	0.8864	<.0001**	
CGN	PH	0.8292	60	0.7287	0.8947	<.0001**	
CGN	EL	0.7154	60	0.5640	0.8203	<.0001**	
FCY	PH	0.8577	60	0.7718	0.9128	<.0001**	
FCY	EL	0.8666	60	0.7855	0.9184	<.0001**	
FCY	CGN	0.8434	60	0.7501	0.9037	<.0001**	
PFR	PH	0.9128	60	0.8576	0.9472	<.0001**	
PFR	EL	0.7664	60	0.6363	0.8541	<.0001**	
PFR	CGN	0.7796	60	0.6555	0.8628	<.0001**	
PFR	FCY	0.7691	60	0.6402	0.8559	<.0001**	
TSS	PH	-0.1769	60	-0.4123	0.0806	0.1763	
TSS	EL	-0.3503	60	-0.5549	-0.1058	0.0061**	
TSS	CGN	-0.0167	60	-0.2695	0.2382	0.8992	
TSS	FCY	-0.2775	60	-0.4964	-0.0253	0.0319*	
TSS	PFR	-0.1891	60	-0.4227	0.0681	0.1479	
ABA	PH	0.4701	60	0.2455	0.6468	0.0002**	
ABA	EL	0.2579	60	0.0043	0.4804	0.0466*	
ABA	CGN	0.3627	60	0.1199	0.5647	0.0044**	
ABA	FCY	0.2888	60	0.0377	0.5057	0.0252*	
ABA	PFR	0.5285	60	0.3171	0.6898	<.0001**	
ABA	TSS	0.0519	60	-0.2047	0.3019	0.6936	



+)FCY: Fresh Cob Yield (t ha^{-1}), CGN: Number of Grains/Per Cob (grain), PH: Plant Height (cm), EL: Ear Length (cm), PFR: Pollen Fertility Rate (%), TSS: Total Soluble Solids (^{0}brix), ABA: Absisic Acid (nmol/g^{-1} DW)

++)*.** significant at 0.05 and 0.01 levels of probability. Respectively

Figure 1

Figure 1: Geographical position of the study area.


Turkey
Area of study
Google Earth

Figure 2

Figure 2: Mean daily temperature values during the tasseling period in both years of the study.

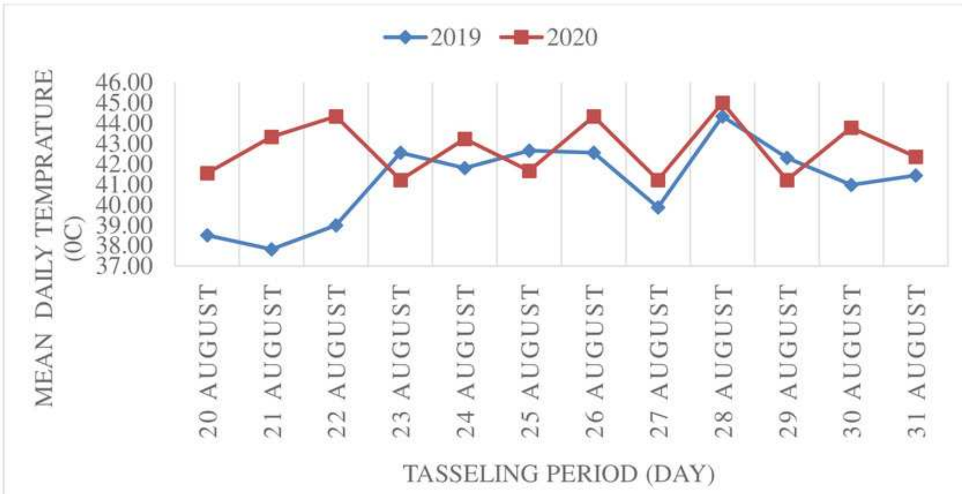

2019
2020
MEAN DAILY TEMPRATURE (0C)
46.00
45.00
44.00
43.00
42.00
41.00
40.00
39.00
38.00
37.00
20 AUGUST
21 AUGUST
22 AUGUST
23 AUGUST
24 AUGUST
25 AUGUST
26 AUGUST
27 AUGUST
28 AUGUST
29 AUGUST
30 AUGUST
31 AUGUST
TASSELING PERIOD (DAY)

Figure 3

Figure 3: Figure 3. Stages such as homogenization process of 100 mg leaf tissue (A) and transfer of homogenates to 15 ml falcon tubes (B) and the falcon tubes with mixtures of 1st and 2nd supernatants (C) and microplate which is consisting of 96-well

Stages such as homogenization process of 100 mg leaf tissue (A) and transfer of homogenates to 15 ml falcon tubes (B) and the falcon tubes with mixtures of 1st and 2nd supernatants (C) and microplate which is consisting of 96-well for ABA readin


A
B
C
D

Figure 4

Figure 4: The mean values in both years of Some parameters such as polen fertility rate (PFR, %), Absisic asit (ABA, nmol/g^{-1} DW), Total soluble solids (TSS, ^{0}brix) and Fresh cob yield (FCY, t ha^{-1}) and the significan

The average values of some of the parameters which are polen fertility rate (PFR, %), Absisic asit (ABA, nmol/g^{-1} DW), Total soluble solids (TSS, ^{0}brix) and Fresh cob yield (FCY, t ha^{-1}) measured in the study are shown with a bar graph

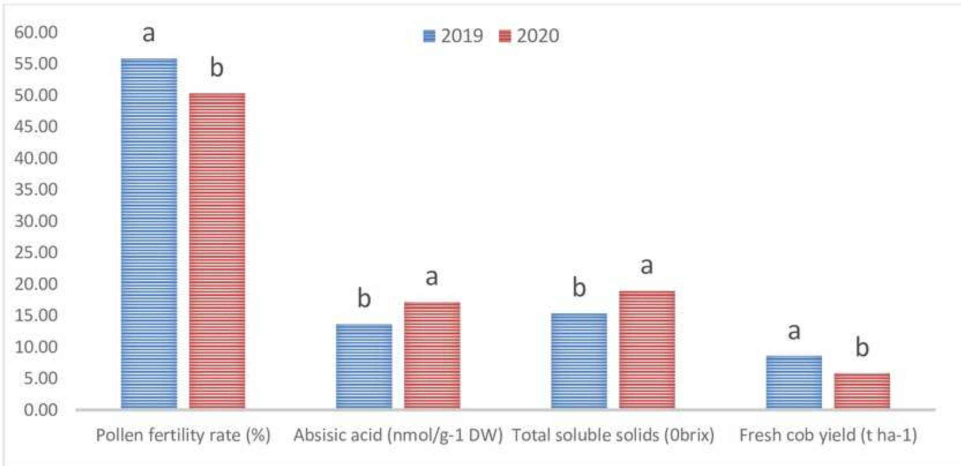
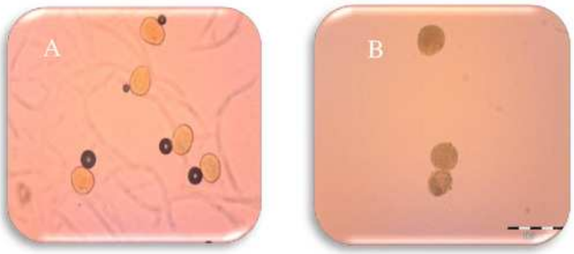

2019
2020
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
a
b
b
a
b
a
a
b
Pollen fertility rate (%)
Absisic acid (nmol/g-1 DW)
Total soluble solids (0brix)
Fresh cob yield (t ha-1)

Figure 5

Figure 5: Pollen fertility (A) and pollen infertility (B) images of ŞADA-18.7 from sweet corn varieties under light microscope.


A
B