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Sweet Sorghum (Sorghum bicolor L.) Yield Parameters as Affected by Physiological Characteristics

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Key Words: Biomass, genotype, physiological characteristics, sugar, sweet sorghum

ABSTRACT

Objectives of this research are to determine physiological characteristics of sorghum (*Sorghum bicolor* L.) genotypes and to investigate the relationships between these characteristics and yield components. Experiments were carried out in randomized block design with 3 replications over the experimental fields of Kahramanmaras Sutcuimam University Agricultural Faculty during the years 2007-2008. Net photosynthesis rate (Pn), stomatal conductance (gs), chlorophyll content (CC), canopy temperature (CT), plant height (PH), plant diameter (PD) and biomass (B) characteristics were investigated. Results revealed negative relations between vegetative state canopy temperature (VSCT) and sugar content (SC), between vegetative state chlorophyll content (VSCC) and flowering state chlorophyll content (FSCC), between PH and FSCC and between vegetative state net photosynthesis rate (VSPn) and PH-B. Positive relations were observed between B and PH-SC, between FSCC and vegetative state leaf area index (VSLAI)- (VSCC), between vegetative state stomatal conductance (VSgs) and VSLAI-VSPn. The genotype Della was found to be prominent with regard to biomass, sugar and plant height like yield components.

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Abbreviations

Gs - stomatal conductance
CC - chlorophyll content
CT - canopy temperature
PH - plant height
PD - plant diameter
B - biomass
VSCT - vegetative state canopy temperature
SC - sugar content
VSCC - vegetative state chlorophyll content
FSCC - flowering state chlorophyll content
VSPn - net photosynthesis rate
VSLAI - vegetative state leaf area index
VSgs - vegetative state stomatal conductance

1. Introduction

Sorghum is among the most significant cereal crops of the world (Krieg, 1983; Moseki, 2011). It is commonly cultivated in tropic and sub-tropic regions of the world (Hassanein *et al.*, 2010). Beside high biomass yield, sweet sorghum also highly resistant against drought, salinity and flooding (Li, 1997; Mastrorilli *et al.*, 1999). Researches indicated sweet sorghum as among the most promising potential raw materials for energy and industry (Gosse, 1996). It is not only used for ethanol production but also widely used for livestock feeding (Yildiz *et al*., 1998; Liu *et al*., 2008). Such superior characteristics continuously raise the significance of sweet sorghum among farmers and producers.

Previous successes in increasing yield potential of sorghum were mostly coming from kernel yield-dependent selection researches. Today, physiological approaches are employed to increase yield, yield-limiting characteristics are determined and tierd to be improved through breeding researches (Kaplan, 2009).
Several researchers reported significant relationships between growth characteristics and yield components of sorghum varieties (El-Hattab *et al.*, 2000; Ahmed *et al.*, 2007). Leaf area index can be improved during the early growing stages and consequently leaf photosynthesis can be increased through increased ligh intake of plants. Such improvement is directly related to yield (Lopez-Castaneda and Richards, 1994; Hafid *et al.*, 1998).
In this research, physiological characteristics of sweet sorghum (*Sorghum bicolor* L.) genotypes were determined and relationships between these characteristics and yield components were investigated.

2 Materials and method

2.1 Plant

Experiments were conducted in randomized block design with 3 replications during the summer cultivation states of the years 2007 and 2008. The genotypes ICSB 297, ICSB 324, ICSB 264 and ICSB 276 supplied from ICRISAT and Della, Dorado, Chiltex and Lian Tang Ai varieties supplied from Texas A&M University were used as the plant material of the study. Plants were planted at 70x14 cm sowing density. A total of 8 kg N and 8 kg P_2O_5 were applied at sowing and 10 kg/da N was applied as topdressing at bolting. Plants were pressed at dough state to determine sugar content.

2.2 Soil and Climate Characteristics of Experimental Site

Experimental site has sand-clay texture in both experimental years. Soils were slightly alkaline with pH values of 7.94 in the first year and 7.93 in the second year. Lime content in the first and second years was 16% and 14%, respectively. Lime content of the first year was classified as over-limed and the second year as medium-limed. Soils of experimental site were found to be poor in organic matter (Anonymous, 2008a).

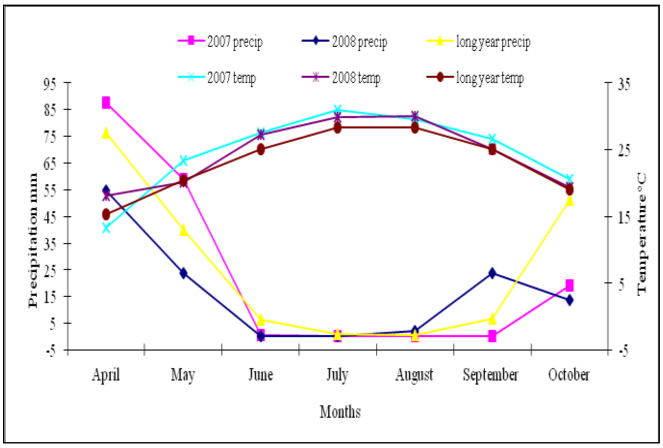


Fig. 1: Ombro-Thermic Climate diagram experimental years and long-term averages

Total precipitations for growing states of experimental years were realized as 166.6 and 118.1 mm. Precipitation was 15.0 mm less than the long-term averages in the first year and 63.5 mm less in the second year. Due to less precipitation, irrigation was applied at 7-10 day intervals. Long term average temperature of Kahramanmaraş for experimental months was 23.1 ^{o}C (Table 1). Average temperatures of the months of experimental years were 24.6 and 24.3 ^{o}C for the years 2007 and 2008, respectively. Both experimental years had higher average temperatures than long-term averages (Anonymous, 2008b).

Table 1. Physical and chemical characteristics of soils of experimental site

Years	Depth (cm)	Texture	pH	$CaCO_3$ (%)	P_2O_5 (kg/da)	K_2O (kg/da)	Organic Matter %
2007	0–30	Sandy-Clay	7.94	16	0.85	3.6	1.49
2008	0–30	Sandy-Clay	7.93	14	1.02	3.6	1.49

2.3 Measurements

Photosynthesis rate and stomatal conductance during vegetative state (45 days after sowing) and flowering state were measured from the top leaves of 5 plants randomly selected from each plot in a fully sunny day between the hours 10^{00} and 16^{00} with LCA+pro type portable gas analyzer. Chlorophyll content was measured with a portable chlorophyll photometer from the top leaves of randomly selected 5 plants in the field during the vegetative and flowering state. Photosynthesis rate and stomatal conductance were able to be measured only in the year 2008 due to faulty of the device. Leaf area index in both states were measured from middle-two rows with LAI-2000 Plant Canopy Analyzer. Canopy temperature was measured by a portable infrared thermometer as ^{o}C. Plant height was measured at the ripening state as the height from the soil surface level to tip of the plant. Plant diameter was measured at just above the first node from the soil surface. Plants were harvested, weighed and biomass yield per decare was determined. Sugar content was measured from sweet sorghum wort extracted by pressing (Kaplan, 2009).

2.4 Data Analysis

Variance and correlation analyses were performed by using SAS (SAS Inst., 1999) software. Duncan test was used to test the significance of the difference between means. The mean values of the genotypes for investigated traits were subjected to genotype-by-trait, biplot analysis of PC1 and 2.

3 Results

The differences among genotypes with regard to vegetative state leaf area index and canopy temperature were not found to be significant. Year x genotype interaction was also found to be insignificant with regard to vegetative state leaf area index and sugar content characteristics. All the other characteristics and year x genotype interactions were found to be significant.

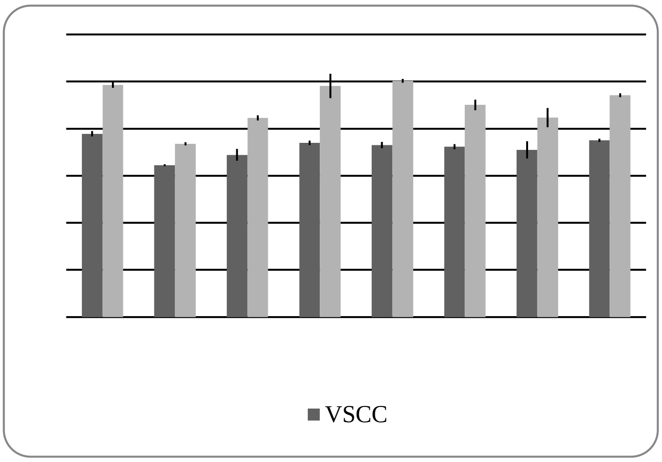


Fig. 2: *Chlorophyll contents of sorghum genotypes in vegetative and flowering states*

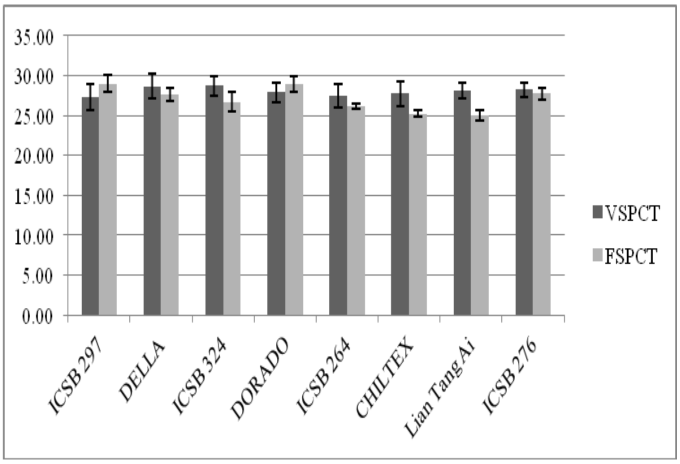
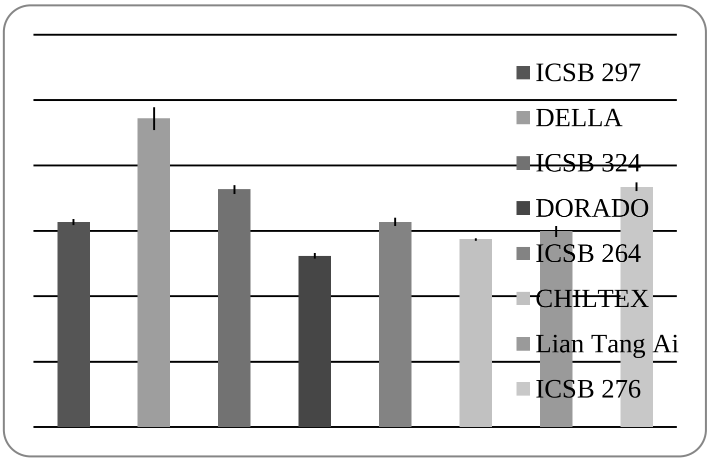


Fig. 3: *Canopy temperatures of sorghum genotypes in vegetative and flowering states*

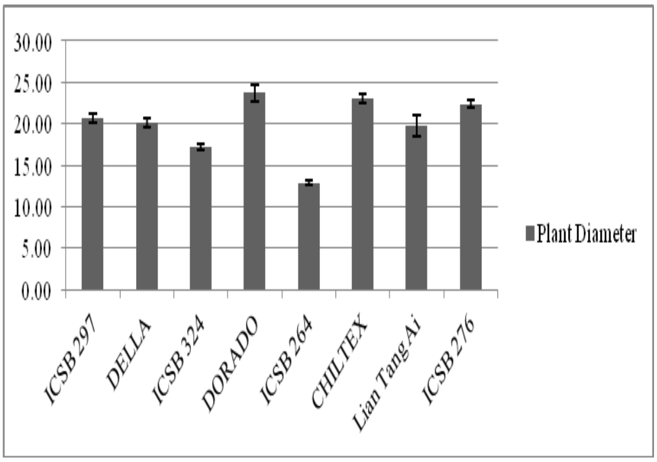
Chlorophyll contents of genotypes in vegetative state varied between 32.23-38.90 mg m^{-2}. The lowest value was obtained from Della variety and the highest value from ICSB 297 line. The lowest value in flowering state was observed in again Della with 36.76 mg m^{-2} and the highest value was seen ICSB 264 genotype with 50.14 mg m^{-2}. The genotypes ICSB 297 and Dorada were also statistically placed into the highest group.

The differences among genotypes with regard to VSPCT were not found to be significant. The lowest canopy temperature in flowering state (FSPCT) was measured as 25.01 ºC from Lian Tang Ai variety and the variety Chiltex was also placed into the lowest group. The highest value was seen in ICSB 297 genotype with 29.04 ºC and the variety Dorado was also placed into the highest group.



*genotypes $p \leq 0.01$;years*genotypes $p \leq 0.01$*

Fig. 4: *Plant heights of sorghum genotypes*



*genotypes p≤0.01;years*genotypes p≤0.01*

Fig. 5: *Plant diameters of sorghum genotypes*

Plant heights varied between 130.83 and 235.78 cm. While the lowest value was observed in Dorado variety, the highest value was obtained from Della variety. The lowest lowest plant diameter was measured in ICSB 264 line with 12.87 mm and the highest value was observed in Dorado variety with 23.69 mm. The variety Chiltex was also statistically placed into the same group.

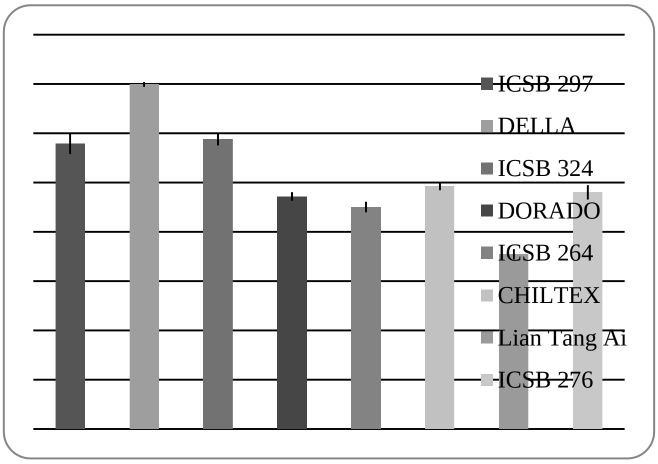


Fig. 6: Biomass of sorghum genotypes

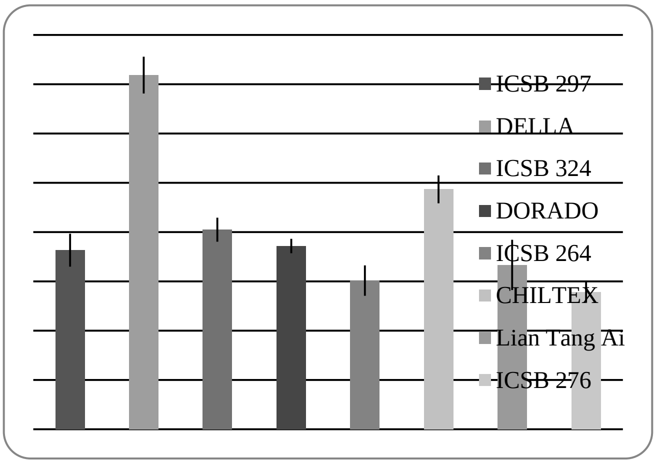


Fig. 7: Sugar content of sorghum genotypes

While the lowest biomass value (3543.7 kg/da) was obtained from Lian Tang Ai variety, the highest value (6989.3 kg/da) was seen in Della variety with the tallest plant height. The lowest SC was obtained from ICSB 276 line with 14.39, the highest value again observed in Della variety with the highest biomass.

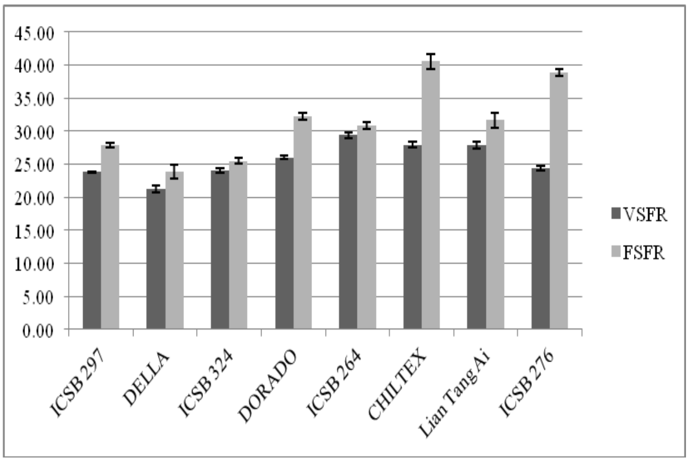


Fig. 8: Photosynthesis rate of sorghum genotypes in vegetative and flowering states

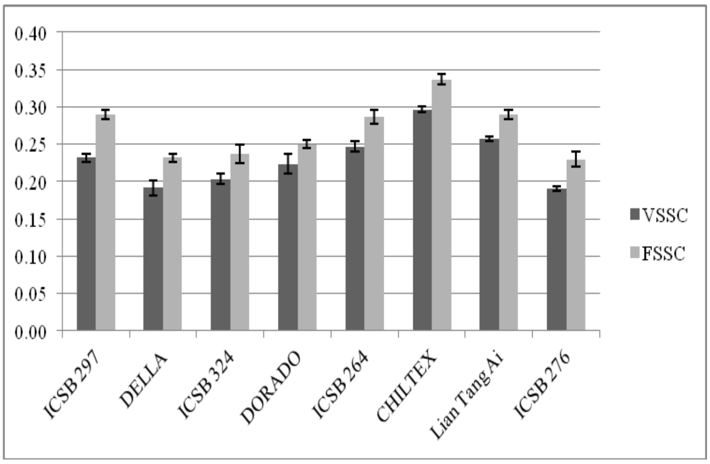


Fig. 9: Stomatal conductance of sorghum genotypes in vegetative and flowering states

Vegetative state photosynthesis rates of genotypes varied between 23.96-29.38 µmolCO_2 $m^{-2}s^{-1}$. While the lowest value was obtained from Della variety, the lines ICSB 324 and ICSB 276 were placed into the same group. The highest value was seen in ICSB 264 line. The lowest photosynthesis rate in flowering state (FSPn) was observed in Della variety with 21.32 µmolCO_2 $m^{-2}s^{-1}$, the highest value was obtained from Chiltex variety with 40.56 µmolCO_2 $m^{-2}s^{-1}$ and ICSB 276 line was included into the highest group.

Stomatal conductance in vegetative state varied between 0.19-0.30 mol H_2O $m^{-2}s^{-1}$. While ICSB 276 yielded the lowest value, the highest value was obtained from Chiltex variety. In flowering state, Della variety yielded the lowest gs with 0.19 mol H_2O $m^{-2}s^{-1}$ and ICSB 324 line was also placed into the lowest group. The highest gs value in flowering state was observed in again Chiltex variety with 0.34 mol H_2O $m^{-2}s^{-1}$.

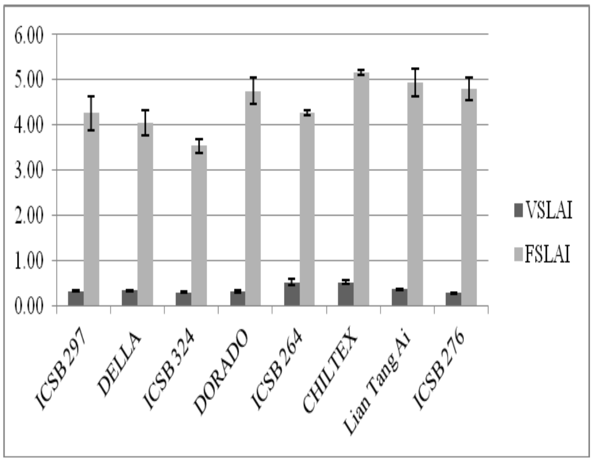


Fig. 10: Leaf area indexes of sorghum genotypes in vegetative and flowering state

Leaf area index of vegetative state was found to be insignificant. The lowest value in flowering state (3.54) was observed in ICSB 324 line and the highest value (5.14) was seen in Chiltex variety. The variety Lian Tang Ai was also included into the highest group.

4 Discussion

Interactions among the investigated characteristics of sorghum genotypes are presented in Table 2. Significant negative relationships were observed between VSCT and VSCC-FSCC. Again a significant negative relationship was observed between PH and FSCC. While a negative correlation was seen between SC and VSCC-FSCC, a positive relationship was observed with biomass. Significant positive relationship was clear between VSPn and VSLAI and a negative relation was determined between PH and biomass.

Table 2. Coefficient of correlation among investigated characteristics

	VSCC	FSCC	VSCT	FSCT	VSLAI	FSLAI	PD	PH	B	SC	VSPn	FSPn	VSGS	FSGS
VSCC	1													
FSCC	**0.904**	1												
VSCT	**-0.798**	**-0.817**	1											
FSCT	0.329	0.292	-0.105	1										
VSLAI	0.016	0.197	-0.495	-0.639	1									
FSLAI	0.394	0.274	-0.409	-0.278	0.331	1								
PD	0.201	-0.053	0.042	0.329	-0.351	0.575	1							
PH	-0.690	**-0.726**	0.675	0.125	-0.319	-0.549	-0.156	1						
B	-0.451	-0.473	0.388	0.469	-0.296	-0.666	0.020	**0.747**	1					
SC	**-0.761**	**-0.771**	0.466	0.029	0.023	-0.251	0.169	0.659	**0.746**	1				
VSPn	0.345	0.513	-0.550	-0.615	**0.727**	0.524	-0.289	**-0.754**	**-0.840**	-0.562	1			
FSPn	0.482	0.411	-0.351	-0.299	0.370	**0.838**	0.452	-0.500	-0.585	-0.407	0.525	1		
VSgs	0.253	0.257	-0.585	-0.610	**0.797**	0.592	0.030	-0.677	-0.528	-0.139	**0.771**	0.490	1	
FSgs	0.342	0.297	-0.683	-0.520	**0.782**	0.534	0.012	-0.613	-0.422	-0.128	0.678	0.444	**0.970**	1

In bold, significant values (except diagonal) at the level of significance alpha=0.050 (two-tailed test

Climate and genetics have significant impacts on yield components (Clark, *et al.*,1997; Peterson *et al.*, 2005). Although dark and wide leaves have high chlorophyll contents, such criteria are not critical for photosynthesis rate (Reynolds *et al.*, 2001). Photosynthetic rate was increased up to 50 percent flowering and thereafter decreased as the crop approached maturity (Surwenshi *et al.*, 2010). Tsiju *et al.* (2003) evaluated three sorghum cultivars under fully watered conditions, and the respective ranges for net photosynthetic rates and stomatal conductance were 23 µmol $m^{-2}s^{-1}$ to 25 µmol $m^{-2}s^{-1}$ and 0.13 mol $m^{-2}s^{-1}$ to 0.19 mol $m^{-2}s^{-1}$ at the late vegetative stage. Kidambi *et al.* (1990), significant genetic variation was observed for A and g in grain sorghum hybrids. The large variation in A-g relationship suggests that an association between these traits may not be species specific, and thus a possibility exists to select for increased A without large increases in gs. There is a significant relation between flowering state stomatal conductance and photosynthesis rate (Jiang *et al.*, 2000). Zhao *et al.* (2008) and Hisir *et al.* (2012) reported no-relationship between photosynthesis rate and chlorophyll content but observed positive relations between stomatal conductance and photosynthesis. Chlorophyll content values of current study are close to ones observed by Yamamoto *et al.* (2002) and Zhao *et al.* (2005). Araghi and Assad (1998) indicated increasing canopy temperatures with increasing ambient temperatures at the time of measurement and also reported higher canopy temperatures for stressed conditions than unstressed conditions. It was reported that plant cover temperature was a response of plant against temperature and drought and lower heating rates of plants even at high ambient temperatures indicated higher resistance against temperature and drought (Fischer, 2001; Reynolds *et al.*, 2001). Despite increasing temperatures, the species of ICSB 324, ICSB 264, CHILTEX, Lian Tang Ai and ICSB 276 exhibited lower plant temperatures in FSCT. Regional temperature differences and measurement dates may cause differences in canopy temperatures. Vegetative state canopy temperatures of the present study were similar to ones observed by Grant *et al.* (2004) and Kaplan (2009).

Plant height and vegetative state leaf area index values of this study were similar to values determined by Hassanein et al. 2010. Stomatal conductance and biomass values were in compliance with the values observed by Mastrorilli *et al.* (1999) and Zhao *et al.* (2005).

Zhao *et al.* (2009) investigated the effects of harvest time, variety and experimental year on sugar content of sweet sorghum and reported the similar finding with present study. While stomatal conductance values of the current study were similar to values observed by Netondo *et al.* (2004) and Zhao *et al.* (2005), photosynthesis rates were similar to findings of Johnson and Day (2002); Tsuji *et al.* (2003) and Zhao *et al.* (2005). Stomatal conductance values of vegetative period were found to be lower the values of flowering period. Stomas close up under insufficient moisture conditions and stomatal conductance decreases accordingly (Cornic, 2000). Also, lower temperatures of June, in which stomatal conductance measurements are taken, caused to have lower stomatal conductance values. It was reported by Bunce (1998) than stomatal conductance was effected by minimum temperatures and decreased with decreasing night temperatures.

Ramazanzadeh and Asgharipour (2011) reported increasing LAI values with the progress of growing and decreasing values with decreasing nutrient and solar radiation. Researchers observed the highest LAI value in flowering state. Findings for flowering state of current study are similar to findings of Kaplan (2009); Lafarge and Hammer (2002); Ottman *et al.* (2001) and Ramazanzadeh and Asgharipour (2011). Austin *et al.* (1980) indicated that dry matter accumulation in kernels were mostly depend on post-flowering photosynthesis rates and additional post-flowering photosynthesis rates might be provided by selecting genotypes with high leaf area index at flowering period. Biomass values of current research are closer to findings of Grant *et al.* (2004). Kaplan (2009) reported positive significant relationships between chlorophyll content and photosynthesis rate-stomatal conductance, between biomass and plant height, between photosynthesis rate and stomatal conductance.

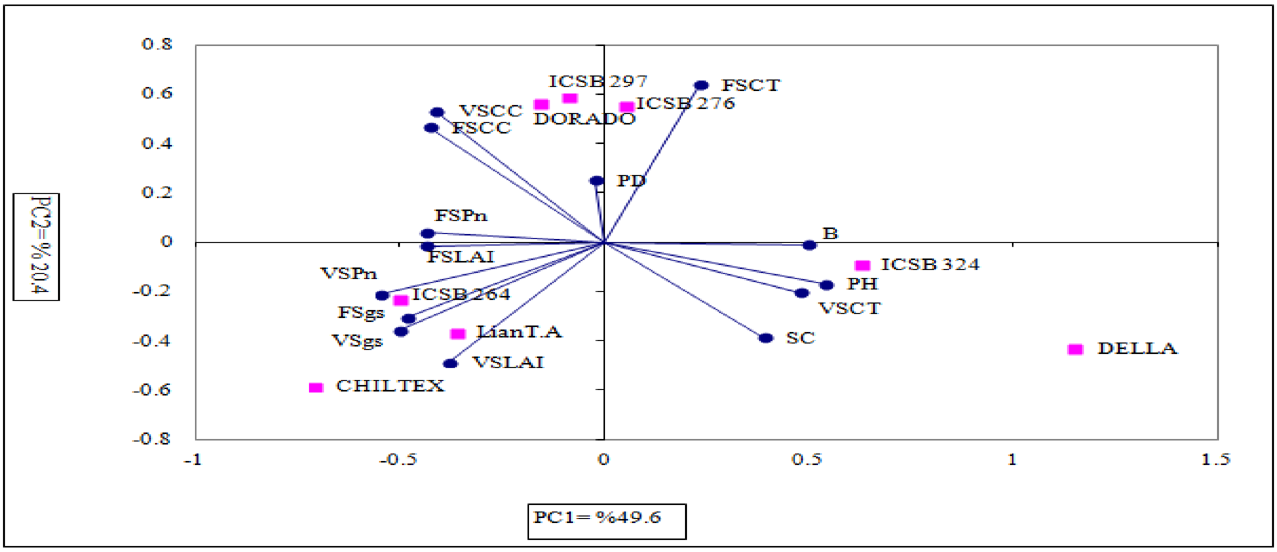


Fig. 11 Biplot polygon for physiological characteristics of sweet sorghum genotypes

Among genotypes Della variety and ICSB 324 line were specialized with regard to plant height, biomass and sugar content. ICSB 264, Lian Tang Ai and Chiltex varieties were placed into the same group and they were distinctive with their leaf area index, stomatal conductance and photosynthesis rates. ICSB 297 and Dorado genotypes were specialized with their chlorophyll contents (Figure 11).
Results of current study revealed increasing biomass and sugar content and consequently increasing wort yield with increasing plant heights. The variety Della was found to be superior over the others with regard to plant height, diameter and leaf area index and consequent biomass yield.

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