Pak. J. Bot., 53(3): 859-863, 2021. DOI: http://dx.doi.org/10.30848/PJB2021-3(34)

RELATIONSHIP BETWEEN PHOTOSYNTHETIC PIGMENTS AND SEED YIELD COMPONENTS IN SOYBEAN CULTIVARS IN A SEMI-ARID REGION

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Abstract

The field experiment was conducted according to a randomized block design with three replications. Most common cultivated soybean cultivars (Arısoy, Atalkişi, Blaze, Bravo, İlksoy, Lider, Mersoy, Nova and Traksoy) in Turkey were selected as the plant materials of the study. Agronomic properties such as plant height, first pod height, number of branches, number of pods, thousand-seed weight, plant seed yield, seed yield, crude oil ratio, crude oil yield, chlorophyll a, b, total chlorophyll and carotenoids contents were determined to assess the yield performances of the soybean cultivars. The results showed that yield and yield components were significantly different among soybean cultivars. Although grown under irrigated conditions, the differences in climate factors between the years caused a significant impact on yield and yield components. Photosynthetic pigments, i.e., chlorophyll a, chlorophyll b, and carotenoids, and consequently, seed yield was affected by stress conditions. The crude oil content of cultivars ranged from 21.45 to 26.6%, and seed yield varied between 1736.8 and 2496.24 kg ha^{-1}. The results revealed that Atakişi and Atasoy cultivars with high photosynthetic pigment contents can be recommended to obtain high seed and oil yields under semi-arid climate condition.

Key words: Soybean, Chlorophyll, Carotenoids, Yield, Oil rate.

Introduction

Soybean [*Glycine max* (L.) Merill] has the highest production ratio among oilseed crops in the world with 352 million tons of production on 123 million ha land (Anon., 2019). Soybean has been an important crop as human nutrition and animal feed in addition to a raw material for different industry sectors due to the high protein (40%), oil (20%) and carbon hydrate (10%) contents of seeds (Seadh & Abido 2013). Soybean production in the world has been increased regularly, while cultivated area and production in Turkey have had between 300.000 and 400.000 ha and from 100.000 to 180.000 tons, respectively (Anon., 2019). The production of soybean does not meet the demand of the country; thus, high amount of soybean has been imported, especially for the livestock sector. Soybean in Turkey can be grown as the main and the second crop due to the suitable ecology in most of the regions. However, soybean production does not increase because of the preferences of alternative crops. Soybean has mainly cultivated in Adana and Mersin provinces which correspond approximately to 84% of the soybean production of Turkey. Medium-early maturing soybean cultivars are preferred in Turkey and commonly used in breeding programs. The yield and yield components may vary significantly among cultivars grown under different conditions. Studies conducted with the new cultivars indicated significant differences in yield traits, and seed yield of soybean cultivars varied between 2240 and 4850 kg ha^{-1} (Çalışkan & Arıoğlu, 2004; Güllüoğlu & Arıoğlu, 2005; Altınyüzük, 2017). Therefore, determining the most fertile cultivars for a region is important. The cultivation area of soybean cannot be increased further in the regions where soybean has already been cultivated, therefore, various yield experiments are needed to expand soybean farming in alternative regions.

Chlorophyll is responsible capturing the solar energy required for photosynthesis, thus is an essential component for plant growth. Therefore, chlorophyll measurement is used to determine the physiological status of vegetation, to assess the effects of stress factors, to identify phenological characteristics of species and to predict the productivity by photosynthesis potential (Ferri *et al*., 2004; Steele *et al*., 2008). Carotenoids, as accessory pigments, are involved in light harvesting and energy transfer to chlorophyll and play important roles in photosynthesis and photoprotection (Demmig-Adams & Adams III, 1992). Carotenoids are potential antioxidants during plant stress (Uarrota *et al.*, 2018). The leaf carotenoids have essential photoprotective roles such as scavenging of reactive oxygen species, quenching of dangerous triplet states of chlorophyll and participating in thermal dissipation of excess light energy (Dhanapal *et al.*, 2015). Therefore, the aim of this study was to improve the cultivation of new high yielding soybean cultivars in an alternative semi-arid region and to determine the relationship between yield components with leaf chlorophyll and carotenoid contents.

Material and Method

The study was conducted on the experimental field of Kırşehir Commodity Exchange in 2016 and 2017. The experimental soil had clayey loam texture and slightly alkaline, high in calcium carbonate and low in organic matter content. Plant available phosphorus concentration was sufficient and available potassium concentration (240.0 mg kg^{-1}) was very high (Table 1). Climate data of the study area during soybean growing periods were given in Table 2. The average temperature in 2016 and 2017 soybean vegetation periods was approximately 1.0°C and 2.3°C higher compared to the average of long-term temperature value. The relative humidity was lower than the long-term average due to the increase in temperature. Total monthly precipitation in 2016 was 57.5 mm higher than the long-term average precipitation, while it was 19.7 mm lower in 2017.

Table 1. Some of soil characteristics of the experimental fields.

Texture	pH	EC (µS/cm)	Salinity (%)	Available P_2O_5 (kg ha^{-1})	$CaCO_3$ (%)	Available K_2O (kg ha^{-1})	OM (%)
Loamy clay	7.96	738.6	0.02	19.7	35.29	482.6	1.09

Table 2. Meteorological data of the study area.

Months	Mean temperature (°C)			Relative humidity (%)			Precipitation (mm)		
	1970-2018	2016	2017	1970-2018	2016	2017	1970-2018	2016	2017
May	15.4	14.9	15.2	60.8	63.7	59.5	44.3	98.0	49.9
June	19.6	21.0	20.7	54.0	53.0	54.3	36.8	16.1	18.4
July	23.1	24.2	26.0	48.1	42.5	36.0	6.8	5.8	0.4
August	22.9	25.7	25.6	48.4	43.8	43.2	4.9	0.0	16.0
September	18.2	18.4	23.1	53.1	48.2	31.7	11.6	42.0	0.0
Mean	19.8	20.8	22.1	52.9	50.2	44.9			
Total							**104.4**	**161.9**	**84.7**

Experiment layout was a randomized block design with 3 replications. Nine soybean cultivars (Arısoy, Atakişi, Blaze, Bravo, Ilksoy, Lider, Mersoy, Nova and Traksoy) were used as the plant materials of the experiment. Soybean seeds were planted in the first week of May (May 6 in 2106 and May 3 in 2017) when the air and soil temperatures were appropriate for the seed germination.

Each plot in the experiment consisted of 6 rows with 6 m length. The seeds were planted at 45 cm interrow and 3 cm intra row spacings. Plant height, the first pod height, number of side branches, number of pods, thousand-seed weight, plant seed yield, seed yield, crude oil ratio, crude oil yield, chlorophyll a, b and total chlorophyll contents of soybean cultivars were determined. For chlorophyll analysis, randomly selected matured leaves were collected from the center rows at the R5 (beginning of seed filling) developmental stage (Fehr *et al*., 1971). Three terminal leaflets of mature, fully irradiated leaves were randomly selected within a row. The chlorophyll content of fully irradiated leaves was determined with the method explained by Arnon (1949). In this method, 0.2 g of leaf sample was homogenized in 8 ml of 80% acetone and the suspension was centrifuged in a cooled centrifuge at +4°C and 3000 rpm for 15 minutes. The absorbance of the supernatant obtained at the end of the centrifugation process was measured in a UV-VIS spectrophotometer at 663 nm, 652 nm and 645 nm wavelengths. Following equations were used to calculate the pigment contents (Lichtenthaler & Wellburn, 1983).

Total Chlorophyll (mg/g) = A_{652} x 27.8 x 20/wt (mg)
Chlorophyll a (mg/g) = (11.75 x A_{663}-2.35 x A_{645}) x 20/wt(mg)
Chlorophyll b (mg/g) = (18.61 x A_{645}-3.96 x A_{663}) x 20/wt(mg)
Carotenoid (mg/g) = ((1000 x A_{470})-(2.27 x Chl.a)-(81.4 x Chl.b)/227) x 20/wt(mg)
A: The measured absorbance values, wt: Weight of sample Chla: Chlorophyll a; Chlb: Chlorophyll b

Statistical analyzes were performed using MSTATC statistical software according to the randomized block split plot experimental design (Russel & Eisensmith, 1983). The differences in yield and yield components of the cultivars were determined by variance analysis. The least significant difference (LSD) test was used as post-hoc to separate the means of cultivars for the yield and yield components. The relationships between the traits were determined by a correlation test.

Results and Discussion

The plant height, first pod height, number of branches and pods, chlorophyll a, b, total and carotenoids content, thousand seed weight, oil ratio, seed and oil yield of nine soybean varieties were compared to investigate the performances of under semi-arid climate conditions. Plant height, the first pod height, number of side branches and number of pods were significantly ($p<0.01$) different among cultivars (Table 3). Plant height, the first pod height and number of pods in 2016 were higher than those recorded in 2017. The results of correlation test showed that plant height had a significant positive (r=0.500**) correlation with the first pod height, while significant negative correlation (r=-0.366**) with the number of side branches (Table 4). The number of pods showed a significant positive correlation with the number of side branches (r=0.311*), and the number of pods ranged from 41.6 to 76.5 per plant. Differences in plant height between years and cultivars were due to variation in temperature between the years. High temperatures cause early maturity of soybean plants, which may cause a decrease in plant height (Farias *et al.*, 2007). Previous studies revealed that plant height and the first pod height of soybean varieties were higher when grown as the main crop due to longer period to maturity than the second crop (Çalışkan & Arıoğlu, 2004; Kumar *et al.*, 2008; Karaaslan, 2011; Altınyüzük, 2017). Plant height has a positive effect on the first pod height which is very important to reduce the harvest losses, especially in machine harvest. The number of side branches decreased by the increase in plant height. The result may be attributed to the response of cultivars to environmental conditions. Many researchers indicated that the first pod height and the number of pods decreased in warmer years (Yilmaz, 1999; Çalişkan *et al*., 2007; Acikgoz *et al*., 2009). The first year of the experiment was warmer and dryer than the second year, therefore the plant height and the first pod height of soybean varieties decreased, and the number of side branches increased.

Table 3. Plant height, first pod height, number of branches, number of pods in soybean cultivars.

Cultivars	Plant height (cm)		First pod height (cm)		Number of branches		Number of pods	
	2016	2017	2016	2017	2016	2017	2016	2017
Arısoy	86.93a	80.37a	14.71ac	14.93a	2.57d	3.6ab	61.63c	50.8bc
Atalişi	87.62a	79.1ab	15.33a	13.97a	3.17c	3.97a	66.33ac	63.2a
Blaze	76.07bc	72.47bc	14.54ac	13.97a	3.74ab	2.8cd	65.86ac	43.13d
Bravo	72.03c	78.67ab	13.75cd	12.63bc	4.29a	2.47d	76.5a	43.87d
İlksoy	79.67ac	77.47ab	12.67de	12.27c	2.47d	3.37ac	63.57bc	52.43bc
Lider	71c	69.5c	12.09e	11.77c	3.83a	3.43ac	73.22ab	44.53cd
Mersoy	86.33a	81.93a	14.13bc	13.87ab	2.73cd	3.17bd	61.33c	62.6a
Nova	84.5ab	69.47c	14.44ac	12.67bc	3.22bc	3.23ad	60.33c	46.4bd
Traksoy	82.6ab	73.27bc	15.17ab	14.67a	2.47d	3.53ac	60c	41.6d
Mean	80.75	75.8	14.09	13.42	3.16	3.29	65.42	49.74
LSD	9.84	6.93	1.19	1.26	0.57	0.77	11.09	6.67

Table 4. Correlation coefficients of 12 traits studied in nine soybean cultivars.

	FPH	*NB*	*NP*	*Chla*	*Chlb*	*Tchl*	*Car*	*TSW*	*SY*	*OC*	*OY*
PH	0.5**	-0.366**	0.262	0.128	0.281*	0.203	0.103	0.104	0.133	-0.297*	-0.003
FPH	1	-0.046	0.136	0.469**	0.306*	0.468**	0.485**	0.120	0.247	-0.202	0.210
NB		1	0.311*	0.028	0.088	0.057	0.117	0.104	0.364**	0.013	0.487**
NP			1	0.052	0.325*	0.176	0.216	0.594**	0.800**	-0.587**	0.669**
Chla				1	0.389**	0.889**	0.941**	0.066	0.274*	-0.283*	0.184
Chlb					1	0.760**	0.538**	0.522**	0.498**	-0.411**	0.394**
Tchl						1	0.917**	0.294*	0.406**	-0.392**	0.286*
Car							1	0.238	0.476**	-0.390**	0.377**
TSW								1	0.756**	-0.781**	0.465**
SY									1	-0.685**	0.868**
OC										1	-0.238

PH: Plant height (cm); FPH: First pod height (cm); NB: Number of branches; NP: Number of pods; TSW: Thousand-seed weight (g); Chla: Chlorophyll a; Chlb: Chlorophyll b; TChl: Total chlorophyll; Carotenoids (Car); SY: Seed yield (kg h-1); OC: Crude oil rate (%); OY: Oil yield (kg h-1)

Chlorophyll a, b, total chlorophyll and carotenoid contents were significantly different ($p<0.01$) among the cultivars investigated. The highest chlorophyll a, b, total chlorophyll and carotenoid contents in both years were obtained from Arısoy cultivar (Table 5). Chlorophyll a content had significantly positive correlation with the first pod height (r=0.469**), chlorophyll b (r=0.389**), total chlorophyll (r=0.889**), carotenoid (r=0,941**) and seed yield (r=0.274*), while chlorophyll a had a significant negative correlation with oil yield (r=-0.283*). Chlorophyll a, b, total chlorophyll and carotenoid contents were significantly different among the cultivars, however, they had positive correlations between each other. The highest correlation coefficients were recorded between carotenoid chlorophyll a (r= 0.941**) and also between carotenoid and total chlorophyll content (r = 0.917**). The chlorophyll b content had a significant correlation with seed yield (r=0.498**), which was higher than the correlation with chlorophyll a. The chlorophyll a, b and total chlorophyll contents differed between the years, and all were lower in 2017 when the precipitation was lower, and the temperature was higher compared to 2016. Carotenoids had also significant positive correlation with the first pod height (r=0.485**), seed yield (r=0,476**) and oil yield (r=0,377**) and negative significant correlation was obtained between carotenoid and oil content (r=*0.390**). Leaf chlorophyll pigment contents were different between the years and cultivars. Warm and dry weather conditions of the second year caused a decrease in the leaf chlorophyll pigment contents. Similar to our results, several other researchers have also indicated that he stress factors adversely affect the chlorophyll content, and a lower chlorophyll content was reported under stress conditions (Ferri *et al*., 2004; Fritschi & Ray, 2007; Steele *et al*., 2008; Makbul *et al*., 2011). Positive correlation of chlorophyll pigment contents with seed yield and yield components can be attributed to the decrease in chlorophyll content under stress conditions and consequently to a decrease in yield. Unlike chlorophyll content, carotenoid content reached higher values in 2017. Carotenoids are not only the plant pigments, but are also important antioxidants that play a significant role in oxidative stress tolerance of plants (Kalefetoğlu & Ekmekci, 2005). The findings of Keleş & Öncel (2002) and Armağan & Mehmet (2017) indicated increased carotenoid contents under different stress conditions. In this study, the increase in carotenoid content due to stress may be related to the responses of soybean cultivars to the stress conditions. Higher content of photosynthetic pigments, i.e., chlorophyll a, chlorophyll b, and carotenoids, had a positive effect on seed yield due to the increasing rate of photosynthesis. Similar to our findings, many researchers reported that photosynthetic pigments have significant correlations with each other and the increase in pigment content had a positive effect on photosynthesis rate (Sadak 2019; Mokhtassi-Bidgoli *et al.*, 2007; Jan *et al.*, 2013; Nouriyani *et al.*, 2012).

Thousand-seed weight, seed yield, crude oil ratio and crude oil yield were significantly between the soybean cultivars. Blaze and Lider cultivars reached the highest thousand-seed weight in 2016, and Lider variety reached the highest thousand-seed weight in 2017. The lowest thousand-seed weight in both years was obtained from

Ilksoy cultivar. The thousand-seed weight had significant positive correlations with the number of pods (r=0.594**), chlorophyll b (r=0.522**), total chlorophyll (r=0.294*), seed yield (r=0.756**) and oil yield (r=0.465**), while significant negative correlation was recorded between crude oil content (r= -0.781**). The crude oil ratio was higher in 2017 and a significant negative correlation (r=-0.685**) was obtained between crude oil content and yield. The yield had significant positive correlations with the number of pods (r=0.800**) and thousand-seed weight (r=0.756**) which showed a significant negative correlation with crude oil content. The strength of correlation for the number of side branch with seed yield (r=0.364**) was lower than that of crude oil yield (r=0.487**) (Table 4). The result is related to the positive but statistically insignificant effect of side branch number on crude oil content.

The highest seed yield in the first year was obtained from Bravo (2497.39 kg ha^{-1}) and Lider (2496.24 kg ha^{-1}) cultivars, while the highest seed yield in the second year was recorded from Atakişi (2133.89 kg ha^{-1}) and Arısoy (2103.56 kg ha^{-1}) cultivars (Table 6). The changes in crude oil ratio between cultivars and years were statistically significant and higher crude oil ratio was obtained in warm and dry season. The highest crude oil ratio (23.63%) in the first year of the experiment was obtained from Traksoy cultivar.

High rainfall in the first year of the experiment had a positive effect on plant characteristics; thus, seed yield and crude oil yield were higher in 2016 than the second year. The increase in the number of pods and the thousand-seed weight led to an increase in seed yield and a decrease in the crude oil ratio. Since oil yield depends on seed yield, the factors increasing the seed yield had also a positive effect on oil yield. The differences in seed yield performances of cultivars under arid conditions and the effects of changes in climate on seed yield should be taken into consideration in determining the suitable variety for a region. Atakişi and Arısoy cultivars were identified as more suitable in both rainy and warmer dry periods and higher yields were obtained compared to the average yield of other cultivars. High chlorophyll content of Atakişi variety in both years had a positive effect on the yield, therefore, the yield variation between the years was lower. The seed yields of soybean grown as the main and second crop in different environmental conditions were reported between 800 and 4500 kg ha^{-1} (Grichar, 2007; Tayyar & Gül, 2007; Seadh & Abido, 2013; Bakal *et al*., 2016; Öztürk, 2019). The highest crude oil ratio (26.60%) in the second year was obtained from İlksoy cultivar. The soybean variety with the lowest crude oil content in 2017 had a higher crude oil content in 2016. In addition the crude oil content of Ilksoy variety was higher than the crude oil content of Bravo, Mersoy, Nova and Traksoy varieties which had the highest crude oil content in 2016. The results revealed that the increase in temperature with sufficient irrigation had a significant positive effect on crude oil contents of soybean cultivars. Seed yield and crude oil yield are important parameters to meet the crude oil demand and provide highly economic processing of seed in the industry. Bravo variety had the highest oil yield (589.66 kg ha^{-1}) in the first year of the study, while in second year Atakişi (528.54kg ha^{-1}) and Arısoy (523.24 kg ha^{-1}) cultivars had a higher crude oil yield.

Table 5. Thousand-seed weight, chlorophyll a, b and total chlorophyll contents of soybean cultivars.

Cultivars	Chlorophyll a		Chlorophyll b		Total Chlorophyll		Carotenoid	
	2016	2017	2016	2017	2016	2017	2016	2017
Arısoy	3.03a	2.93a	2.18a	2.06a	5.21a	4.99a	1.14a	1.15a
Atalişi	2.69b	2.64b	1.72b	1.53c	4.41b	4.16b	0.94b	0.97b
Blaze	2.65bc	2.62b	1.7b	1.54c	4.36b	4.15b	0.92bc	1.01c
Bravo	2.57d	2.44c	1.58cd	1.44d	4.15bc	3.88c	0.86c	1.01c
İlksoy	2.4e	2.09de	1.38e	1.29e	3.78cd	3.37d	0.66d	0.79f
Lider	2.22f	2.15de	2.08a	1.71b	4.3b	3.86c	0.68d	0.96e
Mersoy	1.75h	1.69f	1.77b	1.77b	3.52d	3.47d	0.54e	0.67h
Nova	2.11g	2.04e	1.5d	1.26e	3.61d	3.3d	0.7d	0.76g
Traksoy	2.6cd	2.55b	1.67bc	1.55c	4.27b	4.1b	0.92bc	1.02b
Mean	2.45	2.35	1.73	1.57	4.18	3.92	0.82	0.93
LSD	0.08	0.11	0.11	0.08	0.41	0.17	0.008	0.075

Table 6. Result of variance analysis and means of seed yield, crude oil ratio and crude oil yield.

Cultivars	Thousand-seed weight (g)		Seed yield (kg h^{-1})		Crude oil ratio (%)		Oil yield (kg h^{-1})	
	2016	2017	2016	2017	2016	2017	2016	2017
Arısoy	128.2bc	114.17b	2154.63d	2103.56a	22.47ab	24.87bc	484.46de	523.24a
Atalişi	126.99c	110.56bc	2218.97cd	2133.89a	22.69ab	24.76bc	503.76ce	528.45a
Blaze	143.85a	114.13b	2404.09ab	1809.14bc	21.45b	25.59ab	515.44bd	462.55bc
Bravo	126.18c	107.06c	2497.39a	1765.44bc	23.61a	24.69bc	589.66a	435.75c
İlksoy	123.97c	106.01c	2084.57de	1736.8c	22.72ab	26.60a	473.55de	461.94bc
Lider	142.79a	126.84a	2496.24a	1812.69bc	22.45ab	24.25c	560.4ab	439.58bc
Mersoy	135.52ab	115.45b	2313.33bc	1863.53b	23.5a	25.48ab	543.64ac	474.8bc
Nova	124.45c	107.12c	1969.84e	1878.32b	23.2a	25.53ab	456.81e	479.58b
Traksoy	125.42c	113.08b	2088.93de	1850.79bc	23.63a	25.31bc	493.81de	468.45bc
Mean	130.82	112.71	2247.56	1883.8	22.86	25.23	513.5	475.93
LSD	8.36	5.83	143.6	123.9	1.43	1.22	49.49	40.64

Conclusion

Soybean yields obtained in this study can be considered satisfactory compared to the yields reported from soybean cultivated areas in the world. The yields are lower compared to the soybean yields reported in Adana and Mersin provinces where the most intensive soybean cultivation takes place in Turkey. The results indicated that soybean cultivation in the semi-arid region must be carried out under irrigated conditions to meet the crude oil and animal feed demand. The decreases in chlorophyll a, chlorophyll b and carotenoids contents of cultivars under stress conditions adversely affected the photosynthesis and, consequently, caused a significant decrease in yield. However, the results of two year study revealed that yield losses were lower in cultivars with high photosynthetic pigment contents.

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(Received for publication 10 July 2019)