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Combining Ability, Heritability and Heterosis Estimates in Faba Bean (*Vicia faba* L.) under Two Water Regimes

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IN ORDER to study drought tolerance among faba bean genotypes, five cultivars of faba bean, Giza 843 (P1), Giza 3 (P2), Maser 3 (P3), Sakha 3 (P4) and Sakha 1 (P5) were used for carrying out half diallel mating design in 2014/2015 winter season to study combining ability, heritability and heterosis for growth, leaf anatomical, photosynthetic pigments and yield characteristics under stress condition. Parents and their crosses were evaluated in a yield trial, in 2015/2016 winter season under two water regimes which were well-watered (100% from ETo) and severe water stress (60% from ETo) at the experimental farm of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt. Results were showed highly significant of general (GCA) and specific (SCA) combining ability for all measured characters under two water deficit, indicating that GCA and SCA were important in the inheritance of these traits. The results of studied characters were indicated that the majority of crosses exhibited highly significant heterosis estimates for mid parents (MP). Heritability in narrow sense was low to moderate and ranged from 1.68 to 58.6%. These results showed that these characters were greatly influenced by dominance and environmental condition. All preceding parents were studied to be good general combiners for its distinct characters. Also, results recommend that three of parental genotypes; P5, P2 and P4 were good combiners to improve the most characters and could be used as genetic resources for drought tolerance. The cross P1xP5 showed good SCA effects and significant values of heterosis for most characters under two water regimes. Also, the three crosses, P3xP4 (for growth characters), P1xP2 for (anatomical characters) and P2xP5 (for photosynthetic pigments characters and seed yield/plant) exhibited desirable SCA effects and significant heterosis values under two water regimes. These crosses might be used in faba bean breeding programs to produce pure lines have high yielding ability and drought tolerance.

Keywords : Water stress, Faba bean, Combining ability, Heterosis, Heritability, Leaf anatomy.

Inroduction

Each crop has different responses to environmental stresses such as drought. Major challenge for plant breeders is the improving of genetic resistance and different mechanisms for drought tolerance (Chaves et al., 2003). Faba bean is an important grain legume for protein (ranges from 20 to 40%) security of demographically expanding and climatically changing world (Bishnoi et al., 2012). It has important value in improving the soil fertility by fixing nitrogen (Bishnoi et al., 2018a). Faba bean is a diploid (2n=2x=12) autogamous annual plant with partial allogamy ranging from 20 to 80%. The degree of out crossing depends on pollinator insect population and environmental conditions. Heterozygosity increase yield due to outcrossing has been well supported in faba bean. In view of, heterosis, resulting from the combined action and interaction of interallelic and allelic genes improved yield and obtained by hybrid combinations (Bishnoi et al., 2012 and Ibrahim, 2010).

Faba bean production isn't enough to feed the ever-growing world population. Numerous biotic and abiotic factors were caused reducing of yield (Abdelmula et al., 1999 and Abdelmula et al., 2012). Especially, Water deficit is the most important environmental and detrimental factor that decrease growth and productivity of plants

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with an average yields loss for most strategically crops by more than 50% (Bray, 1997). Faba bean cultivation is unsuitable particularly in arid and semi-arid regions because this crop is not sufficiently water deficit tolerant (Loss et al., 1997). Also, bean plants exhibit a great quantity of Agro-physiological and biochemical modifications occur for drought tolerance (Jaleel et al., 2008; Farooq et al., 2008; Khan et al., 2010; Cortés et al., 2012; Ammar et al., 2014; Khazaei, 2014; Mohamed, 2015; Siddiqui et al., 2015; Abid et al., 2017; Ammar et al., 2017 and Ping et al., 2018).

In addition, inhibitive effect of water deficit supply on anatomical structure (lamina thickness and size of main vascular bundle) of tomato leaves. Moreover, the decrease in lamina thickness under drought stress was mostly due to the decrement induced in both palisade and spongy tissues (Selim & El-Nady, 2011).

Combining ability had an important role in crop improvement. It could determine the magnitude and nature of genetic effects which controlling yield traits, in addition preparation the promising parents to use in the creation of genetic variability for eventual use in varieties improvement. Diallel analysis was an excellent means of obtaining information about differential parents and parental combinations in terms of general combining ability (GCA) and specific combining ability (SCA) (Griffing, 1956). The correspondence of better combining genotypes is conclusive for successful exploitation of heterosis. Also, evaluation of parental genotypes is essential for enveloping better hybrids. The estimates of combining ability effects supply important penetrative in selection of parents that could give rise to better hybrids upon crossing. Besides, the knowledge about the nature and magnitude of gene effects is importance for developing high yielding ability of varieties in faba bean (Beyene, 2016 and Ibrahim, 2010). Present investigation was carried out to understand; the type of gene action governing growth, anatomical, photosynthetic pigments and yield characters under water stress and detection good parents and hybrids, which could be exploited for future breeding programs.

Materials and Methods

This study was carried out during the two growing seasons of 2014/2015 and 2015/2016 at the experimental farm of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt. Five different local faba bean (*Vicia. faba* L.) cultivars, Giza 843 (P1), Giza 3 (P2), Maser 3 (P3), Sakha 3 (P4) and Sakha 1 (P5), were used in this study representing a wide range of variability in their agronomic traits. In the winter season of 2014/2015, the seeds of all parents were sown on 30th October and crossed in a half diallel mating design to produce 10 F1 hybrids. In 2015/2016 season, the five parental genotypes and their crosses were sown under two water regimes.

Meteorological data and irrigation treatments

Relative humidity (RH), evaporation (E0), maximum and minimum temperature and solar radiation were recorded daily from sowing until harvest by a weather station located approximately 1km from the experimental field. The temperature average about 16.8°C and the relative humidity average about 56% during winter 2015/2016 season were used for calculating reference crop evapotranspiration (ETo) according to Penman-Monteith equation (Allen et al., 1998). Irrigation water was supplied by surface to provide the two water regimes which were well-watered (100% from ETo) and severe water stress (60% from ETo), which represented 2800 and 1680m^3 of water/faddan, respectively. Each experimental plot consisted of three ridges of 3m length and 60cm width. Hills were spaced 20cm with two plants per hill. All other agricultural practices were followed as recommended. A split-plot arrangement in randomized complete block design (RCBD) with three replications was used. Main plots were devoted to water treatments. Sub-plots were devoted to 15 genotypes (five parents and ten crosses).

Measurements

Data were recorded on ten competitive plants (five guarded hills) from each plot in each replications for the following four main group characters:

1- Growth characters

Number of leaves/plant, number of branches/plant, shoot fresh weight/plant (g), shoot dry weight/plant (g), root fresh weight/plant (g) and root dry weight/plant (g).

2- Anatomical characters

Number of xylem vessels, thickness of mysophyll (µm), thickness of midrib (µm), thickness of palisade tisuue (µm), thickness of spongy tisuue (µm) and thickness of vascular bundle (µm) were determined.

The third visible leaf from the plant apex of five parental genotypes and their crosses at flowering stage was used to study the anatomy of the leaves. Killing and fixation of leaf sample in 70% F.A.A. solution, dehydration and clearing with ethyl-alcohol and xylene, infiltration and embedding in pure parafine wax (M. P. 56-58^{o}C) were carried out as described by Nassar & El-Sahhar (1998). Using a rotary microtome, sections of leaf (15µ) were obtained and stained with safranin and light green. Sections, in such cases were microscopically examined and analyzed with the image processing program. Anatomical examination and measurements were achieved using a Leica light Research Microscope model PN: DM 500/13613210 supplied with a digital camera.

3- Photosynthetic pigments

Chlorophyll a, b and carotenoids were determined according to Fadeel (1962).

4- Seed yield per plant (g)

Some measurements about seed yield per plant (g) were determined

Statistical analysis

Testing the significance of genotypic differences: Data collected was initially subjected to analyses of variance (ANOVA) according to Steel & Torrie (1980) using the COSTAT system for Window, version 6.311 (cohort software, Berkeley, CA, USA). Griffing (1956) model; method II, analysis was used to estimate general combining ability (GCA) and specific combining ability (SCA). The analyses were performed using the Diallel 98 program software computer package (Ukai, 2002). Heritability in narrow sense h (n.s) was calculated according to Mather & Jinks (1982).

Heterosis:

Heterosis was estimated according to mid – parent.

$$\% \text{ Heterosis (MP)} = \frac{F_1 - m.P}{m.\overline{p}} x100$$

A test of significance for the F1 crosses mean from the mid parent values was calculated according to Bhatt (1971).

Results and Discussion

Mean performance of genotypes

The mean performances for studied characters of faba bean genotypes under two water regimes are given in Tables 1, 2, 3 and 4. Mean comparison were performed by least significant differences (LSD)

Growth characters

The data in Table 1 revealed to significant decreasing effects on growth performance of studied genotypes by water deficit. This decreasing was resulted from several inhibited changes of cell metabolisms (Farooq et al., 2012). The parent Giza 843 (P1) exhibited the highest values for number of leaves/plant and shoot fresh weight/plant (g) (70 and 115.7, respectively) under drought stress. The parent Giza 3 (P2) recorded high values for shoot dry weight/plant (g) and root fresh weight/plant (g) (19.7 and 19.7) under drought stress. For branches number/plant; the parental genotype Sakha1 (P5) recorded the highest value (3.3) under severe water stress. Concerning root dry weight/plant (g), the parental Maser 3 (P3) gave the highest value (3.8) under water stress.

With respect to the F1 crosses, results indicated that the cross P1xP2 recorded high values forroot fresh weight/plant (g) and root dry weight/plant (g) (27.3 and 6.3, respectively) under severe drought stress. The cross P1xP4 exhibited the highest values for shoot fresh weight/plant (g) and shoot dry weight/plant (g) (203.3 and 35.7, respectively) under severe water stress. For number of leaves/plant the cross P1xP5 recorded the highest value (68) under severe water stress. Concerning number of branches/plant, the cross P2xP4 gave the highest value (4.7) under severe water stress. These results suggest that the above mentioned parents and F1 crosses may be used for improving drought tolerance in faba bean breeding programs.

Anatomical characters

Data in Table 2 and Plates 1, 2 illustrated the values of number of xylem vessels, thickness of mesophyll (µm), thickness of midrib (µm), thickness of palisade tissue (µm), thickness of spongy tissue (µm) and thickness of vascular bundle (µm). Faba bean parent P5 (Sakha 1) gave the maximum values in most of anatomical characters under two water regimes, followed by P2 (Giza 3).

TABLE 1. Mean performance of faba bean genotypes for growth characters under water deficit.

Characters / Genotypes	No. of leaves/plant			No. of branches/plant			Shoot fresh weight/plant (g)		
	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean
P_1	84.3	70.0	77.2	5.0	2.0	3.5	260.0	115.7	187.9
P_2	94.3	33.7	64.0	5.7	2.7	4.2	310.0	88.3	199.2
P_3	70.3	50.3	60.3	7.0	2.7	4.9	258.3	98.3	178.3
P_4	66.7	53.3	60.0	5.0	2.7	3.9	110.0	92.7	101.4
P_5	51.0	38.7	44.9	2.0	3.3	2.7	100.0	95.0	97.5
P_1xP_2	91.7	66.7	79.2	5.0	3.0	4.0	260.0	188.3	224.2
P_1xP_3	80.7	62.3	71.5	4.3	3.7	4.0	188.3	130.0	159.2
P_1xP_4	116.0	37.3	76.7	6.3	3.7	5.0	216.7	203.3	210.0
P_1xP_5	95.7	68.0	81.9	6.0	3.3	4.7	355.0	165.0	260.0
P_2xP_3	81.7	43.3	62.5	4.0	2.7	3.4	250.0	195.0	222.5
P_2xP_4	93.3	45.0	69.2	6.0	4.7	5.4	210.0	155.0	182.5
P_2xP_5	86.7	63.3	75.0	5.0	3.0	4.0	140.0	100.0	120.0
P_3xP_4	109.7	55.0	82.4	7.3	4.0	5.7	393.3	140.0	266.7
P_3xP_5	145.0	45.0	95.0	9.0	3.0	6.0	450.0	64.7	257.4
P_4xP_5	112.7	54.3	83.5	5.7	2.3	4.0	330.0	61.7	195.9
Mean	92.0	52.4	72.2	5.6	3.1	4.3	255.4	126.2	190.8
$LSD_{0.05}$	Genot.	Water	G*W	Genot.	Water	G*W	Genot.	Water	G*W
	2.35	3.8	3.3	0.57	0.63	0.8	11.8	11.2	16.7

Characters / Genotypes	Shoot dry weight (g)			Root fresh weight (g)			Root dry weight (g)		
	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean
P_1	43.7	18.7	31.2	45.7	14.3	30.0	14.3	3.3	8.8
P_2	43.0	19.7	31.4	56.0	19.7	37.9	16.7	3.3	10.0
P_3	39.7	19.0	29.4	27.3	17.3	22.3	8.0	3.8	5.9
P_4	23.3	14.7	19.0	20.7	11.7	16.2	6.3	3.0	4.7
P_5	19.7	13.0	16.4	18.0	9.0	13.5	5.0	2.5	3.8
P_1xP_2	33.7	27.7	30.7	37.7	27.3	32.5	11.7	6.3	9.0
P_1xP_3	37.3	30.3	33.8	35.0	21.7	28.4	13.0	4.3	8.7
P_1xP_4	42.7	35.7	39.2	34.3	19.0	26.7	15.3	3.0	9.2
P_1xP_5	62.3	34.3	48.3	27.7	16.7	22.2	11.0	3.5	7.3
P_2xP_3	37.3	28.3	32.8	27.7	20.7	24.2	9.0	4.3	6.7
P_2xP_4	37.0	27.7	32.4	33.3	19.0	26.2	11.0	5.2	8.1
P_2xP_5	52.7	32.3	42.5	28.3	23.0	25.7	8.7	4.0	6.4
P_3xP_4	65.0	26.3	45.7	42.0	17.0	29.5	10.0	3.8	6.9
P_3xP_5	62.7	31.7	47.2	65.0	17.7	41.4	24.3	4.0	14.2
P_4xP_5	56.3	22.0	39.2	30.0	13.0	21.5	13.3	2.8	8.1
Mean	43.8	25.4	34.6	35.2	17.8	26.5	11.8	3.8	7.8
$LSD_{0.05}$	Genot.	Water	G*W	Genot.	Water	G*W	Genot.	Water	G*W
	2.8	3.2	4.0	2.4	0.25	3.4	0.63	0.41	0.9

TABLE 2. Mean performance of faba bean genotypes for anatomical characters under water deficit.

Characters / Genotypes	No. of xylem vessels			Thickness of mesophyll µm			Thickness of midrib µm		
	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean
P_1	11.0	13.7	12.4	299.0	271.0	285.0	607.3	581.0	594.2
P_2	12.3	16.0	14.2	470.0	392.7	431.4	668.7	751.0	709.9
P_3	12.3	14.3	12.3	413.7	428.7	421.2	709.7	628.7	669.2
P_4	15.3	10.7	13.0	528.0	357.0	442.5	784.7	785.7	785.2
P_5	21.0	15.7	18.4	607.0	521.0	564.0	941.7	900.3	921.0
P_1xP_2	14.7	19.0	16.9	928.3	500.0	714.2	535.3	850.7	693.0
P_1xP_3	11.0	17.3	14.2	406.0	428.7	417.4	577.3	786.0	681.7
P_1xP_4	11.0	16.3	13.7	413.0	485.7	449.4	585.7	878.7	732.2
P_1xP_5	14.0	16.0	15.0	334.0	414.0	374.0	750.0	906.7	828.4
P_2xP_3	11.7	17.0	14.4	614.0	506.7	567.5	771.0	715.0	743.0
P_2xP_4	11.3	15.0	13.2	777.7	435.7	606.7	928.7	750.3	839.5
P_2xP_5	10.0	13.0	11.5	500.3	435.0	467.7	678.0	763.3	720.7
P_3xP_4	15.0	15.0	15.0	443.0	357.0	400.0	642.3	628.7	635.5
P_3xP_5	20.0	15.0	17.5	350.7	428.7	389.7	743.0	642.3	692.7
P_4xP_5	15.0	10.0	12.5	585.3	392.7	489.0	891.0	714.0	802.5
Mean	14.1	14.4	14.3	549.7	452.3	501.0	721.0	752.2	736.6
$LSD_{0.05}$	Genot.	Water	G*W	Genot.	Water	G*W	Genot.	Water	G*W
	1.2	0.7	1.7	0.73	0.44	1.0	1.7	2.99	2.9

Characters / Genotypes	Thickness of palisade tisuue µm			Thickness of spongy tisuue µm			Thickness of vascular bundle µm		
	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean
P_1	121.7	112.0	116.9	178.7	160.0	169.4	213.7	200.0	206.9
P_2	142.7	114.7	128.7	328.7	278.7	303.7	235.7	214.0	224.9
P_3	185.3	143.0	164.2	228.7	285.7	257.2	178.3	206.7	192.5
P_4	164.3	121.7	143.0	363.7	235.7	299.7	285.7	185.7	235.7
P_5	200.3	192.7	196.5	407.3	328.7	368.0	263.7	221.3	242.5
P_1xP_2	156.3	142.7	149.5	771.3	356.7	564.0	320.7	285.7	303.2
P_1xP_3	142.7	135.7	139.2	263.7	292.7	278.2	192.3	250.0	221.2
P_1xP_4	142.3	164.3	153.3	271.3	321.7	296.5	213.7	285.7	249.7
P_1xP_5	92.7	164.7	128.7	242.3	250.3	246.3	235.3	271.3	253.3
P_2xP_3	250.7	165.0	207.9	363.7	342.7	353.2	200.3	200.3	200.3
P_2xP_4	356.7	128.3	242.5	421.3	306.7	364.0	306.7	214.3	260.5
P_2xP_5	171.3	142.7	157.0	328.7	292.7	310.7	192.7	214.0	203.4
P_3xP_4	156.3	128.7	142.5	285.7	228.7	257.2	150.3	212.7	181.5
P_3xP_5	128.3	128.7	128.5	221.3	300.3	260.8	213.7	235.7	224.7
P_4xP_5	214.0	142.7	178.4	371.0	250.7	310.9	271.3	221.3	246.3
Mean	175.0	141.8	158.4	336.5	282.1	309.3	231.6	227.9	229.8
$LSD_{0.05}$	Genot.	Water	G*W	Genot.	Water	G*W	Genot.	Water	G*W
	0.7	0.85	1.0	0.64	0.19	0.9	0.7	0.63	1.0

TABLE 3. Mean performance of faba bean genotypes for photosynthetic pigments characters under water deficit.

Characters / Genotypes	Chlorophyll a			Chlorophyll b			Carotenoids		
	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean	100% ETo	60% ETo	Mean
P_1	2.1	2.6	2.4	3.6	4.5	4.1	1.5	2.3	1.9
P_2	1.6	2.6	2.1	2.5	4.5	3.5	1.4	1.4	1.4
P_3	4.2	4.4	4.3	3.3	7.8	5.6	1.3	1.5	1.4
P_4	2.2	2.1	2.2	3.8	3.7	3.8	1.6	2.5	2.1
P_5	3.3	3.1	3.2	6.2	5.4	5.8	1.7	1.5	1.6
P_1xP_2	1.4	2.2	1.8	2.4	3.7	3.1	1.6	1.8	1.7
P_1xP_3	1.8	3.4	2.6	3.1	5.8	4.5	2.2	1.4	1.8
P_1xP_4	2.5	1.3	1.9	4.3	2.2	3.3	0.8	1.8	1.3
P_1xP_5	3.6	3.1	3.4	6.3	5.3	5.8	0.2	1.5	0.9
P_2xP_3	3.2	1.8	2.5	4.4	3.2	3.8	0.4	1.4	0.9
P_2xP_4	3.8	1.8	2.8	6.7	3.4	5.1	1.3	2.8	2.1
P_2xP_5	3.4	1.8	2.6	4.5	3.6	4.1	1.8	2.3	2.1
P_3xP_4	1.8	1.9	1.9	2.8	3.4	3.1	0.8	1.4	1.1
P_3xP_5	2.4	3.2	2.8	4.1	5.6	4.9	1.6	1.7	1.7
P_4xP_5	3.2	2.2	2.7	5.6	3.5	4.6	1.5	1.9	1.7
Mean	2.7	2.5	2.6	4.2	4.4	4.3	1.3	1.8	1.6
$LSD_{0.05}$	Genot.	Water	G*W	Genot.	Water	G*W	Genot.	Water	G*W
	0.08	0.03	0.1	0.06	0.04	0.1	0.08	0.04	0.1

TABLE 4. Mean performance of faba bean genotypes forseed yield/plant (g) under water deficit.

Characters / Genotypes	Seed yield/plant (g)		
	100% ETo	60% ETo	Mean
P_1	100.0	50.3	75.2
P_2	71.7	50.0	60.9
P_3	110.0	34.0	72.0
P_4	105.3	52.3	78.8
P_5	40.0	31.7	35.9
P_1xP_2	63.3	42.0	52.7
P_1xP_3	82.7	51.3	67.0
P_1xP_4	130.0	70.0	100.0
P_1xP_5	180.0	76.7	128.4
P_2xP_3	100.0	27.0	63.5
P_2xP_4	125.0	26.3	75.7
P_2xP_5	122.3	52.7	87.5
P_3xP_4	100.0	42.7	71.4
P_3xP_5	135.0	51.0	93.0
P_4xP_5	93.3	49.0	71.2
Mean	103.9	47.1	75.5
$LSD_{0.05}$	Genot.	Water	G*W
	3.4	2.3	4.9

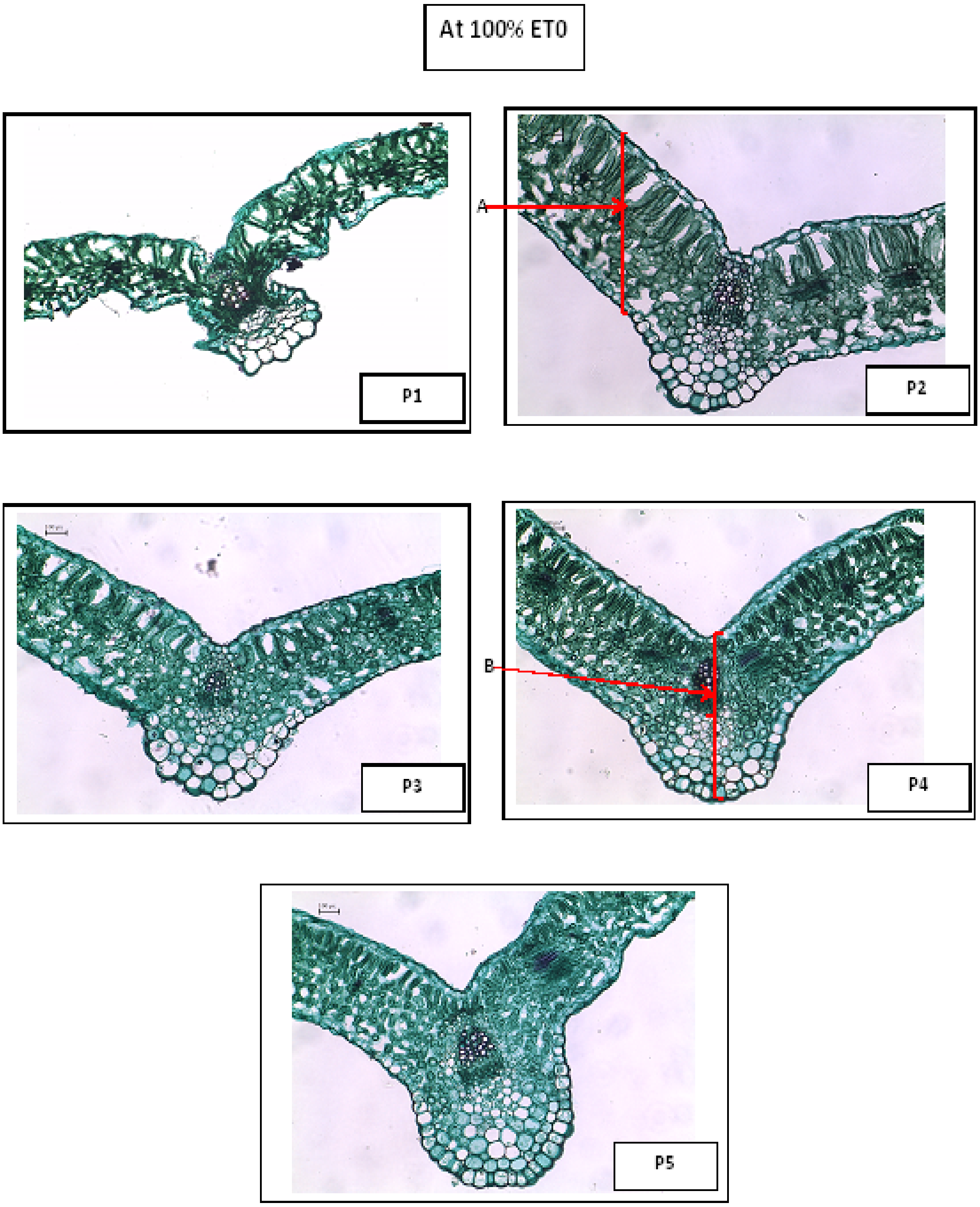

Plate 1. Cross sections of leaves of faba bean cultivars, Giza 843 (P_1), Giza 3 (P_2), Maser 3 (P_3), Sakha 3 (P_4) and Sakah 1 (P_5) at 100% ETo during 2014/2015 and 2015/2016 seasons. A: Mesophyll thickness (µm), B: Midrib thickness (µm) (Bar= 100µm).

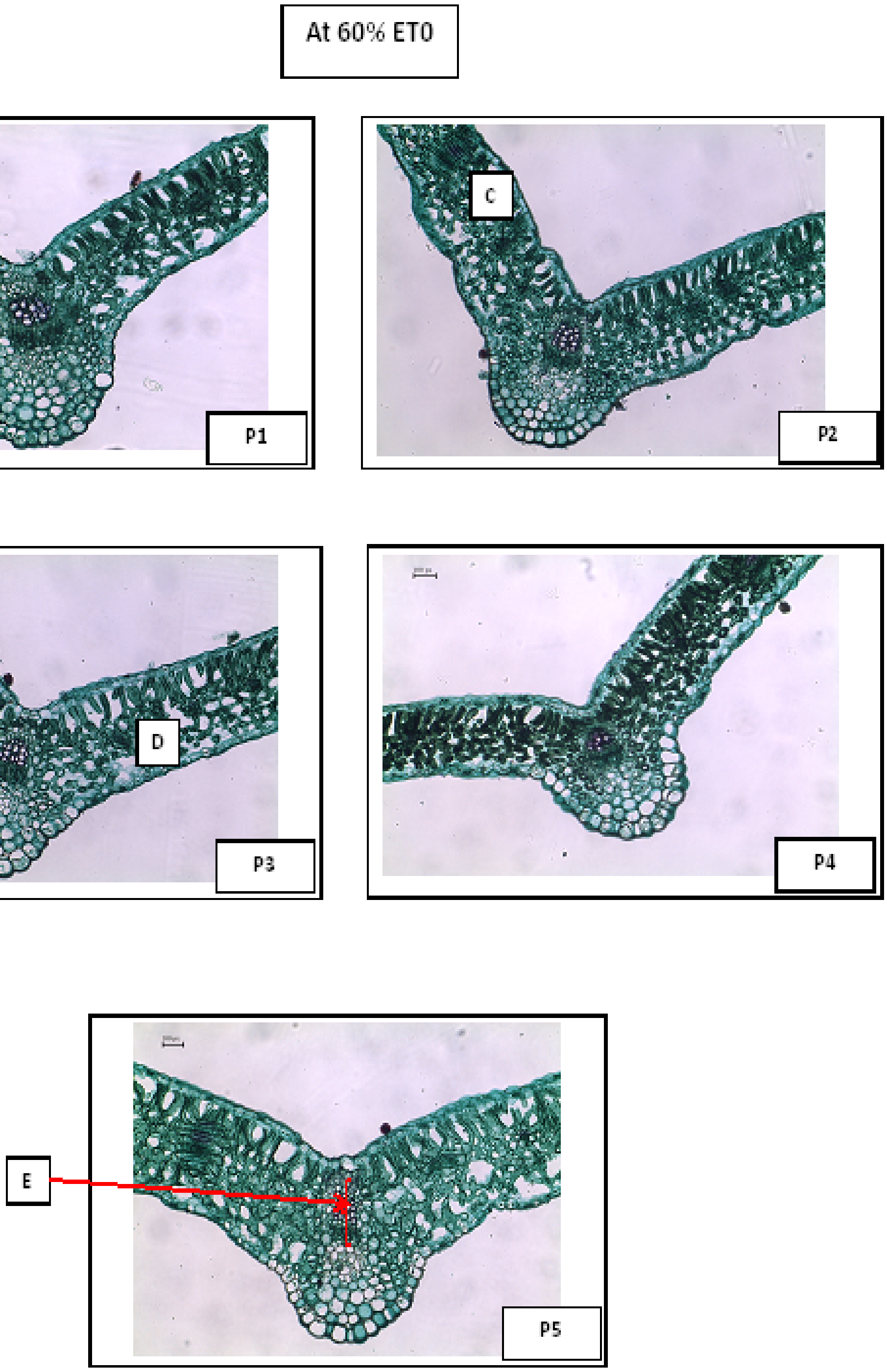

Plate 2. Cross sections of leaves of faba bean cultivars, Giza 843 (P_1), Giza 3 (P_2), Maser 3 (P_3), Sakha 3 (P_4) and Sakah 1 (P_5) at 60% ETo during 2014/2015 and 2015/2016 seasons. C: Palisade tissue (µm), D: Spongy tissue, E: Vascular bundle thickness (µm) (Bar= 100µm).

Data of crosses were presented in Table 2 and Plates 3, 4, 5 and 6. Crosses (P_1xP_2, P_2xP_5, P_1xP_5 and P_2xP_3) appeared more tolerant under water stress, although, water deficit reduced all anatomical characters except number of xylem vessels which is the one of important character related positively with drought. Which is noteworthy that parent P_5 and cross P_3xP_5 the best genotypes in number of xylem vessels. These results were agreement with Boghdady (2009) and Petrov et al. (2012).

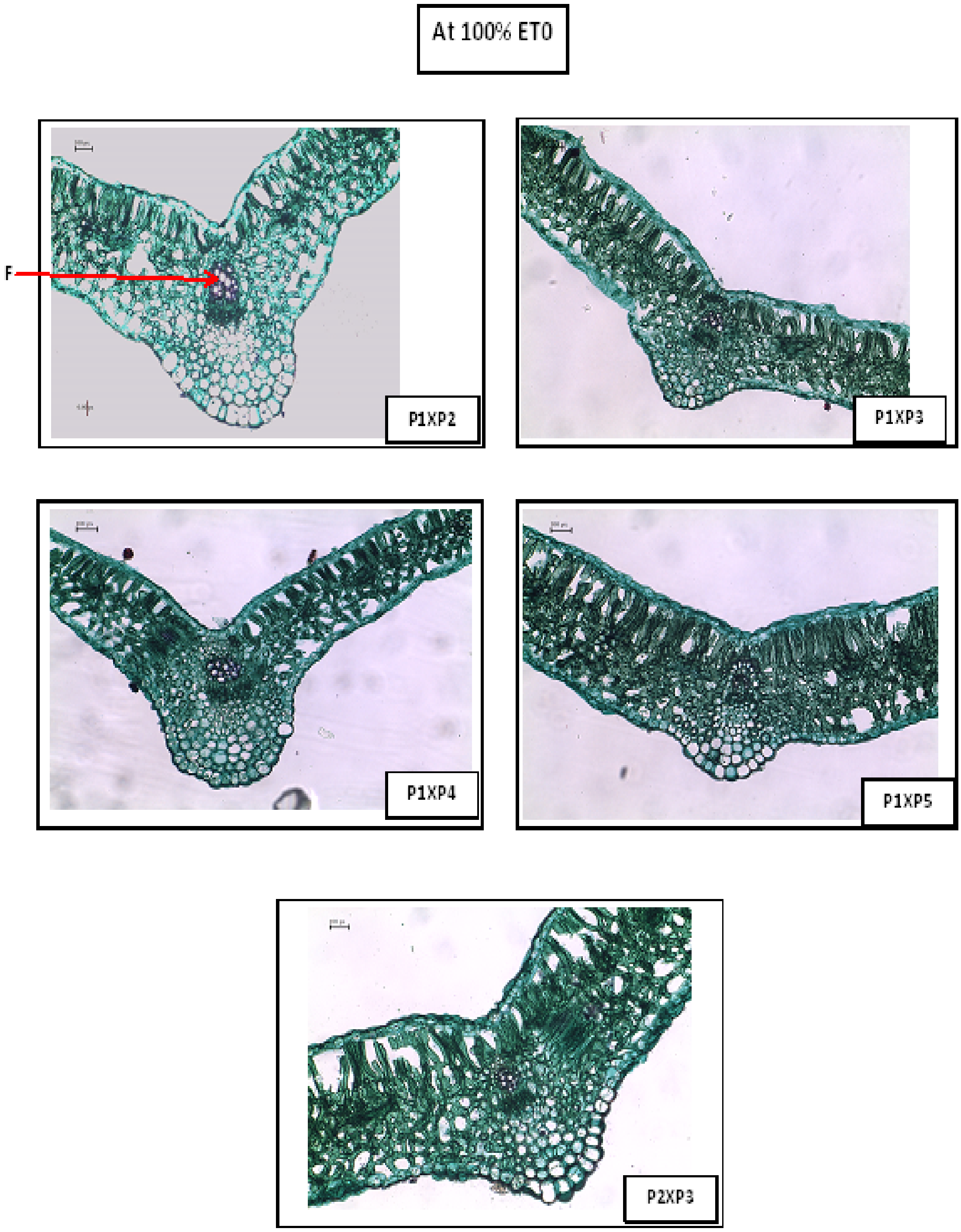

Plate 3. Cross sections of leaves of faba bean cultivars. Giza 843 (P_1), Giza 3 (P_2), Maser 3 (P_3), Sakha 3 (P_4) and Sakah 1 (P_5) and their crosses (10 F_1 hybrids) at 100% ETo during 2014/2015 and 2015/2016 seasons. F: Xylem vessles (Bar= 100µm).

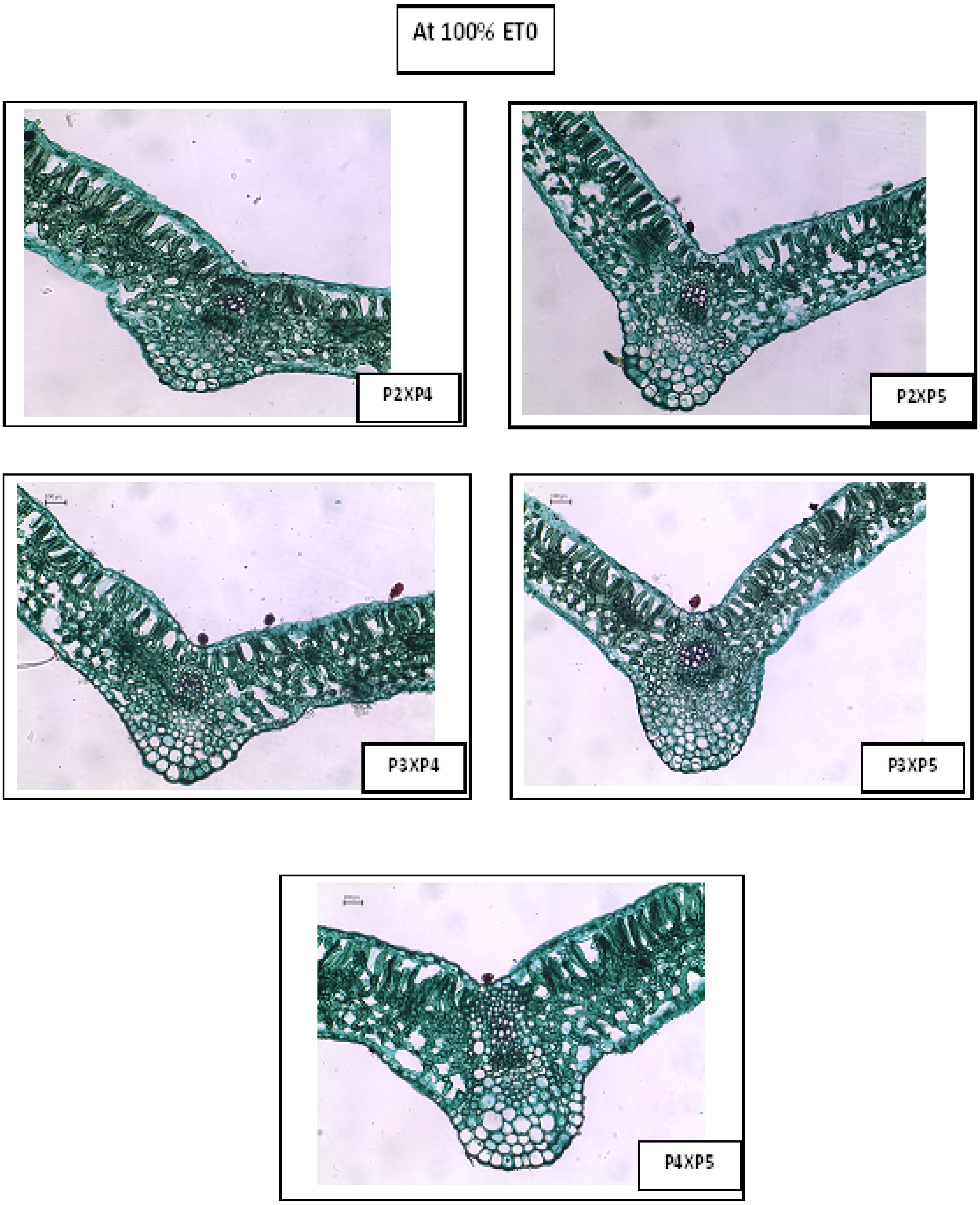

Plate 4. Cross sections of leaves of faba bean cultivars. Giza 843 (P_1), Giza 3 (P_2), Maser 3 (P_3), Sakha 3 (P_4) and Sakah 1 (P_5) and their crosses (10 F_1 hybrids) at 100% ETo during 2014/2015 and 2015/2016 seasons. (Bar= 100µm).

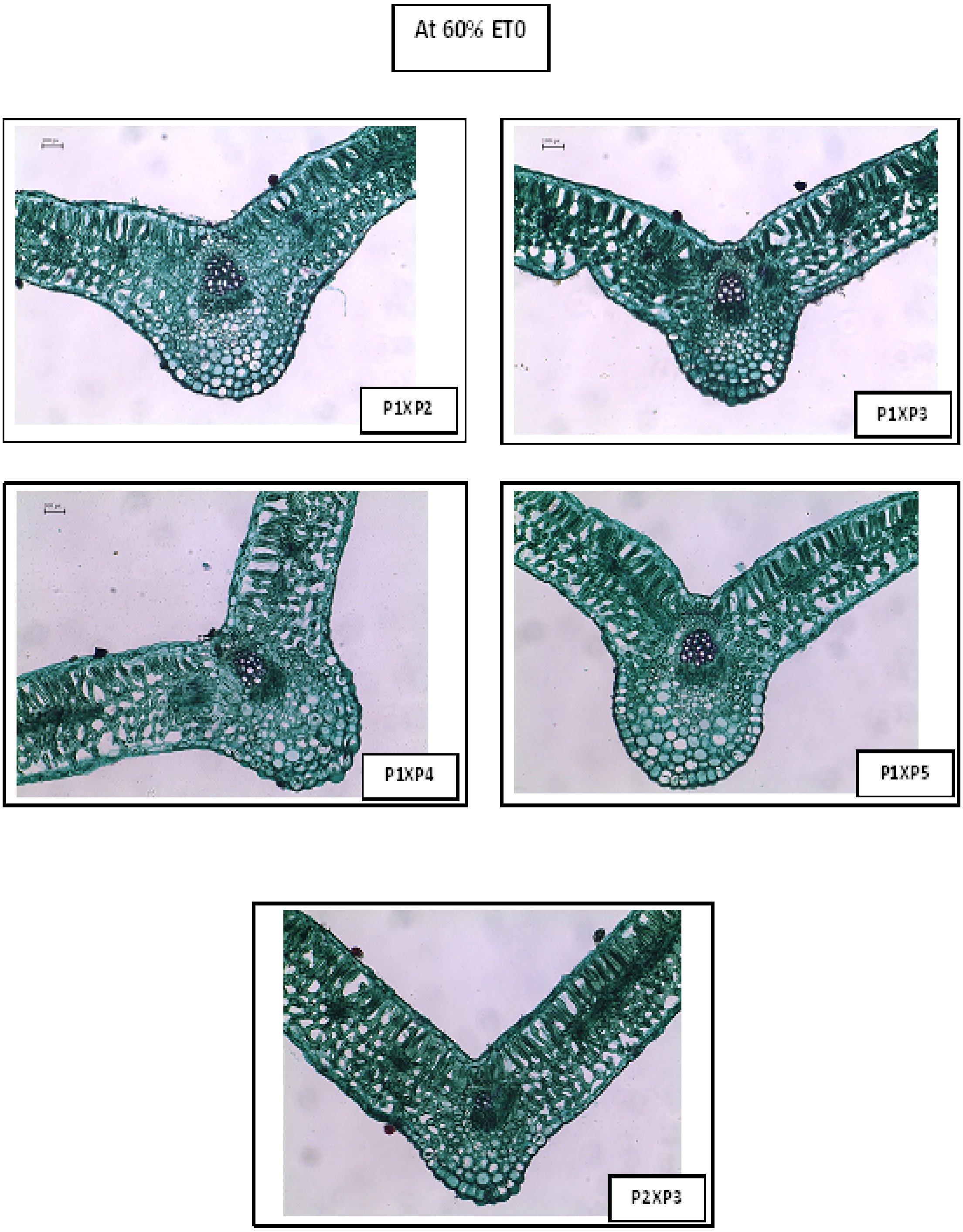

Plate 5. Cross sections of leaves of faba bean cultivars. Giza 843 (P_1), Giza 3 (P_2), Maser 3 (P_3), Sakha 3 (P_4) and Sakah 1 (P_5) and their crosses (10 F_1 hybrids) at 60% ETo during 2014/2015 and 2015/2016 seasons. (Bar= 100µm).

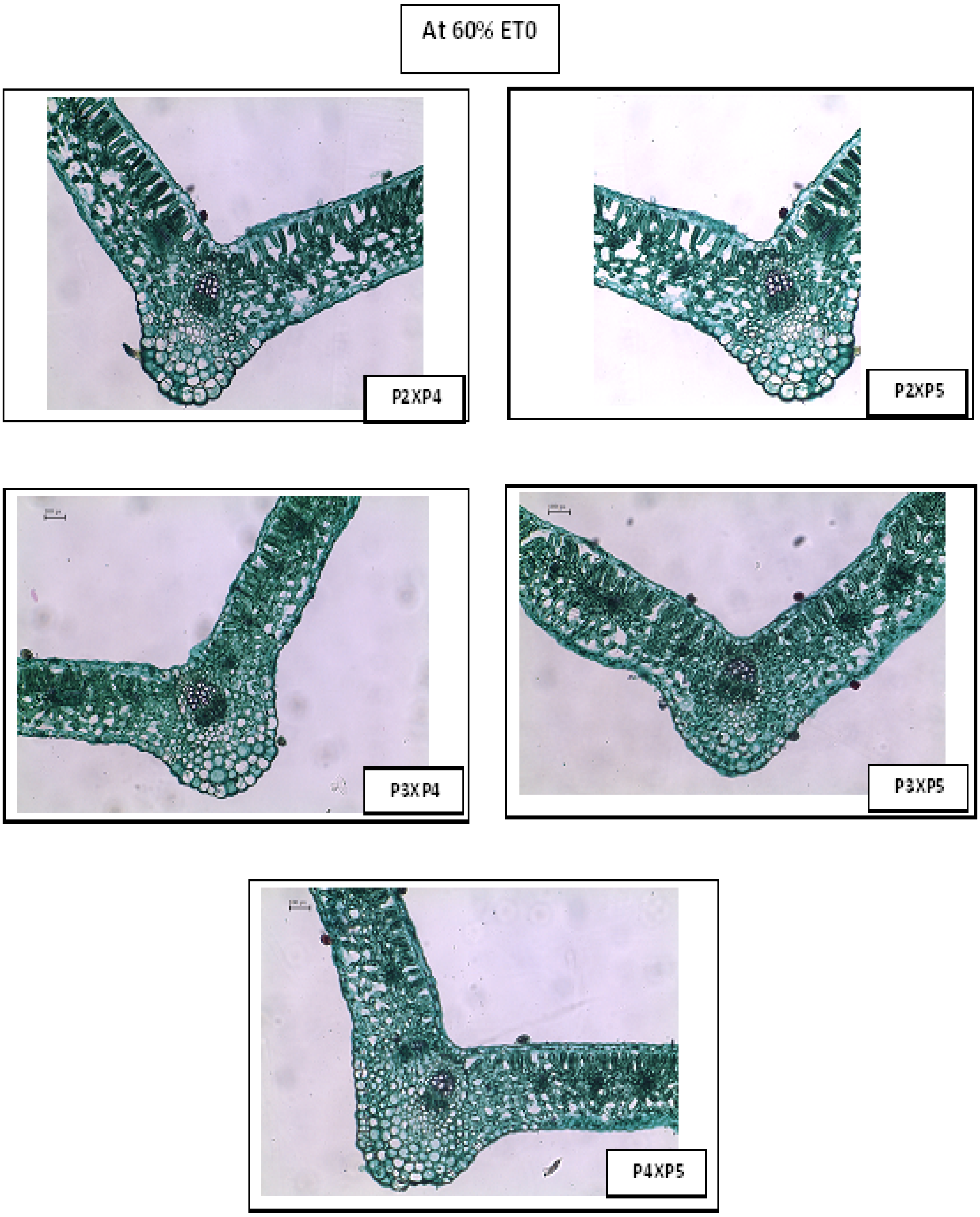

Plate 6. Cross sections of leaves of faba bean cultivars. Giza 843 (P_1), Giza 3 (P_2), Maser 3 (P_3), Sakha 3 (P_4) and Sakah 1 (P_5) and their crosses (10 F_1 hybrids) at 60% ETo during 2014/2015 and 2015/2016 seasons. (Bar= 100µm).

The results obtained by Forouzan et al. (2013) revealed the positive and significant correlations between grain yield with leaf thickness and xylem width under drought stress conditions. Due to this fact, the leaves thickness and xylem width considered key structural features of leaves that manage the ability of a safflower genotype to tolerate water deficit stress. Therefore these traits could be used as criteria to select tolerant genotype that were more tolerant to drought.

Photosynthetic pigments

Data in Table 3 showed the values of chlorophyll a, b and carotenoids. The two parental genotypes Maser 3 (P_3) and Sakha 1 (P_5) exhibited the highest values of chlorophyll a, b (4.4, 7.8 for P_3 and 3.1, 5.4 for P_5, respectively) under severe water stress. The two parental genotypes Giza 843 (P_1) and Sakha 3 (P_4) gave the highest values ofcarotenoids (2.3 and 2.5, respectively) under severe water stress. With respect to the F_1 crosses, results indicated that P_1xP_3 and P_3xP_5 crosses recorded the highest of chlorophyll a, b (3.4, 5.8 for P_1xP_3 and 3.2, 5.6 for P_3xP_5, respectively) under severe water stress. Concerning carotenoids, (P_2xP_4) and (P_2xP_5) crosses exhibited the highest values (2.8 and 2.3, respectively) under water stress. The activity of a chlorophyll degrading enzymes like chlorophyllase enzyme caused decreasing of chlorophyll content (Reddy & Vora, 1986). These findings may suggest that these parents and F_1 crosses had high ability to drought resistance.

Seed yield per plant

Data of seed yield was presented in Table 4. Two parental genotypes; Sakha 3 (P_4) and Giza 843 (P_1) gave the highest values of seed yield/ plant (52.3 and 50.3, respectively) under severe water stress.

Comparison of performance of F_1 crosses to the corresponding highest parents revealed that two crosses had the highest values of seed yield / plant namely P_1xP_5 (76.7) and P_1xP_4 (70.0) under severe water stress. These results suggest that the above mentioned parents and F_1 crosses may be of value for improving seed yield of faba bean. These superior genotypes can be exploits in breeding programs for improving drought tolerance.

General combining ability and heritability estimates

General combining ability (GCA) variances are in general attributed to the additive and additive x additive gene effects, while specific combining ability (SCA) variances are attributed to non-additive gene effects which involve dominance and epistasis components of genetic variation. GCA and SCA mean squares were highly significant for all measured traits under two water conditions or regimes (Tables 5, 6 and 7), indicating that both of them were playing an important role in the inheritance of these traits. Variances of GCA were larger than those for SCA. σ^2 GCA/σ^2 SCA ratio was more than unity for number of xylem vessels, thickness of mysophyll (µm), thickness of midrib (µm), thickness of palisade tissue (µm) and chlorophyll b under two water regimes (100% ETo and 60% ETo). Also, leaves number/plant, shoot fresh weight/plant (g), root fresh weight/plant (g), root dry weight/ plant (g), seed yield/plant (g), chlorophyll a and carotenoids under 60% ETo only, thickness of spongy tissue (µm) and thickness of vascular bundle (µm) under 100% ETo only. The results indicated that GCA variance was more important than SCA ones in the genetics of these traits, explaining the additive gene action in genetic makeup of traits. These finding revealed that these traits could be developed and improved through phenotypic selection. On the other hand, the variance due to SCA was more pronounced for branches number/plant and shoot dry weight/ plant (g) under two water regimes, furthermore, leaves number/plant, shoot fresh weight/plant (g), root fresh weight/plant (g), root dry weight/ plant (g), seed yield/plant (g), chlorophyll a and carotenoids under 100% ETo, while thickness of vascular bundle (mm) under 60% ETo. From these results, it could be concluded that the controlling of the inheritance processes for the measurements characters depend on additive and dominance effects of genetic components, although there were varied contribution of each component according to measurement and water regime (Ahmad & Hager, 2010; Haridy & Amein, 2011; Farag & Afiah, 2012; Hazem et al., 2013; Ashrei et al., 2014; Zeinab & Helal, 2014; Bishnoi, 2016; Ismail, 2016; Abdalla et al., 2017 and Bishnoi et al., 2018a).

The results in Table 5 showed that the values of heritability in narrow sense were ranged from 5.92 to 58.6% for growth characters and ranged from 21.3 to 57.5 % for anatomical characters (Table 6) under two water regimes. Respecting to photosynthetic pigments characters (Table 7), the values of heritability in narrow sense were ranged from 1.68 to 57.5% under two water regimes. With respect to seed yield per plant were 7.5 and 45.8 under two water regimes. These results indicated that these characters are greatly influenced by dominance and environmental conditions. Similar findings were obtained by Abdelmula et al. (1999), Ibrahim (2010), El-Bramawy & Osman (2012), Peyman (2015), Abd El-Zaher (2016) and Ismail (2016).

TABLE 5. Combining ability variance and narrow sense heritability in faba bean genotypes for growth characters under water deficit.

Source of variation	df	No. of leaves/plant		No. of branches/ plant		Shoot fresh weight/ plant (g)		Shoot dry weight/ plant (g)		Root fresh weight/ plant (g)		Root dry weight/ plant (g)	
		100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
Genotypes	14	1555.6**	417.6 **	7.70**	1.4**	30451.8 **	6458.6**	565.2**	153.5 **	480.7**	64.2**	67.8**	2.9**
GCA	4	43**	512.3 **	5.64**	0.3	11056.3 **	6559.3**	102.4**	37.3**	285.2**	123.7 **	18.5**	3.5**
SCA	10	2160.7**	379.7 **	8.52**	1.9**	38209.9 **	6418.3**	750.3**	200**	559.0**	40.4**	87.5**	2.6**
Error	28	3.03	5.2	0.29	0.2	197.46	9.8	5.6	2.5	5.2	3.4	0.4	0.2
σ^2 GCA/ σ^2 SCA		0.02	1.35	0.66	0.17	0.29	1.02	0.14	0.19	0.51	3.06	0.21	1.33
h(n.s)		5.92	29.1	17.7	9.14	13.47	40.62	14.6	8.63	9.2	58.6	5.7	41.2

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE 6. Combining ability variance and narrow sense heritability in faba bean genotypes for anatomical characters under water deficit.

Source of variation	df	No. of xylem vessels		Thickness of mesophyll (µm)		Thickness of midrib (µm)		Thickness of palisade tisuue (µm)		Thickness of spongy tisuue (µm)		Thickness of vascular bundle (µm)	
		100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
Genotypes	14	33.9**	19.9**	113224.5**	31841.5**	48396.4 **	31848.9**	12167.3 **	1447.2**	58904.7**	7727.8**	7193.6**	2950.9**
GCA	4	50.1**	20.8**	126517.9**	38277.3**	101086.9**	36765.0**	21742.2**	1817.2**	75144.8**	7263.3**	11209.8**	2523.3**
SCA	10	27.4**	19.6**	107907.1**	29267.2**	27320.2 **	29882.5**	8337.4 **	1299.2**	52408.7**	7913.6**	5587.2**	3121.9**
Error	28	4.27	1.1	0.5	0.28	3.91	0.33	0.5	0.32	0.3	0.27	0.4	0.37
σ^2 GCA/ σ^2 SCA		1.82	1.06	1.17	1.31	3.7	1.23	2.61	1.40	1.43	0.92	2.0	0.81
h(n.s)		34.7	33.9	34.5	38.0	56.1	38.1	57.5	21.3	40.1	24.4	43.2	39.0

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE 7. Combining ability variance and narrow sense heritability in faba bean genotypes for seed yield/plant (g), chlorophyll a, b and carotenoids under water deficit.

Source of variation	df	Seed yield/plant (g)		Chlorophyll a		Chlorophyll b		Carotenoids	
		100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
Genotypes	4	3351.4**	600.7**	2.4**	2.0**	5.9**	5.8**	0.9**	0.61**
GCA	4	804.9 **	705.7**	2.2**	4.0**	9.4**	11.9**	0.1**	0.86**
SCA	10	4370.0**	558.7**	2.5**	1.2**	4.5**	3.4**	1.2**	0.51**
Error	28	16.0	1.99	0.01	0.01	0.01	0.01	0.01	0.01
σ^2 GCA/ σ^2 SCA		0.18	1.26	0.89	3.30	2.1	3.53	0.05	1.70
h(n.s)		7.5	45.8	23.3	56.8	41.6	57.5	1.68	41.9

*,** Significant at 0.05 and 0.01 probability levels, respectively.

The general combining ability effects of parents are presented in Tables 8, 9 and 10. Result revealed that the parent P5 (Sakha 1) showed positive and highly significant effects for thickness of mysophyll (µm), thickness of midrib (µm), thickness of vascular bundle (µm), chlorophyll a and chlorophyll b under two water regimes, moreover it showed highly significant positive for shoot dry weight/plant (g), number of xylem vessels and carotenoids under 100% ETo only and for thickness of palisade tissue (µm), thickness of spongy tissue (µm) and seed yield/plant (g) under 60% ETo only. P_2 (Giza 3) revealed good combiner for root fresh weight/ plant (g), root dry weight/plant (g), thickness of mysophyll (µm) and thickness of spongy tissue (µm) under two water regimes, furthermore it showed highly significant positive for shoot fresh weight/plant (g), number of xylem vessels and thickness of midrib (µm) under 60% ETo only and for thickness of palisade tissue (µm) and thickness of vascular bundle (µm) under 100% ETo only. P_4 (Sakha 3) demonstrated highly significant positive effects for seed yield/plant (g), thickness of midrib (µm) and branches number/plant under two water regimes; highly significant positive for leaves number/plant, thickness of palisade tissue (µm), thickness of spongy tissue (µm), thickness of vascular bundle (µm) and chlorophyll b under 100% ETo only and for carotenoids under 60% ETo only. P_1 (Giza 843) showed highly positive significant effects for root fresh weight/plant (g) and seed yield/plant (g) under two water regimes, moreover it showed highly significant positive for leaves number/plant, shoot fresh weight/plant (g), shoot dry weight/plant (g), number of xylem vessels, thickness of midrib (µm), thickness of vascular bundle (µm) and carotenoids under 60% ETo while root dry weight/plant (g) under 100% ETo. P_3 (Maser 3) exhibited highly significant positive effects for chlorophyll a under two water regimes, furthermore it showed highly significant positive for seed yield/plant (g)and growth characters except for root dry weight/plant (g) under 100% ETo only and for chlorophyll b and thickness of spongy tissue (µm) under 60% ETo only. Preceding parents are studied to be good general combiners for their particular traits. Also results recommend that three parental genotypes; P_5 (Sakha 1), P_2 (Giza 3) and P_4 (Sakha 3) are a good combiners for improving most characters. These results were in harmony by Alghamdi (2007), Alghamdi (2009), Farag & Afiah (2012), Zeinab & Helal (2014), Bishnoi (2016), Abdalla et al. (2017) and Bishnoi et al. (2018b).

Specific combining ability estimates

Estimates of SCA effects for F_1 crosses were presented in Tables 11, 12 and 13. Three crosses (P_3xP_4, P_3xP_5 and P_1xP_5) had highly positive significant SCA effects for most growth characters under two water regimes, while three crosses (P_1xP_2, P_1xP_3 and P_2xP_3) appeared highly positive significant SCA effects for most anatomical characters under two water regimes. Regarding photosynthetic pigments characters and seed yield/plant (g), crosses P_1xP_5, $P_2x P_4$ and P_2xP_5 exhibited highly significant and positive SCA effects under two water regimes for most of these characters. The superiority crosses which demonstrated desirable SCA effects showed high heterosis values for characters. These superiority hybrids could be used in breeding programs to produce high yielding ability and drought tolerance pure lines of faba bean. These results are in line with those reported by Alghamdi (2009), Ibrhim (2010), Farag & Afiah (2012) and Abdalla et al. (2017), who found the crosses included high and low combiners had best SCA effects.

TABLE 8. General combining ability effects for growth charactersunder water deficit.

Genotypes \ Characters	No. of leaves/ plant		No. of branches/ plant		Shoot fresh weight (g)		Shoot dry weight (g)		Root fresh weight (g)		Root dry weight (g)	
	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
P_1	0.11	8.5**	-0.24*	-0.14	1.0	23**	0.1	1.8**	2.1**	0.9**	1.2**	0.13
P_2	-1.4**	-4.1**	-0.3**	0.00	-7.5**	8.3**	-2.3**	0.4	3.9**	3.2**	0.4**	0.51**
P_3	0.83*	-1.2**	0.76**	0.00	38.0**	-4.4**	2.7**	0.3	1.8**	0.7	0.2	0.18
P_4	1.88**	-2.3**	0.29**	0.19*	-23**	-1.7**	-2.1**	-1.6**	-4.4**	-2.2**	-1.2**	-0.30**
P_5	-1.4**	-0.9*	-0.5**	-0.05	-8.2**	-25**	1.5**	-0.9**	-3.5**	-2.6**	-0.5**	-0.51**
S.E.(gi-gj)	0.34	0.45	0.106	0.086	2.74	0.611	0.46	0.309	0.44	0.36	0.2	0.1

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE 9. General combining ability effects foranatomical characters under water deficit.

Genotypes \ Characters	No. of xylem vessels		Thickness of mesophyll (µm)		Thickness of midrib (µm)		Thickness of palisade tisuue (µm)		Thickness of spongy tisuue (µm)		Thickness of vascular bundle (µm)	
	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
P_1	-1.7**	1.4**	-58.3**	-26.5**	-94.7**	10.2**	-39.0**	-2.8**	-16.1**	-21.6**	-0.1	17.9**
P_2	-0.90*	0.5*	97.0**	39.8**	-10.8**	9.8**	40.8**	-6.1**	97.2**	23.3**	14.6**	-3.6**
P_3	0.52	-0.5*	-90.7**	-19.3**	-24.7**	-69.1**	-0.2	-1.0**	-61.0**	6.1**	-39.5**	-7.9**
P_4	-0.24	-1.2**	-3.3**	-45.0**	41.6**	4.3**	21.1**	-6.2**	8.2**	-16.2**	17.7**	-8.9**
P_5	2.33**	-0.2	55.3**	51.1**	88.5**	44.9**	-22.7**	16.2**	-28.3**	8.4**	7.2**	2.5**
S.E.(gi-gj)	0.4	0.21	0.14	0.103	0.386	0.112	0.138	0.111	0.113	0.102	0.116	0.119

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE 10. General combining ability effects for seed yield/plant (g), chlorophyll a, b and carotenoids under water deficit.

Characters / Genotypes	Seed yield/plant (g)		Chlorophyll a		Chlorophyll b		Carotenoids	
	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
P_1	4.6**	8.3**	-0.4**	0.02	-0.3**	-0.04**	-0.01	0.03*
P_2	-9.9**	-5.0**	-0.2**	-0.32**	-0.3**	-0.47**	0.00	0.03
P_3	2.0**	-6.1**	0.2**	0.59**	-0.6**	1.05**	-0.04**	-0.28**
P_4	5.1**	1.4**	-0.1**	-0.51**	0.2**	-0.90**	-0.04**	0.28**
P_5	-1.8*	1.4**	0.4**	0.22**	1.1**	0.36**	0.09**	-0.06**
S.E.(gi-gj)	0.78	0.275	0.013	0.013	0.013	0.01	0.013	0.015

TABLE 11. Specific combining ability effects for growth characters under water deficit.

Characters / Genotypes	No. of leaves/plant		No. of branches/ plant		Shoot fresh weight(g)		Shoot dry weight (g)		Root fresh weight (g)		Root dry weight (g)	
	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
P_1xP_2	0.98	9.8**	-0.03	0.03	11.0	30.9**	-7.9**	0.02	-3.6**	5.4	-1.8**	**1.9****
P_1xP_3	-12.3**	2.5*	-1.8**	0.7**	-106**	-14.8**	-9.3**	2.8**	-4.2**	2.2	-0.3	**0.2**
P_1xP_4	22.03 **	-21.3**	0.73**	0.5*	-16.6*	55.9**	0.9	10.1**	1.4	2.5	3.5**	**-0.7****
P_1xP_5	4.98**	8.0**	1.21**	0.41	106.7 **	41.0**	16.9**	8.0**	-6.2**	0.6	-1.5**	**0.1**
P_2xP_3	-9.73**	-3.8**	-2.0**	-0.44*	-35.9**	65.0**	-6.9**	2.2**	-13.3**	-1.0	-3.4**	**-0.2**
P_2xP_4	0.89	-1.0	0.44	1.4**	-14.7*	22.2**	-2.4*	3.5**	-1.5	0.2	0.0	**1.1****
P_2xP_5	-2.49**	16.0**	0.25	-0.1	-99.7**	-9.3**	9.6**	7.4**	-7.3**	4.6	-3.0**	**0.2**
P_3xP_4	14.98 **	6.1**	0.73**	0.7**	123.2 **	19.9**	20.6**	2.3**	9.3**	0.7	-0.8*	**0.1**
P_3xP_5	53.60 **	-5.3**	3.21**	-0.1	164.8 **	-32.0**	14.6**	6.8**	31.4**	1.8	12.8**	**0.5***
P_4xP_5	20.22 **	5.2**	0.35	-0.9**	106.0 **	-37.7**	13.2**	-0.9	2.6*	0.05	3.3**	**-0.2**
S.E.(sij - sji)	1.316	1.73	0.41	0.33	10.62	2.37	1.79	1.196	1.7	1.4	0.46	**0.36**

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE 12. Specific combining ability effects for anatomical characters under water deficit.

Characters / Genotypes	No. of xylem vessels		Thickness of mesophyll (µm)		Thickness of midrib (µm)		Thickness of palisade tisuue (µm)		Thickness of spongy tisuue (µm)		Thickness of vascular bundle (µm)	
	100% ETo	**60% ETo**	**100% ETo**	**60% ETo**	**100% ETo**	**60% ETo**	**100% ETo**	**60% ETo**	**100% ETo**	**60% ETo**	**100% ETo**	**60% ETo**
P_1xP_2	3.2**	2.7**	340.0 **	34.4**	-80.2**	78.6**	-20.5**	9.8**	353.7**	72.8**	74.5**	**43.5****
P_1xP_3	-1.9	2.0**	13.0**	22.2**	-24.3**	92.8**	6.8**	-2.4**	4.3**	26.0**	0.2	**12.1****
P_1xP_4	-1.2	1.8**	-75.1**	104.9**	-82.2**	112**	-14.8**	31.5**	-57.3**	77.4**	-35.6**	**48.7****
P_1xP_5	-0.7	0.4	-182.4 **	-62.9**	35.2**	99.5**	-20.7**	9.5**	-49.7**	-18.5**	-3.5**	**23.0****
$P_2x P_3$	3.9**	-3.4**	72.4**	34.0**	85.5**	22.2**	35.1**	30.3**	-9.0**	31.1**	-6.4**	**-16.1****
$P_2x P_4$	-1.6	1.3*	134.3 **	-11.3**	176.9**	-15.9**	119.7**	-1.1**	-20.7**	17.5**	42.8**	**-1.1****
$P_2x P_5$	-5.5**	-1.8**	- 201.6 **	221.2 **	-120.7**	-43.5**	-21.8**	-9.2**	-76.7**	-21.2**	-60.8**	**-12.8****
$P_3x P_4$	0.6	2.3**	-12.7**	-30.9**	-95.6**	-58.7**	-39.6**	-5.9**	2.0**	-43.3**	-59.5**	**1.6****
$P_3x P_5$	3.0**	1.2*	-163.6 **	-55.3**	-41.8**	-85.6**	-23.8**	-28.3**	-25.8**	3.7**	14.3**	**13.2****
$P_4x P_5$	-1.2	-3.0**	-16.4**	-65.6**	39.9**	-87.3**	40.5**	-9.1**	54.6**	-23.6**	14.8**	**-0.2**
S.E.(sij - sji)	1.56	0.796	0.54	0.397	1.49	0.432	0.536	0.429	0.439	0.396	0.449	**0.463**

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE 13. Specific combining ability effects for seed yield/plant (g), chlorophyll a, b and carotenoids under water deficit.

Genotypes \ Characters	Seed yield/ plant (g)		Chlorophyll a		Chlorophyll b		Carotenoids	
	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
P_1xP_2	-35.3**	-8.4**	-0.7**	-0.04	-1.2**	-0.1**	0.30**	-0.07
P_1xP_3	-27.9**	2.0**	-0.7**	0.29**	-0.2**	0.4**	0.93**	-0.17**
P_1xP_4	16.4**	13.2**	0.3**	-0.72**	0.2**	-1.2**	-0.46**	-0.34**
P_1xP_5	73.3**	19.9**	0.9**	0.35**	1.3**	0.6**	-1.19**	-0.29**
P_2xP_3	4.0*	-9.0**	0.5**	-0.98**	1.2**	-1.7**	-0.87**	-0.18**
P_2xP_4	25.9**	-17.2**	1.3**	0.13**	2.6**	0.4**	0.02	0.67**
P_2xP_5	30.2**	9.1**	0.5**	-0.59**	-0.4**	-0.6**	0.40**	0.48**
P_3xP_4	-11.0**	0.2	-1.0**	-0.67**	-1.0**	-1.1**	-0.44**	-0.41**
P_3xP_5	30.9**	8.6**	-0.9**	-0.10**	-0.6**	-0.2**	0.25**	0.25**
P_4xP_5	-13.8**	-1.0	0.1**	0.01	0.1*	-0.3**	0.14**	-0.14**
S.E.(sij - sji)	3.02	1.1	0.05	0.052	0.05	0.033	0.05	0.059

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Heterosis estimate

Tables 14, 15 and 16 were presented the heterosis values relative to mid parents (MP). For growth characters, heterosis percentages were highly significant and positive in two crosses; P_1xP_5 and $P_3x P_4$ under the two water regimes. Regarding anatomical characters, the two crosses; P_1xP_2 and P_2xP_4 exhibited highly significant and positive heterotic effects under the two water regimes. With respect to photosynthetic pigments characters and seed yield/plant (g), crosses P_2xP_5 and P_1xP_5 (except for carotenoids) exhibited highly significant and positive heterotic effects under two water regimes. Hayman (1958) showed that the difference in values of heterosis resulted from diversity among parents with non-allelic interactions. While, Alghamdi (2009) demonstrated the heterosis estimates for most characters was appeared sufficient genetic variability among parents. Moreover, F1 superiority in some traits showed different degrees of gene action in parental combinations that may effect by direct or indirect action on characters (Abdelmula et al., 1999; Omar, 2004; Darwish et al., 2005; Attia & Salem, 2006; El-Hady et al., 2006; Ahmad & Hager, 2010; Link et al., 2010; Ibrahim, 2015; Abd El-Zaher, 2016; Bishnoi, 2016 and Abdalla et al., 2017).

Conclusion

Three parental genotypes; P_5 (Sakha 1), P_2 (Giza 3) and P_4 (Sakha 3) were considered to be good combiners. The crosses; P_1xP_5 (for most of characters), P_3xP_4 (for growth characters), P_1xP_2 (for anatomical characters) and $P_2x P_5$ (for photosynthetic pigments characters and seed yield/plant) exhibited desirable SCA effects and significant heterosis values under two water regimes. All these parents and hybrids could be used in breeding programs for improving drought tolerance.

TABLE 14. Heterosis percentages relative to mid (MP) parent of faba bean for growth characters under water deficit.

Genotypes \ Characters	No. of leaves/plant		No. of branches/plant		Shoot fresh weight (g)		Shoot dry weight (g)		Root fresh weight (g)		Root dry weight (g)	
	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
P_1xP_2	2.55*	22.3**	-6.67	22.2*	-9.6**	45.8**	-28.7**	30.7**	-35**	37.8**	-32.9**	47.4**
P_1xP_3	4.1**	3.5	-38.5**	36.4**	-37.6**	17.7**	-11.6**	37.9**	-4.3	26.9**	14.1**	17.3**
P_1xP_4	34.9**	-65.2**	21.1**	36.4**	14.6**	48.8**	21.5**	53.3**	3.4	31.6**	32.6**	-5.6
P_1xP_5	29.3**	20.1**	41.7**	20.0*	49.3**	36.2**	49.2**	53.9**	-15.1**	30.0**	12.1**	16.7*
P_2xP_3	-0.82	3.1	-58.3**	0.0	-13.7**	52.1**	-10.7**	31.8**	-50.6**	10.5	-37.0**	17.3**
P_2xP_4	13.8**	3.3	11.1*	42.9**	0.0	41.6**	10.4**	38.0**	-15.0**	17.5**	-4.5	38.7**
P_2xP_5	16.2**	42.9**	23.3**	0.0	-46.4**	8.3**	40.5**	49.5**	-30.6**	37.7**	-25.0**	27.1**
P_3xP_4	37.5**	5.8*	18.2**	33.3**	53.2**	31.8**	51.5**	36.1**	42.9**	14.7*	28.3**	10.9
P_3xP_5	58.2**	1.1	50.0**	0.0	60.2**	-49.5**	52.7**	49.5**	65.1**	25.5**	73.3**	20.8**
P_4xP_5	47.8**	15.3**	38.2**	-28.6*	68.2**	-52.2**	61.8**	37.1**	35.6**	20.5*	57.5**	2.9

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE 15.Heterosis percentages relative to mid (MP) parent of faba bean for anatomical characters under water deficit.

Genotypes \ Characters	No. of xylem vessels		Thickness of mesophyll µm		Thickness of midrib µm		Thickness of palisade tisuue µm		Thickness of spongy tisuue µm		Thickness of vascular bundle µm	
	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
P_1xP_2	20.45*	21.9**	48.5**	25.7**	-19.2**	21.7**	-3.0**	20.6 **	62.0**	38.5**	29.9**	27.5**
P_1xP_3	-6.06	25.0**	3.4**	9.2**	-14.1**	23.0**	-7.6**	6.0**	22.8**	23.9**	-1.9**	18.7**
P_1xP_4	-19.70	25.5**	-10.6**	26.5**	-18.8**	22.2**	-0.5	28.9 **	0.1	38.5**	-16.8**	32.5**
P_1xP_5	-14.29	8.3*	-82.2**	-7.0**	-3.3**	18.3**	-42.6**	7.5**	-4.7**	2.4**	-1.4**	22.4**
P_2xP_3	30.19**	-28.8**	21.6**	18.9**	10.6**	3.5**	23.1**	21.9 **	12.6**	17.7**	-3.3**	-5.0**
P_2xP_4	-22.06*	11.1**	29.3**	13.2**	21.8**	-2.4**	48.9**	7.9**	8.5**	16.1**	15.0**	6.8**
P_2xP_5	-66.7**	-21.8**	-51.2**	39.3**	-18.8**	-8.2**	-0.1	-7.7**	-12**	-3.8**	-29.6**	-1.7**
P_3xP_4	7.78	23.3**	-6.3**	-11.0**	-16.3**	-12.5**	-11.8**	-2.8**	-3.7**	-14**	-54.3**	7.8**
P_3xP_5	16.67**	6.7	-93.3**	-12.5**	-11.1**	-19.0**	-27.8**	-30**	-25.9**	-2.3**	-3.4**	9.2**
P_4xP_5	-21.1*	-31.7**	-25.6**	-14.5**	3.1**	-18.1**	28.3**	-10.2**	6.7**	-12.6**	-1.2**	8.1**

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE 16. Heterosis percentages relative to mid (MP) parent of faba beanfor seed yield/plant (g), chlorophyll a, b and carotenoids under water deficit.

Characters / Genotypes	Seed yield/ plant (g)		Chlorophyll a		Chlorophyll b		Carotenoids	
	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo	100% ETo	60% ETo
P_1xP_2	-35.5**	-19.4**	-29.7**	-20.0**	-27.1**	-21.0**	9.9**	-3.1
P_1xP_3	-27.0**	17.9**	-76.3**	-3.2**	-10.9**	-7.0**	36.1**	-37.1**
P_1xP_4	21.0**	26.7**	14.3**	-81.2**	14.6**	-84.9**	-92.2**	-34.0**
P_1xP_5	61.1**	46.5**	25.4**	7.5**	22.3**	6.7**	-676.2**	-28.7**
P_2xP_3	9.2**	-55.6**	9.3**	-95.5**	34.2**	-91.0**	-223.0**	-5.5
P_2xP_4	29.2**	-94.3**	50.1**	-30.0**	53.3**	-19.9**	-16.0**	30.0**
P_2xP_5	54.4**	22.5**	28.4**	-56.6**	3.7**	-36.2**	14.3**	34.5**
P_3xP_4	-7.7**	-1.2	-79.5**	-70.3**	-26.4**	-68.5**	-81.8**	-42.0**
P_3xP_5	44.4**	35.6**	-56.8**	-17.3**	-15.9**	-17.3**	7.0**	11.1**
P_4xP_5	22.1**	14.3**	13.7**	-17.1**	11.2**	-28.9**	-10.1**	-6.5**

*,** Significant at 0.05 and 0.01 probability levels, respectively.

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تقديرات القدرة الائتلافية وكفاءة التوريث وقوة الهجين فى الفول البلدى تحت الإجهاد المائى

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استخدمت خمس أصناف محلية من الفول البلدى وهى جيزة 843 وجيزة 3 ومصر 3 وسخا 3 وسخا 1 فى إجراء التهجين الدائرى فى اتجاه واحد خلال موسم 2015/2014م، بهدف دراسة القدرة الائتلافية وكفاءة التوريث وقوة الهجين لصفات النمو والصفات التشريحية وصبغات البناء الضوئى والمحصول تحت ظروف الإجهاد المائى، لدراسة تحمل الجفاف لهذه التراكيب الوراثية من الفول البلدى. تم تقييم الخمسة آباء بالإضافة إلى العشرة هجن الناتجة منها فى تجربة قطع منشقة بإستخدام تصميم القطاعات كاملة العشوائية RCBD في ثلاث مكررات تحت مستويين من الإجهاد المائى هى 100% و 60% من النتح بخر فى موسم 2016/2015م بمزرعة كلية الزراعة، جامعة قناة السويس بالإسماعيلية. اظهرت النتائج أن تباين القدرة الائتلافية العامة والخاصة كان عالى المعنوية لكل الصفات المدروسة تحت معاملتى الإجهاد المائى مما يدل على أهمية القدرة الائتلافية العامة والخاصة فى وراثة هذه الصفات، وقد كانت قوة الهجين أيضا عالية المعنوية لكل الصفات المدروسة. كما اظهرت النتائج أن كفاءة التوريث من منخفضة إلى متوسطة حيث تراوحت من 1.68 إلى 58.6% حيث أوضحت هذه النتائج أن هذه الصفات متأثرة بالفعل الجينى السيادى والظروف البيئية. وأوضحت النتائج أيضا أن التراكيب الوراثية سخا 1 (P_5) وجيزة 3 (P_2) وسخا 3 (P_4) كانت لها قدرة ائتلافية جيدة فى معظم الصفات المدروسة مما يدل على امكانية استخدامها كمصادر وراثية لتربية الفول البلدى لتحمل الجفاف.

اظهر الهجين P_1xP_5 قدرة ائتلافية خاصة مرغوبة وقوة هجين عالية لمعظم الصفات المدروسة تحت معاملتى الإجهاد المائى، وايضا اظهرت الهجن الثلاثة P_3x P_4 (لصفات النمو) و P_1xP_2 (لصفات التشريح) و P_2x P_5 (للمحصول وصبغات البناء الضوئى) قدرة ائتلافية خاصة معنوية ومرغوبة وقوة هجين عالية تحت معاملتى الإجهاد المائى، مما يدل على امكانية استخدام هذه الهجن فى برامج التربية لإنتاج سلالات من الفول البلدى لها قدرة انتاجية عالية ومتحملة للجفاف.