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Response of Growth, Productivity and Quality For Some Faba Bean (*Vicia faba* L.) Cultivars to Different Irrigation Regimes

M.S.M. Abdelaal

Crop Science Departmet, Faculty of Agriculture, Menofia University, Shebin El- Kom, Egypt.

AT EXPERIMENTAL farm, faculty of agriculture, Menofia university, Egypt, a field experiment was conducted in 2021/2022 and 2022/2023 seasons to study the performance of growth, seed and water productivity as well as drought tolerance of six faba bean cultivars (Giza 3, Giza 461, Giza 716, Sakha 1, Sakha 3 and Sakha 4) to three different irrigation regimes (2, 3 and 4 irrigations). Results showed that decreasing number (no.) of irrigations from 4 to 2 caused a significant reduction in all traits studied, i.e. physiological attributes (total water content "TWC %", relative water content "RWC %" and total chlorophyll "chl."), growth characters (plant height, number of leaves/ plant, leaf area / plant as well as leaves, stem and total dry weight/ plant) and seed yield/ feddan (fed) and its components (no. of pods / plant, no. and weight of seeds / pod, 100-seed weight and seed yield/ plant) as well as the amounts of total used water/ fed, but caused an increase in seed protein % and saved water and water productivity/ fed in both seasons and their combined. Sakha 4 cv. significantly surpassed the other tested varieties in each of chl. most of growth characters, no. of pods / plant and seed yield/ plant and fed as well as water productivity/ fed. However, Giza 716 cv. was superior in TWC % and RWC %, but Sakha 1 cv. was superior in no. and weight of seeds/ pod than the other tested varieties in the two seasons and their combined. According to the combined analysis of both seasons, the interaction between the two tested factors showed generally that the highest values were obtained by Sakha 4 cv. for chl., plant height, leaf area / plant, total dry weight/ plant and no. of pods/ plant, Giza 716 cv. for RWC %, Sakha 1 cv. for no. of seeds / pod, Sakha 3 cv. for 100 seed weight and Giza 3 cv. for seed yield / fed when their plants were irrigated 4 times. In addition, Sakha 4 and Giza 716 are considered to be the most drought tolerant cultivars owing to having the lowest values of drought tolerance indices, i.e. tolerance index (TOL), relative yield reduction (RYR %) and drought susceptibility index (DSI) under drought stress conditions as compared with the other tested cultivars in this study.

Keywords: Cultivars, Drought tolerance, Faba bean, Irrigation, Productivity.

Introduction

Faba bean (*Vicia faba* L.), belongs to fabaceae family, is one of important winter pulse crops in the world and in Egypt. It had high nutritive values and protein content (about 25-26 %), and it is consider as good and cheap alternative protein compared to the expensive animal, poultry and fish productions.

Faba bean is found to be more sensitive to water deficit than the other seed legumes (Khan et al., 2010; Ammar et al., 2014). In this concern, many researchers evaluated faba bean productivity under different water deficit conditions using one or more irrigation regimes, i.e. increasing irrigation intervals (El – Metwally et al., 2007), skipping irrigation number (Ibrahim, 2011) and decreasing either water applied (Fouda et al., 2022)

Corresponding author email: moha3b3al@gmail.com
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or number of irrigations (Eid et al., 2008). Other investigators found that exposing faba bean plants to any water drought stress caused a significant damaging for plant growth (Oukaltouma et al., 2021; Abdelhaleim et al., 2022), seed yield/ plant and its components (El-Emshaty et al., 2021; Yousry et al., 2021) and seed yield/ fed (Abdel-Ghany et al., 2016; EL-Mansoury & Saleh, 2017) but led to an increase in protein % (Mekkei, 2014; Megawer et al., 2017) and water use efficiency (Abdel Samie et al., 2021; Noreldin & Abd-Alla, 2022). Moreover, Fakkar et al. (2016), Tawfik et al. (2018) and El-Gabry & Morsi (2019) found that the faba bean cultivars differed in their behaviour and seed and water productivity under various drought stress conditions.

Therefore, this study aimed to evaluate some faba bean cultivars under different water deficit conditions, i.e. 2, 3 and 4 irrigations during the growing seasons to detect most suitable and promising cultivars having high seed and water yielding ability under the drought stress conditions.

Materials and Methods

Two field experiments were conducted at the Experimental Farm, Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt (Latitude: 30° 33' 31'' and Longitude: 31° 00' 36''), during 2021/2022 and 2022/2023 seasons to study the influence of 3 different irrigation systems , i.e. 4, 3 and 2 irrigations on some physiological attributes, growth, yield and its components, seed quality and water relations of 6 faba bean (*Vicia faba* L.) cultivars, i.e. Giza 3 , Giza 461 , Giza 716 , Sakha 1 , Sakha 3 and Sakha 4. The tested cultivar seeds were obtained from the Legumes Crops Research Section, Field Crops Research Institute, ARC, Giza, Egypt. Soil samples, prior sowing dates in both seasons, were collected from 1-15 cm depth for physical and chemical analysis as described by Jackson (1973) and Chapman & Pratt (1978). Physical and chemical analysis of soil are presented in Table 1. Detailed climatic parameters for experimental area are given in Table 2.

In each experiment, strip plot design with three replications was used, where the horizontal plots (from north to south direction) were devoted to the irrigation number, and the vertical plots (from east to west direction) were allocated by the faba bean cultivars. Schedule of time and number of irrigations for the tested irrigation systems at plant growth periods are shown in Table 3.

TABLE 1. Physical and chemical analysis of soils of the experimental field in 2021/2022 and 2022/2023 seasons

Properties / Seasons	Texture class	Field capacity %	Permanent wilting point %	Available water %	pH	E.C. ds/m	O.M. %	Available nutrients (ppm) N	P	K
2021/2022	Clay loam	39.5	19.5	20.0	7.24	0.50	1.74	31.8	10.3	329.7
2022/2023	Clay loam	39.3	19.8	19.5	7.23	0.65	1.75	32.5	10.8	331.2

TABLE 2. Monthly average of temperature, relative humidity and rain fall rate during the growing periods of faba bean in 2021/2022 and 2022/2023

Month	2021/2022				2022/2023			
	Temperature (c°)		Relative humidity (%)	Rain (mm)	Temperature (c°)		Relative humidity (%)	Rain (mm)
	Max.	Min.			Max.	Min.		
November	28.76	15.98	64.16	0.96	26.85	14.52	59.70	0.04
December	20.25	10.01	70.05	0.44	24.21	12.10	64.96	0.82
January	17.58	6.33	68.90	1.04	21.46	9.07	70.42	1.38
February	20.24	7.24	68.44	0.38	20.03	7.52	68.68	0.54
March	21.81	7.67	61.44	0.63	26.75	11.54	54.40	0.26
April	32.83	13.80	45.59	0.04	30.89	13.91	46.90	0.19

TABLE 3. Time and number of irrigations at each tested irrigation systems during the growing seasons

No. of irrigations (without sowing irrigation)	Time of irrigation (days after sowing, DAS)			
	1st	2nd	3rd	4th
4 irrigations (Normal)	30	30	30	30
3 irrigations (Moderate)	30	40	40	-
2 irrigations (Stress)	30	50	-	-

The preceding crop in experimental site was maize in both seasons. The area of each experimental plot was 12.6m^2, including six rows, 3m long and 70cm apart. Before sowing, phosphorus fertilizer was added as calcium super phosphate (15.5% P_2O_5) at a rate of 100kg/ fed. Seeds were sown in hills at 25cm apart on the two sides of row at 5th and 7th November in the first and second seasons, respectively. At 30 days after irrigation sowing, plants were thinned to two plants /hill. After thinning, nitrogen fertilizer at a rate of 23kg N/ fed (in form of urea, 46.5% N) and potassium fertilizer at a rate of 24kg K_2O/ fed (in form of potassium sulphate, 48% K_2O) were added to plants. Weeds grown in plots were controlled manually and chemically when it was needed. The plants were harvested in 15th and 18th April in the first and second seasons, respectively.

Data collected

In each experimental plot, data were collected on the following characters:

Physiological attributes in leaves at 85 days after sowing (DAS)

1- Total water content (TWC %): using the following formula as described by Gosev (1960) and Kreeb (1990):

$$TWC = \frac{Fw - Dw}{Fw} X100$$

2- Relative water content (RWC %): using the following formula as described by Barrs (1968)

RWC % = (FW–DW) / (TW–DW) × 100

where FW: Fresh weight of leaf sample, DW: Dry weight of leaf sample and TW: Turgid weight of leaf sample (leaf sample was soaked on distilled water for 4h at room temperature).

3- Total chlorophyll: estimated from the 4th leaf of plant using SPAD meter (SPAD 502, Minolta, Japan)

Growth characters (at 100 DAS)

Plant height (cm), number of leaves / plant, leaf area / plant (cm^2), stem dry weight /plant (g.), leaves dry weight /plant (g.) and total dry weight (leaves and stem)/plant (g.).

Seed yield and quality (at harvest)

1- Seed yield and its components

Number of pods/ plants, number of seeds / pods, 100-seed weight (g.), seeds weight / pod (g.) and seed yield/ plant (g.) and seed yield/ feddan (kg) (Feddan "fed" = 4200m^2).

2 - Seed quality

Nitrogen % was determined in dried seeds using Micro Kjeldahl method (AOAC, 2007) and then protein % was calculated by multiplying N% by 6.25.

Water requirement and productivity

1- Total water use (m^3/ fed): - Water pump provided with calibrate water meter was used for irrigation and calculation the total water used.

2- Water saved (m^3/fed) = Total water use at 4 irrigations – Total water use at 3 or 2 irrigations

3- Saved water % = Total water use at 4 irrigations– Total water use at 3 or 2 irrigations/ Total water use at 4 irrigations X 100

4- Water productivity (Kg seeds/ m^3 water): using the following Equation (Michael, 1978):

Water productivity = Seed yield (kg/ fed)/ Total water use (m^3/ fed)

Drought tolerance efficiency

To identify drought tolerance cultivars based on seed yield potential under all stress and normal conditions, the following drought tolerance efficiency were calculated from seed yield/ fed data as shown in Table 4

TABLE 4. The tested drought tolerance indices, formula and references

Drought tolerance indices	Formula	References
Tolerance index (TOL)	YP - YS	Hossain et al. (1990)
Relative yield reduction (RYR %)	1 – (YS / YP)	Golestani & Assad (1998)
Drought susceptibility index (DSI)	$\frac{1 - YS / YP}{1 - \bar{Y}S / \bar{Y}P}$	Fischer & Maurer (1978)

where, Ys and Yp : Seed yield/ fed of each cultivar under drought stress (3 or 2 irrigations) and normal conditions (4 irrigations), respectively. $\bar{Y}S$ and $\bar{Y}p$: Means of seed yield/ fed of all cultivars under drought stress and normal conditions, respectively. The tolerant cultivar had lowest values for TOL and RYR % as well as less than one for DSI

Statistical analysis

Analysis of variance for all data obtained at each season was done separately. Moreover, the homogeneity test of error variances for the two seasons was carried out according to Gomez & Gomez (1984). The test of homogeneity between the two seasons was insignificant, therefore the combined analysis was done for both seasons. Treatment means were compared by Duncan's Multiple Range Test (Duncan, 1955). The mean values designated by the same letter (s) in each column are not significantly at 5% level. All statistical analyses were performed using analysis of variance technique using CoStat computer software package.

Results and Discussion

Physiological attributes

The data in Table 5 show the effect of tested number of irrigations (4, 3 and 2) on the physiological attributes studied in the leaves ,i.e. total water content (TWC %), relative water content (RWC %) and total chlorophyll (chl.) at 85 days after sowing (DAS) in 2021/2022 and 2022/2023 and their combined. The data indicated that decreasing number of irrigations from 4 to 3 and 2 irrigations caused a significant and gradual reduction in all physiological attributes studied in the first and second seasons and their combined. This reduction amounted to 2.70 and 5.48% for TWC%, 11.04 and 17.86% for RWC% and 20.80 and 40.37 % for chl. when the plants were irrigated by 3 and 2 irrigations compared to 4 irrigations, respectively (as a combined of the two seasons). This means that the depression in soil moisture by decreasing irrigation numbers caused a lower absorption of water as well as nutrients and consequently diminish water contents and pigments in the leaves. In this concern, many researchers found that exposing faba bean plants to inadequate moisture caused a reduction in RWC % and total chl. (Abdel Samie et al., 2021; Abdelhaleim et al., 2022) and TWC% (El-Gabry & Morsi, 2019).

The data in Table 6 indicated that there are significant variations among the tested cultivars for all physiological attributes in both seasons and their combined with exception of RWC% in the second season. The data of the combined of the two seasons indicate that Giza 716 cv. had the highest values of TWC (83.99%) and RWC (62.19%), while Giza 3 cv. had the lowest one (82.30 and 56.07%) for the same respective attributes. However, the highest significant values of chl. (3.28) were obtained by Sakha 4 cv. while, Giza 461 produced the minimum values (2.04). These variations among the tested faba bean cultivars in the physiological attributes may be due to the differences in their genetical constituents. Variation among some faba bean cultivars were previously obtained also by El-Gabry & Morsi (2019) and Abdelhaleim et al. (2022) for RWC%, as well as El-Shafey et al. (2016) and Abdel-Baky et al. (2019) for chl. content.

The interaction between the tested number of irrigations and faba bean cultivars was found to be significant for RWC % and total chl. in the leaves in the two seasons and their combined. The combined data graphically illustrated in Fig. 1 showed generally that the highest values of RWC (70.48%) and total chl. (4.03) were obtained when Giza 716 and Sakha 4 cv. cultivars were irrigated 4 times, respectively. However, under severe drought conditions (2 irrigations), Giza 3 and Sakha 3 cultivars exhibited the minimum values (49.43%) for RWC and (1.37) for chl., respectively. From these results, it can be concluded that the differences among the tested faba bean cultivars obtained herein for the physiological attributes may depend on genetic constitutions and severity of water deficits. In this respect, many researchers found significant interaction between water stress conditions and some faba bean genotypes for RWC% (Ouji et al., 2017; Oukaltouma et al., 2021) and chl. content (El-Emshaty et al., 2021; Abdelhaleim et al., 2022).

TABLE 5. Effect of no. of irrigations on some physiological attributes in leaves of faba bean during 2021/2022 and 2022/2023 seasons and their combined (both seasons)

No. of irrigations	Total water content (TWC %)	Relative water content (RWC %)	Total chlorophyll (Spad) (chl.)
2021/2022 season			
4 irrigations	86.35 a	66.83 a	3.17 a
3 irrigations	84.05 b	58.78 b	2.10 b
2 irrigations	80.78 c	53.96 c	1.75 c
2022/2023 season			
4 irrigations	84.74 a	64.19 a	3.28 a
3 irrigations	82.42 b	57.77 b	3.00 a
2 irrigations	80.92 c	53.65 b	2.10 b
Combined of the two seasons			
4 irrigations	85.54 a	65.50 a	3.22 a
3 irrigations	83.23 b	58.27 b	2.55 b
2 irrigations	80.85 c	53.80 c	1.92 c

TABLE 6. Mean performances of some physiological attributes in leaves for tested faba bean cultivars during 2021/2022 and 2022/2023 seasons and their combined (both seasons)

Cultivars	Total water content (TWC %)	Relative water content (RWC %)	Total chlorophyll (Spad) (chl.)
2021/2022 season			
Giza 3	82.57 b	56.54 c	2.30 ab
Giza 461	83.14 ab	57.24 c	2.04 b
Giza 716	84.48 a	64.18 a	2.22 ab
Sakha 1	84.02 ab	59.19 b	2.45 ab
Sakha 3	83.70 ab	59.17 b	2.22 ab
Sakha 4	84.43 a	62.78 a	2.78 a
2022/2023 season			
Giza 3	82.04 b	55.60 a	2.78 bc
Giza 461	82.16 b	56.72 a	2.05 c
Giza 716	83.49 a	60.20 a	2.53 bc
Sakha 1	82.87 ab	58.86 a	3.18 ab
Sakha 3	82.52 ab	58.31 a	2.42 bc
Sakha 4	83.04 ab	61.47 a	3.78 a
Combined of the two seasons			
Giza 3	82.30 d	56.07 b	2.54 b
Giza 461	82.65 cd	56.98 b	2.04 c
Giza 716	83.99 a	62.19 a	2.37 bc
Sakha 1	83.45 ab	59.04 b	2.82 b
Sakha 3	83.11 bc	58.74 b	2.33 bc
Sakha 4	83.73 ab	62.13 a	3.28 a

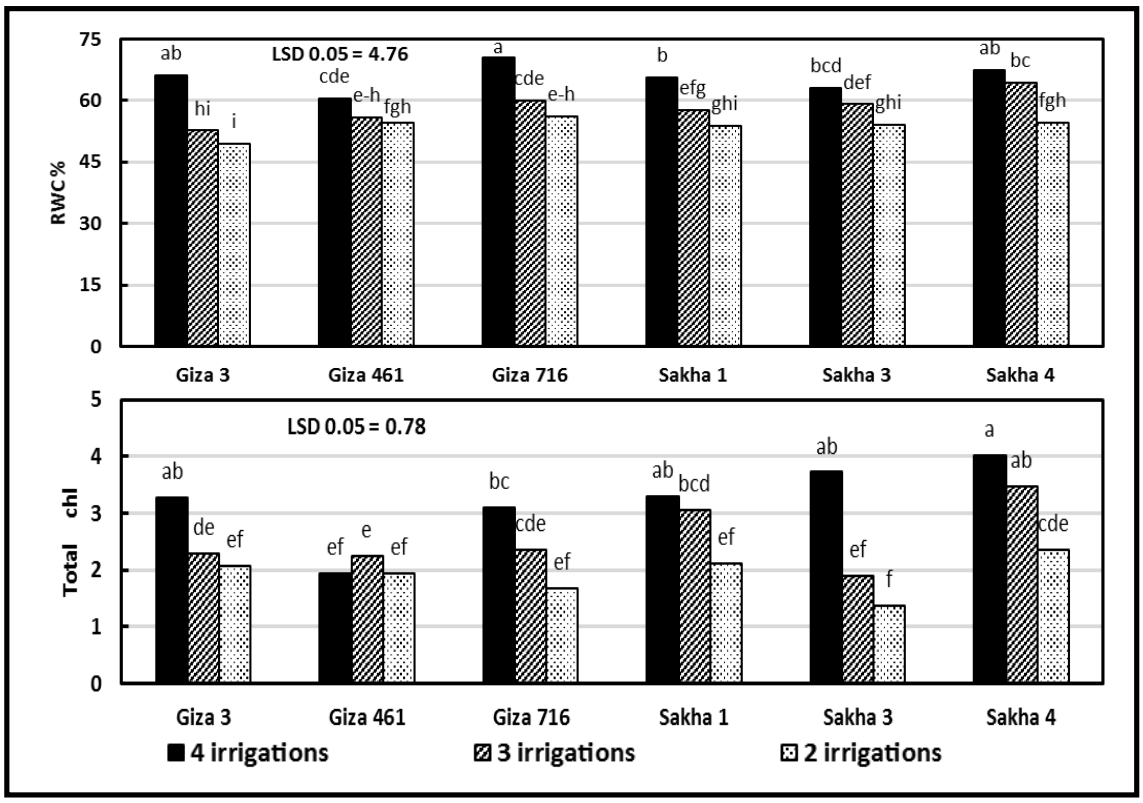

Fig. 1. Effect of the interaction between no. of irrigations and faba bean cultivars on some physiological attributes (combined of the two seasons)

Growth characters

The effect of irrigation numbers on the growth characters studied (plant height, no. and area of leaves/ plant as well leaves, stem and total dry weight/ plant) in the first and second seasons and their combined are presented in Table 7. The data show that exposing faba bean plants to drought stress conditions (3 or 2 irrigations) significantly and gradually decreased all abovementioned growth characters compared to those obtained by plants irrigated with 4 irrigations. This was fairly true in the first and second seasons and their combined. The obvious depression in the growth characters obtained herein by the shortage of irrigation number may be due to decrease in plant capacity of nutrients absorption, photosynthesis efficiency (as previously discussed in Table 5) and consequently decreased stem elongation, dry matter production and other plant growth characters studied. In this connection, other investigators found that exposing faba bean plants to drought stress by decreasing either the no. of irrigations or water applied led to a decrease in growth characters such as plant height, number and area of leaves/ plant (Abdel Samie et al., 2021), leaves dry weight (Girma & haile, 2014), stem dry weight (Oukaltouma et al., 2021) and total dry weight/ plant (El-Gabry & Morsi, 2019).

Data in Table 8 showed that the differences among the six faba bean cultivars were found to be significant for all growth characters studied in both seasons and their combined. Based on the combined analysis over the two seasons, it is clear that Sakha 4 cv. surpassed the other cultivars in each of plant height, no. and area of leaves/ plant as well as stem and total dry weight/ plant. The superiority of Sakha 4 cv. in such growth characters may be resulted from higher total chl. in its leaves as previously discussed in Table 6. On the other hand, Giza 461 cv. had the lowest values of all growth characters studied. In this concern, other investigators found noticeable variation among some faba bean varieties in their plant height as reported by Tawfik et al. (2018), Gomaa & Afifi (2021) and Abdelhaleim et al. (2022) as well as no. of leaves/ plant and total dry weight/ plant as recorded by El-Gabry & Morsi (2019). Moreover, Abdel-Baky et al. (2019) found that Sakha 4 cv. exceeded some faba bean varieties in each of plant height, number and area of leaves/ plant and total dry weight/ plant.

TABLE 7. Effect of number of irrigations on growth characters of faba bean during 2021/2022 and 2022/2023 seasons and their combined (both seasons)

No. of irrigations	Plant height (cm)	No. of leaves/ plant	Leaf area/ plant (cm^2)	Dry weight/ plant (g)		
				Leaves	Stem	Total
2021/2022 season						
4 irrigations	129.90 a	91.96 a	4312.15 a	10.34 a	18.08 a	28.42 a
3 irrigations	124.09 b	89.85 b	3885.37 b	10.11 b	17.33 b	27.44 b
2 irrigations	117.13 c	85.99 c	3339.84 c	9.82 c	16.08 c	25.90 c
2022/2023 season						
4 irrigations	129.89 a	90.86 a	4382.36 a	10.62 a	20.10 a	30.72 a
3 irrigations	126.40 b	89.16 b	3881.67 b	10.13 b	19.54 b	29.67 b
2 irrigations	117.29 c	84.78 c	3381.24 c	9.83 c	18.08 c	27.91 c
Combined of the two seasons						
4 irrigations	129.89 a	91.41 a	4347.25 a	10.48 a	19.08 a	29.56 a
3 irrigations	125.24 b	89.50 b	3883.51 b	10.11 b	18.43 b	28.54 b
2 irrigations	117.20 c	85.38 c	3360.54 c	9.82 c	17.08 c	26.90 c

TABLE 8. Mean performances of growth characters for tested faba bean cultivars during 2021/2022 and 2022/2023 seasons and their combined (both seasons)

Cultivars	Plant height (cm)	No. of leaves/ plant	Leaf area/ plant (cm^2)	Dry weight/ plant (g)		
				Leaves	Stem	Total
2021/2022 season						
Giza 3	126.75 b	90.40 b	4064.12 b	10.64 a	18.34 a	28.98 a
Giza 461	116.43 f	86.82 c	3486.44 f	9.67 c	16.13 b	25.80 b
Giza 716	119.85 e	88.59 bc	3913.44 c	9.87 bc	16.74 b	26.61 b
Sakha 1	122.44 d	86.79 c	3652.14 e	9.89 b	16.62 b	26.51 b
Sakha 3	123.76 c	88.92 bc	3745.52 d	9.94 b	16.49 b	26.43 b
Sakha 4	133.02 a	94.09 a	4213.07 a	10.53 a	18.65 a	29.18 a
2022/2023 season						
Giza 3	126.99 b	88.92 b	4102.43 a	10.92 a	20.82 a	31.74 a
Giza 461	117.02 e	84.17 d	3545.94 c	9.46 c	17.62 b	27.08 c
Giza 716	125.40 c	89.24 b	3773.67 b	9.95 b	18.04 b	27.99 bc
Sakha 1	121.22 d	86.63 c	3723.25 b	10.08 b	18.89 b	28.97 b
Sakha 3	124.59 c	89.62 b	4013.62 a	10.12 b	18.81 b	28.93 b
Sakha 4	131.91 a	91.02 a	4131.63 a	10.63 a	21.25 a	31.88 a
Combined of the two seasons						
Giza 3	126.86 b	89.65 b	4083.27 b	10.77 a	19.57 a	30.34 a
Giza 461	116.72 f	85.49 d	3516.18 f	9.56 d	16.87 c	26.43 c
Giza 716	122.62 d	88.91 b	3843.55 d	9.91 c	17.39 bc	27.30 b
Sakha 1	121.83 e	86.70 c	3687.69 e	9.98 c	17.75 b	27.73 b
Sakha 3	124.17 c	89.26 b	3879.56 c	10.02 c	17.64 b	27.66 b
Sakha 4	132.47 a	92.55 a	4172.35 a	10.58 b	19.95 a	30.53 a

There was significant interaction between the tested irrigation regimes and faba bean cultivars for plant height, leaf area/ plant and total dry weight/ plant in the two seasons and their combined. However, the other growth characters were not significantly affected by such interaction in one or both seasons, therefore their data were excluded. The data of the combined analysis illustrated in Fig. 2 showed that Sakha 4 cultivar was a superior cultivar under well irrigation condition (4 irrigations), where it had the highest significant values of plant height (138.83cm), leaf area/ plant (4809.03cm^2) and total dry weight/ plant (32.77g). However, Giza 461 cultivar produced the lowest values, i.e. 102.62cm, 2172.53cm^2, 24.73g for the same respective traits under the limited irrigation conditions (2 irrigations). Previous studies found significant interaction effect between water stress conditions and some faba bean genotypes for plant height (Yousry et al., 2021; Abdelhaleim et al., 2022), leaf area/ plant (Oukaltouma et al., 2021) and total dry weight (Siam et al., 2017b; El-Gabry & Morsi, 2019).

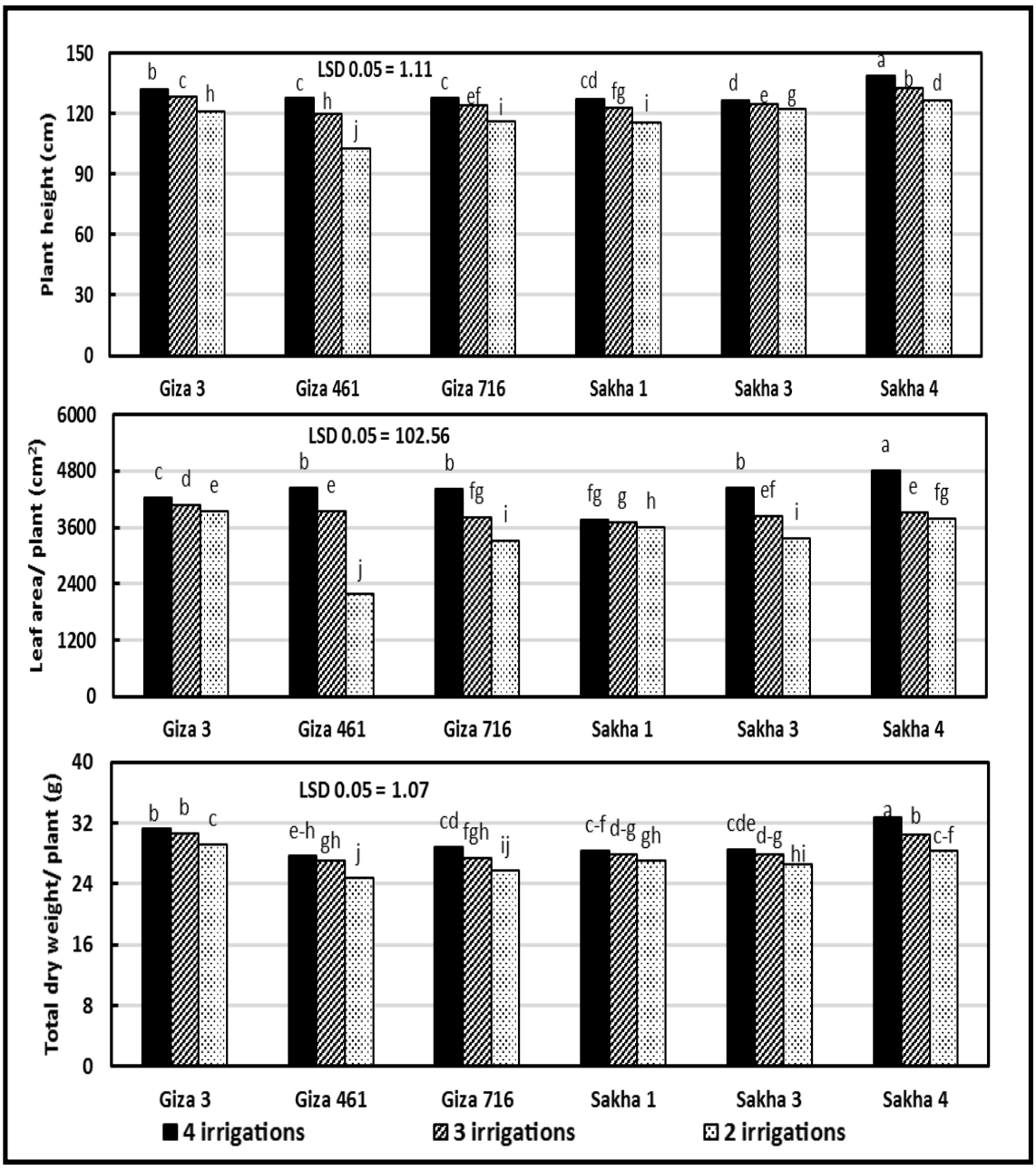

Fig. 2. Effect of the interaction between no. of irrigations and faba bean cultivars on some growth characters (combined of the two seasons)

Seed yield and quality

Data in Table 9 indicated that the three tested irrigation regimes had significant effect on all traits studied of seed yield and quality (protein %) in the first and second seasons and their combined. From the combined data of the two seasons, it could be noticed that exposing plants to limiting irrigation numbers (3 and 2 irrigations) led to a significant decrease in no. of pods/ plant (4.22 and 13.37%), no. of seeds/ pod (3.03 and 6.36 %), 100- seed weight (7.01 and 14.47%), seed weight/ pod (3.45 and 12.64%), seed yield/ plant (10.33 and 23.14%) and seed yield/ fed (4.76 and 30.88%) more than the plants applied with 4 irrigations, respectively. From these results, it can be concluded that decreasing number of irrigations from 4 to 3 or 2 irrigations caused a pronounced reduction in seed yield/ plant and its components (no. of pods/ plants, no. of seeds/ pods, 100 seed weight and seed weight/ pod) and consequently seed yield/ fed. This reduction was coincided with the depression of physiological attributes and growth characters obtained with the same conditions as previously discussed in Tables (5 and 7), respectively. In this respect, El-Emshaty et al. (2021) and Abdelhaleim et al. (2022) found that no. of pods/ plants, 100- seed weight and seed yield/ plant and fed of faba bean were decreased when the plants were grown under drought stress condition by prolonging irrigation intervals. Moreover, Yousry et al. (2021) found that no. and weight of seeds/ pod were decreased when the faba bean plants were irrigated with low water supply (40% of field capacity). Reversely, the obtained data showed that protein % in the seeds was significantly increased by decreasing no. of irrigations from 4 to 2 in both seasons and their combined. The superiority of protein % accompanied with water stress condition may be due to the decrease in 100-seed weight and this in turn decrease in the carbohydrate accumulation and its translocation to the seeds and consequently caused an increase in protein % in the seeds. These results are in agreement with those obtained by other investigators who found that protein % in faba bean seeds was increased when the plants were grown under various water stress conditions such as skipping of irrigation (Mekkei, 2014) or increasing of irrigation intervals (Megawer et al., 2017) and decreasing of irrigation requirements (Tawfik et al., 2018).

TABLE 9. Effect of no. of irrigations on yield and its components and seed quality on faba bean at harvest during 2021/2022 and 2022/2023 seasons and their combined (both seasons)

No. of irrigations	No. of pods/ plant	No. of seeds/ pod	100-seed weight (g)	Seed weight/ pod (g)	Seed yield/ plant (g)	Seed yield / fed (kg)	Total Protein %
2021/2022 season							
4 irrigations	16.93 a	3.35 a	80.85 a	2.65 a	40.63 a	2043.11 a	25.47 c
3 irrigations	15.98 a	3.25 ab	75.23 b	2.52 b	36.51 b	1874.36 b	26.44 b
2 irrigations	14.48 b	3.12 b	67.52 c	2.23 c	30.76 c	1466.51 c	28.01 a
2022/2023 season							
4 irrigations	16.72 a	3.26 a	78.22 a	2.58 a	42.80 a	2110.03 a	26.50 b
3 irrigations	16.26 a	3.17 ab	72.67 b	2.53 a	38.30 b	2080.90 a	26.56 b
2 irrigations	14.67 b	3.07 b	68.52 c	2.34 b	33.36 c	1405.08 b	29.43 a
Combined of the two seasons							
4 irrigations	16.82 a	3.30 a	79.53 a	2.61 a	41.71 a	2076.6 a	25.98 b
3 irrigations	16.11 b	3.20 b	73.95 b	2.52 b	37.40 b	1977.6 b	26.50 b
2 irrigations	14.57 c	3.09 c	68.02 c	2.28 c	32.06 c	1435.8 c	28.72 a

The data in Table 10 indicate that there are a significant variation among the six tested faba bean varieties in the traits studied of yield and yield components in the two seasons and their combined. From the data of the combined analysis, it can be noted that the highest values were obtained by Sakha 4 cv. for no. of pods/ plants (17.85), seed yield/ plant (40.78g) and seed yield/ fed (2115.27kg), Sakha 1 cv. for no. of seeds/ pods (3.40g) and seed weight/ pod (2.64g) and Sakha 3 cv. for 100-seed weight (77.45g). On the other hand, the lowest values were obtained by Giza 461 cv. for number of pods/ plants (13.62) and seed yield/ plant (32.72g), Sakha 3 cv. for no. of seeds/ pods (3.04), Giza 3 cv. for 100-seed weight (71.93g), and Giza 716 cv. for seed weight/ pod (2.32g) and seed yield/ fed (1721.55kg). From these results, it can be suggested that Sakha 4 cv. was found to be a high yielding cultivar. This high yielding was apparently contributed by high chlorophyll content (Table 6) and total dry weight/ plant (Table 8) combined with more no. of pods/ plant and seed yield/ plant (Table 10) as compared with the other tested cultivars. On the other hand, the combined data in the same Table indicated that the highest values of protein (28.61 and 27.93%) were recorded by Giza 3 and Sakha 4 cultivars, respectively without any significant differences between them. In this respect, variation among some faba bean cultivars was previously detected by other investigators such as Abdel-Baky et al. (2019) and Abdelhaleim et al. (2022) for no. of pods/ plant and 100-seed weight , seed yield/ plant and fed as well as Mekkei (2014) and El-Gabry & Morsi (2019) for no. of seeds/ pod. Moreover, El-Shafey et al. (2016), Abo-Hegazy & Badawy (2021) and Alshameri et al. (2021) found that Sakha 4 cv. was superior in no. of pods/ plant, 100 – seed weight and seed yield/ plant and fed, while, Megawer et al. (2017) and Siam et al. (2017a) found that Giza 3 cv. was higher in seed protein % than other faba bean cultivars.

TABLE 10. Mean performances of yield and its components and seed quality for tested faba bean cultivars at harvest during 2021/2022 and 2022/2023 seasons and their combined (both seasons)

Cultivars	No. of pods/ plant	No. of seeds/ pod	100-seed weight (g)	Seed weight/ pod (g)	Seed yield/ plant (g)	Seed yield /fed (kg)	Total protein %
2021/2022 season							
Giza 3	17.16 a	3.18 bc	72.54 cd	2.36 b	39.13 ab	2082.69 a	28.12 a
Giza 461	13.55 c	3.33 ab	76.18 b	2.56 a	31.20 d	1645.89 b	26.72 ab
Giza 716	15.04 b	3.16 bc	72.05 d	2.29 b	32.70 cd	1678.78 b	26.20 b
Sakha 1	15.44 b	3.44 a	74.28 c	2.63 a	35.50 bc	1869.38 ab	25.78 b
Sakha 3	15.60 b	3.08 c	78.43 a	2.47 ab	37.84 ab	2036.71 a	25.87 b
Sakha 4	18.00 a	3.24 bc	73.71 cd	2.47 ab	39.43 a	2087.93 a	27.14 ab
2022/2023 season							
Giza 3	17.30 a	3.13 bc	71.32 d	2.39 c	40.83 ab	2060.57 ab	29.11 a
Giza 461	13.69 c	3.28 ab	72.97 bc	2.55 ab	34.25 c	1871.42 bc	27.31 ab
Giza 716	15.30 b	3.06 c	72.82 bc	2.35 c	33.86 c	1764.33 c	26.45 b
Sakha 1	15.57 b	3.36 a	73.25 b	2.66 a	37.88 b	1979.68 ab	26.04 b
Sakha 3	15.74 b	3.01 c	76.47 a	2.48 bc	39.95 ab	2031.76 ab	27.33 ab
Sakha 4	17.70 a	3.15 bc	71.98 cd	2.48 bc	42.14 a	2142.63 a	28.73 a
Combined of the two seasons							
Giza 3	17.23 a	3.15 c	71.93 d	2.37 c	39.98 a	2071.62 a	28.61 a
Giza 461	13.62 c	3.30 b	74.57 b	2.55 b	32.72 c	1758.65 c	27.01 bc
Giza 716	15.17 b	3.11 cd	72.43 d	2.32 c	33.27 c	1721.55 c	26.32 cd
Sakha 1	15.50 b	3.40 a	73.76 bc	2.64 a	36.68 b	1924.52 b	25.91 d
Sakha 3	15.66 b	3.04 d	77.45 a	2.47 b	38.89 a	2034.23 ab	26.60 cd
Sakha 4	17.85 a	3.19 c	72.84 cd	2.48 b	40.78 a	2115.27 a	27.93 ab

The interaction between the no. of irrigations and faba bean cultivars was significant for the no. of pods/ plant, no. of seeds/ pods, 100-seed weight and seed yield/ fed in the two seasons and their combined. However, the interaction between the two factors was insignificant for rest seed yield components and quality in the first and/ or second seasons, therefore the data were excluded. The combined data illustrated in Fig. 3 noticed that the tested faba bean cultivars differed in their response to various irrigation treatments. The maximum values were obtained by Sakha 4 cv. for no. of pods/ plant (19.20), Sakha 1 cv. for no. of seeds/ pod (3.47), Sakha 3 cv. for 100-seed weight (83.73g) and Giza 3 cv. for seed yield/ fed (2332.51kg) when the plants were watered with 4 irrigations. This means that the application of adequate irrigation is necessary for high yielding for those cultivars. Reversely, exposing faba bean cultivars to water deficit (2 irrigations) produced the lowest values of no. of pods/ plant (12.49) and seed yield/ fed (1226.60kg) by Giza 461 cv. as well as no. of seeds/ fed (2.99) and 100-seed weight (65.05g) by Giza 716 cv. These results are in accordance with those obtained by other investigators who found that faba bean cultivars differed among them according to the diversity of irrigation regimes in number of pods/ plant (Abdel-Ghany et al., 2016; Megawer et al., 2017), number of seeds/ pod (Mekkei, 2014; Yousry et al., 2021), 100 seed weight (El-Gabry & Morsi, 2019; Abdelhaleim et al., 2022) and seed yield/ fed (El-Harty, 2016; Tawfik et al., 2018).

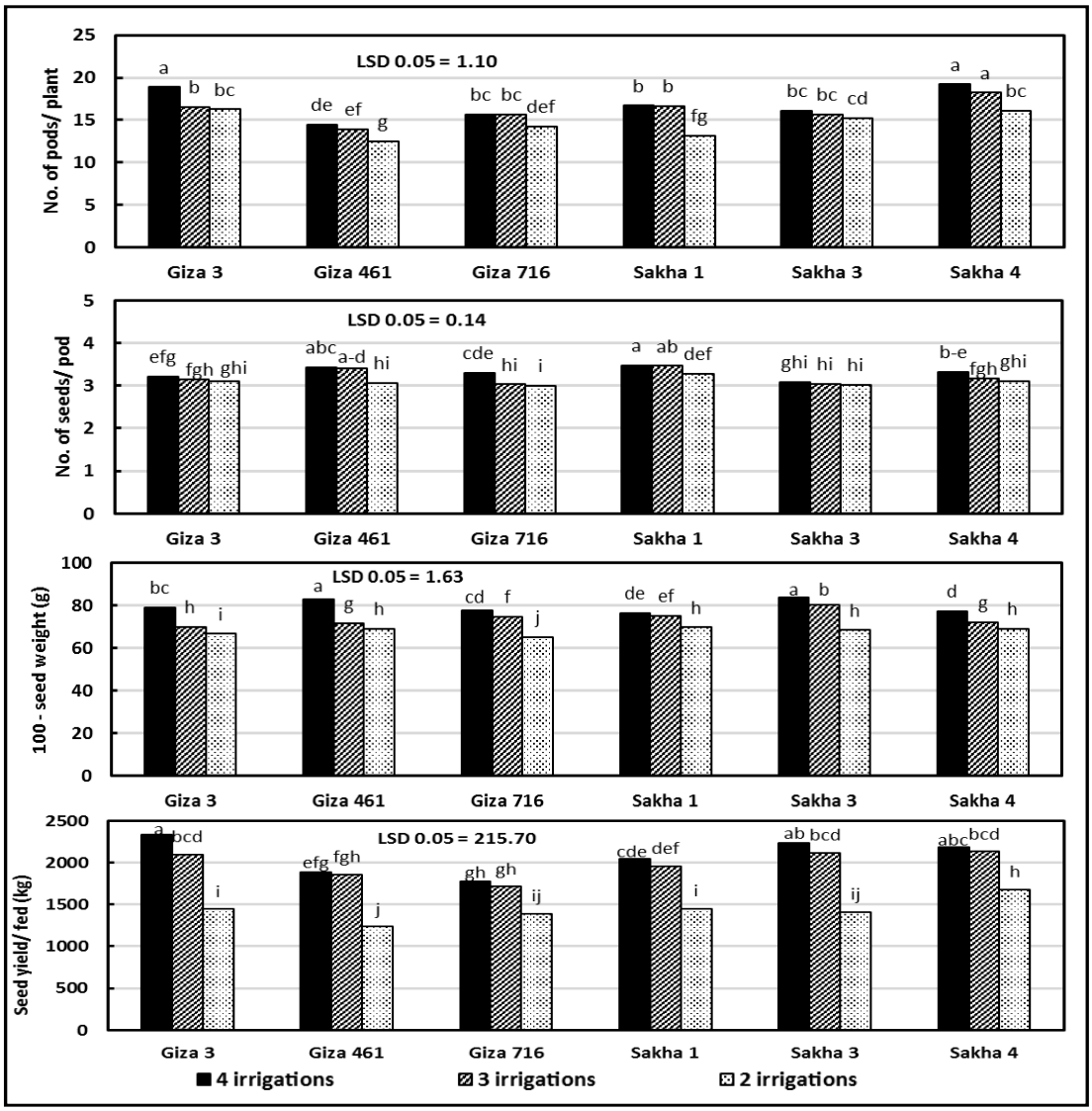

Fig. 3. Effect of the interaction between no. of irrigations and faba bean cultivars on seed yield/ fed and some of its components (combined of the two seasons)

Water relations

The effect of tested irrigation numbers on water relations studied herein, i.e. total water used and saved water % are presented in Table 11 as well as water productivity are detected in Table 12 in both seasons and their combined.

The combined data in Table 11 show that decreasing number of irrigations applied to faba bean plants from 4 to 3 or 2 irrigations caused a gradual decrease in the total used water from 1425 to 1080 and 735m^3/ fed, respectively. This means that the application of 3 and 2 irrigations can save an amount of total used water about 345m^3/ fed (24.21%) and 690 m^3/ fed (48.42%) compared to the application of 4 irrigations, respectively.

On the other hand, the data in Table 12 show that decreasing the no. of irrigations from 4 to 3 or 2 caused an increase in the values of water productivity in both seasons and their combined. As the combined of the two seasons, over all tested cultivars, the data show that the faba bean plants irrigated with two times had the highest significant values of water productivity (1.95kg / m^3) compared to those irrigated with 4 times which produced the lowest one (1.46kg/ m^3). Similar results were obtained by other investigators who found that the values of total water applied to faba bean / fed was decreased, while water use efficiency was generally increased when the plants were exposed to drought stress conditions by decreasing the number of irrigations up to 3 irrigations (Eid et al., 2008) or 4 irrigations (Fakkar et al., 2016).

The data in Table 12, according to the combined data, it can be noticed also that Sakha 4 cv. had the highest values of water productivity (1.93kg seeds/ m^3 water) followed by Giza 3 (1.85kg/ m^3), Sakha 3 (1.82kg/ m^3), Sakha 1 (1.74kg/ m^3) and Giza 461 as well as Giza 716 (1.58kg/ m^3) in a descending order. This means that Sakha 4 cv. is found to be more efficiency for water used than the other tested cultivars. In this concern, Yousry et al. (2021) found variation among some local faba bean genotypes in their water productivity. Moreover, Fakkar et al. (2016) reported that faba bean cultivars Sakha 4 cv. was superior to some faba bean cultivar in the water use efficiency.

The interaction effect of the number of irrigations and tested faba bean cultivars on the water productivity was found to be significant in both seasons and their combined. The data of combined analysis graphically illustrated in Fig. 3 showed that water productivity for each cultivar was mostly increased with exposing faba bean plants to water shortage (decreasing the number of irrigations up to 2). The water productivity was more significant pronounced by Sakha 4 cv. when its plants were watered with two irrigations (2.28 Kg / m^3). However, the application of water abundance (4 irrigations) negatively influenced water productivity for all tested cultivars especially Giza 716 and Giza 461 cultivars which produced the minimum significant values, i.e. 1.25 and 1.33kg seeds/ m^3 water, respectively. In this concern, significant interaction effect between faba bean cultivars and the amount of water applied on their water productivity were recorded by Siam et al. (2017a), Tawfik et al. (2018) and El-Gabry & Morsi (2019) who found that the water productivity of faba bean plants varied from cultivar to another according to the water stress conditions.

TABLE 11. Effect of no. of irrigations on the amounts of total used and saved water (m^3/fed) during 2021/2022 and 2022/2023 seasons and their combined

No. of irrigations	2021/2022 season			2022/2023 season			Combined of the two seasons		
	Used water (m^3/fed)	Saved water		Used water (m^3/fed)	Saved water		Used water (m^3/fed)	Saved water	
		(m^3/fed)	%		(m^3/fed)	%		(m^3/fed)	%
4 irrigations	1450	-	-	1400	-	-	1425	-	-
3 irrigations	1100	350	24.14	1060	340	24.29	1080	345	24.21
2 irrigations	750	700	48.28	720	680	48.57	735	690	48.42

TABLE 12. Effect of no. of irrigations and faba bean cultivars and their interactions on water productivity (Kg seeds / m³ water) during 2021/2022 and 2022/2023 seasons and their combined.

Cultivars	2021/2022 season				2022/2023 season				Combined of the two seasons			
	No. of irrigations			Mean	No. of irrigations			Mean	No. of irrigations			Mean
	4	3	2		4	3	2		4	3	2	
Giza 3	1.66 fgh	1.79 ef	2.04 c	1.83 AB	1.62 de	2.09 ab	1.89 bc	1.87 AB	1.63 de	1.94 b	1.96 b	1.85 AB
Giza 461	1.22 k	1.58 ghi	1.53 g-i	1.44 D	1.43 ef	1.86 bcd	1.84 bcd	1.71 BC	1.33 gh	1.72 cd	1.68 cde	1.58 D
Giza 716	1.20 k	1.49 hij	1.85 def	1.51 CD	1.29 f	1.68 cde	1.97 ab	1.65 C	1.25 h	1.59 def	1.90 b	1.58 D
Sakha 1	1.36 jk	1.67 fg	1.99 bcd	1.67 BC	1.51 ef	1.96 ab	1.96 ab	1.81 ABC	1.44 fg	1.82 bc	1.98 b	1.74 C
Sakha 3	1.54 ghi	1.84 cde	2.01 bc	1.80 AB	1.60 de	2.08 ab	1.83 bcd	1.83 AB	1.57 def	1.96 b	1.92 b	1.82 BC
Sakha 4	1.46 ij	1.85 cde	2.35 a	1.89 A	1.60 de	2.10 ab	2.22 a	1.97 A	1.53 ef	1.98 b	2.28 a	1.93 A
Mean	1.41 *C*	1.70 *B*	1.96 *A*		1.51 *B*	1.96 *A*	1.95 *A*		1.46 *C*	1.83 *B*	1.95 *A*	

Drought tolerance efficiency

The data in Table 13 show three drought tolerance indices studied herein, i.e. tolerance index (TOL), relative yield reduction (RYR %) and drought susceptibility index (DSI) for each faba bean variety as affected by the drought stress conditions (3 or 2 irrigations) compared to normal irrigation system (4 irrigation) in the two seasons and their combined analysis. These parameters are considered to be an indicator to drought tolerant for the tested genotypes. Any cultivar had DSI values less than one (<1) and exhibited smaller values of TOL and RYR % under drought stress compared to non – drought conditions is considered relatively drought tolerant comparing with other cultivars (Fischer & Maurer, 1978; Kilic & Yağbasanlar, 2010). In the present study, the combined data indicated that Giza 716 and Sakha 4 cultivars had smaller DSI values (<1) and exhibited smaller yield reductions when they were irrigated with either 3 or 2 irrigations. This means that Giza 716 and Sakha 4 cultivars can be considered to be most drought tolerant compared to the other tested cultivars. The superiority of such cultivars for drought tolerance may be because of they had the higher values of RWC % than the other tested cultivars as shown previously in Table (6) and Fig (1). In this respect, Ashraf et al. (1994) found that the genotypes with higher RWC % were mostly more drought tolerant. Moreover, Teulat et al. (1997) reported that RWC % in the leaves can be used as screening techniques for drought resistance. Reversely, the data showed that Giza 3 and Sakha 3 cultivars had DSI values more than one as well as had the highest values of TOL and RYR %, indicating that those cultivars were relatively drought sensitive under water deficit conditions compared to the other tested cultivars. In this concern, high variation among some faba bean genotypes in their DSI values was previously recorded by Abdel-Ghany et al. (2016), Ouji et al. (2017), El-Gabry & Morsi (2019) and Abdelhaleim et al. (2022).

Conclusion

Finally, it can be noticed that exposing faba bean plants to water deficit by decreasing number of irrigations from 4 to 2 times during the growth period caused adverse effect on growth characters and crop productivity, but increased seed protein% and water productivity for most tested faba bean cultivars. In comparison among

the tested cultivars, it can be concluded that Sakha 4 cultivar is considered the best one for high yielding and drought tolerant, since it had the highest values of seed yield and water productivity / fed as well as the lowest values of drought tolerance indices (TOL, RYR % and DSI) under the tested drought stress conditions in the present study.

TABLE 13. Effect of no. of irrigations on drought tolerance indices (TOL, RYR % and DSI) of some faba bean cultivars during 2021/2022 and 2022/2023 seasons

No. of irrigations / Cultivars	Seed yield/ fed (kg)			TOL		RYR %		DSI	
	4	3	2	3	2	3	2	3	2
2021/2022 season									
Giza 3	2405.07	1968.91	1526.97	436.16	878.1	18.14	36.51	2.196	1.294
Giza 461	1778.45	1738.87	1146.06	39.58	632.39	2.23	35.56	0.269	1.260
Giza 716	1747.12	1641.58	1367.85	105.54	379.27	6.04	21.71	0.731	0.769
Sakha 1	1973.03	1832.04	1491.52	140.99	481.51	7.15	24.40	0.865	0.865
Sakha 3	2237.69	2028.27	1504.71	209.42	732.98	9.36	32.76	1.133	1.161
Sakha 4	2117.32	2036.52	1761.96	80.80	355.36	3.82	16.78	0.462	0.595
2022/2023 season									
Giza 3	2259.95	2217.91	1360.43	42.04	899.52	1.86	39.80	1.348	1.191
Giza 461	2002.71	1975.50	1324.15	27.21	678.56	1.36	33.88	0.984	1.014
Giza 716	1798.23	1782.57	1418.14	15.66	380.09	0.87	21.14	0.631	0.633
Sakha 1	2113.19	2084.34	1411.54	28.85	701.65	1.37	33.20	0.989	0.994
Sakha 3	2237.69	2199.77	1319.20	37.92	918.49	1.69	41.05	1.228	1.229
Sakha 4	2248.41	2225.33	1597.06	23.08	651.35	1.03	28.97	0.744	0.867
Combined of the two seasons									
Giza 3	2332.51	2093.41	1443.70	239.10	888.81	10.25	38.11	1.772	1.243
Giza 461	1890.58	1857.19	1235.10	33.39	655.48	1.77	34.67	0.627	1.137
Giza 716	1772.68	1712.07	1393.00	60.61	379.68	3.42	21.42	0.681	0.701
Sakha 1	2043.11	1958.19	1451.53	84.92	591.58	4.16	28.95	0.927	0.930
Sakha 3	2237.69	2114.02	1411.96	123.67	825.73	5.53	36.90	1.181	1.195
Sakha 4	2182.87	2130.92	1679.51	51.95	503.36	2.38	23.06	0.603	0.731

TOL = tolerance index,
RYR % = relative yield reduction %
DSI = drought susceptibility index

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استجابة نمو وانتاجية وجودة بعض أصناف الفول البلدى لنظم رى مختلفة

محمد سيد محمود عبد العال
قسم المحاصيل – كلية الزراعة – جامعة المنوفية -شبين الكوم – مصر.

أجريت تجربة حقلية بمزرعة كلية الزراعة جامعة المنوفية خلال موسمي 2021/2022 و 2022/2023 لدراسة معدلات النمو والانتاجية المحصولية والمائية وقياس مدى التحمل لظروف الجفاف ل 6 أصناف من الفول البلدى (جيزة 3 ، جيزة 461 ، جيزة 716 ، سخا 1 ، سخا 3 ، سخا 4) وذلك تحت 3 نظم رى مختلفة (2 ، 3 ، 4 ريات) ، هذا وقد استخدم تصميم الشرائح المتعامدة في 3 مكررات في تنفيذ التجربة حيث وزعت معاملات الري في الشرائح الافقية والاصناف في الشرائح الرأسية ويمكن تلخيص اهم النتائج المتحصل عليها كما يلي :

1- أدى تقليل عدد الريات من 4 ريات الي ريتين الي نقص معنوى في كل الصفات الفسيولوجية (محتوى الماء الكلي والنسبي والكلوروفيل في الاوراق) ، صفات النمو (طول النبات ، عدد ومساحة الاوراق/ نبات ، الوزن الجاف لكل من الاوراق والساق والنبات الكلي) ، صفات محصول البذور للفدان ومكوناته (عدد القرون/ نبات ، عدد ووزن البذور / قرن ، وزن 100 بذرة ، محصول البذور للنبات) وكذلك الكمية الكلية للمياه المستخدمة لرى الفدان في حين أدى ذلك الي زيادة النسبة المئوية للبروتين في البذور وكمية المياه الموفرة وكفاءة استخدام مياه الري للفدان خلال موسمي الزراعة والتحليل المشترك لهما.

2- تفوق الصنف سخا 4 تفوقا معنويا في محتوى الورقة من الكلوروفيل وفي معظم صفات النمو المدروسة ، وكذلك في عدد القرون/ نبات ومحصول البذور للنبات والفدان وكفاءة استخدام مياه الري للفدان ، في حين تفوق الصنف جيزة 716 في صفات محتوى الماء الكلي والنسبي في الاوراق ، وصنف سخا 1 في عدد ووزن البذور/ القرن وذلك مقارنة ببقية الاصناف المختبرة الاخرى خلال موسمي الزراعة والتحليل المشترك لهما.

3- تشير نتائج التحليل المشترك للتفاعل بين عاملي الدراسة الي ان الرى بمعدل 4 ريات قد أعطي أعلي القيم لصفات الكلوروفيل ، طول النبات ، مساحة الاوراق / النبات ، وزن النبات الجاف الكلي ، عدد القرون / نبات في صنف سخا 4 ، محتوى الماء النسبي في صنف جيزة 716 وعدد البذور/ قرن في صنف سخا 1 ، وزن 100 بذرة في صنف سخا 3 ومحصول البذور للفدان في صنف جيزة 3.

4- سجل كل من الصنفين سخا 4 وجيزة 716 أقل القيم لكل من دليل الجفاف ، معدل النقص النسبي لمحصول الفدان ، دليل حساسية الجفاف مما يشير الي ان هذين الصنفين كانا أكثر اصناف الفول البلدى المختبرة تحملا للجفاف مقارنة ببقية الاصناف.