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Yield and Yield Components of Faba Bean (*Vicia faba* L.) as Influenced by Supplemental Irrigation under Semi-arid Region of Tunisia

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Abstract A field experiment was conducted at the research station of Higher Agriculture School of Kef located in a semi-arid region of Tunisia to study the effect of supplemental irrigation on yield and yield components of four Tunisian faba bean genotypes (Bachaar, Badii, Chahbi and locale). Two supplemental irrigations were applied at the flowering and pod formation stages. Results showed a significant effect of supplemental irrigation on biological yield (BY/P), seed number per plant (SN/P), 100-seed weight (100 SW), grain yield (GY/m^2), harvest index (HI) and number of days to maturity (NDM). Grain yields under supplemental irrigation varied from 83.9 to 208.7 g/m2, and they varied from 18.6 to 65.8 g/m^2 under drought conditions. Average 100-seeds weight increment due to supplemental irrigation condition was 52.8%. Results showed also that under rain fed condition, Bachar genotypes required minimum number of days to maturity (134.3 days). Drought susceptibility index (DSI) values for grain yield ranged from 0.8 to 1.13. Chahbi was relatively drought resistant (DSI values <1). This genotype proved high yielding and drought tolerant and can be incorporated in stress breeding programme for the development of drought tolerant faba bean varieties.

Keywords: *faba bean (Vicia faba L.), yield, yield components, rainfall, supplemental irrigation, Semi-arid, Tunisia*

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1. Introduction

Faba bean (*Vicia faba* L.) is the fourth important pulse crop in the world after dry bean, dry peas, and chickpeas [1] (Kumari and Van Leur 2011). It contains between 20 and 40% protein, depending on the variety and the environmental conditions under which they are grown [2] (Tewodros et al, 2015). Because of its nutrient-rich seeds, it becomes one of the most important legume crops used as food for human consumption in developing countries and as animal feed in advanced countries.

In Tunisia, faba bean is the major grain legumes cultivated. With chickpea and peas, it represents an important legume crop for human nutrition. It also plays an important role in increasing and maintaining soil fertility and the recovery of marginal lands, especially in semi-arid regions.

Drought, one of the environmental stresses, is the most significant factor restricting plant production in the majority of agricultural fields of the world [3] (Hasan and Tacettin, 2010) which cause significant damaging for plant growth, productivity and mineral nutrition losses to crop yield [4] (Shao et al, 2009; [5] Stolf-Moreira et al, 2011; [6] Osakabe et al, 2013b). Water stress is considered a detrimental factor for the production of crops worldwide. Globally, more thaan 50% of the average yield of most major crops is lost due to drought stress [7] (Zlatev and Lidon 2012). Drought affects also many morphological and physiological processes as mentioned by [8] Toker et al, (1998). The morphological and physiological changes in response to drought stress can be used to help identify resistant genotypes or produce new genotypes of crops for better productivity under drought stress [9] (Nam et al, 2001).

The reactions of plants to drought stress depend on the intensity and duration of stress as well as the plant species and its stage of growth [10] (Parameshwarappa et al, 2008). [11] Al-Hamadany et al, (2005) confirmed that pod development and seed filling stages were the most droughts sensitive. [12] Khan et al., (2010) reported that faba bean is one of the most important and drought sensitive grain legumes. This can due to its relatively superficial rooting and its disability to adjust osmotically to water stress.

[13] Theib Oweis et al (2005) reported that the period during which the crop's evaporative demand is high coincides with the end of the rainy season; consequently, faba bean exposed to water stress during the reproductive

growth stage produces poor yields. Limited water supply - through supplemental irrigation can boost and stabilize faba bean production [14] (Manzoor, 2013).

In Tunisia, faba bean is one of the most grown and consumed food legumes and is grown mostly in the north of the country where rainfalls reach more than 400 mm per year in average [15] (Kharrat and Ouchari 2011). The development of faba bean is facing to biotic and abiotic constraints. It is worthy mention that drought is the major problem facing grain legumes production in Tunisia North West semi-arid region. In this situation, supplemental irrigation can improve significantly the crop yield. The objective of this study was to evaluate the influence of supplemental irrigation on yield and yield components of 4 Tunisian faba bean genotypes in order to select the most suitable ones for the Tunisian semi-arid region.

2. Materials and Methods

2.1. Field Experiments and Methodology

Field trials were conducted during the cropping season 2012- 2013 at the research station of Higher Agriculture School of Kef (ESAK) located in a semi-arid zone in north-western Tunisia. The Ombrothermic diagram related to the research location and growing period are shown in Figure 1. Total precipitation for the growing period (from Sepember to May) was 283.2mm. Maximum was registered in October (57.6mm) and minimum in November (11mm). Monthly mean maximum and minimum temperature was recorded in September (22.3°C) and February (7°C) respectively.

The treatments included four faba bean varieties namely Chahbi (*Vicia faba* var. major) and Bachar, Badï, and Local (*Vicia faba* var. minor) (Facor A) and 2 moisture regimes (rain-fed'I0' and supplemental irrigation'I1') (Factor B). For the irrigated plots, two additional irrigations of 20 and 25 mm through sprinkler system were applied at the flowering and pod formation stages respectively.

The experiment was laid out in a randomized complete block design with three replications. The seeding rate and rows spacing was maintained at 120 kg/ha and 50 cm, respectively with row length of 4 m. The experimental fields and experimental units were managed as per the recommended practices for faba bean. The crop was maintained free from weeds, diseases and pests by adopting appropriate plant protection measures. Sowing was made on 14 December 2012.

2.2. Studied Parameters

2.2.1. Relative Water Content (RWC)

Relative water content at flowering (RWCF) and pod formation (RWCP) stages were determined according to [16] Barrs (1968) and as described by [17] Ouji et al, (2016).

Relative water content was calculated from the following equation:

$$\text{RWC\%} = \left[\frac{(\text{fresh weight} - \text{dry weight})}{(\text{turgid weight} - \text{dry weight})}\right] \times 100.$$

2.2.2. Agronomic Parameters

The collected data for biological yield per plant (BY/P), seed number per plant (SN/P), 100-seed weight (100 SW), grain yield per m^2 (GY/m^2), harvest index (HI) and number of days to maturity (NDM) were recorded under rainfed and supplemental irrigation.

Drought susceptibility index (DSI) was used to characterize each genotype in the rain fed condition (stress treatment). Low values of S (S<1) are considered as indicators of high drought tolerance whereas high S values show drought susceptibility as mentioned by [18].

Drought susceptibility index was estimated by the formula suggested by Fischer and Maurer (1978):

DSI= (1 -Yd/Yp)/D. Where, Yd = Grain yield of the genotype under rain fed condition, Yp = Grain yield of the genotype under supplemental irrigation condition.

D= (1 -YD/YP). Where, YD= Mean yield of all genotypes under rain fed condition, YP= mean yield of all genotypes under supplemental irrigation condition.

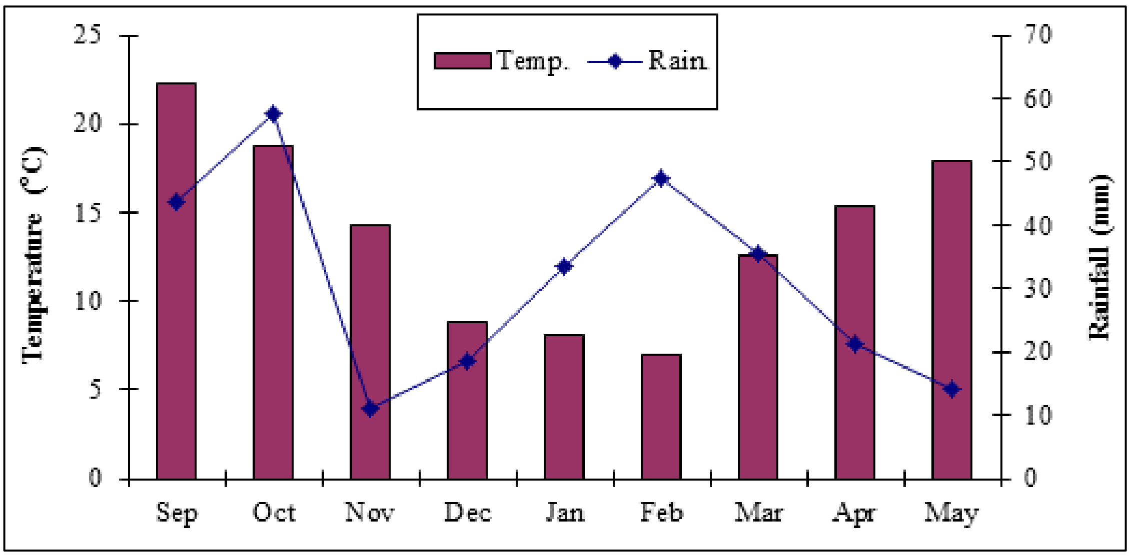

Figure 1. Ombrothermic diagram during 2012/2013 cropping season

2.3. Statistical Analysis

Collected data were subjected to analysis of variance followed by a Duncan test using statistica computer software. A difference was considered to be statistically significant when $P < 0.05$.

3. Results and Discussion

3.1. Relative Water Content (RWC)

Statistical analysis carried out on RWC at flowering and pod formation stages in response to supplemental irrigation revealed a significant difference (p<0.01) among genotypes between drought stress and irrigated condition (Table 1). Thus, faba bean genotypes having been subjected to supplemental irrigation has accumulated more water in its leaves (Figure 2). The relative water content varied markedly as a function of growing stage. Lowest relative water content was recorded under non-irrigated rainfed condition (I1) both at flowering and pod development stages.

In water stress condition, higher values of RWC were recorded in Bachaar faba bean genotype at both flowering and pod development stages (Figure 2). The effect of water stress on relative water content (RWC) varied between genotypes. Indeed, at flowering stage, Chahbi genotype showed a significant increase in RWC under supplemental irrigation. However, Bachar, Badï, and locale genotypes showed no significant change in their RWC under supplemental irrigation treatment. Results observed at pod formation stage showed that RWC of Chahbi and locale genotypes increased. Whereas, relative water content of Bachar and Badï genotypes were not affected. Results showed also that supplemental irrigation has exerted a positive effect on RWC (combined genotypes). This reduction is much greater at pod formation stage. Indeed, during this stage, the percentage of reduction was 18% compared to the irrigated plots.

3.2. Yield and Yield Components

There were significant effect of supplemental irrigation on biological yield (BY/P), seed number per plant (SN/P), 100-seed weight (100 SW), grain yield per m^2 (GY/m^2), harvest index (HI) and number of days to maturity (NDM) (Table 1).

Results shown in Figure 3 showed a clear effect of supplemental irrigation on biological yield. Indeed, results showed that faba bean genotypes significantly gave better biological yields under supplemental irrigation compared to under rain fed condition. Bachaar and Chahbi genotypes comparatively were the highest biological-yielding genotype under rainfed condition and supplemental irrigation respectively. Significant increase of biological yield under supplemental irrigation regime, in both Badii and Chahbi genotypes, was recorded.

Table 1. Analysis of variances for Relative Water Content at flowering (RWC_F), Relative Water Content at pod formation (RWC_P, biological yield per plant (BY/P), seed number per plant (SN/P), 100-seed weight (100 SW), grain yield per m^2 (GY/m^2), harvest index (HI) and number of days to maturity (NDM) of faba bean genotypes grown under rain fed and supplemental irrigation conditions

	Genotype (A)		Treatment (B)		Interaction A*B	
	M.S.	F value	M.S.	F value	M.S.	F value
RWC_F (%)	10,2	0,28ns	662,5	17,8**	15,3	0,41ns
RWC_P (%)	76,4	1,88ns	796,3	19,6**	36	0,88ns
BY/P (g/plant)	30,4	0,82ns	947,9	25,5**	58,3	1,57ns
SN/P	179,6	6,75**	1014	38,1**	104,1	3,91*
100 SW (g)	11968, 5	175,7**	1656,2	24,3**	23,13	0,33ns
GY/m^2 (g/ m^2)	8524,4	5,2*	72001,7	43,9**	3955,7	2,4ns
HI	0,03	2,9ns	0,19	18,01**	0,017	1,66ns
NDM (days)	0,61	0,43ns	181,5	128,1**	3,27	2,31ns

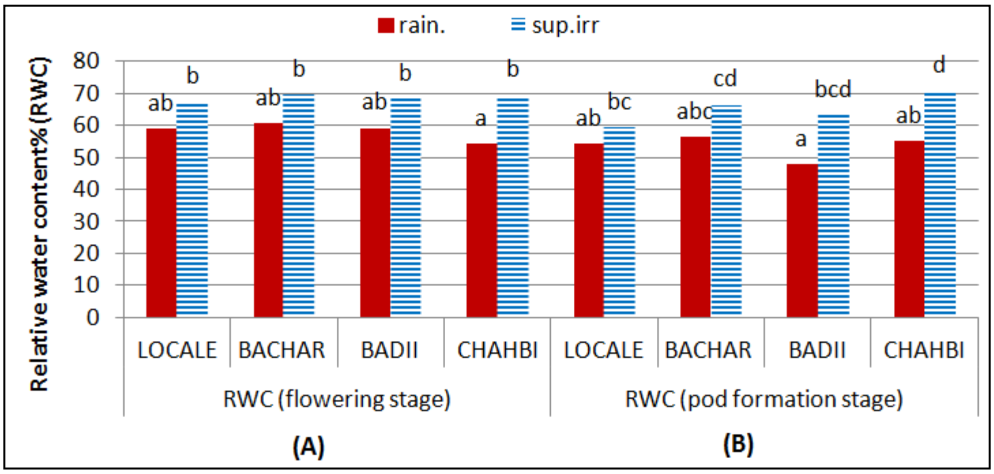

Figure 2. Relative water content (RWC) of faba bean genotypes grown under rain fed and supplemental irrigation conditions (A: at flowering stage, B: at pod development stage)

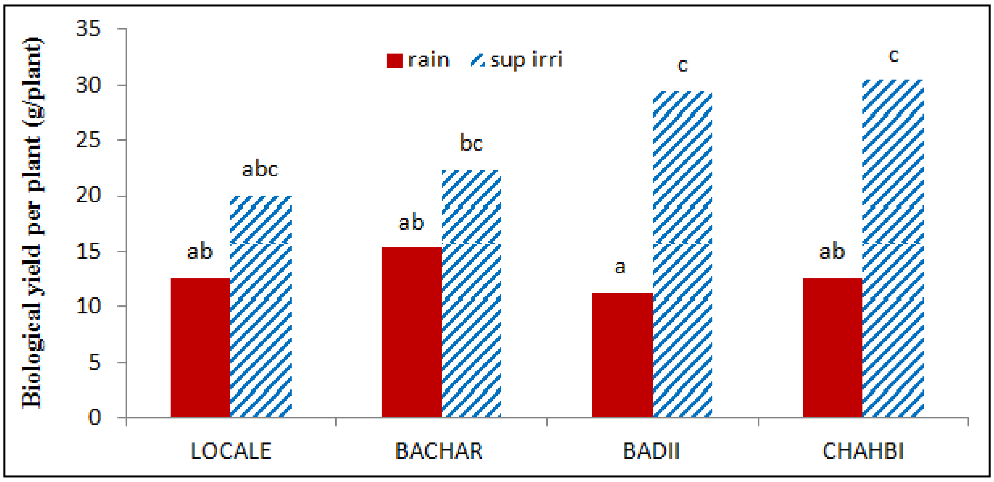

Figure 3. Biological yield (g/plant) of faba bean genotypes grown under rain fed and supplemental irrigation conditions

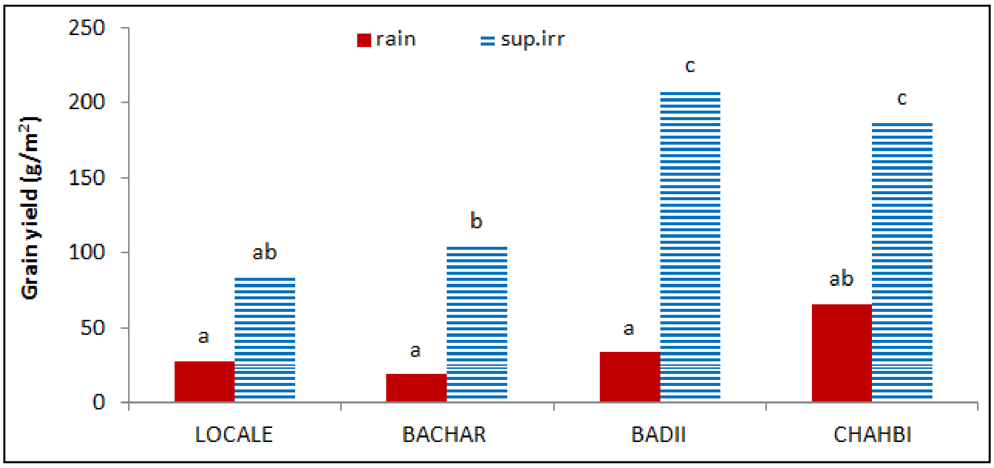

Figure 4. Grain yield of faba bean genotypes grown under rain fed and supplemental irrigation conditions

Table 2. Means of yield components of faba bean genotypes under supplemental irrigation and rain fed conditions

Genotypes	Water regimes	100 SW (g)	SN/P	HI	NDM (days)
Locale	rain fed	23.9a	7a	0.13ab	136.3ab
	Sup. irr	35.4ab	16bc	0.29bc	141.3d
Bachar	rain fed	22.2a	5a	0.1a	134.3a
	Sup. irr	39.8b	19.3c	0.35c	142d
Badii	rain fed	25.1a	7.3ab	0.16ab	136ab
	Sup. irr	41.4b	31.3d	0.42c	141d
Chahbi	rain fed	110.1c	3.7a	0.35c	136.7c
	Sup. irr	131.1d	8.3ab	0.38c	141d
Mean	rain fed	45 .3	5.8	0.18	135.8
	Sup. irr	61.9	18.8	0.36	141.3

The effect of supplemental irrigation regimes on grain yield (calculated as g/m^2) is showed in Figure 4. Grain yields under supplemental irrigation varied from 83.9 to 208.7 g/m^2, and they varied from 18.6 to 65.8 g/m^2 under the drought condition. Average yield reduction due to drought condition was 75.1%. Badii faba bean genotype was the best yielding under supplemental irrigation conditions, while Chahbi faba bean genotype was the best yielding under rainfall condition. Increase of grain yield under supplemental irrigation regime was significant for all faba bean genotype except for locale genotype.

The 100 seeds weight was significantly affected by irrigation (Table 1). Indeed, supplemental irrigation increased the 100-seeds weight (Table 2). 100-seeds weight varied from 19.1% for Chahbi to 79.3% for Bachar genotype, respectively. Average 100-seeds weight increment due to supplemental irrigation condition was 52.8%. The 100-seed weight under supplemental irrigation varied from 35.4 to 131.1 g and from 22.1 to 110.1 g under the drought condition.

Imposition of water stress caused a significant reduction by 33.1% of seed number per plant under rain fed condition as compared to supplemental irrigation (Table 2). Supplemental irrigation increased faba bean seed number per plant. Indeed, the mean seed number per plant observed under rain fed and supplemental irrigation were 2.1 and 6.75, respectively. The seed number per plant varied from 4.3 to 10 and from 2 to 2.3 under supplemental irrigation and under drought condition respectively.

Harvest index (HI) was significantly affected by supplemental irrigation (Table 2). The lowest and the highest harvest index values varied from 0.29 to 0.42 under supplemental irrigation condition and from 0.1 to 0.35 and under drought condition (Table 2). As expected, faba bean harvest index values were lower at low irrigated plots. Based on our results, irrigations improved harvest index. It is interesting to note that the harvest index of Locale and Chahbi genotypes maintained highest values under rain fed as well under supplemental irrigation conditions.

Early maturity is an important trait to avoid drought stress due to the onset of severe water deficits. In the present investigation, days to maturity reduced by 5.5 days (Table 2). Chahbi and Badii genotypes required minimum number of days to maturity under supplemental irrigation (141 days) while under rainfed condition, Bachar and Badii genotypes required minimum number of days to maturity (134.3 and 136, respectively). Yield is the main selection index used under drought stress conditions. DSI values for grain yield (Table 3) ranged from 0.8 to 1.13. Chahbi and locale genotypes were relatively drought resistant (DSI values <1), while Bachar and Badii genotypes were relatively drought susceptible (DSI > 1). Genotypes with low DSI values (less than 1) can be considered to be drought resistant [19] (Bruckner et al, 1987), because they exhibited smaller yield reductions under water stress compared with well-watered conditions than the mean of all genotypes.

[20] Teulat et al. (1997) reported that leaf relative water content can be used as screening techniques for drought resistance in breeding programs. [21] Ashraf et al. (1994) found that genotypes with higher RWC were more droughts tolerant. In the present study, the RWC reduction was recorded under water stress conditions. According to [22] Siddique et al. (2000), drought stress during plant development reduced significantly RWC values. [23] Molnar et al., (2002) mentioned that reduction in RWC has affected the growth and yield of the plants.

The identification of physiological traits responsible for drought tolerance should be considered in the breeding program because grain yield and drought resistance are controlled at independent genetic loci as mentioned by [24] Morgan (1984). So it is necessary to gain knowledge concerning the genetics and physiology of tolerance mechanisms as mentioned by [25] Inoue et al, (2004). The relative water content (RWC) parameter, in particularly, is considered as one of the easiest agricultural parameters that can be used to screen for plants drought tolerance [26] (Boutraa et al, 2010).

Our results showed that drought reduces average yields in faba bean. This is in accordance with study made by [27] Mwanamwenge et al. (1999) who mentioned that drought reduces average yields in faba bean at different stage of plant development, particularly at early podding stage when 50% of faba bean yield reduction can be registered.

[28] Ramirez-Vallejo and Kelly (1998) mentioned that the development of common bean genotypes that are more resistant to water stress is a practical and economical approach to lessen the negative effects of drought on the productivity of this crop.

Drought tolerance is considered as a valid breeding target in the stabilization of crop performance. The sensitivity of grain yield to drought was found to be depended upon the severity of stress and the stage when it was applied. In the current study, seed yield and the yield components were reduced significantly by drought imposed during flowering and pod formation stages. This is in agreement with the study made by [29] Dornbos et al., (1989) who mentioned that water stress reduced seed number per pod and per plant. Moreover, yield and yield components of the plant in drying soil are reduced even in tolerant genotypes.

As faba bean is one of the most drought sensitive according to [30] and [31], any episode of drought during the life cycle of crop may substantially reduce its grain yield as confirmed by [27] Mwanamwenge et al. (1999) and [12] Khan et al. (2010). In this regard, development of drought-tolerant faba bean genotypes is imperative to improve its yield stability under water deficit conditions as considered by [12] Khan et al. (2010). Several studies showed that faba bean yield has been affected negatively by water deficit [27] (Mwanamwenge et al. 1999; [32] Ahmed et al, 2008).

The combined stress at flowering and pod formation stages caused reduction in grain yield. So it would be reasonable to conclude that grain yield is severely reduced if irrigation is not applied at flowering and pod formation.

Table 3. Drought susceptibility index (DSI) of faba bean genotypes

Genotypes	DSI
Locale	0.84
Bachar	1.02
Badii	1.13
Chahbi	0.80

4. Conclusions

This study was conducted to determine the effect of supplemental irrigation on faba bean yield and its components under semiarid climatic conditions. It was concluded that Chahbi proved high yielding and drought tolerant and can be incorporated in stress breeding programme for the development of drought tolerant faba bean varieties.

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