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Genotypic Variability in Faba Bean (*Vicia faba* L.) for Seed Yield and Protein Content under Drought Stress during Vegetative and Reproductive Stages

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Abstract: Faba bean (*Viciafaba* L.) is subjected to drought stress during different growth stages. In this study, variability in seed yield and protein content was investigated when drought occurred during the vegetative and reproductive stages. Twenty-two genotypes of faba bean were field-evaluated under three levels of drought stress at two locations in the Sudan. The three levels of drought were normal watering (non-stress), drought during the vegetative stage and drought during the reproductive stage. Data were collected on yield and vegetative traits and protein content. The results showed that yield, as well as other traits, were reduced by drought. The genotypes exhibited significant differences for 100-seed weight, plant height and protein content. The interaction between the genotypes and drought was significant for yield/plant. Some genotypes were more sensitive when drought occurred during the vegetative stage, some when drought occurred at the reproductive stage, and others were more stable under the three levels of drought. Yield/plant showed significant covariance with pods/plant and plant height. The association between different characters varied according to the trait and the time of drought incidence. The correlation of yield/plant with protein content was negative under all drought levels, and the average correlation coefficient was - 0.32. It could be concluded that the specific adaptation and the wide adaptation have great implication for improving faba bean under drought. To select for high seed yield under drought, secondary characters, such as pods/plant and plant height could be of great importance. Drought could reduce protein content and affect its association with yield/plant.

Key words: Faba bean; genotypic variability; drought; protein; yield

INTRODUCTION

Faba bean (*Vicia faba* L) is one of the main leguminous crops used as a source of protein for animal and human. The crop is grown in autumn in northern Africa, southern Europe, U.K., and south-east China, and in early spring in northern and western China as well as in central and eastern Europe. Faba bean is grown under rain-fed conditions (e.g. in Europe) and irrigation (e. g. in the Nile Valley) and also grown under both systems (in China and in Morocco). Shortage of water leads to yield fluctuation from year to year (Karamanos and Giménez 1991). Like in other crops, drought is one of the most common environmental factors limiting productivity of faba bean (Abdelmula *et al*. 1999; Khan *et al.* 2010).

Crops are subjected to drought stress during different stages of their life cycle; however, certain stages, such as germination and flowering, are the most critical for drought stress damage. In Faba bean, as well as in other crops, drought stress reduces plant growth and causes several morphological and biochemical alterations, due to changes in metabolism and gene expression (Leopold 1990), ultimately leading to loss in yield. The drought tolerance in plants is controlled by certain genes, but these genes are expressed only under particular developmental stages (Mckersie and Leshem 1994). Therefore, the reactions of plants to environmental stresses are complex and involve many kinds of physiological and biochemical responses.

Faba bean is well-known to be unstable in yield, where it gives high yields under favourable conditions but low yields may result from wet conditions due to excessive vegetative growth (indeterminate cultivars), fungal diseases and lodging, or from drought stress (Grashoff 1990a; Karamanos and Giménez 1991). This yield instability leads faba bean breeders to exert great efforts to develop cultivars that are more suitable and adaptable to environmental conditions, particularly drought whose occurrence is unpredictable. Faba bean is reported to be more sensitive to drought after flowering, whereas a mild water shortage during flowering may be preferable to plenty of water in order to limit vegetative growth and stimulate early reproductive growth (Grashoff 1990a). However, some workers reported that it is equally sensitive to drought stress during all developmental phases (Husain *et al*. 1990).

In addition to its effect on yield, drought affects quality traits such as seed protein content. Stressful conditions adversely affect protein metabolism in plants. The level of total as well as soluble proteins is altered in plant growing under water-stressed environments compared with plants growing under non-stressed conditions. Various workers have observed either a decrease (e.g., Gogorcena*et al*. 1995) or an increase (e.g., Kumar and Singh 1991) in the levels of total or soluble proteins in different organs of plants subjected to water stress. In faba beans, wide variation of protein content (20% - 41%) has been reported (Chaven*et al*. 1989).

The consequences of drought on the growth and development of faba bean were determined by watering intervals and the plant stage at which drought occurred (Younise 2002). Research on the different responses of faba bean genotypes to different drought treatments is lacking; however, some investigations had been carried out on a small number of genotypes, e. g. (Grashoff 1990b). Faba bean genotypes showed genetic variability in response and sensitivity to terminal drought (Abdelmula*et al*. 1999; Link *et al*. 1999); therefore, the investigation of pattern of genotypes reaction to drought at different growth stages is becoming more important and of interest.

The objectives of this study were (1) to determine the genetic variability for yield, yield components and protein when drought occurs at vegetative and at reproductive stages, (2) to identify secondary traits that can be used as selection criteria for drought tolerance, and (3) to detect genotypes that could combine high yield and high protein content under drought.

MATERIALS AND METHODS

Twenty-two genotypes of faba bean were used in this study. These were locally originated advanced breeding lines and two released commercial varieties, used as check varieties (Table 1). Most of these genotypes were developed in the Northern State and River Nile State of Sudan, either by selection in crosses carried out at Hudeiba Research Station or by selection in different faba bean traditional production areas. The genotypes were evaluated for drought tolerance at two locations in Sudan: Shambat (Lat. 15^0 40` N., Long. 32^0 32’ E., and 380 m above sea level) and Hudeiba (Lat. 17^0 34’ N., long. 33^0 56’ E., and 350 m above sea level). The experiments were carried out during the winter season of 2001/2002.

To induce drought stress, three water treatments were applied as follows:

1. Irrigating every seven days throughout the growing season (non-stress, NS).
2. Irrigating every 14 days during the vegetative stage until end of flowering, then irrigating every seven days during the reproductive stage till maturity (drought in the vegetative stage, DV).
3. Irrigating every seven days during the vegetative stage until end of flowering, then irrigating every 14 days during the reproductive stage till maturity (drought in the reproductive stage, DR).

A split plot design was used with three replications, and the water treatments were assigned randomly to the main plots, while the genotypes were allocated randomly to the sub-plots.

Sowing and cultural practices

Every genotype was grown on both sides of the ridge, which was three metres in length, at a rate of two seeds per hole, spaced at 20 cm between holes and 60 cm between ridges. Sowing date was 13 Nov. 2001 at Shambat and 6 Nov. 2001 at Hudeiba. Water treatments and the total number of irrigations are given in Table 2. The crop received three irrigations with interval of seven days for establishment. At Shambat, weeding was carried out twice by hand hoeing; and at Hudeiba, graminae herbicide (2,4-D) was sprayed before the first irrigation, and hand hoeing was used only once. At Shambat, the crop was first sprayed twice with folimat against thrips (*Echinothripsamericanus*), leaf minor (*Laphigmaexigua*) and aphids (*Aphis fabae*); and late in the season, another spray with perimore was applied against aphids (*Aphis fabae*).

Table 1. The 22 faba bean genotypes tested for drought tolerance at Shambat and Hudeiba, Sudan, during the season 2001/02

Code	Name	Origin	100-seed weight (g)	Yield/plant (g)
1	PM/1	BaladiMussiab	48.4	13.0
2	C86	From a cross in Hudeiba*	54.0	12.4
3	C34	From a cross in Hudeiba	49.6	13.6
4	C52/1/1/1	From a cross in Hudeiba	49.9	13.1
5	C28	From a cross in Hudeiba	49.5	13.9
6	Daba1/1	Daba	50.7	14.7
7	F402/7	Egyptian line	50.4	12.6
8	C80/1	From a cross in Hudeiba	46.8	13.4
9	C36	From a cross in Hudeiba	44.4	14.3
10	SuperL85	Dongola	47.9	13.2
11	DE2	Dem El-Garrai	44.6	13.4
12	Bulk1/2	Bulk of cross in Hudeiba	49.0	15.1
13	C22	From a cross in Hudeiba	50.9	13.4
14	C42/1/1/1	From a cross in Hudeiba	57.6	12.0
15	BB25	Basabeer	54.0	13.3
16	Golid1	Golid	54.2	12.4
17	ZBF/1/1	Zeidab	49.9	13.0
18	Berber1	Berber	43.7	12.2
19	Mass55	Mass selection from Hudeiba	49.1	14.3
20	C42	From a cross in Hudeiba	53.7	12.1
21	BB7	Basabeer (check variety)	49.8	14.4
22	H93	Hudeiba (check variety)	50.0	13.9

*Hudeiba refers to Hudeiba Research Station, Edamar, River Nile State, Sudan. Other names refer to locations in the River Nile and Northern States.

Table 2. Number of waterings given for each treatment at Shambat and Hudeiba, Sudan, during the season 2001/02

Water treatments	Location		Mean
	Shambat	Hudeiba	
NS	16	17	16.5
DV	12	14	13
DR	13	12	12.5
Total	41	43	
Mean	13.7	14.3	

NS = Non-stress, DV = Drought at vegetative stage, DR = Drought at reproductive stage

Data collection and statistical analysis

Ten randomly selected plants per each subplot at Shambat and Hudeiba were used for data collection. The data were recorded on the following traits.

A) Yield traits:

1- Seed yield/ha; determined from the total yield of the subplot.
2- Seed yield/plant
3- Number of podded nodes/plant
4- Number of pods/podded node
5- Number of pods/plant
6- Number of seeds/pod
7- Number of seeds/plant
8- 100-seed weight

B) Vegetative traits:

1- Plant biomass, i.e. total weight of the straw and seeds per plant
2- Harvest index
3- Plant height at maturity
4- Number of branches/plant
5- Days to 50% flowering, i.e. the number of days from sowing to the day when 50% of the plants in the subplot started to flower.
6- Days to 75% maturity, i.e. the number of days from sowing to the day when 75% of the plants in the subplot reached maturity

C) Quality traits:

Protein quantity was determined by the Infra-red-spectroscopy (NIRS) at the Institute of Agronomy and Plant Breeding of the University of Georg-August at Goettingen (Germany), during 2003/2004. The samples were milled and then the spectra were measured and identified. These spectra were used to develop a calibration to estimate the protein content.

Combined analyses of variance and covariance were carried out, and the results of the covariance are presented only for those traits that showed significant co-variation between genotypes and treatments. Correlations between all the studied characters were estimated under the different drought treatments, and only the results for some traits are given in this paper.

RESULTS

Effect of drought

Variability between locations: There was no significant difference in temperature between the two locations (Table 3), but they differed in relative humidity (41.2% at Hudieba and 21.3% at Shambat). The two locations showed significant differences for all the traits except plant height (Table 4). Drought during the vegetative stage reduced mean seed yield/plant by 21% at Shambat and by 6% at Hudeiba, while drought during the reproductive stage reduced mean seed yield/plant by 16% at Shambat and by 3% at Hudieba (data not shown).
The genotypes exhibited significant differences in 100-seed weight/ plant, plant height and protein content (Table 4). The interaction between treatments and the genotypes was significant only for yield/plant.

The results of covariance are presented only for those traits that showed significant co-variation between genotypes and treatments, e. g. yield/plant which showed strong and significant covariance with plant height under all water treatments (Table 5), and the phenotypic correlation was r = 0.43. For yield/plant and pods/plant, the covariance was highly significant for genotypes, interactions of genotypes with locations and treatments (Table 5), and the phenotypic correlation was r=0.67. Protein content and number of branches/plant exhibited highly significant covariance for the interaction of genotypes with treatments, and the correlation was r = 0.45.

Table 3. Means of temperature and relative humidity per month at Shambat and Hudeiba, Sudan, during the season 2001/02

Month	Temperature (^{0}C)		Relative humidity (%)	
	Shambat	Hudeiba	Shambat	Hudeiba
November	27.1	28.2	27.0	42.0
December	25.3	24.4	32.0	45.0
January	21.7	19.6	25.0	44.0
February	24.9	24.3	24.0	46.0
March	27.3	27.3	26.0	29.0
Mean	25.2	24.7	24.8	41.2

Table 4. Variance components for different traits due to location (L), irrigation treatment (T), interaction (LxT), genotype (G), interactions (GxL, GxT) of 22 faba bean genotypes

Trait	Variance component					
	L	T	LxT	G	GxL	GxT
DF	1	2	2	21	21	42
Yield/plant (g)	2.02*	0.59	0.60*	0.28	0.34	0.41*
100-seed weight (g)	27.40**	2.77	1.19*	10.93**	0.17	0.57
Maturity (days)	23.59**	4.42	6.57*	0.02	-0.07	0.02
Plant height (cm)	10.43	42.77	31.04*	5.60**	0.08	0.35
Protein (%)	0.25*	0.05	0.11	0.24**	-0.02	-0.02

*, ** =Significant at 5% and 1% levels, respectively

Table 5. Analysis of covariance due to treatment (T), genotype (G), interaction of genotype by location (GL) and GT, and phenotypic correlations of some traits of 22 faba bean genotypes

Trait		Covariance component				Correlation
		T	G	GL	GT	
	DF	2	21	21	42	
Yield/plant vs. plant height		3.745	0.458	-0.204	0.634**	r = 0.43 **
Yield/plant vs. pods/plant		0.350	0.441**	0.168**	0.197**	r = 0.67 **
Protein (%) vs. branches/plant		0.008	0.007	0.013	0.016**	r = 0.45 **

*, ** =Significant at 5% and 1% levels, respectively

Generally, higher values of yield/plant, 100-seed weight and protein content were exhibited at Hudeiba under drought-stress as well as under non-stress conditions (Table 6). On the other hand, higher reduction in maturity due to drought was obtained at Hudieba than at Shambat. The pattern of reduction varied depending on the growth stage and the character. Some characters showed more reduction when drought occurred earlier during the vegetative stage, e. g. yield/plant, and plant height about. Other characters, e. g. 100-seed weight, days to maturity and protein content, were more reduced when drought occurred terminally at the reproductive stage (Table 6).

Performance of the genotypes under drought: The genotypes exhibited variation in yield/plant under different water treatments (Fig. 1). Some were more sensitive to drought and their yield was highly reduced when drought stress occurred at the two growth stages, e. g. C80/1, and SuperL85. Some genotypes were more stable under the two drought conditions, e. g. Bulk1/2 and ZBF/1/1, and C28 and C34 were affected only when drought occurred at the vegetative stage. DE2 and F402/7 were affected only when drought occurred at the reproductive stage. Comparatively, some of these advanced breeding lines showed superiority over the two check varieties (BB7 and H93) in yield and yield stability under both drought conditions, e. g. Bulk1/2 (Fig. 1). However, some genotypes exhibited transgressive effect for yield when drought occurred at vegetative (e. g. Bulk1/2) and at reproductive (e. g. BB7) stages.

The variation in the performance of genotypes in response to drought treatments resulted in different estimates of broad-sense heritability for yield/plant. Similar values were obtained under non-stress ($h^2 = 0.48$) and when drought occurred during the reproductive stage ($h^2 = 0.46$). Low estimate ($h^2 = 0.16$) was obtained when drought occurred at the vegetative stage. The genotypes also exhibited variation in protein content due to drought effect (Fig. 2), however, some of them showed almost stable protein content when drought occurred at both growth stages, e. g. ZBF1/1 and Bulk1/2.

Correlation between traits

Yield under drought vs. yield under non-stress: The association of yield under non-stress with yield under drought treatments (DV and DR) of all genotypes is given in Fig. 3. When drought occurred at the vegetative stage (Fig. 3a), the correlation was very low (r = 0.09) and non-significant. Bulk1/2 and BB7 gave higher yield/plant when drought was during the vegetative stage as well as under non-stress conditions. On the other hand, C80/1 and SuperL85 were higher yielding only under non-stress conditions. The correlation between yield under non-stress condition and yield when drought was during the reproductive stage (Fig. 3b) was positive (r = 0.33) but non-significant. C36 and BB7 gave higher yields under terminal drought and reasonably high yield under non-stress condition.

Table 6. The mean performance of 22 faba bean genotypes for different traits evaluated under all water treatments: The non-stress (NS), and when drought was applied at vegetative (DV) and reproductive (DR) growth stages, at Shambat and Hudeiba, Sudan

Location	Water treatment	Trait				
		Yield/ plant (g)	100-seed weight (g)	Plant height (cm)	Maturity (days)	Protein (%)
Shambat	NS	14.0	47.6	86.1	103.8	30.63
	DV	11.0	47.8	65.2	105.7	29.87
	DR	11.8	43.0	86.0	96.8	30.00
	Mean	12.3	46.1	79.1	102.1	30.17
	LSD (0.05)	1.5	3.0	8.7	1.9	1.01
Hudeiba	NS	14.8	54.1	85.7	96.7	31.12
	DV	14.0	54.3	80.0	95.0	31.28
	DR	14.4	52.4	86.7	93.9	30.32
	Mean	14.4	53.6	84.1	95.2	30.91
	LSD (0.05)	1.7	0.1	9.2	5.2	0.88

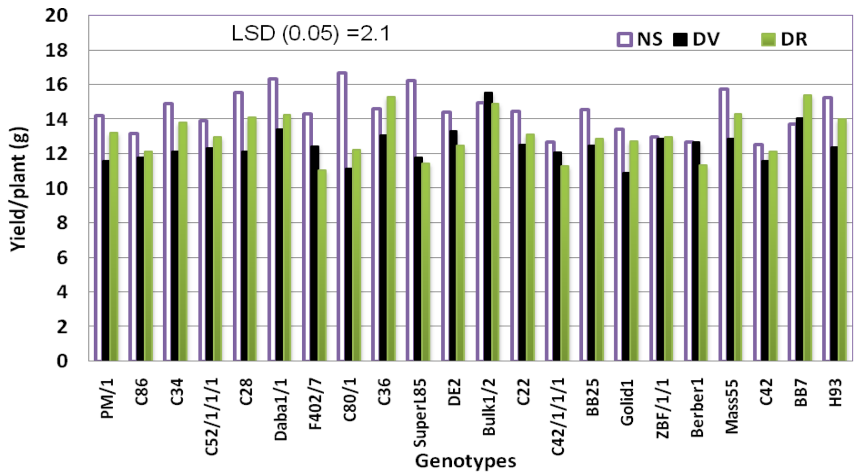

Fig. 1. Yield/plant of 22 faba bean genotypes determined under three drought conditions (NS, DV, DR), averaged over two locations

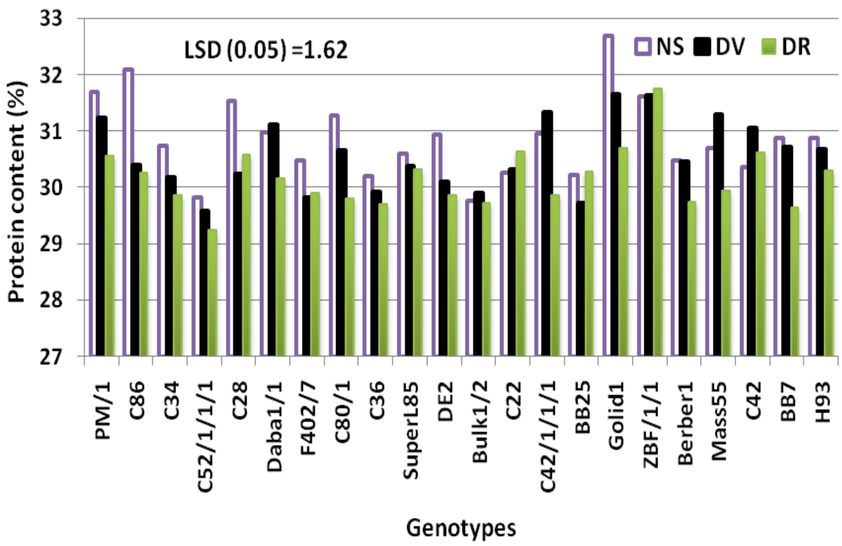

Fig. 2. Protein content (%) of 22 faba bean genotypes determined under three drought conditions (NS, DV and DR), averaged over two locations

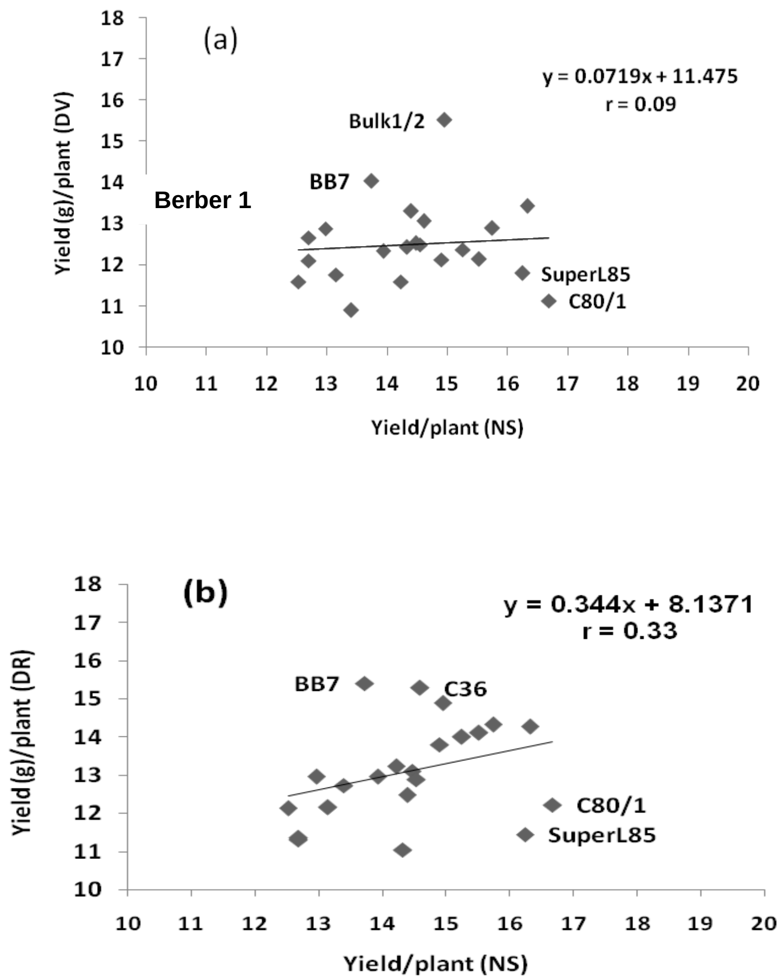

Fig. 3. Correlation of yield under non-stress condition (NS) with yield when drought was applied at the vegetative stage (a) and at th reproductive stage (b) of 22 genotypes of faba bean.

Association between yield and other traits: Generally, the association between the studied characters varied depending on the water treatment and the character itself (Table 7). Yield/plant showed negative, but non-significant correlation, with 100-seed weight and was higher when drought was applied at the vegetative stage. Similar trend of correlation was observed between yield/plant and protein content. Positive and significant correlation (r = 0.47) was obtained between yield/plant and plant height under non-stress condition, and the association was lower when drought occurred at the reproductive stage. There was almost no correlation (r =0.08) between yield/plant and days to maturity under non-stress conditions, however, it was positive and non-significant under DR and negative under DV.

One hundred seed weight exhibited positive and significant correlation (r = 0.50) with maturity under DV, and very low negative association under NS and DR conditions. Positive non-significant correlations were obtained between 100-seed weight and protein content under all conditions (NS, DV and DR). Maturity showed a strong positive and highly significant (r = 0.62) association with plant height under DR and positive non-significant (r = 0.39) with protein content under DV. The correlation of plant height with protein content was positive, but non-significant and was higher under DV.

Association between yield and protein content: The correlation of yield/plant with protein content was negative under all water treatments (Table 7). The average correlation across all treatments was negative (r = - 0.32). The genotypes that expressed high seed protein content were low-yielding, e. g., Golid1 and those with high yields were low in protein content, e.g. Bulk1/2. However, there were some genotypes with high protein content and considerably high yield, e.g. ZBF/1/1 and PM/1 (Fig. 4).

Table 7. Correlation coefficients between some traits of faba bean genotypes, averaged over all water treatments (AV), under non-stress (NS), and when drought was applied at vegetative (DV) and reproductive (DR) growth stages

Trait		Trait			
		100-seed wgt (g)	Maturity (days)	Plant height(cm)	Protein (%)
Yield/plant (g)	AV	-0.81**	-0.03	0.24	-0.32
	NS	-0.32	0.08	0.47*	-0.12
	DV	-0.36	-0.34	0.24	-0.29
	DR	-0.16	0.30	0.22	-0.12
100-seed wgt (g)	AV		0.30	-0.11	0.30
	NS		-0.14	-0.06	0.21
	DV		0.50*	-0.02	0.26
	DR		-0.02	-0.13	0.35
Maturity (days)	AV			0.26	0.31
	NS			0.07	0.05
	DV			-0.07	0.39
	DR			0.62**	-0.12
Plant height (cm)	AV				0.11
	NS				0.13
	DV				0.21
	DR				0.04

*, ** = Significant at 5% and 1% level, respectively

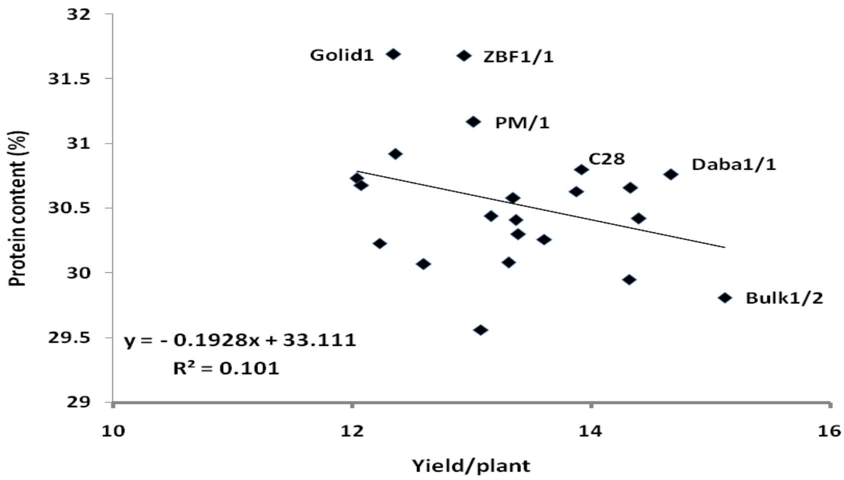

Fig. 4. Correlation of yield/plant (g) with protein content (%) of 22 genotypes of faba bean

DISCUSSION

Environments and effect of drought

The environmental variation between Shambat and Hudeiba was reflected in the effect and severity of drought stress in reducing yield/plant. This indicates that the effect of drought could be modified and influenced by the prevailing environmental conditions. This was confirmed by the significant interaction of drought treatments and locations for most of the studied traits. The main causes of this variation were humidity and the onset and duration of winter in Hudeiba, where it is usually cooler and longer, compared with Shambat. Therefore, the environmental conditions at Hudeiba made the adverse effect of drought less severe, leading to low reductions in yield under both drought conditions, compared with Shambat location. Similar variable effects of environments on yield of faba bean were reported by Abdelmula *et al*. (1999). Such findings were obtained by Ceccarelli and Grando (1996) who indicated that drought stress interacts with other biotic and abiotic environmental factors and stresses.

The higher and pronounced reduction of yield/plant and other traits when drought occurred during the vegetative stage could be attributed to the fact that in faba bean water shortage during the vegetative stage affects mainly the leaf area. The effect on yield becomes severe because the young flowers and young pods are weaker sinks for assimilates in comparison with other plant organs (Karamanos and Giménez 1991). Therefore, the consequences of a possible shortage of assimilates at the initial stages of flowering and pod setting will be more severe on the reproductive organs, and it is the main cause of poor fruit setting and consequently low seed yield. Karamanos and Giménez (1991) reported that water shortage increases flower and pod abortion, and the partition of dry matter to the reproductive organs is restricted by an intense intra-plant competition between the reproductive and the vegetative organs. However, 100-seed weight and protein content were more reduced when drought was terminal. Grashoff (1990a) reported that mild water shortage during flowering has a positive effect on the development of an early and strong reproductive sink, and after flowering a high water supply is important to support the assimilate requirements of that reproductive sink, which is the seed filling.

Differences in response to drought

The observed variable yield responses of genotypes to drought could be attributed to the differences in drought tolerance mechanisms such as plant phenology, early plant vigour and shoot and root characteristics (Subbaro *et al*. 1995). In this study, some genotypes exhibited no changes due to incidence of drought, e.g. Bulk1/2 and ZBF/1/1. This indicates that these genotypes possess genes for wide adaptation and for drought tolerance at both vegetative and reproductive stages. This stability can be ascribed by the ability of these two genotypes to respond to the actual environmental conditions by producing the particularly best adapted phenotype. Examples of this could be drought-induced early maturity combined with the ability to extend the growth duration and produce higher yields in wet seasons (Ludlow and Muchow 1990), or plasticity in the depth of root proliferation as a function of seasonal rainfall (Specht and Laing 1993). Generally, it should be pointed out that different combinations of adaptation traits are likely to confer high yields under different stress conditions (Ceccarelli *et al*. 1991).

Although the correlation between the reductions in yield of genotypes under both drought stresses (DV and DR) was high (r = 0.73), there were some genotypes that exhibited specific adaptations or drought tolerance when drought occurred during either the vegetative (Berber1, in Fig. 3a) or the reproductive (C36, in Fig. 3b) stage. This specific adaptation increases the choice of the optimum environment for selection, like non-stress *versus* drought during the vegetative, or non-stress *versus* drought during the reproductive stage. Nevertheless, the estimated values of heritability for yield under these drought conditions were variable, and were much reduced when drought was applied at the vegetative stage, which is indicative of the severity of drought at this stage. This low heritability under drought was also reported by Abdelmula *et al*. (1999) in faba bean.

Correlation of yield with other traits

The low correlation coefficient (r = 0.09) between yield/plant under non-stress and when drought was during the vegetative stage is indicative of large interaction between genotypes and the drought stress. This high genotype x environment interaction could be attributed to the severity of drought induced during this stage, in comparison with that when drought occurred during the reproductive stage. Similar results were reported by Ceccarelli (1994), where the association between yield under drought condition and potential yield decreased under more severe stress conditions. However, this relationship was variable depending on the genetic structure of the population used (Abdelmula *et al*.1999). The positive correlation between yield/plant under non-stress with yield under drought during the reproductive stage indicates the presence of some common genes that control yield under both contrasting environmental conditions.

The reduction of yield and plant height due to drought were highly correlated under both drought conditions, and the covariance was significant, showing phenotypic correlation of r = 0.63. This strong correlation under stress and non-stress conditions supports the use of plant height as a secondary selection trait for high yield under drought condition. Similar strong correlation of reduction of number of pods/plant with that of yield due to drought leads to the conclusion that the number of pods/plant should be an important selection criterion for yield in faba bean under drought conditions as well as under non-stress conditions. The importance of number of pods in improving yield of faba bean was reported by De Costa *et al*. (1997) and Loss *et al*. (1997).

The association between other traits was highly influenced by environment. It depends on the trait and time of drought incidence and the trend of correlation under drought could be variable in magnitude, significance and direction according to the severity of stress and the developmental pattern of the trait. This is attributed to the fact that the balance of assimilate supply and partitioning of dry matter among the various organs in faba bean is very sensitive to environmental stress, especially water availability (Grashoff 1990b; Karamanos and Giménez 1991). This variation in association between traits can be observed in the significant positive association of maturity with 100-seed weight (r = 0.50) at DV, and with plant height (r = 0.62) at DR, where there was no association under the other water treatments (Table 7).

Seed protein content was negatively correlated with yield /plant under all drought conditions, but strongly when drought occurred at the vegetative stage. Negative association between yield and seed protein in legumes was obtained by Helms and Orf (1998), who found that selection for increased protein content resulted in decreased yield in soybean. Protein concentration is influenced by both genetic and environmental factors, and its inheritance is additive with some partial dominance (Bond *et al*. 1985). Although the genotypes that were high in seed protein content were low in yield, there were some genotypes that combine high protein and a considerable high yield, like ZBF/1/1 and PM/1.

CONCLUSION

The specific adaptation of faba bean has great implication for its improvement under drought conditions, because of the interaction between genotypes and drought. Accordingly, some genotypes may be selected to be grown only in areas characterized by either early drought during the vegetative stage (e.g. Berber1) or by terminal drought during the reproductive stage (e.g. C36). However, some genotypes, e. g. Bulk1/2, had wide adaptation and showed tolerance to early and terminal drought as well as relatively high yield under non-stress conditions compared with the check varieties (BB7 and H93). Such genotype is of great importance to be grown in areas suffering from unpredictable drought periods. To select for high seed yield under drought, secondary characters such as plant height and number of pods/plant could be used. Seed protein content in faba bean is reduced due to drought, especially under terminal drought stress and also its association with yield could be altered, according to time of drought incidence.

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REFERENCES

Abdelmula, A.A.; Link, W.; Kittlitz, E. von. andStelling, D. (1999). Heterosis and inheritance of drought tolerance in faba bean, *Vicia faba* L. *Plant Breeding* 118, 485-490

Bond, D.A.; Lawes D.A.; Hawtin, G.C.; Saxena, M.C. and Stephens, J.S. (1985).Faba bean (*Vicia faba* L.), pp. 199-265. In: R.J. Summerfield and E.H. Roberts (Edts.), *Grain Legume Crops*. William Collins Sons Co. Ltd. 8 Grafton Street, London, WIX 3LA, U.K.

Ceccarelli.S. (1994). Specific adaptation and breeding for marginal conditions. *Euphytica* 77, 205-219.

Ceccarelli, S. and Grando, S. (1996). Drought as a challenge for the breeder..*Plant Growth Regulation* 20, 149-155.

Ceccarelli, S.; Acevedo, E. and Grando, S. (1991). Breeding for yield stability in unpredictable environments: single traits, interaction between traits, and architecture of genotypes.*Euphytica* 56, 169-185.

Chaven, J.K.; Kute, L.S. and Kadam, S.S. (1989). In: *CRC Handbook of World Legumes*, pp. 223-245. D.D. Salunkhe and S. S. Kadam (Edts.), Boca Raton, Florida, U.S.A. :CRC Press

De Costa, W.A.J.M.; Dennet, M.D.; Ratnaweera, U. and Nyalemegbe, K. (1997). Effects of different water regimes on field-grown determinate and indeterminate faba bean (*Vicia faba* L.). II. Yield and yield components and harvest index. *Field Crops Research* 52, 169-178.

Gogorcena, Y.; Iturbeormaetxe, I.; Escuredo, P.R. and Becana, M. (1995). Antioxidant defences against activated oxygen in pea nodules subjected to water stress. *Plant Physiology* 108, 753-759.

Grashoff. C. (1990a). Effect of pattern of water supply on *Vicia faba* L. 1. Dry matter partitioning and yield variability. *Netherlands Journal of Agricultural Science* 38, 21-44.

Grashoff, C. (1990b). Effect of pattern of water supply on *Vicia faba* L. 2. Pod retention and filling, and dry matter partitioning, production and water use. *Netherlands Journal of Agricultural Science* 38, 131-143.

Helms, T.C. and Orf, J.H. (1998). Protein, oil, and yield of soybean lines selected for increased protein. *Crop Science* 38, 707-711.

Husain. M.M.; Reid. J.B.; Othman, H. and Gallagher J.N. (1990). Growth and water use of faba beans (*Vicia faba* L.) in a sub-humid climate. I. Root and shoot adaptations to drought stress. *Field Crops Research* 23, 1-17.

Karamanos, A.J. and Giménez, C. (1991). Physiological factors limiting growth and yield of faba beans. Options Méditerranéennes - SérieSéminaires - n.O, 10.79-90.

Khan, H.R.; Puall, J.G.; Siddique, K.H.M. and Stoddard, F.L. (2010).Faba bean breeding for drought-affected environments: A physiological and agronomic perspective. *Field Crop Research* 115, 279-286.

Kumar, P.K., and Singh, R.A. (1991). Germination and metabolism in susceptible and tolerant mung bean genotypes under moisture stress. *Indian Journal of Plant Physiology* 34, 267-270.

Link, W.; Abdelmula, A.A.; Kittlitz, E. von; Bruns, S.; Riemer, H. andStelling, D. (1999).Genotypic variation for drought tolerance in *Vicia faba*L.*Plant Breeding* 118, 477-483.

Leopold, A.C. (1990). Coping with desiccation. In: R.G. Alscher. andJ. R. Cumming (Edts.), *Stress Responses in Plants*: *Adaptation and Acclimation Mechanisms*. New York, Wily-Liss,pp, 37-56.

Loss, S.P.; Siddique, K.H.M. and Martin, L.D. (1997). Adaptation of faba bean (*Viciafaba* L.) to dry Mediterranean-type environments. II. Phenology, canopy development, radiation absorption and biomass partitioning. *Field Crops Research* 54, 29-41

Ludlow, M.M. and Muchow, R.C. (1990). A critical evaluation of traits for improving crop yields in water-limited environments. *Advances in Agronomy* 43, 107-152.

Mckersie, B.D. and Leshem, Y.Y. (1994).Desiccation.In: B.D. Mckersie and Y. Y. Leshem (Edts.). *Stress and Stress Coping in Cultivated Plants*, pp. 132-144. Kluwer Academic Publishers. The Netherlands.

Specht, J.E. and Laing, D.R. (1993). Selection for tolerance to abiotic stresses: Discussions. pp 381-382 In: Bruxton, D.R., Shibles, R., Forsberg, R.A., Blad, B.L., Asay, K.H., Paulsen, G.M. and Wilson, R.F. (Edts.) *International Crop Science* 1, Crop Society of America, Madison, Wisconsin, U.S.A.

Subbaro, G.V.C.; Johansen, A.E.; Slinkard, R.C.; Nagesware R.; Saxena, N.P. and Chauhan, Y.S. (1995). Strategies for improving drought resistance in grain legumes. *Critical Reviews in Plant Sciences* 14, 469-523.

Younise, I.D. (2002). *Effect of Water Stress at Different Growth Stages on Growth and Productivity of Faba Bean (Vicia faba* L.*)* .M.Sc. thesis. University of Khartoum, Sudan.

التباين الوراثي في محصول الفول المصري للإنتاجية ومحتوى البروتين تحت ظروف الإجهاد المائي أثناء الطور الخضري والطور الثمري

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المستخلص: يتعرض محصول الفول المصري للإجهاد المائي اثناء أطوار نموه المختلفة. في هذا البحث تمت دراسة التباين الوراثي للإنتاجية والمحتوى من البروتين عند حدوث إجهاد مائي في الطور الخضري و الطور الثمري. تم تقييم 22 طرازاً وراثياً لمحصول الفول المصري في الحقل تحت ثلاثة مستويات من الإجهاد المائي وذلك في موقعين بالسودان. وكانت الثلاثة مستويات من الإجهاد المائي كالآتي: ري طبيعي (بدون إجهاد)، و إجهاد مائي اثناء الطور الخضري، وإجهاد مائي اثناء الطور الثمري. جمعت بيانات عن الإنتاجية والصفات الخضرية ومحتوى البروتين. اظهرت النتائج ان هنالك نقصاً في الإنتاجية وفي الصفات الاخرى بسبب الإجهاد المائي. اظهرت الطرز الوراثية إختلافات معنوية في صفات المائة حبة وطول النبات والمحتوى من البروتين. وكان التفاعل بين الطرز الوراثية والإجهاد المائي معنوياً للإنتاجية/النبات. بعض الطرز الوراثية كانت حساسة عندما كان الإجهاد المائي اثناء الطور الخضري، والبعض عندما كان الإجهاد المائي اثناء الطور الثمري، بينما كان أداء بعض الطرز الوراثية ثابتاً تحت الثلاثة مستويات من الإجهاد المائي . اظهرت صفة الإنتاجية/النبات تبايناً مشتركاً معنوياً مع صفتي عدد القرون/النبات وطول النبات. وقد اختلف الإرتباط بين الصفات تبعاً للصفة والوقت الذي حدث فيه الإجهاد المائي. وكان إرتباط الإنتاجية/النبات مع المحتوى من البروتين سالباً تحت كل مستويات الإجهاد

المائي، وكان متوسط معامل الإرتباط بينهما 0.32. يمكن الإستنتاج أن للتأقلم الخاص والواسع تأثيرات كبيرة على تحسين محصول الفول المصري تحت ظروف الإجهاد المائي. وعند الإنتخاب لرفع الإنتاجية تحت الإجهاد المائي، تكتسب الصفات الثانوية مثل عدد القرون/النبات وطول النبات أهمية كبيرة. قد يؤدي الإجهاد المائي الى نقص محتوى البروتين ويؤثر على إرتباطه بالإنتاجية/النبات.