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USE OF GENETIC VARIABILITY ESTIMATES AND INTERRELATIONSHIPS OF AGRONOMIC AND BIOCHEMICAL CHARACTERS FOR SELECTION OF LUPIN GENOTYPES UNDER DIFFERENT IRRIGATION REGIMES

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ABSTRACT

Lupin is important grain legume crop and component of the sustainable farming system of the Mediterranean climate region. Low yield and lack of stability of currently registered varieties make white lupin acreage is small. Therefore, the relationships among grain yield and its components are controversial subjects in agronomic studies, especially under stress conditions. Five genotypes of yellow lupinus were tested in 2-year field trials (2008/2009 and 2009/2010) under two watering regimes: fully irrigated (W_0) and water stress (W_s), and two inoculation treatments (commercial inoculation and un-inoculation). The objective was to evaluate the responses of 11 agronomic and biochemical traits to water stress based on estimation of genetic parameters and contribution to seed yield. Results showed that, all traits were significantly affected by irrigation treatments, except number of primary branches and 100 seed weight under W_0, and number of primary branches and pods plant^{-1} under W_s. According to the analysis of linear regression of the measured traits against seed yield per ha, nodule dry weight, root dry weight, pods plant^{-1} and 100-seed weights with the greatest genotypic variation, contributed the highest to drought tolerance. However, the contribution of catalase (CAT) was higher under Ws compared to Peroxides POD. The values of phenotypic coefficient of variation in Ws were higher than the corresponding genotypic coefficient of variation values for all characters, but the differences between them were low for all traits. Catalase and peroxidase activity, seed yield, root and nodule dry weight showed high genetic advance (GA%) and heritability estimates. Drought tolerance index (DTI) and geometric mean (GM) were found to be effective indices for selection of superior drought-tolerant genotype (LR1) with good yield potential under both conditions. Genotype-by-trait biplot analysis showed that, all measured traits had strong positive effects on yield hectare^{-1} under Ws conditions, except protein percentage and branches plant^{-1}.

Key Words: Biplot, drought stress, *Lupinus albus*

RÉSUMÉ

Le lupin constitue une importante graine de légumineuses et un composant d'un système d'agriculture durable de la région climatique méditeranéenne. Le rendement bas ainsi que le manque de stabilité des variétés utilisées font que le lupin blanc soit pratiqué sur de petites étendues. Cependant, les relations entre le rendement en grains et ses composants sont des sujets controversants dans des études agronomiques, spécialement en conditions de stress. Des essais étaient conduits en champs sur cinq génotypes des lupins jaunes pendant deux ans (2008/2009 and 2009/2010) avec deux regimes d'arrosage: irrigué completement (W0) et stress hydrique (Ws), ainsi que deux traitements avec inoculation (inoculation commerciale et témoins sans inoculation). L'objectif était d'évaluer les réponses de 11 traits agronomiques et biochimiques au stress hydrique en se basant sur des paramètres génétiques et le rendement en grains. Les résultats ont montré que tous les traits étaient significativement affectés par les traitements d'irrigation, excepté le nombre des branches primaires et le poids de 100 grains sous W0 ainsi que le nombre de gousses par plant sous Ws. En se basant sur l'analyse de la regression linéaire des traits measurés contre le rendement en grains par hectare, le poids sec des nodules, le poids sec des racines, le nombre des gousses par plant et le poids de 100 grains avec la plus grande variation génotypique, ont considérablement contribué à la tolérance à la sécheresse. Cependant, la contribution de la catalase (CAT) était plus élevée sous Ws en comparaison aux peroxides POD. Les valeurs du coefficient phénotypique dans Ws étaient plus élevées que celles des coefficients de variation génotypique correspondantes pour tous les caractères, mais leurs différences étaient petites pour tous les traits. La catalase et l'activité péroxydase, le rendement en grains et le poids sec des racines et des nodules ont montré une avance génétique élevée (GA%) et les estimations de l'héritabilité. L'indice de tolérance à la sécheresse (DTI) et la moyenne géométrique (GM) s'étaient avérés efficaces pour la sélection des génotypes de tolérance supérieure à la sécheresse (LR1) avec un bon rendement potentiel dans toutes les deux conditions. L'analyse biplot du génotype par trait a montré que tous les traits mesurés avaient manifesté des forts effets positifs sur le rendement par hectare sous conditions Ws, sauf le pourcentage en protéines et le nombre des branches par plant.

Mots Clés: Biplot, stress dû à la sécheresse, *Lupinus albus*

INTRODUCTION

White lupin (*Lupinus albus*, L.) is an ancient crop in Egypt, the cultivated area of which is approximately 1503 ha (FAO, 2010 http://faostat.fao.org). It is a potential source for protein (33-47%), though low in starch content, slight deficient in sulfur amino acids and lysine, oil content (6-13%) and high in concentration of polyunsaturated fatty acids (Musquiz *et al*., 1993). High yielding modern varieties of lupin have not been developed for Egypt (only two registered cultivars are available). Hence, the crop is out-competed by improved cereal cultivars and other more developed crops. Therefore, farmers are cultivating old and low yielding landraces of lupin (Christiansen *et al*., 2000).

In spite of large intraspecific variation in *L. albus* as a result of both natural and human selection, it has been subsided to little breeding efforts and selection pressure (Noffsinger *et al.*, 2000). For future breeding and selection, it is important to ascertain the variation available for plant structure and yield components in these species (Rubio *et al*., 2004). In addition, information on the relative merits of architectural traits to seed yield is necessary. Literature on lupin confirmed the proposition that large genetic diversity exists in morphological and agronomic traits (Lagunes-Espinoza, 2000; López-Bellido *et al*., 2000).

Some authors reported that among yield components, the number of pods plant^{-1} has the highest positive correlation with yield (Shield *et al*., 1996). Julier *et al*. (1995) studied the genetic and environmental variation of architecture and yield components in determinate autumn-sown white lupin using forty-three genotypes. They observed that flowering dates and architectural characters were highly correlated. Rubio *et al.* (2004) reported that genotypes with the highest yields were the latest in flowering both on their main stem and on the lowest first-order branches. Moreover, yield on first-order branches, was especially important to achieve high total yield. Yield on the main stem was related positively to main stem flowering date (r = 0.576). These authors concluded that late flowering of the main stem was a positive factor for yield.

The primary goal of numerous breeding institutions in the world is to identify superior genotypes evaluated on the basis of multi-environment trials (MET) and multiple traits. Although statistics such as means, ranges and variances are helpful in providing information on the diversity of accessions in germplasm collections, they do not enable the simultaneous comparison of the accessions and the plant attributes (Harch *et al.*, 1995). The genotype-by-trait (GT) biplot has been applied to study relations among studied traits in a set of genotypes, to examine GT data usefulness in visualising crop trait relationships and its application in genotype evaluation comparison, and selection (Yan and Rajcan, 2002; Rubio *et al.*, 2004; Yan and Fregeau-Reid, 2008; Aghaee *et al*., 2010; Thangavel *et al*., 2011).

Water deficit is a major constraint, which reduces the productivity of crops. Thus, increasing crop tolerance to water limitation would be the most economical approach to enhance productivity and reduce agricultural use of fresh water resources (Khamssi *et al*., 2011). Plants have evolved a number of morphological, physiological and biochemical responses to survive against the stress (Gao *et al*., 2008). Traditionally, cultivated legumes such as common beans, chickpea and soybean present considerable yield losses when exposed to drought stress (Farooq *et al*., 2009). Thus, it is necessary to consider cultivation of alternative legume species, such as Lupinus (Jacobsen and Mujica, 2007).

This study aimed at evaluating the patterns of genotypic variation in drought tolerance of lupin genotypes through screening Egyptian germplasm.

MATERIALS AND METHODS

Plant materials and treatments. Five lupin genotypes were used, including two local cultivars and three landraces. The two local cultivar, Giza 1 and Giza 2, were developed by the Legume Crops Research Department, Agricultural Research Center, Giza, Egypt about 30 years ago (ARC, 1994). Both cultivars were bred based on individual selection from local landraces; Giza1 is adapted to northern region of Egypt; whereas Giza2 is adapted to Upper Egypt region. The three landraces were collected from farmers' fields at Ismailia (LR1), Al-Salhia (LR2) and Almhsma (LR3) provinces.

Field experiments were conducted during two growing seasons, namely, November 15 - April 15, 2008/2009 and November 15 - April 15, 2009/2010 at Suez Canal University, Ismailia. Mean seasonal rainfall was 0 mm for 2008/2009 and 0 mm for 2009/2010. Maximum and minimum seasonal temperatures were 28 to 16 °C for 2008/2009 and 2009/2010, respectively.

The tested genotypes were subjected to two contrasting water regimes and two inoculation treatments. Water regimes included normal irrigation (W_0), where irrigation was done regularly depending on weather conditions and plant needs. Whereas the water stress (W_s) treatment involved irrigation when plants showed drought symptoms including loss of leaves.

Irrigation treatments started when plants reached 40 days after planting. Soil moisture content was determined for each irrigation regime gravimetrically (Black, 1973). Mean soil moisture content for the control and Ws treatments were 2.67 and 1.72% for the first season, whereas for the second season the values were 2.00 and 1.35%, respectively. Inoculation treatments consisted of un-inoculation, and commercial Bradyrhizobium inoculum obtained from Department of Microbiology, ARC, Giza, Egypt.

The experiment was laid out in a randomised complete block, in a split-split plot arrangement, with three replications. Main plots were irrigation regimes, split-plots were inoculation treatments and split-split plots the five lupin genotypes. Each plot had two rows of 3 m length with 20 cm inter-row spacing and 50 cm between rows.

The traits recorded. Root dry weight (RDW) and nodule dry weight (NDW) were recorded after drying at 70 °C for 72 hr, of five plants after 60 days from planting. At harvest, the following traits were recorded: plant height (PH), branches plant^{-1} (BP), pods plant^{-1} (PP), 100-seed weight (HSW), and seed yield. A sub-sample of 50 g of grains was ground and the N concentration determined using the Kjeldahl method (Bremner, 1960) before protein content of seeds was calculated by multiplying N% by 6.25. Peroxidase (Vetter *et al*., 1958) and Catalase (Luck, 1974) activities were measured on fresh leaf samples (0.5 g) collected 60 days after planting.

Statistical analysis. Analysis of variance was performed using MSTAT-C for each irrigation treatment separately, averaged over growing seasons and inoculation treatments to estimate the genetic parameters such as phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad-sense heritability (h_b^2), genetic advance (GA) as suggested by Burton and DeVane (1953) and Johnson *et al*. (1955).

Linear regression analysis was performed at each irrigation treatment in order to determine relationships SYH (y variable) and all measured parameters.

Drought indices of each genotype were estimated for SYH at each trial as follows:

Drought susceptibility index (DSI) = (1-(Ys / Yp)) /(1- (Xs / Xp)),

Geometric Mean (GM) = (Ys X Yp) 1/2

Drought tolerance index (DTI) = (Yp X Ys)/ Xp2

According to the equations for SSI (Fisher and Maurer, 1978), GM, STI and SI (Fernandez, 1993), respectively; Ys and Yp indicate genotypic yield under stress and non-stress conditions; and Xs and Xp are the mean yields of all genotypes per trial under stress and non-stress conditions, respectively.

Genotype × trait averaged across growing seasons was investigated using biplots and performed by GenStat software, version 4. These biplots were constructed for visualisation of the genetic correlation among traits, and evaluation of the genotype on the basis of multiple traits (Lee *et al*., 2003). Biplots were conducted in the dimension of first two principal components (PC1 and PC2).

RESULTS AND DISCUSSION

Genetic variability estimates. There were significant genotypic differences for all the characters in W0 (except for PB and HSW) and Ws (except for PP and PB) (Table 1). The reduction

TABLE 1. Estimation of mean squares, means, range and different variability parameters for each character under irrigation schemes for five lupin genotypes

Characters	Traits	MS	Mean	Range	Coefficients of variation		Heritability (h_b^2)	Expected Genetic advance (GA)
					Phenotypic (PCV)	Genotypic (GCV)		
W_0	PH	28.74*	71.68	67.74-75.28	4.4801	4.23	89.33	8.24
	PB	0.048	4.31	4.14-4.48	4.5677	1.59	12.07	1.13
	PP	6.39*	12.03	10.22-14.24	13.899	11.15	64.35	18.42
	HSW	2.93	37.82	36.23-38.59	3.4647	2.06	35.34	2.52
	Pro%	11.79*	32.79	29.45-34.52	6.1857	5.97	93.27	11.88
	RDW	5.049*	5.75	3.77-6.88	23.455	22.11	88.89	42.94
	NDW	1.64*	1.41	0.68-2.24	52.417	52.37	99.82	107.78
	POD	6165.40*	548.70	475.50-596.33	8.6076	8.08	88.19	15.64
	CAT	2.61*	4.45	2.94-5.43	21.062	20.94	98.86	42.89
	SYP	6.18*	11.26	9.49-12.70	12.818	12.59	96.45	25.47
	SYH	42982.12*	944.72	790.59-1062.09	13.136	12.43	90.00	24.23
W_s	PH	36.68*	54.28	50.84-58.94	6.89	6.20	81.07	11.51
	PB	0.061	5.37	5.20-5.60	4.15	1.40	11.41	0.97
	PP	4.48	9.73	8.23-11.39	16.49	10.04	37.07	12.59
	HSW	8.54*	36.14	33.72-37.83	5.08	4.44	76.37	7.99
	Pro%	10.23*	39.42	36.47-41.52	4.79	4.63	93.22	9.21
	RDW	1.42*	5.13	4.34-6.00	16.02	11.88	55.04	18.16
	NDW	0.30*	1.07	0.78-1.53	30.04	29.60	97.10	60.09
	POD	23588.40*	652.77	538.17-737.17	13.93	13.41	92.72	26.60
	CAT	18.08*	5.85	2.74-8.30	42.74	41.57	94.59	83.29
	SYP	5.88*	8.62	6.68-10.25	16.60	16.07	93.75	32.06
	SYH	48934.66*	716.14	538.53-846.09	36.82	35.08	89.55	68.86

* Significant at 0.05 level of probability; PH = Plant height, PB = Primary branches; HSW = Hundred Seed Weight; Pro%= Protein%; RDW = Root Dry Weight; NDW = Nodule Dry Weight; POD = Peroxidase activity; CAT = Catalase activity; SYP = Seed Yield plant^{-1}; SYH = Seed Yield hectare^{-1}

in the measured traits in response to water stress reached the maximum for SYP (23.45%), SYH (24.20%) and NDW (24.11%); whereas, PB (+24.59%), Protein (+20.22%), POD (+18.97%) and CAT (+31.46%) recorded increasing values. The least reduction due to water stress was observed for HSW (4.44%) and RDW (10.78%). RDW was not significantly affected by Ws compared to W0 condition. Kumar and Sharma (2009) and Thangavel *et al*. (2011) reported that, droughted mungbean diverted higher dry matter to roots and stems, while well-watered plants diverted to pods and grains. Also Sangakkara *et al*. (2000) mentioned that drought tolerant mungbean diverted more carbon to roots under moisture stress. Munier-Jolain *et al.* (1998) found that a reduction in assimilate availability did not decrease seed growth rate in white lupin (*Lupinus albus* L.), pea, and soybean, but the duration of seed filling was reduced. Since individual seed weight is the product of seed growth rate by duration of seed filling, a reduced seed filling period caused by environmental conditions such as higher temperatures and terminal drought would leave the seeds in pods formed late during reproductive stage without sufficient time to be filled to their maximum capacity.

This paper reports slight reduction in RDW under W_s which is supported by the finding of Carvalho *et al*. (2004) who recorded decreases in root biomass ranging from 13.40-39.87% in W_s lupin compared with controls in *L. albus and L. mutabilis,* respectively. Conversely, Lizarazo *et al.* (2010) found an increase in root dry weight of lupins genotypes grown under water stress and attributed it to the increases in root density, as water stress activate an increase in root growth through the production of lateral roots to allow more water extraction from deeper soil layers. However, two genotypes (LR1 and LR3) showed increased RDW under W_s treatment (Hefny, 2011). Therefore, increased root length, density and biomass are principal traits of drought avoidance and allow more water extraction from deeper soil layers. Therefore, both genotypes have an advantageous root system and, thus it can be a promising material in breeding programmes to improve lupin for drought stress conditions, especially when correlated with high seed production.

Genetic variability in the base population plays an important role in any crop-breeding programme. The amount of diversity in a crop determines the limits of selection for improvement; therefore, a large amount of variation in the material under investigation is a prerequisite. The important economic characters are generally quantitative in nature and exhibit a considerable degree of interaction with the environment. Thus, it becomes necessary to compute the variability present in the breeding material and its partitioning into its components under each investigated environment.

The estimates of the GCV, PCV, broad-sense heritability and GA for each trait in each irrigation condition are given in Table 1. The values of PCV in both treatments were higher than the corresponding GCV values for all characters. The highest GCV values under normal irrigation were recorded for NDW (52.37), RDW (22.11) and CAT (20.94) and under Ws conditions were CAT (41.57), SYH (35.08) and NDW (29.60). The least GCV values were demonstrated by PH (6.20), PB (1.40), HSW (4.44) and protein% (4.63). Moderate values were recorded in PP, RDW, POD and SYP. However, the relative amount of genetic variation was high under Ws for PH, HSW, POD, CAT, SYP and SYH compared to W_0, which indicates better performance of those traits under stress environments. Our results are in accordance with those reported by Mohammadi and Pourdad (2009) and Manggoel *et al*. (2012) who found higher PCV values than the corresponding GCV values on spring safflower and cowpea grown under rained conditions for all studied characters. In turn, they affirmed that all characters were less influenced by the environment and that the existing variability in these characters was under genetic influence, consequently improvement could be achieved through selection.

The heritability estimate provides information on the magnitude of the inheritance of quantitative traits, but provides no indication of the amount of genetic progress that would result from selecting the best individuals. Low heritability values were recorded for PB (11.41%)

and PP (37.07%) under Ws condition; whereas a relatively high heritability value was demonstrated by RDW (55.04%). Other traits recorded high values and ranged from 76.37% (HSW) to 97.10% (NDW). SYP and SYH rerecorded low heritability estimated under Ws compared to W0 conditions.

High expected GA, expressed as a percentage of the mean GG, was observed for CAT followed by SYH, NDW, SYP and POD under W_s conditions. PP and PH recorded moderate values (12.59 and 11.51%, respectively) broad sense heritability estimates obtained by Toker (2004) on faba bean (83% for PH, 43% for PP and 62% for HSW and 62% for SYH).

Lesech and Huyghe (1991) reported that the broad sense heritabilities of lupin were 82-92% for main stem height, 76-94% for the seed weight and 45-78% for the seed yield. Most of traits showed lower heritability estimates under stress conditions compared to optimum conditions, therefore selection would be higher in well-watered than drought stress condition (Link *et al.*, 1999).The lowest GA% was recorded for protein, HSW and PB. For the control treatment, the highest GA% was observed in NDW (107.78%), RDW (42.94%) and CAT (42.89%). However, other traits recorded low to moderate GA% values. Similarly, Atta *et al.* (2008) obtained lower genetic advance values than 15% for plant height and primary branches of chickpea, and relatively high (>25%) genetic advance expectations for seed yield plant^{-1}. In contrast, they recorded higher GA values for pods plant^{-1}, and 100 seed weight than those obtained in the present study. High heritability estimates were obtained for SYP and PH similar to what has been recorded in the present study, but PP showed higher value compare to value under Ws.

Mohammadi and Pourdad (2009) recorded high values of heritability similar to present study for TKW (67.9%), PH (62.2%), and SY (59.7%); whereas high values of genetic gain were found for SY (60.3%) followed by TKW (23.6%), PH (22.2%). It is interesting to mention that GA for CAT and POD activity increased by two and one-half folds under water stress compared with irrigation. This means that the genetic improvement for both enzymes is high under stress compared to control conditions, so both enzymes are selection criteria for drought tolerance.

The heritability estimates indicate the relative importance of genetic makeup in the expression of the characters. However, the higher value of heritability suggests that selection will be more effective and improvement can be expected for that trait in future breeding programmes for similar conditions. But, high heritability alone does not generally guarantee a large enough gain to make sufficient improvement through selection in advance generations unless accompanied by a substantial amount of GA (Bhargava *et al.*, 2003).

It has been emphasized that without GA, the heritability values would not be of practical importance in selection based on phenotypic appearance (Mohammadi and Pourdad, 2009).

So, the genetic advance should be considered along with heritability in coherent selection breeding programmes (Johnson *et al.*, 1955). Traits CAT, SYH, NDW, RDW, SYP and POD showed high GA% and heritability estimates, in addition to moderate to high GCV. Therefore, they are amenable for improvement in the investigated population under water stress conditions, because additive gene action has the major role in the inheritance of these characters.

The relationships between the measured traits and SYH were further analysed using linear regression (Table 2). It became clear that, PP, NDW, RDW, SYP, HSW and CAT were the dominant factors that affected SYH production in lupin under water stress conditions, as represented by high slope and coefficient of determination. That means the drought resistant genotypes of lupin have higher pods number plant^{-1}, heavier seeds, higher root, nodule dry weight, high seed yield plant^{-1} and high catalase activity.

Drought indices in lupin genotypes. The geometric means (GM), drought tolerance index (DTI) and drought susceptibility index (DSI) were used to evaluate the genotypic performance under drought stress condition (Table 3). LR1 and LR2 showed high DTI and GM, and relatively high DSI values in the first trial. In the second season, Giza2 and LR1 demonstrated high DTI and GM in addition to the least DSI values. Based on GM and DTI, it was possible to identify the tolerant and susceptible lupin genotypes to

TABLE 2. Equations of linear regression, slopes and determination coefficients between seed yield ha^{-1} (y) and the other measured traits (x) at W_0 and W_s treatments over two years

Irrigation treatments	Parameter	Regression equations	Slope	R^2
W_0	PH	Y = -1545.40 + 34.74 X	34.74	0.81*
	PB	Y = -1994.10+ 682.72 X	682.72	0.52*
	PP	Y = 648.29 + 24.65 X	24.65	0.09
	HSW	Y = -2630.56 + 94.54 X	94.54	0.61*
	Pro%	Y = 1578.68 - 19.33 X	-19.33	-0.10
	RDW	Y = 620.5 + 56.408 X	56.408	0.37*
	NDW	Y = 782.85 + 114.47 X	114.47	0.50*
	POD	Y = 1629.4 -1.248 X	-1.248	-0.22
	CAT	Y = 800.18 +32.94 X	32.94	0.06
	SYP	Y = -0.365 + 83.377 X	83.38	1.00*
W_s	PH	Y = -864.85 + 29.13 X	29.13	0.64*
	PB	Y = 2754.9 - 379.72 X	- 379.72	-0.18
	PP	Y = -227.618 + 97.04 X	97.04	0.86*
	HSW	Y = -1941.63 + 73.54 X	73.54	0.94*
	Pro%	Y = 1835.687-28.40 X	-28.40	-0.17
	RDW	Y = -119.4 +163.02 X	163.02	0.77*
	NDW	Y = 405.6 + 288.96 X	288.96	0.52*
	POD	Y = -134.212+ 1.30 X	1.30	0.81*
	CAT	Y = 425.44 + 49.66 X	49.66	0.90*
	SYP	Y = -62.833 + 90.39 X	90.39	0.98*

PH = Plant height; PB = Primary Branches; PP = Pods plant; HSW = Hundred Seed Weight; Pro% = Protein%

TABLE 3. Analysis of the geometric mean (GM), drought susceptibility index (DSI) and drought tolerance index (DTI) on seed yield ha^{-1} under water stress conditions for each growing season

Genotype	2008/2009				2009/2010				Sum[2]	Genotype ranking[3]
	GM	DSI	DTI	Rank[1]	GM	DSI	DTI	Rank[1]		
Giza1	751.32	0.01	0.64	5	958.64	1.422	0.95	3	8	4
Giza2	798.64	1.05	0.72	3	1035.74	0.906	1.11	1	4	2
LR1	917.90	1.17	0.95	1	975.71	0.504	0.99	2	3	1
LR2	836.91	1.17	0.79	2	630.43	0.947	0.41	4	6	3
LR3	757.28	1.37	0.65	4	547.68	1.25	0.31	5	9	5

[1]Ranked by DTI; [2]Sum of the two growing seasons; [3]Based on sum of the growing seasons

drought conditions. From the results, LR1 and Giza2 were ranked as the most tolerant genotypes, whereas Giza1 was ranked as the least tolerant for the first year trial. Giza2 was ranked the most tolerant, and LR3 was the most susceptible in the 2nd year. For ranking based on sum of both growing seasons, LR1 was the most drought tolerant genotype, while LR3 was the most drought-sensitive genotype. For the second growing season, DTI and GM were able to select the susceptible genotypes implying that both selection indices (DTI and GM) recorded the highest and lease values for the genotypes Giza 2 and LR3. Porch (2006), used the geometric mean (GM), stress tolerance index (STI) and stress susceptibility index (SSI) to evaluate common bean genotypes performance for heat stress and low-stress conditions and reported that, STI and GM, were found to be effective stress indices for the selection of genotypes with good yield potential under heat stress and low-stress conditions. They also found that HTI and GM were all correlated with yield under heat stress, and concluded that both indices should be useful for breeding for heat tolerance. In their study on wheat germplasm under fully irrigated and rained-out plot shelter, Sio-Se Mardeh *et al.* (2006) suggested SSI to be a useful indicator for wheat breeding for drought stress where the stress is severe. Dodig *et al*. (2008) proposed that improving drought tolerance in new cultivars of wheat for the variable rainfed conditions should be based on genotypes with high MP coupled with low SSI. Nevertheless, Dodig *et al*. (2012) recorded positive and weak correlation between mean productivity (MP) with SSI and STI, where all low SSI landraces (SSI < 1) in the trials showed low mean productivity.

Genotype-by-trait biplot analysis. The GT biplots for the control and water stress treatments averaged over two years are presented in Figure 1. They explained 90.55 and 95.80% of the total variation of the standardised data, respectively. According to Kroonenberg (1995) the fundamental patterns among the traits should be captured by the biplots. In the GT biplot, a vector is drawn from the biplot origin to each marker of the traits to facilitate visualisation of the relationships between and among the traits. Provided that the biplot explained a sufficient amount of the total variation, the correlation coefficient between any two traits is approximated by the cosine of the angle between their vectors (Yan and Rajcan, 2002). For the present study, the largest variation explained for both treatments by biplot came from all measured traits, except PB in W_s and CAT in W_0, as indicated by the relative length of their vectors. Under stress condition, the most important relations revealed by biplot is a positive and strong association among SYH, PH, PP, RDW, NDW, HSW, CAT and POD (acute angles). These traits were negatively correlated with protein% and PB (obtuse angle). Under control irrigation, SYH correlated positively with PH, HSW, PB, RDW NDW and SYP, and negatively with protein% and PP. On the otherhand, it was independent of CAT activity and number of PP (near 90° angle). RDW correlated negatively with PP. These associations suggest a possibility of combining higher seed yield, high PP, long stems, high POD and CAT activity in one lupin genotype under drought conditions.

Similarly, López-Bellido *et al.* (2000) recorded strong correlation and direct effect of pods plant on lupin yield, and a negative effect of plant height when using Pearson correlation and path coefficient analysis. On the other hand, the present results are in partial agreement with those of Rubio *et al.* (2004) in a study on biplot analysis of trait relations of white lupin under rainfed conditions. They recorded a positive and strong association among PH and yield. Inversaly, they found that PB was the single factor most strongly influencing lupin yield (direct effect and positive correlation). Harzic *et al*. (1996) and Noffsinger *et al*. (2000) found that PB constitutes the largest portion of total yield in lupin.

It is worth to note that, although correlation estimates indicate the validity of biplot to describes the interrelationships among the traits, the exact match is not to be expected, because the biplot describes these relations on the basis of overall pattern of the data, whereas correlation coefficients only describe the relationship between two traits (Yan and Rajcan, 2002). GT biplots have been used to compare lupin genotypes on the basis of multiple traits and to identify those that are particularly good in certain characteristics, and therefore, can be candidates for parents in lupin breeding. Giza2 and LR1 combined the highest SYP, SYH, HSW, RDW, NDW and CAT and POD activity, LR3 had the highest response for protein%, whereas, LR2 and LR3 had the least RDW and NDW values, CAT and POD activities. However, PB was poor in discrimination genotypes due to its short vector. Christiansen *et al*. (2000) reported that local landrace germplasm may be an important source of alleles for shortening the vegetative period, reducing plant height and stem length, and for improving some yield components such as number of pods and seeds plant^{-1} in locally adapted germplasm. Therefore, they confirmed the possibility of Egyptian landrace germplasm

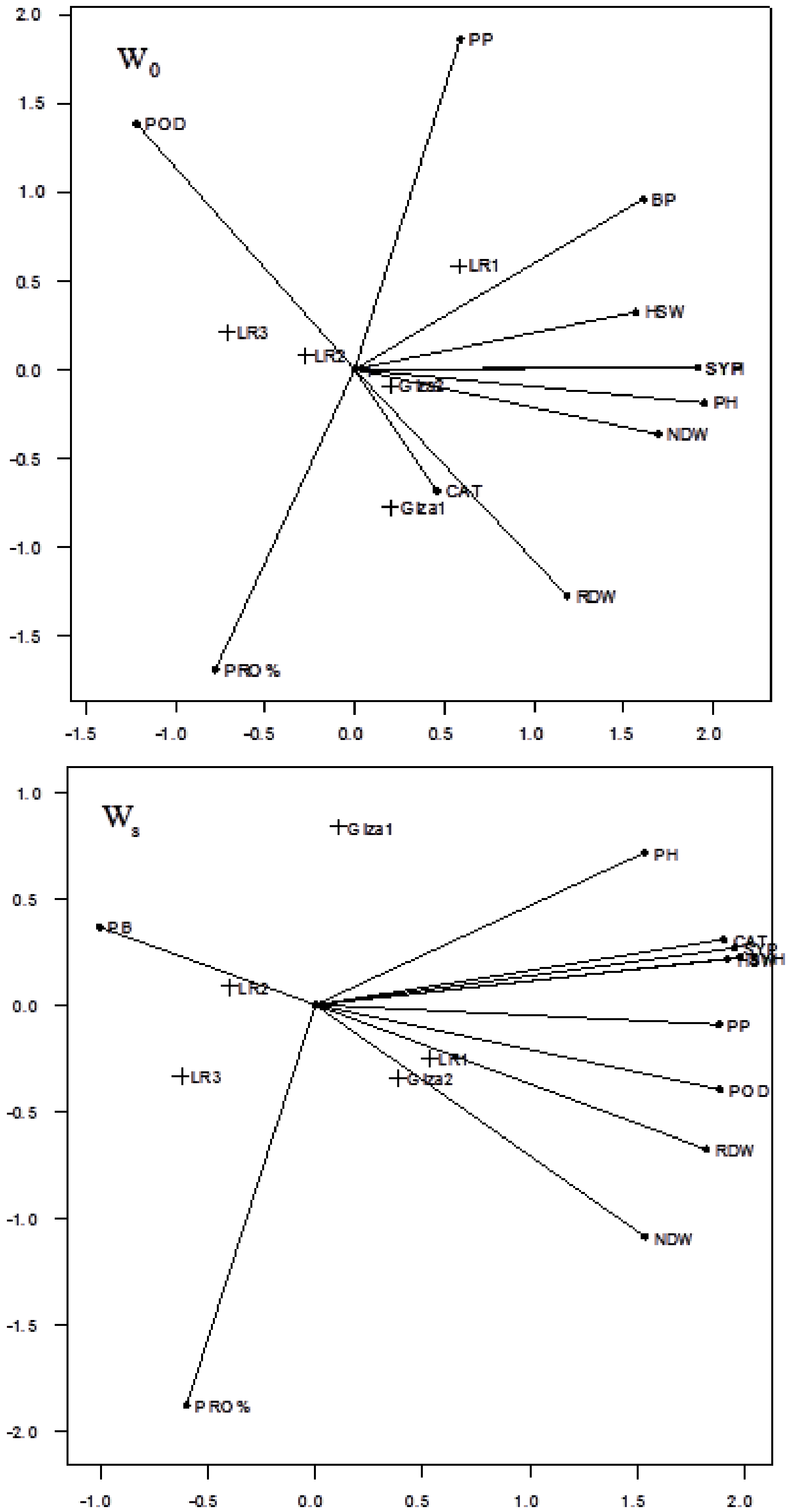

Figure 1. White lupin genotype by trait biplot for the irrigation treatments showing the interrelationship among all measured traits. The signs are genotypes and the vectors are traits.

for the genetic improvement of most characteristics. They also added, only a few landraces outyielded the local checks (Giza 1 and Giza 2). Therefore, if it is desirable to further improve the protein% of LR1 and Giza2 and the SY of LR3, crosses of LR3 x LR1 and LR3 x Giza2 may be useful. In accordance with Aghaee *et al.'s* (2010) findings, the traits with strong positive associations tend to discriminate accessions in similar fashions and those with negative associations tend to discriminate accessions in opposite direction.

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