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Yield Criteria in Faba Bean (Vicia faba L.)

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Abstract—Most of yield criteria are redundant and breeder spends extra efforts, time and labor to record and evaluate them. Therefore, this study was aimed to elucidate fundamental and redundant yield criteria in faba bean (*Vicia faba* L.) using correlation, path coefficient and heritability. A total of 109 genotypes of faba bean were sown in autumn at highland of Mediterranean region of Turkey, and grown in two successive years under rainfed conditions. As qualitative traits, rosette-like growth habit and pigmentation during seedling stage were fundamental traits for cold tolerance. Biological yield and harvest index as quantitative traits were found to be the most fundamental traits. As the other fundamental trait, the seed weight could be considered for selection in early breeding generations because they had the highest heritability.

***Keywords*—Faba bean, *Vicia faba*, heritability, path coefficient, selection criteria**

I. Introduction

Faba bean (*Vicia faba* L.) is referred to as the only species under cultivation of the section *Faba* (Miller) Ledep., and divided two subspecies (1-2); *V. faba* subsp. *paucijuga* Murat. and *V. faba* subsp. *faba* L. According to statistical database of Food and Agriculture Organization (FAOSTAT), faba bean is grown in 58 countries in the world. Its production is globally about 3,4 million t from a planted area of about 2.1 million ha. With an increase of 755 kg per ha, average dry seed yield have ranged from 896 kg per ha in 1961 to 1651 kg per ha in 2013. The major faba bean producer countries are China, Ethiopia, France, Egypt and Australia (3). In spite of the high yield potential of faba bean, recorded as about 9 t per ha (3), average dry seed yield is quite low and instable due to mainly diseases, parasitic weeds, drought and cold damage and a combination of these stresses (4-6).

Seed yield in faba bean as in the other crop plants is a complex quantitative trait that controlled by genetic and environmental factors. To improve seed yield, selection on yield could be misleading. Path coefficient is a useful analysis in determining the direct correlation with yield and the indirect correlation with other agro-morphological traits on seed yield (7).

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Many qualitative and quantitative agro-morphological traits have been used as selection criteria of faba bean in breeding programs (4,6,8). Most of these selection criteria are redundant because records and evaluations of these selection criteria are taken extra time, effort and labor of plant breeders. On the other hand, some of the selection criteria are considered as fundamental traits. Use of direct and indirect relationships between yield and yield related traits via correlation and path coefficients were suggested and studied some plant species (9, 10-13). Similar direct and indirect relationships among selection criteria were reported even in faba bean (8,14). Prior to the present study, there was no study on use of correlation, path coefficient and heritability with large number of genotypes from different region of the world (15). In the present study, we evaluated fundamental and redundant selection criteria in faba bean genotypes using path and correlation coefficients and heritability.

II. Materials and Methods

A. Genetic Materials

109 faba bean (*Vicia faba* L.) genotypes were sown in the first week of November, 2005 and the third week of November, 2006 at Urkutlu location (37^o 19' N, 30^o 18' E and 832 m above sea level) in the west Mediterranean region of Turkey.

B. Agronomic Managenets

Genetic materials were grown in a randomized complete block design with two replications. Plots were designed in two rows of 2 m length. Distance from a row to a row and space among plants within a row were 45 cm and 10 cm, respectively. Plants were grown in rainfed conditions. Nitrogen (N) and phosphorous (P_2O_5) were applied at a rate of 18 kg and 46 kg per hectare. Weeds were removed by hand at seedling stage and prior to flowering.

C. Yield Criteria

The following traits quantitative an qualitative traits were evaluated according to Toker (16): plant height (PH), first pod height (FH), branches number per plant (BP), pod number per plant (PP), seed number per pod (SP), biological yield (BY), seed yield (SY), 100-seed weight (SW) and harvest index (HI).

Growth habit was recorded as ‘prostrate’ or ‘erect’, whereas pigmentation was recorded as ‘present’ or ‘absent’ during vegetative stage before and after freezing, respectively.

The genotypes were evaluated for cold tolerance using a visual score (1 = Highly cold tolerant, 3 = Intermediate, and -5 Susceptible), and the findings were reported by Inci and Toker (6).

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D. Statistical Analyses

Analyses of variance (ANOVA) for quantitative traits were performed using the statistical analysis program MINITAB, while ANOVA was not performed for growth habit and stem pigmentation (qualitative traits). Path coefficient analysis (7) and phenotypic correlations were used to evaluate direct and indirect relationships between yield and agro-morphological traits. Heritability for agro-morphological traits was estimated according to Canci and Toker (10):

$$h^2 = \sigma^2_g/\sigma^2_p, \quad [1]$$

where σ^2_g and σ^2_p are genotypic variance and phenotypic variance, respectively. The phenotypic variance, σ^2_p was determined as:

$$\sigma^2_g = \sigma^2_g + (\sigma^2_{gy}/y) + (\sigma^2_e/ry), \quad [2]$$

where y, g and r are number of years, genotype, and replication, respectively. The σ^2_g, σ^2_{gy} and σ^2_e are the components of genotypic, genotypic by year and error variances, respectively. The following formula was used for standard error:

$$SE = (1 - h^2) - [1 + (b - 1) h^2/2/(bf)]^{1/2}, \quad [3]$$

where b and f are blocks and degrees of freedom of error, respectively.

III. Results

A. Weather Conditions

During 2005-2006, the extreme minimum and maximum temperatures were -9.6 and 34.7°C, respectively; whereas they were -9.2 and 33.6°C in 2006-2007, respectively (Table 1). The total rainfall was annually recorded as 331.3 mm during the 2005-2006 growing season, whereas it was recorded as 212.7 mm during 2006-2007 growing season. Freezing days in 2005-2006 and 2006-2007 were recorded as 86 and 65 days, respectively.

TABLE I. MONTHLY RAINFALL (MM), EXTREME MINIMUM AND MAXIMUM TEMPERATURES (°C) AT URKUTLU LOCATION DURING THE TWO GROWING SEASONS, 2005-2006 AND 2006-2007.

Months	Min Temperatures		Max Temperatures		Rainfall	
	2005-6	2006-7	2005-6	2006-7	2005-6	2006-7
Nov	-6.5	-4.6	18.2	19.3	45.4	42.2
Dec	-9.6	-9.2	18.5	18.2	6.1	0.7
Jan	-9.4	-6.0	13.6	15.8	30.9	45.4
Feb	-9.5	-6.2	17.2	14.3	46.1	46.6
Mar	-5.0	-1.6	17.8	19.5	64.3	7.7
Apr	2.9	-1.7	23.0	23.6	77.9	24.3
May	2.8	4.6	30.6	30.4	20.9	22.0
Jun	9.7	33.6	34.7	33.6	9.7	33.6

B. Yield Criteria

In faba bean genotypes, results of analysis of variance showed that a genotypic effect was statistically significant ($P < 0.05$) for plant height, seed number per pod, and 100-seed weight (Data not shown). Genotype and year interactions were statistically significant ($P < 0.05$) only for plant height, seed number per pod, biological and seed yields, harvest index, 100-seed weight (Data not shown).

In faba bean genotypes, genotypic effect was found to be statistically significant ($P < 0.05$) for plant height, branches and pod number per plant, seed number per pod, harvest index and 100-seed weight (Data not shown). Only for pod number per plant and 100-seed weight, genotype and year interactions were resulted in statistically significant ($P < 0.05$) (Data not shown).

Descriptive statistics with mean ± standard errors, minimum and maximum values of agro-morphological traits in faba bean were given in Table 2. Plant height, first pod height, branches per plant, pods per plant, seeds per pods, biological and seed yields, harvest index and 100-seed weight were found as 57 cm, 11 cm, 4, 13, 3, 539 g, 223 g, 39% and 91 g, respectively. Most of the genotypes had stem pigmentation and erect growth habit during seedling stage (Data not shown). Mean values for most agro-morphological traits in faba bean genotypes were detected higher in the first year than that of the second year (Data not shown).

C. Relationships among Yield Criteria

The direct and indirect effects of agro-morphological traits on seed yield using path coefficients were given in Table 3. Biological yield (0.9543) and harvest index (0.1441) had the highest direct effects, while 100-seed weight (0.0053) and branches per plant (-0.0151) had the lowest direct effects on seed yield. Seed yield (-0.7503) had the highest indirect effect on cold tolerance via biological yield. The indirect effect of 100-seed weight (0.6712), plant height (0.5679) and harvest index (0.4434) via biological yield was positive and high. The similar relationships between seed yield and biologic yield (r = 0.972**), between seed yield and 100-seed weight (r = 0.722**) and between seed yield and harvest index (r = 0.593**) using correlation coefficients were found to be statistically and positively significant. There were statistically and positively significant relationships between seed yield and the other agro-morphological traits.

TABLE II. DESCRIPTIVE STATISTICS AND HERITABILITY FOR SEED YIELD AND AGRO-MORPHOLOGICAL TRAITS

Traits	$\bar{X} \pm S\bar{x}$	Min	Max	$h^2 \pm SE$
Plant height (cm)	57±0.7	20	86	76±0.04
First pod height (cm)	11±0.3	2	22	42±0.08
Branches per plant	4±0.1	1	14	30±0.09
Pods per plant	13±0.5	4	42	66±0.06
Seeds per pod	3±0.1	2	5	90±0.02
Biological yield (g)	539±20.0	20	1596	65±0.06
Seed yield (g)	223±10.1	4	750	58±0.07
Harvest index (%)	39±0.8	3	63	65±0.06
100-seed weight (g)	91±1.8	12	149	94±0.01

D. *The Broad-Sense Heritability*

As can be seen in Table 2, 100-seed weight (94%) and seed number per pod (90%) were estimated as having the highest broad-sense heritability, while branch number per plant (30%), first pod height (42%), seed yield (58%), biological yield (65%), harvest index (65%) had the lowest broad-sense heritability. Plant height (76%) had the moderate broad-sense heritability.

IV. Discussion

Most of the agro-morphological traits in faba bean genotypes were higher in the first year than that of the second year (6) because rainfall was more regular and higher in the first year than that of the second year (Table 1). Plants were exposed to the lowest extreme minimum temperature of -9.6^{o}C (Table 1) without snow cover (6). A rosette-like winter growth habit during seedling stage had enormous advantage for cold tolerance. Fukuta and Yukawa (17) found similar results in faba bean. Also, Fukuta et al. (18) pointed out that the thick and dark green leaves in the dwarfed plant of faba bean had an advantage for cold tolerance. Annicchiarico and Iannucci (19) concluded that a rosette-like winter growth habit was correlated with winter survival in faba bean, pea and white lupine. In general, purple-flowered and pigmented genotypes were observed as the more cold tolerant than those of white-flowered genotypes (6). In lentil, prostrate growth habit and anthocyanin pigmentation were found as indirect selection criteria for cold tolerance (20).

Flowers in some faba bean genotypes was fall downed by the negative effect of the maximum extreme temperatures since plants were exposed to high temperatures of 33.6^{o}C during the flowering stage in the second year. Drought and heat stresses are also affected crop yield (Table 1).

Path analysis indicated that biological yield was a key to increasing seed yield since biological yield had not only the highest direct effect on yield, but also the highest correlation coefficient with seed yield (Table 3). These results are in agreement with those findings in faba bean of Bora et al. (8) and chickpea of Canci and Toker (10). Biological yield and harvest index could be suggested as useful agro-morphological traits under cold conditions. Similarly, biological yield and harvest index were found as the highest direct effect on yield in lentil by Karadavut (11) and in mung bean by Canci and Toker (13).

The seed weight were estimated as the most important constant trait and it was followed by seed number per plant, whereas branch number per plant, first pod height, seed yield, biological yield, harvest index were found to be the most affected traits over the 2 years of this study (Table 2). A similar result on heritability of the seed weight in faba bean was reported by Toker (16). These results on heritability of the seed weight were in agreement with findings in chickpea of Canci and Toker (10). Link et al. (2010) found that heritability for frost tolerance in faba bean was estimated as $h^2 = 0.89$. Since the seed weight and seed number per plant (Table 3) and cold tolerance (5) with high heritability were the least affected traits across changing environmental conditions, they should be considered for selection in early breeding generations.

In conclusion, biological yield and harvest index were found to be the most fundamental traits to improve seed yield in faba bean since path and correlation analyses suggested that biological yield and harvest index should be evaluated in selection for high yield ahead of many agro-morphological traits. Also, the seed weight should be considered for selection in early breeding generations because it had the most constant traits with high heritability. Rosette growth habit and anthocyanin pigmentation were considered as appropriate morphological traits for cold tolerance under cold conditions. Cold tolerant and susceptible genotypes selected in the study are used to help identify biochemicals (jasmonic acid, xilose, fructose, glucose, sucrose and total sugars), suitable as markers for cold tolerance.

TABLE III. PATH AND CORRELATION COEFFICIENTS BETWEEN SEED YIELD AND AGRO-MORPHOLOGICAL TRAITS

Traits	PH	FH	BP	PP	SP	BY	HI	SW	Correlation
Plant height (PH)	**-0.0604**	-0.0213	0.0001	-0.0099	0.0066	0.5679	0.0191	0.0028	0.505**
First pod height (FH)	-0.0403	**-0.0319**	0.0000	-0.0095	0.0055	0.3235	-0.0311	0.0012	0.217 *
Branches per plant (BP)	0.0005	0.0000	**-0.0151**	0.0149	-0.0051	0.2452	-0.0222	0.0004	0.219 *
Pods per plant (PP)	0.0191	0.0097	-0.0072	**0.0312**	-0.0075	-0.3315	-0.0559	-0.0034	0.346**
Seeds per pod (SP)	-0.0091	-0.0040	0.0017	-0.0054	**0.0437**	0.1877	0.0426	0.0014	0.259**
Biological yield (BY)	-0.0359	-0.0108	-0.0039	-0.0108	0.0086	**0.9543**	0.0669	0.0037	0.972**
Harvest index (HI)	-0.0080	0.0069	0.0023	-0.0121	0.0129	0.4434	**0.1441**	0.0034	0.593**
100-seed weight (SW)	-0.0318	-0.0070	-0.0012	-0.0201	0.0119	0.6712	0.0932	**0.0053**	0.722**

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