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ENVIRONMENTAL INFLUENCE ON HERITABILITY AND SELECTION RESPONSE OF MORPHO-PHYSIOLOGICAL TRAITS IN MUNGBEAN

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Abstract

Thirty mungbean (*Vigna radiata* (L.) Wilczek) genotypes were evaluated at two locations of North West Frontier Province of Pakistan during 2007 and 2008 using randomized complete block design with three replications. Highly significant differences ($p \leq 0.01$) were observed among the genotypes for morpho-physiological traits across years at both locations as well as across years and locations. Location × year effect was highly significant ($p \leq 0.01$) for days to flowering, plant height and nodes plant^{-1}. Genotype × location interaction was highly significant ($p \leq 0.01$) for days to flowering, maturity, plant height and leaf area, indicating differential performance of mungbean genotypes over the two test locations. Means for flower initiation, physiological maturity, plant height, leaves plant^{-1}, nodes plant^{-1} and leaf area at Peshawar and Swat were 47.2 vs 50.5 days, 86.5 vs 84.2 days, 55.5 vs 52.3 cm, 8.1 vs 8.5, 10.6 vs 10.3 and 181.8 vs 202.4 cm^2, respectively. The genetic variances were greater in magnitude than environmental variances for most of the traits at both locations. Heritability estimates for the morpho-physiological traits were generally greater in magnitude at Peshawar than Swat: 0.63 vs 0.53, 0.75 vs 0.60, 0.81 vs 0.84, 0.73 vs 0.49, 0.56 vs 0.52 and 0.50 vs 0.37 for days to flowering, maturity, plant height, leaves plant^{-1}, nodes plant^{-1}, and leaf area, at Peshawar and Swat, respectively. Expected selection response for all traits was greater at Peshawar than Swat suggesting that selection of desirable mungbean genotypes can be effectively carried out at Peshawar.

Introduction

Mungbean (*Vigna radiata* (L.) Wilczek) is an important pulse crop of Asia and is widely grown in India, Bangladesh, Sri Lanka, Thailand and Pakistan. It is also known as the crop of sub-continent and up to three crops per year can be grown successfully (Malik, 1994). In Pakistan, it is grown as a supplemental and cash crop on 245.9 thousand hectares with a total production of 177.7 thousand tons and an average yield of 636 kg ha^{-1}. Maximum average yield of 663 kg ha^{-1} from an area of 9.5 thousand hectare was obtained in the North West Frontier Province (NWFP) of Pakistan due to suitability and proper adaptation of mungbean to the agro-climatic conditions of the area (Anon., 2009). The average yield of mungbean is low due to its indeterminate growth habit, late and non-synchronous maturity, lodging, pod shattering and severe losses due to insect pests (Fernandez & Shanmugasundaram, 1988). Diversifying the limited genetic variability for traits of interest and developing new mungbean cultivars are demand of the era. In order to increase yield per hectare, new cultivars must be developed with outstanding performance and uniform maturity. The knowledge of genetic variation and heritability of agronomic traits and their interrelationship helps in understanding yield components and yield potential in mungbean.

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Assessment of genetic variation is the most appropriate statistical tool to find out the magnitude of heritability, genetic coefficient of variation and response to selection using appropriate selection intensity for traits of interest. Makeen *et al.*, (2007) evaluated 20 mungbean genotypes to estimate genetic variability, heritability and genetic advance for quantitative characters and reported highly significant differences for all traits with greater magnitude of heritability for plant height and test weight. Similarly, Siddique *et al.*, (2006) reported highly significant genetic variation for days to flowering, maturity, pods plant^{-1}, and grain yield among eight mungbean genotypes. Rohman *et al.*, (2003) reported that plant height and days to flowering were mostly governed by additive genes effects. Sriphadet *et al.*, (2005) reported 89.9, 98.9, 93.7 and 93.2% heritability for leaves number plant^{-1}, seed hardness, pod length and pod width, respectively. Seed yield is reported to be positively correlated with traits like days to flowering, plant height, branches plant^{-1}, pods plant^{-1}, and pod length. Malik (1994) reported positive correlation of number of pods and branches plant^{-1} with seed yield. Similarly, Khan *et al.*, (2001) reported strong association among branches plant^{-1} and pods plant^{-1} leading to increased yield per unit area.

The objectives of this study were to estimate genetic, genotype × year and environmental variances to compute heritabilities and predict selection response for important morpho-physiological traits of mungbean at two locations of NWFP, Pakistan.

Materials and Methods

Thirty mungbean genotypes including three check cultivars (NM-92, NM-98 and Ramzan) obtained from the Nuclear Institute for Food and Agriculture (NIFA), Peshawar were evaluated for two years (2007 and 2008) at two locations of NWFP viz., Agricultural University, Peshawar and Agricultural Research Institute, Mingora, Swat.

Soil analysis and fertilizer applications: Information regarding seasonal rainfall, temperature, altitude and soil characteristics about the two test locations is given in Table 1. Experiments at Peshawar and Swat were planted on 5th and 29th May, 2007 and 2nd and 15th May, 2008, respectively. The experiments at each location during both years were laid out in randomized complete block design with three replications. Plot size for a mungbean genotype in each replication was 3.6 m^2. Each plot had 4 m long three rows with row to row and plant to plant distance of 0.30 and 0.10 m, respectively. A single row between adjacent plots was kept fallow to facilitate data recording. To avoid dense plant population, thinning was carried out at 2-4 leaf stage. Soil analysis for available nutrients were carried out prior to conducting the experiments at both locations through Farmer Advisory Centre, Fauji Fertilizer Company Limited, Pakistan (Table 2). Based on soil analysis results, NPK @ 60:110:50 kg ha^{-1} and Zinc sulfate 23% @ 25 kg ha^{-1} were applied to experiments at Peshawar. Similarly, NPK @ 50:100:45 kg ha^{-1} and Zinc sulfate 21% @ 25 kg ha^{-1} were applied to experiments at Swat. Nitrogen was applied in the form of urea, phospahatic fertilizer as P_2O_5 in the form of di-ammonium phosphate, and potassium as K_2O in the form of sulphate of potash. Required amount of chemical fertilizers was applied at the time of soil preparation at both locations. Recommended dose of Thiodan 35% E.C of Bayer @ 2.47 litre ha^{-1} containing 32.9 W/W actual ingredients of Endosulphan was sprayed to control insects like shoot fly, thrips and bugs before bud initiation. Weeds were controlled manually at both locations.

Table 1. Seasonal rainfall, temperature, altitude/latitude and soil type about the two test locations used for evaluation of mungbean genotypes.

		Peshawar				Swat			
		2007		2008		2007		2008	
Monthly rainfall (mm)	May	25.9		4.1		41.7		61.9	
	June	77.0		41.9		183.7		95.3	
	July	69.9		46.8		94.2		232.1	
	August	22.1		212.4		168.2		141.8	
	Average	**48.7**		**76.3**		**121.9**		**132.8**	
		Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Average monthly temperature (°C)	May	22.7	35.9	23.6	36.6	14.7	30.4	14.2	30.9
	June	26.2	38.5	26.8	37.5	18.9	32.1	20.8	32.4
	July	26.5	36.2	26.4	36.1	19.8	30.7	20.0	31.8
	August	26.4	36.2	24.9	34.9	19.4	31.0	19.1	30.5
	Average	**25.5**	**36.7**	**25.4**	**36.3**	**18.2**	**31.1**	**18.5**	**31.4**
Latitude and longitude		Lat. 34° 01′ 10.37 N″ Long. 71° 28′ 01.69″ E Elevation. 365.5m				Lat. 34° 46′ 48.57 N″ Long. 72° 19′ 41.42″ E Elevation. 973 m			
Soil type		Silt loam/alkaline pH 8.2-8.3				Sandy loam/neutral pH 7.2-7.3			

Table 2. Soil characteristics and available macro and micro nutrients based on soil test of two locations.

	Soil salinity and sodicity		Macro nutrients				Micro nutrients		
Locations	**Dissoluble salt EC (1:2.5) dS/m**	**Exchangeable Na (mmolc/100g)**	**O.M. (%)**	**N (%)**	**P (ppm)**	**K (ppm)**	**Iron (ppm)**	**Zinc (ppm)**	**Boron (ppm)**
Peshawar	0.14-0.16 (Adequate)	0.1-0.2 (Adequate)	0.73-0.82 (Average)	0.05-0.06 (Average)	5-6 (Weak)	90-110 (Average)	5.25-5.50 (Adequate)	0.73-0.75 (Deficient)	0.66-0.72 (Adequate)
Swat	0.17-0.18 (Adequate)	0.2-0.2 (Adequate)	0.96-1.02 (Average)	10-13 (Optimum)	11-14 (Average)	140-160 (Optimum)	6.13-7.40 (Adequate)	0.92-0.98 (Deficient)	0.56-0.61 (Adequate)
Threshold level	----	----	≤ 2.5 %	≤ 2.0 %	≤ 15 ppm	≤ 150ppm	≤ 4.5 ppm	≤1.0 ppm	≤ 0.7ppm

Parameters studied: Data were recorded on the following traits at both locations.

1. Days to flowering: Days to flowering for each genotype were recorded from the date of planting to the appearance of 50% flowers in each plot in a replication.

2. Days to maturity: To screen the early and late maturing mungbean genotypes, data on days to maturity was recorded when pods in 90% plants turned black in a plot.

3. Plant height: Plant height was measured with the help of a meter rod from ground level to the node of the plant with trifoliate leaf on ten randomly selected plants.

4. Number of leaves plant^{-1}: Number of leaves were counted from first trifoliate leaf to the uppermost trifoliate leaf on the ten randomly selected plants in a plot.

5. Number of nodes plant^{-1}: Number of nodes was counted from first node bearing trifoliate leaf to the point from which the plant starts bearing pod cluster.

6. Leaf area: Leaf area of leaves at 6th node position was calculated as average length × average width × 0.75. Average leaf length and width was determined from 10 randomly selected leaves.

Statistical analysis: The two years data obtained at each location were statistically analyzed using appropriate model for randomized complete block design as proposed by Annicchiarico (2002). Genotypic, genotype-by-year and error variances for the traits were worked out from the analysis of variance across two years under each location to determine broad-sense heritability (h^2_{BS}) using the following formula of Rowe & Brink (1993).

$$h^2_{BS} = \frac{V_g}{V_p} = \frac{V_g}{(V_g + V_{gy} + V_e)}$$

where,

V_g = Genetic variance

V_{gy} = Genotype-by-year variance

V_e = Error variance

V_p = Phenotypic variance

Selection response (R_e) for a trait at each location was predicted as,

$$R_e = i_X \sigma_{PX} h^2_X$$

where,

i_X = Selection intensity for trait x,

h^2_X = Heritability for trait x,

and σ_{PX} = Square root of the phenotypic variance of trait x.

A similar selection intensity of 20% (1.44) was used in predicting the selection responses at both locations (Falconer & Mackay, 1996; Atlin & Frey, 1989).

Results and Discussion

The analysis of variance across years and locations exhibited highly significant ($p \leq 0.01$) genetic variation among mungbean genotypes for days to flowering, maturity, plant height, leaves plant^{-1}, nodes plant^{-1} and leaf area (Table 3). The two test locations differed significantly ($p \leq 0.01$) for days to flowering and leaves plant^{-1} only. Similarly, differences among the two years were highly significant ($p \leq 0.01$) for days to flowering, plant height and leaves plant^{-1}. Location-by-year (L×Y) interaction effect was evident for days to flowering, plant height and nodes plant^{-1} ($p \leq 0.01$). Genotype-by-year (G×Y) interaction effect was non-significant for all the traits except nodes plant^{-1}. As expected, genotype-by-location (G×L) interaction effect was highly significant ($p \leq 0.01$) for days to flowering, maturity, plant height and leaf area. This indicates differential performance of mungbean genotypes for these traits at the two test locations (Peshawar and Swat). Genotype-by-location-by-year (G×L×Y) interaction effect was non-significant for most of the traits except leaves and nodes plant^{-1}. Significant genetic variation for morphological traits like days to flowering, maturity and plant height is also reported by Rozina *et al*., (2008) in mungbean. Similarly, Siddique *et al*., (2006) and Rohman *et al*., (2003) have also observed significant genetic variability for agronomic traits in mungbean.

Days to flowering of mungbean genotypes ranged from 41.6 to 50.3 at Peshawar vs. 44.2 to 57.0 at Swat (Table 4). About 83% of the mungbean genotypes reached the flowering stage at Swat later than Peshawar. Averaged over 30 mungbean genotypes, days to flowering at Peshawar and Swat were 47.2 and 50.5, respectively. Maximum difference of nine days to flowering was observed for check cultivar Ramzan followed by NFM-5-63-10 (6.5 days) at Swat. NFM-5-63-4 reached flowering stage by 2.1 days earlier at Swat than Peshawar. Averaged across years and locations, minimum days to flowering were recorded for NFM-7-13 (43.5 days) followed by NFM-8-1 (44.3 days) and NFM-8-22 (45.8 days) while maximum days of 53.3 to flowering were taken by genotype NFM-14-5 followed by genotype NFM-5-63-13 and check cultivar Ramzan each taking 52.2 days.

Of 30 mungbean genotypes, 60% took less days to maturity at Swat than Peshawar. Averaged over two years and locations, the early maturing genotype was NFM-8-1 with 78.3 days to maturity followed by NFM-7-13 (Table 4). In contrast, NFM-12-8 (90.5 days), NFM-12-3 (90.0 days) and NFM-11-3 (89.4 days) were late maturing genotypes. Due to shorter plant stature, genotype NFM-8-1 matured earlier than taller genotypes. Similarly, NFM-12-8 was one of the taller genotypes which matured later due to its prolonged vegetative phase.

Averaged across years and locations maximum plant height of 74.9 cm was attained by genotype NFM-11-3 followed by NFM-12-8 (71.7 cm), NFM-5-63-4 (66.4 cm) and NFM-14-5 (63.8 cm). Genotype NFM-8-1 had shortest stature measuring 38.5 cm only. Plant height was reduced in 63% of the mungbean genotypes at Swat compared to Peshawar (Table 4). Maximum reduction in height of 41.7 cm was recorded for genotype NFM-5-63-4 at Swat followed by cultivar Ramzan (12.0 cm).

Twenty five mungbean genotypes had more leaves plant^{-1} at Swat than Peshawar. Averaged across years and locations maximum number of 9.9 leaves plant^{-1} were recorded each for genotypes NFM-5-63-4, NFM-11-3 and NFM-12-8 followed by NFM-12-6 and NFM-12-3 with average leaves of 9.1 and 8.9, respectively (Table 5). Least number of 7.4 leaves plant^{-1} was recorded for genotypes NFM-5-63-10 and NFM-5-63-57. Genotype NFM-8-22 and cultivar NM-92 had similar number of 7.7 leaves plant^{-1}.

Table 3. Mean squares for days to flowering, maturity, plant height, leaves plant^{-1}, nodes plant^{-1} and leaf area of leaf at 6th position of 30 mungbean genotypes evaluated at two locations of NWFP during 2007 and 2008.

Source of variation	Degrees of freedom	Days to flowering	Days to maturity	Plant height	Leaves plant^{-1}	Nodes plant^{-1}	Leaf area
Location (L)	1	934.4**	476.1^{NS}	936.4^{NS}	15.6**	13.2^{NS}	38165.6^{NS}
Year (Y)	1	1269.4**	37.4^{NS}	211.9**	16.5**	3.4^{NS}	158.3^{NS}
L×Y	1	2250.0**	28.9^{NS}	51.5**	2.0^{NS}	61.7**	186.7^{NS}
Rep (L×Y)	8	60.5	192.9	264.9	0.95	3.9	8844.9
Genotype (G)	29	74.4**	108.3**	936.3**	5.9**	9.6**	4913.8**
G×L	29	21.7**	83.4**	253.0**	2.0^{NS}	1.4^{NS}	1780.3**
G×Y	29	9.8^{NS}	21.9^{NS}	8.1^{NS}	0.78^{NS}	2.0**	1464.9^{NS}
G×L×Y	29	9.0^{NS}	18.7^{NS}	7.0^{NS}	2.4**	3.7**	665.9^{NS}
Error	**232**	**15.49**	**18.26**	**63.47**	**0.65**	**1.09**	**1477.08**

NS= Non significant, ** = Significant at 1% probability level.

Table 4. Means for days to flowering, maturity and plant height of 30 mungbean genotypes evaluated at two locations of NWFP during 2007 and 2008.

Genotypes	Days to flowering			Days to maturity			Plant height (cm)		
	Pesh	Swat	Mean	Pesh	Swat	Mean	Pesh	Swat	Mean
NFM-5-63-4	49.3	47.2	48.3	93.8	80.2	87.0	87.2	45.5	66.4
NFM-5-63-10	45.3	51.8	48.6	84.5	84.3	84.4	42.1	45.0	43.6
NFM-5-63-13	50.2	54.2	52.2	85.3	88.3	86.8	61.8	50.9	56.4
NFM-5-63-19	48.2	47.5	47.9	85.5	84.3	84.9	52.1	51.0	51.6
NFM-5-63-20	48.5	47.3	47.9	86.3	85.5	85.9	57.7	55.4	56.6
NFM-5-63-34	48.3	52.2	50.3	87.2	90.0	88.6	55.7	69.7	62.7
NFM-5-63-35	45.5	51.5	48.5	84.5	88.2	86.4	52.1	45.8	49.0
NFM-5-63-48	46.3	50.0	48.2	84.3	86.5	85.4	53.9	50.5	52.2
NFM-5-63-49	47.5	52.8	50.2	82.3	86.0	84.2	51.9	54.3	53.1
NFM-5-63-57	50.3	52.2	51.3	84.7	86.7	85.7	41.7	41.1	41.4
NFM-11-3	49.2	53.5	51.4	92.5	86.2	89.4	73.6	76.1	74.9
NFM-12-3	48.8	52.7	50.8	93.0	87.0	90.0	57.6	52.3	55.0
NFM-12-6	48.2	50.2	49.2	90.2	82.8	86.5	60.5	64.9	62.7
NFM-12-7	47.8	51.5	49.7	89.3	85.7	87.5	66.2	59.8	63.0
NFM-12-8	48.2	52.5	50.4	93.2	87.7	90.5	71.5	71.9	71.7
NFM-12-12	50.3	53.7	52.0	94.0	84.2	89.1	61.0	54.7	57.9
NFM-12-15	49.3	52.7	51.0	85.5	86.0	85.8	52.9	52.8	52.9
NFM-13-1	47.0	45.5	46.3	87.0	81.2	84.1	56.8	49.5	53.2
NFM-14-3	46.3	46.0	46.2	87.7	78.8	83.3	49.3	46.8	48.1
NFM-14-5	49.5	57.0	53.3	93.0	76.8	84.9	62.2	65.3	63.8
NFM-14-6	46.2	49.2	47.7	84.6	87.2	85.9	44.9	38.7	41.8
NFM-14-7	46.5	47.2	46.9	84.5	80.5	82.5	50.1	41.4	45.8
NFM-3-3	47.7	50.3	49.0	83.0	85.2	84.1	51.2	54.0	52.6
NFM-6-5	44.0	47.8	45.9	80.2	82.5	81.4	50.4	40.5	45.5
NFM-7-13	42.8	44.2	43.5	81.8	75.8	78.8	45.3	47.5	46.4
NFM-8-1	41.6	47.3	44.3	78.7	77.8	78.3	38.6	38.4	38.5
NFM-8-22	44.8	46.7	45.8	79.5	80.5	80.0	47.6	51.7	49.7
NM-92	43.0	48.8	45.9	84.0	86.8	85.4	48.1	49.8	49.0
NM-98	48.5	53.7	51.1	86.2	85.0	85.6	55.3	49.1	52.2
Ramzan	47.7	56.7	52.2	87.8	87.5	87.7	65.2	53.2	59.2
Mean	47.2	50.5	---	86.5	84.2	---	55.5	52.3	---
LSD (0.05)	3.1	4.0	2.6	6.0	4.4	3.9	2.6	3.7	2.4

Pesh: Peshawar

Table 5. Means for leaves plant^{-1}, nodes plant^{-1} and leaf area of leaf at 6th position of 30 mungbean genotypes evaluated at two locations of NWFP during 2007 and 2008.

Genotypes	Leaves plant^{-1}			Nodes plant^{-1}			Leaf area (cm^2)		
	Pesh	Swat	Mean	Pesh	Swat	Mean	Pesh	Swat	Mean
NFM-5-63-10	7.0	7.8	7.4	9.7	9.2	9.5	179.8	201.5	190.7
NFM-5-63-13	8.3	8.7	8.5	12.0	9.8	10.9	156.2	204.9	180.6
NFM-5-63-19	7.8	9.0	8.4	11.0	10.5	10.8	163.2	202.0	182.6
NFM-5-63-20	7.7	8.5	8.1	10.8	10.7	10.8	198.9	216.3	207.6
NFM-5-63-34	7.5	8.2	7.9	10.5	10.8	10.7	198.0	207.2	202.6
NFM-5-63-35	7.5	8.2	7.9	8.7	9.7	9.2	150.3	205.7	178.0
NFM-5-63-4	11.5	8.3	9.9	14.3	12.3	13.3	246.1	236.3	241.2
NFM-5-63-48	7.7	8.5	8.1	9.8	10.2	10.0	181.5	233.2	207.4
NFM-5-63-49	7.0	8.2	7.6	9.2	9.3	9.3	145.9	200.7	173.3
NFM-5-63-57	7.0	7.8	7.4	9.8	9.5	9.7	132.9	182.9	157.9
NFM-11-3	9.7	10.0	9.9	11.8	11.8	11.8	209.2	227.7	218.5
NFM-12-3	8.8	9.0	8.9	10.8	11.2	11.0	206.4	227.6	217.0
NFM-12-6	8.8	9.3	9.1	10.5	10.7	10.6	200.9	197.8	199.4
NFM-12-7	8.3	9.2	8.8	10.8	10.3	10.6	202.4	193.7	198.1
NFM-12-8	9.8	10.0	9.9	12.0	11.8	11.9	201.3	187.2	194.3
NFM-12-12	9.2	9.2	9.2	11.3	10.8	11.1	200.5	207.8	204.2
NFM-12-15	8.0	8.7	8.4	11.2	10.3	10.8	190.2	209.2	199.7
NFM-13-1	7.8	7.7	7.8	10.3	9.5	9.9	134.1	171.8	153.0
NFM-14-3	8.3	7.7	8.0	10.2	9.3	9.8	199.3	175.3	187.3
NFM-14-5	7.3	9.0	8.2	10.3	10.5	10.4	221.1	220.0	220.6
NFM-14-6	7.7	8.3	8.0	10.0	10.0	10.0	192.5	211.7	202.1
NFM-14-7	7.7	8.3	8.0	11.3	9.8	10.6	179.5	225.5	202.5
NFM-3-3	8.7	8.3	8.5	11.5	10.3	10.9	171.8	193.3	182.6
NFM-6-5	8.0	8.3	8.2	10.0	9.5	9.8	150.2	160.5	155.4
NFM-7-13	7.5	8.5	8.0	10.5	10.3	10.4	160.3	182.1	171.2
NFM-8-1	7.3	7.8	7.6	9.5	9.7	9.6	162.9	234.1	198.5
NFM-8-22	7.3	8.0	7.7	10.3	9.8	10.1	164.4	193.9	179.2
NM-92	7.3	8.0	7.7	9.3	9.2	9.3	158.8	180.8	169.8
NM-98	7.8	8.3	8.1	10.2	10.0	10.1	183.6	188.9	186.3
Ramzan	8.2	8.3	8.3	11.3	10.7	11.0	213.2	193.8	203.5
Mean	8.1	8.5	---	10.6	10.3	---	181.8	202.4	---
LSD (0.05)	1.7	1.2	0.7	2.3	1.6	1.2	49.9	22.0	32.0

Pesh: Peshawar

About 27% of the genotypes had more number of nodes at Swat than Peshawar. Maximum number of 13.3 nodes plant^{-1} were recorded for genotype NFM-5-63-4 followed by NFM-12-8 (11.9 nodes plant^{-1}) and NFM-11-3 (11.8 nodes plant^{-1}). Genotype NFM-5-63-35 had minimum number of nodes plant^{-1} (9.2).

About 77% of the genotypes had more leaf area at Swat than Peshawar due to high rainfall and low temperature which enhanced mungbean growth at Swat (Table 5). Maximum leaf area of leaf at 6th position of 241.2 cm^2 was recorded for genotype NFM-5-63-4 followed by NFM-14-5 (220.6 cm^2), NFM-11-3 (218.5 cm^2) and NFM-12-3 (217.0 cm^2). Genotype NFM-13-1 had the lowest leaf area of 153.0 cm^2.

Genetic, genetic × year and environmental variances, estimates of heritability and response to selection for various traits are given in Table 6. Genetic variances for days to flowering, maturity, plant height, leaves plant^{-1}, nodes plant^{-1} and leaf area were 4.0, 14.1, 105.8, 0.6, 0.5 and 437.5 at Peshawar vs 8.9, 11.0, 89.8, 0.2, 0.3 and 323.0 at Swat, respectively. Thus genetic variances for days to maturity, plant height, leaves plant^{-1}, nodes plant^{-1} and leaf area were 1.3, 1.2, 3.0, 1.7 and 1.4 times greater at Peshawar than Swat, respectively. Similarly, the genetic variance for days to flowering was 0.6 and 0.4 times greater than the error variance at Peshawar and Swat, respectively. Similarly, genetic variance for days to maturity was 1.0 and 0.5 times greater than error variance at Peshawar and Swat, respectively. Genetic variance for plant height was 1.4 and 1.7 times greater than error variance at Peshawar and Swat, respectively, and the genetic × year variance were negligible for plant height at both locations. For leaves plant^{-1} the error variance at both locations was relatively greater in magnitude than the genetic variance, while genetic variance was 1.2 and 1.8 times greater than the genetic × year variance. Genetic variance for leaf area was 0.3 and 0.2 times less than the error variance at Peshawar and Swat, respectively, but genetic variance for leaf area was 2.8 times greater than the genetic × year variance at Peshawar. These results are in accordance with Idress *et al.,* (2006) who reported varying magnitudes of genetic and environmental variances for morphological traits in a set of mungbean mutants.

Broad sense heritabilities for days to flowering, maturity, plant height, leaves plant^{-1}, nodes plant^{-1} and leaf area were 0.63, 0.75, 0.81, 0.73, 0.56 and 0.50 at Peshawar vs. 0.53, 0.60, 0.84, 0.49, 0.52 and 0.37, respectively at Swat. Thus magnitude of heritabilities for all traits at Peshawar was higher than Swat except plant height. Greater heritability estimates for most of the morpho-physiological traits revealed that these traits are governed by additive genes. Plant height was the least affected trait across year at both locations followed by days to maturity and leaves plant^{-1} at Peshawar only. Broad sense heritability for plant height was high in magnitude both at Peshawar (0.81) and Swat (0.84) suggesting greater possibility of genetic improvement in this important trait. Makeen *et al*., (2007) and Sriphadet *et al*., (2005) have also reported moderate to high heritability for various morphological traits in mungbean. Due to high heritability estimates, the traits are expected to remain stable under varied environmental conditions encountered in NWFP and could easily be improved through selection (Khattak *et al*., 1997; Siddique *et al*., 2006).

Using 20% intensity, selection response for flowering, maturity, plant height, leaves plant^{-1}, nodes plant^{-1} and leaf area were 2.22 days, 4.56 days, 12.96 cm, 0.92, 0.78 and 20.68 cm^2 at Peshawar vs 3.03 days, 3.60 days, 12.15 cm, 0.44, 0.57 and 15.35 cm^2, respectively at Swat. Thus, selection response was greater for all traits at Peshawar than Swat.

Conclusions

Highly significant genetic variation was observed among mungbean genotypes for important morpho-physiological traits across years and locations. Highly significant genotype × location interaction for most of the important morpho-physiological traits (flower initiation, maturity, plant height and leaf area) necessitate the development of mungbean genotypes with specific adaptation to the two test locations (Swat and Peshawar) of NWFP. High heritabilities for most traits at Peshawar indicate that these characters are controlled by additive genes and will respond positively to phenotypic selection at Peshawar than Swat.

Table 6. Genetic variance (V_g), genetic by year variance (V_{gy}), environmental variance (V_e), broad-sense heritability (h^2) and expected selection response (R_e) for morpho-physiological traits of 30 mungbean genotypes evaluated at two locations of NWFP during 2007 and 2008.

Components	Days to flowering (no.)		Days to maturity (no.)		Plant height (cm)		Leaves plant^{-1} (no.)		Nodes plant^{-1} (no.)		Leaf area (cm^2)	
	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat
V_g	4.0	8.9	14.1	11.0	105.8	89.8	0.6	0.2	0.5	0.3	437.5	323.0
V_{gy}	0.1	-4.1§	4.0	-2.7§	-23.3§	-13.9§	0.5	0.1	0.8	0.3	154.7	-429.2§
V_e	7.0	24.0	13.9	22.5	75.0	51.9	0.6	0.6	1.2	0.9	1318.5	1635.7
h^2	0.63	0.53	0.75	0.60	0.81	0.84	0.73	0.49	0.56	0.52	0.50	0.37
R_e	2.22	3.03	4.56	3.60	12.96	12.15	0.92	0.44	0.78	0.57	20.68	15.35
CV (%)	5.6	9.7	4.3	5.6	15.6	13.8	9.9	9.4	10.6	9.3	19.9	19.9

§ Negative variances were considered zero

References

Anniechirico, P. 2002. Genotype × environment interaction: Challenges and opportunities for plant breeding and cultivar recommendations. *FAO Plant Prod. and Prot. Paper*. 174.

Anonymous. 2009. *Agriculture Statistics of Pakistan*. Ministry of Food, Agric. and Livestock, Econ. Wing, Islamabad.

Atlin, G.N. and K.J. Frey. 1989. Predicting the relative effectiveness of direct versus indirect selection for oat yield in three types of stress environments. *Euphytica*, 44:137-142.

Falconer, D.S. and T.F.C. Mackay. 1996. *Introduction to quantitative genetics*. 4th Ed. Longman Scientific and Technical, England.

Fernandez, G.C.J and S. Shanmugasundaram. 1988. The AVRDC mungbean improvement program: The past, present and future. In: *Proceedings of the 2nd International Mungbean Symposium*, Asian Vegetable Research and Development Center, Shanhua, Taiwan. pp. 58-70.

Idress, A., M.S. Sadiq, M. Hanif, G. Abbas and S. Haider. 2006. Genetic parameters and path co-efficient analysis in mutated generations of mungbean, *Vigna radiata* L. Wilczek. *J. Agric. Res*., 44(3): 181-191.

Khan, M., K. Nawab, A. Khan and M.S. Baloch. 2001. Genetic variability and correlation studies in mungbean. *J. Bio. Sci*., 1: 117-119.

Khattak, G.S.S., Razi-ud-Din, F. Hanan and R. Ahmad. 1997. Genetic analysis of some quantitative characters in mungbean. *Sarhad J. Agric*., 13(4): 371-376.

Makeen, K., G. Abrahim, A. Jan and A.K. Singh. 2007. Genetic variability and correlations studies on yield and its components in mungbean (*Vigna radiata* (L.) Wilczek). *J. Agron*., 6(1): 216-218.

Malik, B.A. 1994. *Grain legume. In: Crop production*. (Eds.): E. Bashir and R. Bantel. National Book Foundation, Islamabad, Pakistan, pp. 277-328.

Rohman, M.M, A.S.M.I. Hussain, M.S. Arifin, Z. Akhter and M. Hasanuzzaman. 2003. Genetic variability, correlations and path analysis in mungbean. *Asian J. Plant Sci*., 2: 1209-1211.

Rowe, D.E and G.E. Brink. 1993. Heritabilities and genetic correlations of white clover clones grown in three environments. *Crop Sci*., 33: 1149-1152.

Rozina, G., H. Khan, G. Mairaj, S. Ali, Farhatullah and Ikramullah. 2008. Correlation study on morphological and yield parameters of mungbean (*Vigna radiata*). *Sarhad J. Agric*., 24(1): 11-16.

Siddique, M., M.F.A. Malik and I.A. Shahid. 2006. Genetic divergence, association and performance evaluation of different genotypes of mungbean (*Vigna radiata*). *Intl. J. Agric. Biol*., 8(6): 793-795.

Sriphadet, S., J.L. Cristopher and P. Srinives. 2005. Inheritance of agronomic traits and their interrelationship in mungbean (*Vigna radiata* (L.) Wilczek). *J. Crop Sci. Biotech*., 10(4): 249-256.

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