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Full Length Research Paper

Genotype × environment interaction, heritability and selection response for yield and yield contributing traits in mungbean

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Developing and identifying suitable genotypes for diversified environment is the key factor of breeding programs. Thirty mungbean (*Vigna radiata* (L.) Wilczek) genotypes were evaluated at two locations of Khyber Pakhtunkhwa during 2007 and 2008 using randomized complete block design with replications. Highly significant differences ($P \leq 0.01$) were observed among the genotypes for yield and yield associated traits across years at both locations and also across years and locations. L × Y effect was highly significant ($P \leq 0.01$) for peduncle length, pods cluster^{-1}, seeds pod^{-1}, 1000 grain weight and grain yield ha^{-1}. G × L interaction was highly significant ($P \leq 0.01$) for pods plant^{-1}, clusters plant^{-1}, pods cluster^{-1}, pod length, seeds pod^{-1}, 1000 grain weight and grain yield ha^{-1} indicating differential performance of mungbean genotypes over the two test locations and showing narrow adaptability. Means for peduncle length, pods plant^{-1}, clusters plant^{-1}, pods cluster^{-1}, pod length, seeds pod^{-1}, 1000 grain weight, harvest index and grain yield ha^{-1} were 9.2 versus 8.3 cm, 15.6 versus 31.6, 6.1 versus 8.3, 3.5 versus 4.6, 9.1 versus 10.6 cm, 10.3 versus 12.4, 58.8 versus 68.6 g, 27.6 versus 28.7% and 2128.5 versus 2961.6 kg, respectively. The genetic variances for harvest index and grain yield were higher than environmental variance at both locations, and greater for pod length, seeds pod^{-1} and 1000 grain weight at Swat only. Similarly genetic × year variances were non-existent for most of the traits. Heritability estimates for all the traits and expected response to selection for most of the traits were generally greater in magnitude at Swat than Peshawar, except peduncle length.

Key words: G × E interaction, heritability, quantitative traits, *Vigna radiata*, selection response.

INTRODUCTION

Continuous cultivation of major crops like wheat, rice, maize and sugarcane reduces soil fertility and productivity level that ultimately affect the water table, and raised salinization problems which encourage the population of insect/pests and diseases. The only acceptable way to overcome these problems is the introduction of leguminous crops such as mungbean [*Vigna radiata* (L.) Wilczek] which is rich in protein and has the ability to fix atmospheric nitrogen through symbiotic activity and eventually sustain soil productivity and interrupt the life cycle of prevalent diseases. Global warming is no more clandestine threat to the modern day world and mungbean has the power to play a major role in minimizing this critical issue due to its low chemical fertilizer consumption that prevent water resources from nitrate pollution (Pirbalouti et al., 2006).

The experimental yield of mungbean per unit area is far from national average yield in Pakistan. During the year 2007-08, mungbean was cultivated on an area of 245.9 thousand hectares with a total production of 177.7 thousand tons, which reduced by 6 and 11.4%, respectively, in the year 2009 (MINFAL, 2009). This gap in area and production might be due the low yielding cultivars which fail to justify the cost of production that can be overcome by developing high yielding varieties, bringing fallow land under cultivation and encouraging intercropping with rice, sugarcane and maize.

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Table 1. Trial location description of thirty mungbean genotypes evaluated at Khyber Pakhtunkhwa.

Parameter		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	
Average monthly temperature (°C)		**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
	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 to 8.3				Sandy loam/neutral pH 7.2 to 7.3			

Assessment of genetic variance is the most appropriate statistical tool to find out the magnitude of heritablities, genetic coefficient of variation and response to selection at specific selection intensity. Sarwar et al. (2004) stated that the best selection criteria for developing high yielding cultivars will only be effective if emphasis is given to pods plant^{-1} followed by seeds pod^{-1} and strongly ignore the single stem plants selection. Biradar et al. (2007) reported highly significant genetic variation and moderate to high heritability of 25.8, 86, 85.7, 78 and 74.1% for pods cluster^{-1}, pod length, seeds pod^{-1}, 100 seed weight, and grain yield plant^{-1}, respectively in 120 mungbean genotypes. Sriphadet et al. (2005) reported 63.1, 93.7 and 58.4% heritability for seed weight plant^{-1}, pod length and seeds pod^{-1}, respectively. Similarly, Khan et al. (2001) reported strong association among clusters plant^{-1} and pods plant^{-1}, resulting in increased yield per unit area. Positively and statistically significant relationship between seed yield and pods plant^{-1}, seeds plant^{-1}, harvest index and 1000 seed weight is reported by Celal (2004).

Quality crop improvement program mainly depends on the nature and magnitude of genetic variability of particular crop. The greater the existence of variation, the better the chances to evolve outstanding genotypes. Out of the released varieties are NM-92 and NM-98 which are predominantly grown at commercial scale in major mungbean growing areas of Punjab province. Due to high acreage under cultivation of NM-92, it is shows sparsely symptoms of MYMV. Moreover, adoption of only these two varieties may narrow the genetic base of mungbean (Sadiq et al., 2004). In contrast, the only cultivated variety Ramzan is adaptable to the environment of Khyber Pakhtunkhwa. Mungbean cultivation in conventional and non-traditional areas mainly depends on its competitive nature with other crops and its adaptability over a wide range of environmental conditions (Popalghat et al., 2001). So an attempt was made to screen the stable germplasm which tend to high yield under the diversified environment of Khyber Pakhtunkhwa.

The knowledge of genetic variation, heritability and selection response of yield and yield associated traits and their interrelationship helps in understanding yield components and yield potential in mungbean. The aim of this study was to screen high yielding lines and to determine the genotype × environment interaction, heritabilities and response to selection for important yield with associated traits of mungbean at two locations of Khyber Pakhtunkhwa, Pakistan.

MATERIALS AND METHODS

Thirty mungbean germplasm 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, viz. Agricultural University, Peshawar and Agricultural Research Institute, Mingora, Swat of Khyber Pakhtunkhwa.

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 using randomized complete block design with three replications. Plot size for a mungbean genotype in each replication was 3.6 m^2. Each unit 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 population, thinning was carried out in 2 to 3 trifoliate leaf

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

Locations	Soil salinity and sodicity		Macro nutrients				Micro nutrients		
	Dissoluble salt EC (1:2.5) dS/m	Exchangeable Na (mmolc/100 g)	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

stage. Soil test for available nutrients was carried out prior to sowing in the experiments at both locations through Farmer Advisory Centre, Fauji Fertilizer Company Limited, Pakistan (Table 2). The fertilizers, NPK at 60:110:50 kg ha^{-1} and Zinc sulfate 23% at 25 kg ha^{-1} were applied to the experiment at Peshawar based on soil test. Similarly, NPK at 50:100:45 kg ha^{-1} and Zinc sulfate 21% at 25 kg ha^{-1} were applied during the experiment at Swat. Fertilizer 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. Irrigation, weeding and pest control measures were taken as needed at both locations. The trials were planted using randomized complete block (RCB) design. Data were recorded on peduncle length, pods $plant^{-1}$, clusters $plant^{-1}$, pods $cluster^{-1}$, pod length, seeds pod^{-1}, 1000 grain weight, harvest index and grain yield ha^{-1} at both locations.

Statistical analysis

The two years data obtained at each location were statistically analyzed using appropriate model for RCB design as proposed by Annicchiarico (2002). Genotypic, genotype-by-year and error variances for the traits were worked out from the analysis of variances in two years under each location to determine heritabilities (h^2_{BS}) using the following procedure of Rowe and 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_p = phenotypic variance; V_{gy} = genotype–by-year variance, and V_e = error 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; σ_{PX} = square root of the phenotypic variance of trait x. A similar selection intensity of 20% (1.44) was assumed in predicting direct selection responses at both locations (Falconer and Mackay, 1996; Atlin and Frey, 1989).

RESULTS AND DISCUSSION

Pooled analysis

The analysis of variance across years and locations exhibited highly significant ($P \leq 0.01$) genetic variation among mungbean genotypes for all traits except peduncle length and pods $cluster^{-1}$ which were non-significant (Table 3). The two test locations were also different significantly ($P \leq 0.01$) for all the traits studied except peduncle length which was significantly different at $P \leq 0.05$. Similarly, differences among the two years were highly significant ($P \leq 0.01$) for peduncle length, pods $plant^{-1}$, clusters $plant^{-1}$, pod length, seeds pod^{-1}, thousand grain weight and grain yield ha^{-1} (Table 3). Location-by-year (L×Y) interaction effect was evident for peduncle length, pods $cluster^{-1}$, seeds pod^{-1}, 1000 grain weight and grain yield ha^{-1} ($P \leq 0.01$). Genotype-by-year (G×Y) interaction effect was non-significant for all the traits except peduncle length, harvest index and grain yield ha^{-1}. As expected, genotype-by-location (G×L) interaction effect was highly significant ($P \leq 0.01$) for all the traits except peduncle length and harvest index due to erratic rainfall distribution during the study at both locations. 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 harvest index. The significant second order interaction revealed that the sources of variances might be environmental fluctuation especially maximum precipitation due to rainfall in the month of August. Significant genetic variation for yield and yield associated traits like pods $plant^{-1}$, seeds pod^{-1}, 100 seed weight, seed yield, biological yield and harvest index is also reported by Singh et al. (2006) in mungbean varieties under rainfed environments. Similarly, Siddique et al. (2006) have also observed significant genetic diversity for agronomic and yield associated traits

Table 3. Mean squares for peduncle length, pods plant^{-1}, clusters plant^{-1}, pods cluster^{-1}, pod length, seeds pod^{-1}, 1000 grain weight, harvest index and grain yield of 30 mungbean genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2007 and 2008.

Sources of variation	Degrees of freedom	Peduncle length	Pods plant^{-1}	Clusters plant^{-1}	Pods cluster^{-1}	Pod length	Seeds pod^{-1}	1000 grain weight	Harvest index	Grain yield ha^{-1}
Location (L)	1	76.5*	23652.0**	432.3**	111.1**	213.1**	414.3**	8726.1**	117.5**	62462922.2**
Year (Y)	1	74.1**	4120.9**	60.9**	6.7*	5.7**	44.5**	472.4**	2.6^{NS}	5620975.7**
L × Y	1	163.6**	26.7^{NS}	1.3^{NS}	5.9**	0.2^{NS}	15.0**	547.6**	40.6^{NS}	527153.9**
Rep (L×Y)	8	13.5	342.1	11.4	2.1	1.7	5.0	166.1	8.7	164510.8
Genotype (G)	29	7.8^{NS}	184.4**	16.7**	2.1^{NS}	2.9**	4.0**	449.9**	104.9**	968674.3**
G × L	29	3.5^{NS}	141.5**	8.7**	2.4**	1.2**	2.4**	111.7**	15.6^{NS}	451001.7**
G × Y	29	4.9**	44.6^{NS}	2.7^{NS}	1.2^{NS}	0.4^{NS}	0.8^{NS}	51.9^{NS}	15.6**	82419.2**
G × L × Y	29	2.9^{NS}	12.9^{NS}	1.1^{NS}	0.6^{NS}	0.3^{NS}	0.5^{NS}	17.7^{NS}	12.0**	55214.9^{NS}
Error	232	2.0	40.9	3.6	1.0	0.3	0.9	56.6	5.2	37176.9

NS, Non significant; * and **, significant at 5 and 1% probability level.

in mungbean. On the basis of second-order interactions, G x Y x S, which were large in magnitude than the first-order interactions (G x Y, G x S) for seed yield, pods plant^{-1}, and seeds pod^{-1} Fernandez and Chen (1989) suggested three seasons with 3 years and three replications for effective selection of promising lines.

Means across years and locations

About 77% of the mungbean genotypes have longest peduncle at Peshawar than Swat. Peduncle length of mungbean genotypes ranged from 7.5 to 12.1 at Pesha-war versus 7.2 to 10.0 at Swat (Table 4). In average, over 30 mungbean genotypes, peduncle length at Peshawar and Swat were 9.2 and 8.3, respectively. Maximum difference of 3.5 cm of peduncle length was observed for NFM-14-5 followed by NFM-5-63-4 (3.0 cm) at Peshawar. Check cultivar Ramzan has 1.4 cm long peduncle at Swat than Peshawar. Average across years and loca-tions shortest peduncle length were recorded for NFM-5-63-4 (7.4 cm) followed by NFM-13-1 (7.6 cm) and NFM-5-63-20 (7.7 cm), while maximum peduncle length of 10.6 were recorded for genotype NFM-14-3 followed by genotype NFM-14-5 and NFM-14-7 each having 10.4 and 9.9 cm long peduncle.

About 76% of the tested genotypes produced more than 20 pods plant^{-1}. Average of over two years and locations maximum number of pods plant^{-1} of 33.4 was recorded for genotype NFM-14-6 followed by NFM-13-1 (29.4), NFM-12-3 (28.8) and NFM-12-12 (28.7). Genotype NFM-3-3 had minimum pods plant^{-1} of 18.3 numbers. Maximum variation was found among the genotypes for pods plant^{-1}, all the tested genotypes produced more numbers of pods at Swat than Peshawar. Maximum increase in pods plant^{-1} of 31.7 was recorded for genotype NFM-14-6 followed by NFM-12-3 (27.9). None of the genotypes were found for reduction of pods plant^{-1} at Swat in consecutive cropping seasons.

Clusters plant^{-1} of mungbean genotypes ranged from 4.4 to 9.1 at Peshawar vs. 5.0 to 14.3 at Swat. Of the thirty mungbean genotypes, 93% achieved more clusters plant^{-1} at Swat than Peshawar. Average of over two years and locations clusters plant^{-1} ranged from 4.8 to 10.3. Maximum number of clusters plant^{-1} of 10.3 was recorded for genotype NFM-12-12 which ranked 3rd by maximum number of pods plant^{-1} followed by NFM-12-15 with an average of 8.8 clusters plant^{-1}. In contrast, genotypes NFM-5-63-35 (4.8 no.), NFM-14-7 (5.5 no.) and NFM-5-63-57 (5.9 no.) produced less number of clusters plant^{-1}. More numbers of clusters at Swat may be due to prolonged vegetative growth and low range of temperature which encouraged the formation of clusters.

Average of over two years and locations maximum number of 5.2 pods cluster^{-1} was recorded for genotype NFM-14-7, followed by NFM-7-13 average pods of 4.9. Least number of 3.4 pods cluster^{-1} was recorded for genotype NFM-11-3

Table 4. Means for peduncle length, pods plant^{-1} and clusters plant^{-1} of mungbean genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2007 and 2008.

Genotype	Peduncle length (cm)			Pods plant^{-1}			Clusters plant^{-1}		
	Pesh	Swat	Means	Pesh	Swat	Means	Pesh	Swat	Means
NFM-5-63-4	11.3	8.3	9.8	11.8	32.2	22.0	4.8	7.2	6.0
NFM-5-63-10	7.6	7.2	7.4	11.8	25.0	18.4	6.0	6.2	6.1
NFM-5-63-13	8.3	7.7	8.0	15.3	30.5	22.9	5.2	7.4	6.3
NFM-5-63-19	10.1	7.7	8.9	16.2	23.8	20.0	5.1	7.5	6.3
NFM-5-63-20	8.4	7.0	7.7	15.2	28.7	22.0	5.8	7.1	6.5
NFM-5-63-34	8.7	8.9	8.8	16.0	29.0	22.5	6.9	9.3	8.1
NFM-5-63-35	9.5	8.9	9.2	11.7	28.0	19.9	4.5	5.0	4.8
NFM-5-63-48	9.5	8.0	8.8	13.8	27.5	20.7	5.3	7.0	6.2
NFM-5-63-49	9.5	8.1	8.8	12.2	33.5	22.9	4.4	7.5	6.0
NFM-5-63-57	9.8	7.2	8.5	12.7	27.8	20.3	5.3	6.5	5.9
NFM-11-3	9.0	8.4	8.7	19.7	22.7	21.2	7.2	8.7	8.0
NFM-12-3	10.2	8.9	9.6	14.8	42.7	28.8	5.6	10.3	8.0
NFM-12-6	8.6	7.5	8.1	19.0	36.3	27.7	6.1	8.3	7.2
NFM-12-7	9.4	8.5	9.0	15.2	31.5	23.4	6.1	9.0	7.6
NFM-12-8	7.8	8.7	8.3	14.8	25.8	20.3	7.0	8.6	7.8
NFM-12-12	9.2	9.0	9.1	15.0	42.3	28.7	6.3	14.3	10.3
NFM-12-15	9.3	9.4	9.4	23.0	30.0	26.5	9.1	8.5	8.8
NFM-13-1	7.7	7.4	7.6	17.5	41.2	29.4	6.7	9.9	8.3
NFM-14-3	11.4	9.7	10.6	13.8	25.8	19.8	5.1	8.2	6.7
NFM-14-5	12.1	8.6	10.4	16.7	37.5	27.1	5.3	9.2	7.3
NFM-14-6	9.8	7.8	8.8	17.5	49.2	33.4	6.6	10.6	8.6
NFM-14-7	9.7	10.0	9.9	13.2	37.3	25.3	5.1	5.8	5.5
NFM-3-3	9.2	8.1	8.7	15.8	20.7	18.3	6.6	6.3	6.5
NFM-6-5	8.1	7.4	7.8	16.7	35.3	26.0	6.5	9.0	7.8
NFM-7-13	8.2	8.4	8.3	16.0	39.0	27.5	6.2	8.9	7.6
NFM-8-1	9.0	9.3	9.2	21.5	32.2	26.9	7.6	9.0	8.3
NFM-8-22	8.0	8.0	8.0	17.7	38.0	27.9	6.2	9.8	8.0
NM-92	9.7	8.1	8.9	13.8	25.7	19.8	6.8	7.2	7.0
NM-98	9.0	7.7	8.4	18.2	31.2	24.7	7.3	9.0	8.2
Ramzan	7.5	8.9	8.2	12.8	25.3	19.1	5.9	7.0	6.5
Mean	9.2	8.3	----	15.6	31.9	----	6.1	8.3	----
LSD (0.05)	2.7	1.9	1.9	5.1	7.3	5.6	1.8	1.5	1.4

followed by NFM-5-63-57, NFM-12-12, NFM-12-8 and check cultivar Ramzan each had 3.6 pods cluster^{-1}. Genotype NFM-5-63-13, NFM-5-63-48 and check cultivar NM-92 had equal number of 3.7 pods cluster^{-1}. About 93% of mungbean genotypes had more pods cluster^{-1} at Swat than Peshawar (Table 5). It was observed that more number of mature pods cluster^{-1} at Swat was due to low and favorable temperature along with high humidity that made the stalk flexible and hence the shattering was low as compared to Peshawar. It was also observed that the visual effect of sucking/piercing insect/pest at Swat was low when compared with Peshawar which causes little abscission of the pods.

Pod length of mungbean genotypes ranged from 7.9 to 10.1 cm at Peshawar versus 9.4 to 11.5 at Swat. An average of over two years and locations maximum pod length of 10.8 cm was recorded each for genotype NFM-3-3 and NFM-7-13 followed by NFM-12-3 and NFM-12-6 each which had 10.6 cm long pod. NFM-7-13 was one of the maximum pods cluster^{-1} bearing genotype. NFM-5-63-57 and NFM-14-5 had shortest pod length of 8.7 and 8.9, respectively. As stated, the NFM-5-63-57 had one of the least number of pods cluster^{-1} producing genotype. Across years and locations, an elongation of 3.2 cm was observed in check cultivar NM-92 followed by NFM-5-63-10 (2.7 cm) and NFM-12-12 (2.5 cm).

About 50% of the genotypes had 11 numbers of seeds pod^{-1}, and 46% had 12 numbers of seeds pod^{-1}. Mean maximum number of seeds 12.7 pod^{-1} was recorded for genotype NFM-12-6 which was one of the longest pod length genotype followed by NFM-7-13 and NM-98 each which had 12.2 number of seeds pod^{-1}. NFM-7-13 also

Table 5. Means for pods cluster^{-1}, pod length and seeds pod^{-1} of mungbean genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2007 and 2008.

Genotype	Pods cluster^{-1}			Pod length (cm)			Seeds pod^{-1}		
	Pesh	Swat	Means	Pesh	Swat	Means	Pesh	Swat	Means
NFM-5-63-4	3.4	4.5	4.0	9.4	10.8	10.1	9.3	12.9	11.1
NFM-5-63-10	3.1	4.4	3.8	8.0	10.7	9.4	9.8	12.3	11.1
NFM-5-63-13	3.5	3.8	3.7	8.9	10.5	9.7	9.5	11.8	10.7
NFM-5-63-19	4.0	3.7	3.9	9.3	9.8	9.6	9.8	12.1	11.0
NFM-5-63-20	3.7	4.3	4.0	9.2	10.1	9.7	9.2	11.9	10.6
NFM-5-63-34	3.8	4.4	4.1	9.3	10.9	10.1	9.9	12.9	11.4
NFM-5-63-35	3.6	5.7	4.7	8.7	10.3	9.5	8.7	11.6	10.2
NFM-5-63-48	3.4	3.9	3.7	9.1	10.8	10.0	9.2	12.1	10.7
NFM-5-63-49	3.1	5.3	4.2	8.7	10.5	9.6	9.5	12.1	10.8
NFM-5-63-57	2.9	4.2	3.6	7.9	9.4	8.7	10.8	12.2	11.5
NFM-11-3	3.8	3.0	3.4	9.8	9.9	9.9	11.2	12.2	11.7
NFM-12-3	3.4	4.7	4.1	9.7	11.5	10.6	10.2	13.6	11.9
NFM-12-6	3.5	5.0	4.3	9.7	11.4	10.6	12.1	13.3	12.7
NFM-12-7	3.2	4.4	3.8	9.3	9.9	9.6	10.6	12.1	11.4
NFM-12-8	3.2	3.9	3.6	9.7	10.7	10.2	10.5	11.9	11.2
NFM-12-12	3.2	3.9	3.6	8.7	11.2	10.0	9.8	13.1	11.5
NFM-12-15	3.8	4.1	4.0	9.1	10.5	9.8	10.9	11.6	11.3
NFM-13-1	3.1	5.9	4.5	8.1	10.5	9.3	10.0	13.2	11.6
NFM-14-3	3.5	4.3	3.9	8.9	10.6	9.8	10.4	11.9	11.2
NFM-14-5	3.9	4.7	4.3	8.3	9.4	8.9	10.6	13.0	11.8
NFM-14-6	3.1	5.4	4.3	9.2	10.9	10.1	10.8	12.6	11.7
NFM-14-7	3.4	6.9	5.2	8.9	10.9	9.9	9.9	12.2	11.1
NFM-3-3	3.2	4.7	4.0	10.1	11.4	10.8	10.7	12.3	11.5
NFM-6-5	4.0	4.8	4.4	9.2	10.4	9.8	9.7	11.6	10.7
NFM-7-13	3.9	5.8	4.9	10.0	11.5	10.8	11.2	13.2	12.2
NFM-8-1	3.8	5.1	4.5	9.7	10.8	10.3	11.6	12.6	12.1
NFM-8-22	4.2	4.5	4.4	9.5	11.4	10.5	9.0	12.5	10.8
NM-92	3.1	4.3	3.7	8.3	11.5	9.9	9.9	13.0	11.5
NM-98	3.8	4.3	4.1	8.9	10.2	9.6	11.8	12.6	12.2
Ramzan	2.9	4.2	3.6	9.1	10.7	9.9	10.9	12.0	11.5
Mean	3.5	4.6	----	9.1	10.6	----	10.3	12.4	----
LSD (0.05)	1.0	1.3	0.9	0.9	0.4	0.5	1.3	0.4	0.7

had the maximum pod length. Genotype NFM-5-63-35 had the lowest number of 10.2 seeds pod^{-1} followed by NFM-5-63-20 with an average of 10.6 seeds. NFM-5-63-13, NFM-5-63-48 and NFM-6-5 each had 10.7 number of seeds pod^{-1}.

A thousand grains weight of mungbean genotypes ranged from 46.2 to 67.4 g at Peshawar versus 51.8 to 86.3 at Swat (Table 6). Average of over 30 mungbean genotypes, thousand grains weight ranged from 49.0 to 74.3 g. Means of two years and locations, grain weight at Peshawar and Swat were 58.8 and 68.6, respectively. An increase from 1.6 to 24 g was observed in all the tested genotypes. Maximum increase of 24 g of thousand grain weight was observed for NFM-5-63-48 followed by NFM-12-15 (22.8 g) at Swat. However, genotype NFM-5-63-10 and NFM-8-22 ranked 2nd, each with grain weight of 73.6 g. The increase in thousand grain weight was due to the appropriate seed filling period supported by humid environment and low incidence of heat shock. These findings are in line with the work of Khattak et al. (2003) who has reported significant differences for 1000 grain weight, and communicated that the differences might be due to environmental stress like temperature and insect attacks.

Out of thirty mungbean genotypes, about 74% had more harvest index at Swat than Peshawar. Harvest index in term of percentage ranged from 22.4 to 33.6 at Peshawar versus 23.6 to 34.1 at Swat. Genotype NFM-3-3 had the maximum harvest index at both locations followed by NFM-5-63-34, which had maximum harvest index at Swat only. Minimal difference of 0.2 units in-term of harvest index was recorded each for genotype NFM-5-

Table 6. Means for 1000 grain weight, harvest index and grain yield ha^{-1} of mungbean genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2007 and 2008.

Genotype	1000 grain weight (g)			Harvest index (%)			Grain yield (kg)		
	Pesh	Swat	Means	Pesh	Swat	Means	Pesh	Swat	Means
NFM-5-63-4	59.9	69.7	64.8	24.1	27.5	25.8	1669.5	3012.8	2341.2
NFM-5-63-10	66.4	80.8	73.6	26.9	27.1	27.0	2412.7	2949.9	2681.3
NFM-5-63-13	59.3	75.9	67.6	29.2	30.9	30.1	2233.3	2775.7	2504.5
NFM-5-63-19	59.6	73.8	66.7	25.2	27.4	26.3	2255.3	3102.5	2678.9
NFM-5-63-20	58.9	70.0	64.5	26.6	27.9	27.3	1943.9	2369.7	2156.8
NFM-5-63-34	66.6	68.2	67.4	32.1	34.1	33.1	2549.2	3074.5	2811.9
NFM-5-63-35	65.4	74.3	69.9	26.6	30.9	28.8	2129.4	2761.1	2445.3
NFM-5-63-48	62.3	86.3	74.3	26.3	26.7	26.5	2140.5	3081.6	2611.1
NFM-5-63-49	64.3	67.4	65.9	27.4	25.0	26.2	2178.4	2785.7	2482.1
NFM-5-63-57	51.7	70.7	61.2	23.4	26.5	25.0	1839.4	2670.0	2254.7
NFM-11-3	64.2	66.6	65.4	31.2	33.3	32.3	3051.6	3231.9	3141.8
NFM-12-3	56.9	59.4	58.2	24.8	24.3	24.6	1772.3	2841.5	2306.9
NFM-12-6	56.3	62.5	59.4	30.9	26.9	28.9	2725.5	3058.4	2892.0
NFM-12-7	57.7	63.0	60.4	25.9	28.0	27.0	1870.3	2626.8	2248.6
NFM-12-8	49.4	59.7	54.6	28.5	32.1	30.3	1930.6	3280.9	2605.8
NFM-12-12	57.4	61.5	59.5	26.8	25.3	26.1	1861.5	2878.7	2370.1
NFM-12-15	55.6	78.4	67.0	24.4	31.4	27.9	1839.1	2729.6	2284.4
NFM-13-1	51.0	54.6	52.8	27.6	29.9	28.8	1806.7	3341.4	2574.1
NFM-14-3	57.1	65.8	61.5	23.4	28.1	25.8	1809.0	2687.3	2248.2
NFM-14-5	46.2	51.8	49.0	22.4	23.6	23.0	1541.8	2675.3	2108.6
NFM-14-6	56.4	65.2	60.8	25.4	25.2	25.3	2312.6	2975.1	2643.9
NFM-14-7	51.1	65.0	58.1	25.3	23.6	24.5	1682.8	2747.8	2215.3
NFM-3-3	67.0	78.8	72.9	33.6	34.1	33.9	2486.4	2727.3	2606.9
NFM-6-5	62.4	65.3	63.9	30.8	31.1	31.0	2018.3	3548.6	2783.5
NFM-7-13	60.5	65.4	63.0	33.2	33.4	33.3	2495.5	3913.9	3204.7
NFM-8-1	58.5	71.3	64.9	32.5	32.7	32.6	2150.6	3536.5	2843.6
NFM-8-22	67.4	79.7	73.6	24.6	26.6	25.6	1896.7	2658.6	2277.7
NM-92	56.8	72.9	64.9	28.6	28.0	28.3	2472.1	2903.0	2687.6
NM-98	55.7	60.2	58.0	29.7	31.4	30.6	2703.1	3101.3	2902.2
Ramzan	60.6	74.2	67.4	30.5	29.0	29.8	2077.8	2801.0	2439.4
Mean	58.8	68.6	----	27.6	28.7	----	2128.5	2961.6	----
LSD (0.05)	8.5	5.0	6.0	4.3	4.5	3.3	372.7	230.3	239.7

63-10, NFM-7-13 and NFM-8-1. An average of over two years and locations highest harvest index of 33.9% was recorded for genotype NFM-3-3 which also had maximum pod length followed by genotype NFM-7-13 (33.3%) which had maximum number of pods $cluster^{-1}$. Minimum harvest index of 23% was recorded for genotype NFM-14-5 which had the 2nd longest peduncle, minimum pod length as well lowest 1000 grain weight, followed by genotype NFM-14-7 with a harvest index of 24.5%. Check cultivars NM-98, Ramzan and NM-92 ranked 7th, 10th and 14th, respectively on the basis of harvest index ratio. Ghafoor et al. (2000) reported that genotypes with a harvest index of 25 to 40% will be a good selection criteria for mungbean improvement.

Experimental grain yield expressed in kg ha^{-1} of mungbean genotypes ranged from 1541.8 to 3051.6 kg at Peshawar versus 2369.7 to 3913.9 kg at Swat with mean yield of 2128.5 kg at Peshawar and 2961.6 kg at Swat. Average of two years and locations grain yield ha^{-1} ranged from 2108.6 to 2156.8 kg. Maximum grain yield ha^{-1} of 3204.7 kg was produced by genotype NFM-7-13 followed by genotype NFM-11-3 (3141.8 kg) and check cultivar NM-98 (2902.2 kg). Genotype NFM-7-13 performed well across year and locations, however NFM-11-3 which was the 2nd highest yielding genotype on the basis of mean performance stood on 1st and 6th position, respectively, at Peshawar and Swat. On the basis of harvest index, NFM-7-13 was the second highly stable genotype and also had maximum pods $cluster^{-1}$, pod length and seeds pod^{-1}. In contrast, the low yielding (2108.6 kg) genotype NFM-14-5 had the lowest harvest index, minimal 1000 grain weight and almost the shortest

Table 7. Genetic variance (V_g), genetic x year variance (V_{gy}), environmental variance (V_e), broad-sense heritability (h^2_{BS}) and expected selection response (R_e) for yield and yield associated traits of 30 mungbean genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2007 and 2008.

Component	Peduncle length (cm)		Pods plant^{-1}		Clusters plant^{-1}		Pods cluster^{-1}		Pod length (cm)		Seeds pod^{-1}		1000 grain weight (g)		Harvest index (%)		Grain yield (kg)	
	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat	Pesh	Swat
V_g	0.4	0.2	4.7	40.1	0.7	2.9	0.0	0.4	0.2	0.3	0.5	0.3	21.1	61.0	7.8	7.7	113553	100121
V_{gy}	0.9	0.5	-1.8§	-6.3§	-0.4§	-0.8§	-0.1§	0.0	0.0	-0.0§	-0.1§	-0.1§	-0.4§	-14.1§	2.4	3.3	18704	2389
V_e	2.6	1.3	24.5	57.4	3.4	3.8	0.8	1.1	0.4	0.3	1.6	0.3	52.7	60.1	5.7	4.7	43497	30857
h^2_{BS}	0.33	0.25	0.36	0.68	0.37	0.70	0.04	0.54	0.63	0.80	0.50	0.77	0.55	0.75	0.81	0.83	0.89	0.91
R_e	0.52	0.27	1.83	7.29	0.69	2.00	0.03	0.67	0.53	0.72	0.73	0.68	4.75	9.47	3.51	3.53	444.3	421.9
CV (%)	17.5	14.1	31.6	23.8	30.3	23.7	26.3	22.7	7.1	4.7	12.4	4.3	12.4	11.3	8.6	7.5	9.8	5.9

§ Values with negative sign are considered zero; CV, cumulative variance.

pod length. Due to neutral nature of the soil, the grain yield was comparatively greater at Swat than Peshawar which was almost alkaline in nature. Zubair et al. (2007) also reported that more numbers of pods plant^{-1} are positively correlated with high grain yield. Out of thirty genotypes, two produced more grain yield ha^{-1} than the check cultivar NM-98, six genotypes from NM-92 and 16 genotypes from Ramzan. Similar findings reported by Rao et al. (2006) for mungbean showed that clusters plant^{-1} have positive impact on grain yield.

Heritability and response to selection

Genetic, genetic × year and environmental variances, estimates of heritability and response to selection for the traits are given in Table 7. Genetic variances for peduncle length, pods plant^{-1}, clusters plant^{-1}, pods cluster^{-1}, pod length, seeds pod^{-1}, 1000 grain weight, harvest index and grain yield ha^{-1} were 0.4, 4.7, 0.7, 0.0, 0.2, 0.5, 21.1, 7.8 and 113553 at Peshawar versus 0.2, 40.1, 2.9, 0.4, 0.3, 0.3, 61.0, 7.7 and 100121 at Swat, respectively. Thus, genetic variances for most of the traits were relatively higher at Swat than Peshawar except for peduncle length, seeds pod^{-1}, harvest index and grain yield ha^{-1}. The genetic variances for pods plant^{-1}, clusters plant^{-1}, 1000 grain weight and grain yield ha^{-1} were 8.5, 4.1, 3.0 and 1.1 times greater at Swat than Peshawar, respectively. Similarly, the genetic variances for harvest index and grain yield were 1.4 and 2.6 versus 1.6 and 3.3 times greater than the error variance at Peshawar and Swat, respectively. Genetic × year variances were not-existent for pods plant^{-1}, clusters plant^{-1}, pods cluster^{-1}, pod length, seeds pod^{-1} and 1000 grain weight at both locations. For peduncle length, pods plant^{-1}, clusters plant^{-1}, pod length, seeds pod^{-1} and 1000 grain weight, the error variance at both locations were relatively larger than the genetic variance, while genetic variance was 3.3 and 6.1 times greater than the genetic × year variance for harvest index and grain yield at Peshawar versus 2.3 and 41.9 times at Swat, respectively. As stated, the greater instability of environmental factors causes the error variances which ultimately raise the level of environmental variation. These results are in accordance with Idress et al. (2006) who reported varying magnitudes of genetic and environmental variances in a set of mungbean mutants.

Broad sense heritabilities (h^2_{BS}) for peduncle length, pods plant^{-1}, clusters plant^{-1}, pods cluster^{-1}, pod length, seeds pod^{-1}, 1000 grain weight, harvest index and grain yield ha^{-1} were 0.33, 0.36, 0.37, 0.04, 0.63, 0.50, 0.55, 0.81 and 0.89 at Peshawar and 0.25, 0.68, 0.70, 0.54, 0.80, 0.77, 0.75, 0.83 and 0.91, respectively, at Swat. Thus, magnitude of h^2 for all traits at Swat was comparatively higher than Peshawar except peduncle length. Greater h^2_{BS} of most yield associated traits revealed that these traits are governed by additive genes. Harvest index and grain yield were the least affected trait in years at both locations followed by pod length, seeds pod^{-1} and 1000 grain weight at Swat only. Broad sense heritability for pod length (0.63 versus 0.80), harvest index (0.81 versus 0.83) and grain yield (0.89 versus 0.91) was high in magnitude at Peshawar and Swat, respectively, suggesting greater possibility of genetic improvement in these important traits through direct selection. Our results are in agreement with Idress et al. (2006) for pods plant^{-1}, pod length and seed yield but in contrast with Bains et al. (2007) who have reported moderate heritability for pod length and seed yield in mungbean genotypes. Due to high h^2_{BS}, the traits are expected to remain stable under varied environmental conditions and could easily be improved through selection (Khattak et al., 1997; Siddique et al., 2006). Kalia and Sood (2004) reported that high heritability along with high genetic advance for pod yield indicate the additive gene action in broad bean

Using 20% intensity, selection response for peduncle length, pods plant^{-1}, clusters plant^{-1}, pods cluster^{-1}, pod length, seeds pod^{-1}, 1000 grain weight, harvest index and grain yield ha^{-1} were 0.52 cm, 1.83, 0.69, 0.03, 0.53 cm, 0.73, 4.75 g, 3.51% and 444.3 kg at Peshawar versus 0.27 cm, 7.29, 2.00, 0.67, 0.72 cm, 0.68, 9.47 g, 3.51% and 421.9 kg, respectively, at Swat. Selection response was greater for most of the traits at Swat than Peshawar. Padi (2008) reported 5.3 to 3.9 g per 100 seed in two populations of cowpea.

Conclusion

Highly significant genetic differences were observed among mungbean genotypes for yield and yield associated traits across years and locations. Highly significant genotype × location interaction indicates that the genotypes respond differently to the environments with narrow adaptability; however, few genotypes produced more yield across years and locations consistently than check cultivars, which guaranteed these lines to have greater potential to be released as a variety or should be incorporated in breeding program for diversified environments of Pakistan, or neighbouring mungbean growing countries.

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