African Journal of Biotechnology Vol. 10(49), pp. 9992-10000, 31 August, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.1288
ISSN 1684–5315 ©2011 Academic Journals

Full Length Research Paper

Relationships and variability of agronomic and physiological characters in mungbean

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Accepted 5 July, 2011

This study was conducted to determine the variability, heritability and correlations among agronomic and physiological characters of mungbean (*Vigna radiata* (L.) Wilczek) and to identify their direct and indirect effects on seed yield. Fifty six mungbean accessions were evaluated at Suranaree University of Technology Farm, Nakhon Ratchasima, Thailand using a randomized complete block design with 4 replications. Fourteen characters were collected and analyzed for genotypic coefficient of variation, phenotypic coefficient of variation, environmental coefficient of variation, heritability estimates in broad sense, phenotypic and genotypic correlation coefficients and path coefficients. It was found that genotypes differed significantly for all characters studied. The highest heritability values were recorded on days to flowering and pod length. Seed yield was significantly and positively correlated with pods per plant, clusters per plant, total dry matter (TDM), seeds per pod, seeds per plant, biomass, leaf area index and branches per plant, and negatively correlated with days to maturity. Clusters per plant showed the highest positive direct effect on seed yield followed by 100 seed weight, seeds per pod, TDM and pods per plant. However, the effect of 100 seed weight was substantially minimized by the negative indirect effects of clusters per plant, pods per plant and seeds per pod. These results demonstrate that clusters per plant, seeds per pod, TDM and pods per plant should be used as selection criteria for yield improvement in mungbean.

Key words: Agronomic characters, correlation analysis, mungbean, path coefficient analysis, physiological characters, variability, *Vigna radiata*, yield components.

INTRODUCTION

Mungbean (*Vigna radiata* (L.) Wilczek) is an important pulse crop in Asia because of its high protein content and ability to improve soil fertility (Asim et al., 2006). In Thailand, it is widely cultivated and occupied a cultivated area of 143,931 ha with the production of 102,799 t of grain in 2009 (Office of Agricultural Economics, 2010).

There has been considerable improvement in yield of mungbean during the past mostly due to the empirical selection for yield per se. However, currently both potential and actual yields are leveling off in mungbean because genetic gains in yield are becoming harder to achieve, partly due to the lack of appropriate genetic variability (Khan et al., 2001; Sharma-Natu and Ghildiyal, 2005). Recently, the very high genetic similarity (> 0.9) found among 12 Thai recommended mungbean varieties further substantiated that genetic base of mungbean was quite narrow which might limit continued breeding success (Tantasawat et al., 2010).

Yield is a complex quantitative character that is difficult to select directly. The levels of yield depend largely on several agronomic and physiological characters including branches per plant, clusters per plant, pods per plant, seeds per pod, pod length, seeds per plant, seed size, days to flowering, days to maturity, plant height, biomass,

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Abbreviations: ECV, Environmental coefficient of variation; **GCV,** genotypic coefficient of variation; $\mathbf{h^2_b}$, broad sense heritability estimate; **LAI,** leaf area index; **PCV,** phenotypic coefficient of variation; **PI,** plant introduction; $\mathbf{r_g}$, genotypic correlation coefficient; $\mathbf{r_p}$, phenotypic correlation coefficient; **SUT,** Suranaree University of Technology; **TDM,** total dry matter.

total dry matter (TDM), leaf area index (LAI), harvest index (HI) etc. The relative contributions of these different characters to seed yield can be estimated by correlation analysis. The path coefficient analysis further allows the partitioning of correlation coefficients of yield-related characters into their direct and indirect effects. The importance of correlation and path coefficient analysis is particularly appreciable when highly heritable characters associated with complex trait like yield are identified and successfully used as criteria for effective selection to achieve high yield (Rani et al., 2008). The analyses have been performed in several crops such as soybean, sorghum, sunflower, maize as well as mungbean (Iqbal et al., 2003; Ezeaku and Mohammed, 2006; Makeen et al., 2007; Saleem et al., 2007; Machikowa and Saetang, 2008). In mungbean, different combinations of agronomic and physiological characters have been reported as important criteria for yield improvement (Shamsuzzaman et al., 1983; Francisco Junior and Maeda, 1989; Poehlman, 1991; Jan et al., 1993; Khan et al., 2001; Makeen et al., 2007; Hakim, 2008; Tabasum et al., 2010). However, the results appeared to vary depending on different plant populations and environmental conditions used for the analysis. For the characters found to affect yield, their estimates of heritability will provide clues on possible improvement and hence breeding success (Makeen et al., 2007). Taken together, the information on both heritability and the relationships among characters will be crucial for obtaining appropriate breeding strategies to achieve breeding goals (Painawadee et al., 2009). This study was undertaken to evaluate the variability, the heritability and the correlation of fourteen agronomic and physiological characters, and to perform path coefficient analysis using diverse 56 mungbean accessions collected at Suranaree University of Technology (SUT) including 41 plant introductions, 8 Thai recommended varieties, 3 promising breeding lines and 4 SUT developed varieties. The information achieved would be useful to arrive at certain physiological and/or agronomic parameters that could be used as selection criteria in the mungbean breeding program for yield improvement. Furthermore, the findings will also be useful for identifying promising lines to be used as parents in the future breeding programs.

MATERIALS AND METHODS

Fifty six mungbean accessions including 41 plant introductions (PIs; V1067, V1110, V1132, V1323, V1327, V1330, V1364, V1380, V1471, V1573, V1844, V1944, V1946, V2022, V2075, V2106, V2688, V2773, V2774, V2815, V3092, V3131, V3384, V3387, V3388, V3404, V3484, V3495, V4451, V4535, V4718, V4758, V4785, V4956, V5036, V5197, V5926, V6009, V1414AG, V1415AG and V2802BR), 8 Thai recommended varieties (CN36, CN60, CN72, KPS1, KPS2, PSU1, SUT1 and UT1), 3 promising breeding lines (M4-2, M5-1 and M5-5) and 4 SUT developed varieties (SUT2, SUT3, SUT4 and SUT5) were used for correlation and path coefficient analysis. The checks were KPS1 and SUT2. All accessions were planted at SUT Farm in randomized complete block design (RCBD) with four replications in February 2005. Each replication consisted of seventy-two 5 m rows with a spacing of 50 cm between rows and 25 cm between hills. Each hill was planted with 3-4 seeds and thinned to two seedlings per hill 14 days after germination. In total fourteen characters consisted of eleven agronomic characters (days to flowering, days to maturity, number of branches per plant, number of clusters per plant, number of pods per plant, pod length, number of seeds per pod, number of seeds per plant, 100 seed weight, seed weight (seed yield; kg/ha), plant height) and three physiological characters (LAI, biomass, TDM) were recorded on ten randomly selected plants from each accession, in each replication. The data were analyzed by computing genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), environmental coefficient of variation (ECV), and heritability estimates in broad sense (h^2_b) following Singh and Chaudhary (1979). Genotypic (r_g) and phenotypic (r_p) correlation coefficients and path coefficient analysis were estimated adopting the procedure suggested by Dewey and Lu (1959), and analysis of variance was perform using SPSS version 14.0 (Levesque and SPSS Inc., 2006).

RESULTS AND DISCUSSION

Variability and heritability of agronomic and physiological characters

The mean, range, coefficient of variation and heritability of fourteen agronomic and physiological characters are given in Table 1. The analysis of variance revealed highly significant differences for all 14 characters among accessions, indicating substantial variation among these 56 accessions of mungbean (Table 1). PCV and GCV were the highest in seeds per plant followed by pods per plant and LAI. The magnitude of differences between PCV and GCV were minimal for days to flowering, pod length and days to maturity, suggesting minimum role of environment on the expression of genes controlling these characters. Broad sense heritability estimates were higher than 50% for days to flowering (94.41%), pod length (94.07%), 100 seed weight (79.17%), plant height (77.33%), seeds per pod (76.49%), seeds per plant (74.48%), pods per plant (62.95%) and branches per plant (59.57%), suggesting that these characters were less influential by the environment, and should be able to improve through individual plant selection with greater success (Table 1). High heritability in days to flowering, pod length, plant height, seeds per pod, pods per plant, as well as days to maturity was also found by Makeen et al. (2007). The three physiological characters including biomass, TDM and LAI had lower than 50% of heritability showing that these characters were affected by environmental factors.

Among these diverse accessions, several PIs with high yield potential were identified, some of which had higher seed yields than recommended varieties (Table 2). Moreover, some of these accessions such as V4758 and V4785 were also found to be resistant to powdery mildew and should be useful for the future breeding programs (Khajudparn et al., 2010).

Table 1. Mean squares, coefficients of variation, range, mean and heritability of 14 agronomic and physiological characters among 56 accessions of mungbean.

Characters	MSE			Coefficient of variation (%)			Range	Mean	h^2_b (%)
	Block	Treatment	Error	Environmental	Genotypic	Phenotypic	Min - Max		
Seed yield (kg/ha)	6823240.95**	821264.39**	279084.38	25.92	18.06	31.59	955.0 - 3176.0	2038.3	32.69
Days to flowering	9.32**	43.17**	0.63	1.94	7.96	8.19	33.8 - 52.3	41.0	94.41
Days to maturity	19.07**	63.06**	4.90	3.82	6.57	7.60	51.3 - 71.0	58.0	74.80
Branches per plant	1.96**	1.16**	0.17	14.64	17.77	23.02	1.8 - 4.3	2.8	59.57
Clusters per plant	37.44**	14.57**	3.18	20.27	19.18	27.91	5.3 - 13.8	8.8	47.26
Pods per plant	1188.65**	248.00**	31.81	23.90	31.15	40.29	12.2 - 49.2	23.6	62.95
Pod length (cm)	0.49**	5.80**	0.90	3.70	14.75	15.21	5.0 - 10.5	8.1	94.07
Seeds per pod	0.36ns	4.93**	0.35	5.99	10.81	12.36	6.1 - 11.6	9.9	76.49
Seeds per plant	56362.14**	32262.77**	2545.94	25.05	42.80	49.59	82.6 - 597.0	201.4	74.48
100 seed weight (g)	1.22*	5.62**	0.35	11.33	11.26	12.65	2.4 - 7.6	5.2	79.17
Plant height (cm)	65.13*	267.99**	18.30	8.99	16.60	18.88	30.7 - 62.2	47.6	77.33
LAI	7.06**	1.87**	0.56	31.04	23.88	39.16	1.2 - 4.0	2.4	37.18
Biomass (g)	4532.39**	1532.85**	400.64	25.76	21.65	33.65	31.3 - 119.7	77.7	41.40
TDM (g)	493.81**	73.43**	24.29	22.82	16.23	27.99	12.0 - 31.9	21.6	33.59

** = Significant at 1% level, * = significant at 5% level, ns = non significant.

Table 2. Means of 14 agronomic and physiological characters among the 14 highest yielding accessions of mungbean.

Characters/ Accessions	Seed yield (kg/ha)	Days to flowering	Days to maturity	Branches per plant	Clusters per plant	Pods per plant	Pod length (cm)	Seeds per pod	Seeds per plant	100 seed weight (g)	Plant height (cm)	LAI	Biomass (g)	TDM (g)
V2106	3176.0	44	54	4.3	13.4	49.2	7.2	11.5	597.0	4.2	56.3	3.8	103.6	30.0
V4785	3146.9	40	54	2.9	11.3	37.8	7.3	11.3	396.7	3.9	50.1	2.8	77.8	22.5
V4758	3093.7	41	55	2.6	10.6	40.4	7.5	11.6	405.6	4.0	48.8	1.6	97.2	27.3
KPS2	2814.8	39	54	2.0	7.1	20.5	9.6	11.2	210.9	6.7	41.2	2.2	58.5	18.6
V1946	2718.3	37	53	2.5	8.3	20.0	9.9	10.2	168.5	7.6	40.2	2.3	109.8	31.9
SUT5	2610.3	40	54	2.7	10.5	34.0	7.1	10.5	321.6	4.1	39.8	2.1	72.1	22.8
V1380	2600.7	43	60	2.6	8.0	19.1	9.7	10.3	172.4	6.6	52.7	2.4	82.7	22.7
V4956	2582.4	43	60	3.1	12.5	34.5	6.9	10.3	312.4	4.1	47.2	2.0	74.0	22.8
V4451	2360.7	40	59	2.6	10.0	30.6	7.1	11.5	322.6	3.7	50.0	2.3	64.7	17.0
V2075	2338.4	49	62	4.0	10.1	29.1	8.2	10.7	246.1	4.5	59.3	4.0	98.0	22.8
V3384	2324.2	43	59	3.3	10.2	25.5	7.9	10.9	230.0	5.1	48.1	2.9	85.7	24.5
V3495	2292.1	36	58	4.1	13.8	37.8	7.4	9.9	341.9	3.5	50.1	2.9	76.0	20.4

Table 2. Contd.

KPS1	2256.4	40	58	2.8	9.0	21.1	8.8	9.6	169.6	6.3	52.8	2.6	93.7	25.9
V4535	2254.5	42	61	2.7	8.4	22.1	8.7	10.0	187.4	5.4	46.6	2.3	72.0	20.0

Correlation coefficient analysis

Associations of agronomic and physiological characters with seed yield

The degree of correlation observable among attributes depends on the development relations between them and genetic linkage or pleiotropic effect of genes (Madhur and Jinks, 1994). Phenotypic and genotypic correlations among seed yield and yield contributing characters revealed that seed yield were significantly and positively correlated with pods per plant (r_p = 0.622**; r_g = 0.599) and clusters per plant (r_p = 0.529**; r_g = 0.601; Table 3), indicating that having more pods per plant and clusters per plant potentially produce higher yield. For example, accessions V2106, V4785 and V4758 which exhibited the top three highest yield produced the highest pods per plant (49.2, 37.8 and 40.4, respectively; Table 2). Seed yield was also significantly and positively correlated with seeds per pod (r_p = 0.477**; r_g = 0.526) and seeds per plant (r_p = 0.457**, r_g = 0.684; Table 3). In this study, the three highest yielding accessions, V2106, V4785 and V4758, possessed the highest seeds per plant (597.0, 396.7 and 405.6, respectively) and high seeds per pod (Table 2).

Physiological characters like TDM (r_p = 0.518**; r_g = 0.702), biomass (r_p = 0.347**, r_g = 0.477) and LAI (r_p = 0.321**, r_g = 0.431) were also significantly and positively correlated with seed yield (Table 3). Three high yielding accessions, V2106, V1946 and V2075, appeared to have high TDM, biomass and/or LAI (Table 2). These results are in agreement with the positive associations of seed yield with LAI and TDM noticed by Islam and Razzaque (2010). Recent report of a strong positive correlation between seed yield and TDM in segregating F populations of two crosses between low and high TDM mungbean varieties / lines further substantiated the association (Khajudparn et al., 2011). Similarly, a positive correlation between seed yield and biomass was also previously observed by Khan et al. (2001) and Sadeghipour (2009). In addition, a significantly positive correlation between branches per plant and seed yield (r_p = 0.230*, r_g = 0.259) was also observed (Table 3). However, seed yield was not significantly correlated with 100 seed weight, plant height, pod length and days to flowering but negatively correlated with days to maturity (r_p = -0.244*, r_g = -0.290; Table 3). The non-significant associations between seed yield and 100 seed weight and/or between seed yield and pod length were also recently reported by Gul et al. (2008) and Tabasum et al. (2010). Conversely, seed size was found to be the most important yield component in recombinant inbred line population developed from a cross between wild *Vigna* subspecies *sublobata* and a commercial cultivar (Sriphadet et al., 2007).

The associations between these different agronomic and physiological characters and seed yield were supported by the results of many authors although the positive or negative nature of these associations varied in each study. For example, Khan et al. (2001) who performed correlation analysis on 15 divergent genotypes of mungbean found that seed yield was positively correlated with branches per plant, pods per plant and biomass, and found non-significant association of seed yield with days to 50% flowering and pod length similar to our results. Recently, Makeen et al. (2007) evaluated correlations in respect of various desirable characters in 20 genotypes of mungbean and indicated that pods per plant, clusters per plant and seeds per pod also had significantly positive correlation with seed yield. However, significantly positive correlation was also found between yield and 100 seed weight, plant height, pod length, days to flowering and days to maturity of which we found no or negative correlation. Similarly, Zhang (1995) found positive associations between seed yield and clusters per plant, seeds per pod, TDM as well as days to flowering, days to maturity, plant height, pod length and 1000 seed weight among 21 AVRDC mungbean accessions. Correlation among 9 agronomic characters of 350 mungbean accessions with their yield suggested that pods per plant and plant height were positively correlated with seed yield but seed size was negatively correlated with seed yield (Hakim, 2008). While correlation among 12 agronomic characters of 240 mungbean accessions with their yield suggested that pods per plant, seeds per pod, branches per plant, plant height and seed size characters showed the highest contribution to seed yield (Shamsuzzaman et al., 1983). Overall, most previous reports showed significantly positive correlations between seed yield and pods per plant, clusters per plant or seeds per

Table 3. Estimation of phenotypic (r_p) and genotypic (r_g) correlation coefficients of 14 characters among 56 accessions of mungbean.

Characters	Days to flowering	Days to maturity	Branches per plant	Clusters per plant	Pods per plant	Pod length	Seeds per pod	Seeds per plant	100 seed weight	Plant height	LAI	Biomass	TDM
Yield (kg/ha)	-0.101 ns (-0.131)	-0.244 * (-0.290)	0.230 * (0.259)	0.529 ** (0.601)	0.622 ** (0.599)	0.130 ns (0.026)	0.477 ** (0.526)	0.457 ** (0.684)	0.071 ns (0.007)	0.101 ns (0.092)	0.321 ** (0.431)	0.347 ** (0.477)	0.518 ** (0.702)
Days to flowering		0.723 ** (0.756)	0.498 ** (0.539)	0.163 ns (0.136)	0.136 ns (0.143)	-0.162 ns (-0.167)	0.233 * (0.243)	0.098 ns (0.194)	-0.445 ** (-0.474)	0.516 ** (0.538)	0.421 ** (0.495)	0.152 ns (0.175)	-0.011 ns (-0.024)
Days to maturity			0.391 ** (0.435)	0.054 ns (0.047)	-0.032 ns (-0.020)	-0.127 ns (-0.138)	0.002 ns (0.006)	0.077 ns (0.041)	-0.278 * (-0.303)	0.587 ** (0.636)	0.420 ** (0.526)	0.286 * (0.355)	0.058 ns (0.086)
Branches per plant				0.631 ** (0.714)	0.520 ** (0.595)	-0.300 * (-0.337)	0.233 * (0.235)	0.228 ** (0.574)	-0.469 ** (-0.525)	0.477 ** (0.522)	0.607** (0.789)	0.314 ** (0.385)	0.255 * (0.301)
Clusters per plant					0.859 ** (0.973)	-0.598 ** (-0.694)	0.172 ns (0.194)	0.564 ** (0.848)	-0.526 ** (-0.645)	0.173 ns (0.167)	0.222 * (0.284)	0.157 ns (0.131)	0.271 * (0.266)
Pods per plant						-0.652 ** (-0.717)	0.243 ns (0.235)	0.640 ** (0.936)	-0.609** (-0.702)	0.114 ns (0.111)	0.216 ns (0.267)	0.079 ns (0.097)	0.245 ns (0.288)
Pod length							0.325 ** (0.313)	-0.427 ** (-0.483)	0.678 ** (0.692)	0.183 ns (0.183)	0.158 ns (0.183)	0.365 ** (0.420)	0.208 ns (0.239)
Seeds per pod								0.400 ** (0.518)	-0.214 ns (-0.224)	0.470 ** (0.497)	0.498 ** (0.571)	0.388** (0.458)	0.328 ** (0.387)
Seeds per plant									-0.578 ** (-0.661)	0.133 ns (0.239)	0.105 ns (0.146)	0.025 ns (0.205)	0.079 ns (0.350)
100 seed weight										-0.209 ns (-0.240)	-0.065ns (-0.076)	0.154 ns (0.181)	0.182 ns (0.199)
Plant height											0.730 ** (0.89)	0.718 ** (0.850)	0.478 ** (0.559)
LAI												0.640 ** (0.837)	0.498 ** (0.684)
Biomass													0.840 ** (0.880)

** = Significant at 1% level, * = significant at 5% level, ns = non significant, value in parentheses = genotypic correlation coefficients.

pod, while the correlations between seed yield and 100 seed weight, days to flowering, height, pod length and days to maturity were inconsistent, depending on the plant materials and environmental conditions used in each study (Singh and Singh,1973; Shamsuzzaman et al., 1983; Poehlman, 1991; Chaudhary, 1992; Jan et al., 1993; Naidu and Rosaiah, 1993; Sharma, 1999; Amanullah and Hatam, 2000; Khan et al., 2001; Biradar, 2007; Makeen et al., 2007; Tabasum et al., 2010). In addition, selection for pods per plant has frequently been regarded as important for seed yield improvement of mungbean by various authors (Singh and Singh, 1973; Shamsuzzaman et al., 1983; Francisco Junior and Maeda, 1989; Chaudhary, 1992; Jan et al., 1993; Zhang, 1995; Amanullah and Hatam, 2000; Khan et al., 2001; Biradar, 2007; Makeen et al., 2007; Gul et al., 2008; Hakim, 2008; Tabasum et al., 2010).

Interrelationships among agronomic and physiological characters

In addition to seed yield, many of these characters were also associated with each other. For all positively related characters, the improvement of one character will result in the simultaneous improvement of the others. Number of clusters per plant was significantly and positively associated with branches per plant, pods per plant, seeds per plant, LAI and TDM. This is not surprising since the pods are produced by the clusters, which are in turn produced by the branches. Similar findings were also reported by Chaudhary (1992), Khattak et al. (1995) and Zhang (1995) who found positive correlations between clusters per plant and pods per plant. Zubair and Srinives (1986) also found associations between clusters per plant and branches per plant as well as pods per plant. By contrast, negative associations were found between clusters per plant and pod length as well as 100 seed weight in agreement with Biradar (2007) and Zubair and Srinives (1986).

Moreover, we found significantly positive correlations between pods per plant and seeds per plant. However, a significantly negative correlation was found between pods per plant and pod length and between pods per plant and 100 seed weight. Similar findings were reported by Sandhu et al. (1979), Zhihui (1999) and Hakim (2008). Days to flowering was significantly and positively associated with days to maturity, branches per plant, seeds per pod, plant height and LAI, suggesting that selection for early varieties may reduce branches per plant, seeds per pod, plant height and LAI. However, days to flowering had no association with seed yield in accordance with Khattak et al. (1995).

Number of seeds per plant was significantly correlated with 6 characters, four of which were positive (branches per plant, clusters per plant, pods per plant and seeds per pod) while the other two were negative (pod length and 100 seed weight). Number of branches per plant was significantly correlated with all the other twelve characters, two of which were negative (pod length and 100 seed weight) while the other ten were positive. Similarly, previous reports found that branches per plant was positively correlated with days to flowering (Francisco Junior and Maeda, 1989; Khattak et al., 1995), clusters per plant (Zubair and Srinives, 1986; Biradar, 2007), plant height and seeds per pod (Biradar, 2007), and negatively correlated with 100 seed weight (Khattak et al., 1995; Biradar, 2007).

Number of seeds per pod was positively correlated with days to flowering, branches per plant, pod length, seeds per plant, plant height, LAI, biomass and TDM. Similar findings were reported by Zhang (1995) who found associations of seeds per pod with plant height, pod length and TDM. Zubair and Srinives (1986) and Makeen et al. (2007) also found correlations between seeds per pod with branches per plant and pod length. In addition, number of seeds per pod was also reported to be correlated with pod length by Chaudary (1992) who also observed associations between seeds per pod and clusters per plant, pods per plant and 1000 seed weight.

Pod length was significantly correlated with 7 characters, three of which were positive (seeds per pod, 100 seed weight and biomass) while the other four were negative (branches per plant, clusters per plant, pods per plant and seeds per plant). Similar findings were reported by Chaudhary (1992) and Biradar (2007) who found positive correlations between pod length with seeds per pod and 100 seed weight. Makeen et al. (2007) also found an association between pod length and seeds per pod. In addition, a similar negative correlation between pod length and clusters per plant was reported by Zubair and Srinives (1986).

A hundred seed weight was significantly correlated with 7 characters, six of which were negative (days to flowering, days to maturity, branches per plant, clusters per plant, pods per plant and seeds per plant) while the other one was positive (pod length). These results are in accordance with those reported by Raje and Rao (2000) and Biradar (2007) who found a positive association between 100 seed weight and pod length but negative associations between 100 seed weight and clusters per plant, branches per plant as well as days to flowering. By contrast, significantly positive correlations had been observed between 100 seed weight and plant height, clusters per plant and pods per plant (Chaudhary, 1992).

Plant height was significantly and positively correlated with days to flowering, days to maturity, branches per plant, seeds per pod, LAI, biomass and TDM. The association between plant height and days to maturity was observed in several studies (Khalil et al., 1986; Amanullah and Hatam, 2000; Makeen et al., 2007). In addition, Biradar (2007) found an association of plant height with branches per plant.

The positive correlations were found among three physiological characters, biomass and TDM, biomass

Table 4. Direct and indirect effects of 9 agronomic and physiological characters on seed yield among 56 accessions of mungbean.

Influence on yield through	Branches per plant	Clusters per plant	Pods per plant	Seeds per pod	Seeds per plant	100 seed weight	LAI	Biomass	TDM	Total correlation
Branches per plant	**-0.121**	0.557	0.154	0.132	-0.091	-0.306	-0.093	-0.123	0.150	0.259
Clusters per plant	-0.086	**0.780**	0.252	0.109	-0.135	-0.375	-0.032	-0.044	0.132	0.601
Pods per plant	-0.072	0.758	**0.259**	0.132	-0.149	-0.409	-0.023	-0.042	0.143	0.599
Seeds per pod	-0.028	0.151	0.061	**0.562**	-0.082	-0.130	-0.110	-0.089	0.192	0.526
Seeds per plant	-0.069	0.661	0.243	0.291	**-0.159**	-0.385	-0.049	-0.023	0.174	0.684
100 seed weight	0.063	-0.503	-0.182	-0.126	0.105	**0.582**	-0.044	0.012	0.099	0.007
LAI	-0.047	0.102	0.025	0.257	-0.033	0.105	**-0.241**	-0.131	0.438	0.431
Biomass	-0.095	0.221	0.069	0.321	-0.023	-0.044	-0.201	**-0.156**	0.340	0.477
TDM	-0.036	0.207	0.075	0.217	-0.056	0.116	-0.212	-0.107	**0.497**	0.702

Underlined figures denote path coefficients and direct effect; the rest of the figures denote indirect effects.

and LAI and TDM and LAI, suggesting that selection based on one of these characters would affect the other 2 characters. Moreover, significantly positive correlations were also found between biomass and five agronomic characters; days to maturity, branches per plant, pod length, seeds per pod and plant height. These results are in accordance with Sadeghipour (2009) who found a positive association between biomass and plant height. The positive correlation of biomass with seed yield and the other characters suggested that increase in biomass would increase seed yield. In other words, the large plants will produce more yields as compared to thin plants. Positive correlations were found between LAI and several agronomic characters including days to flowering, days to maturity, branches per plant, clusters per plant, seeds per pod and plant height. TDM was also positively correlated with branches per plant, clusters per plant, seeds per pod and plant height. Similarly, TDM was found to be significantly and positively correlated with clusters per plant and seeds per pod by Zhang (1995).

Path coefficient analysis

In order to understand the true significance of the correlation studies, the data were subjected to path coefficient analysis. Clusters per plant (0.780) showed maximum direct effect on seed yield followed by 100 seed weight (0.582), seeds per pod (0.562), TDM (0.497) and pods per plant (0.259; Table 4). These positive direct effects of mungbean were supported by the results of many authors (Zubair and Srinives, 1986; Chaudhary, 1992; Khattak et al., 1995; Biradar, 2007; Makeen et al., 2007; Hakim, 2008). Note that the correlation coefficients between clusters per plant, seeds per pod, TDM and pods per plant with seed yield were positively significant (Table 3). These results indicated that high yielding mungbean genotypes could be obtained by selecting large plants with high number of clusters per plant, seeds per pod and pods per plant, and a direct selection through these characters should be effective. The direct effect of 100 seeds weight (0.582) character was reduced by clusters per plant, pods per plant and seeds per pod, all of which had high direct effect on seed yield, thereby causing low correlation between this character and seed yield (r_p = 0.071). In such situation, large seed size selection with medium number of clusters per plant, pods per plant and seeds per pod or vice versa, medium seed size selection with high number of clusters per plant, pods per plant and seeds per pod should be considered. Correlation coefficients between seeds per plant and LAI with seed yield were positive and significant but the direct effects were negative (-0.159 and -0.241, respectively). Positive indirect causal effects to the seed yield were found via clusters per plant, seeds per pod, pods per plants, or TDM (Table 4). Therefore, the direct selection through number of seeds per plant and LAI will not be effective and the number of clusters per plant, pods per plant, seeds per pod and TDM should be considered simultaneously for high yield.

Other characters such as biomass and branches per plant showed negative direct effect on seed yield (Table 4). These findings are in accordance with findings of Chaudhary (1992), Khattak et al. (1995) and Hakim (2008). As with correlation analysis, path coefficient analysis also indicated that high yielding mungbean genotypes could be obtained by selecting large plants with high number of clusters per plant, pods per plant and seeds per pod. By contrast, characters like biomass, seeds per plant, LAI and branches per plant were not important contributing factors for seed yield. This information therefore, could be used for yield improvement in mungbean. Similarly, Makeen et al. (2007) identified pods per plant and seeds per pod as major components of seed yield in mungbean. Malhotra et al. (1974) also found strong association between yield and pods per plant and clusters per plant in mungbean. Conversely, correlation and path coefficient analysis of 10 genotypes of high yielding mungbean showed that clusters per plant had no correlation with yield, and seed size (seed weight) was the best index of selection for high yield in mungbean (Khattak et al., 1995). These differences were not surprising since it had been known that correlation and path coefficient analysis varied according to both genetic differences (genotypes) and environmental factors affecting growth and development. Although we also found high direct effect of 100-seed weight on yield, its effect was substantially minimized by the negative indirect effect of clusters per plant, pods per plant and seeds per pod. The counteraction effect between seed weight with pods per plant and clusters per plant were widely reported (Singh and Malhotra, 1970; Zubair and Srinives, 1986; Khattak et al., 1995; Biradar, 2007; Hakim, 2008).

Conclusion

Number of clusters per plant, seeds per pod, TDM and pods per plant showed positive and significant correlations and considerable direct positive effects on seed yield. It is concluded that these characters are the most important contributing factors to seed yield and should be used as selection criteria for yield improvement in mungbean. Therefore, selection for seed yield of mungbean, especially among these accessions should be made through the selection for large plants with high number of clusters per plant, pods per plant and seeds per pod. Several accessions with high TDM, high number of clusters per plant, pods per plant and/or seeds per pod were identified in this study such as V2106, V4758, V1946, V4451 and V3495 etc. These accessions are currently used as parents in the mungbean breeding programs for yield improvement.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Dr. Paisan Laosuwan and Dr. Thitiporn Machikowa for meaningful suggestions, advice and seeds of SUT developed varieties. We also thank Asian Vegetable Research and Development Center (AVRDC) and Chai Nat Field Crop Research Center for providing the seed germplasm. This research is partially supported by grants from Suranaree University of Technology and the Center of Excellence on Agricultural Biotechnology, Science and Technology Postgraduate Education and Research Development Office, Office of Higher Education Commission, Ministry of Education (AG-BIO/PERDO-CHE), Thailand.

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