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IDENTIFICATION OF PRINCIPAL YIELD ATTRIBUTING TRAITS OF INDIAN MUSTARD [*BRASSICA JUNCEA* (L.) CZERNJ AND COSSON] USING MULTIVARIATE ANALYSIS

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ABSTRACT

The study is a synthesis of available information on different yield attributing traits of Indian mustard as influenced by varied irrigation schedules and sulphur levels. Pooled data of two years of study (*rabi*, 2010-11 and 2011-12) on nineteen traits were subjected to principal component analysis (PCA). Among the variables, test weight had the highest correlation with seed yield followed by net assimilation rate (NAR) at 40 - 75 DAS and dry matter accumulation (DMA) at 75 DAS, respectively. Out of nineteen, only two factors had eigen value greater than one and these components accounted for 72.42% of total variance. The loadings of each variable onto each component were analyzed from the rotated factor matrix obtained through varimax rotation. First component accounted for 51.84% of total variation and associations of traits that are highly correlated with seed yield among which NAR at 40 - 75 DAS and at 75 -110 DAS and test weight were most important. Second component with 20.58% of total variation had higher loadings of variables having comparatively lower association with seed yield and among those, relative growth rate (RGR) at 75-110 DAS, plant height at 110 DAS and number of siliquae per plant were most important.

INTRODUCTION

Indian mustard (*Brassica juncea*) has been cultivated in India since ancient times. India, the third largest producer of rapeseed-mustard after China and Canada in the world, produces about 6.41 m t (DRMR, 2011) rapeseed and mustard from an area of about 5.53 m ha (Anonymous a, 2011). In West Bengal, area of rapeseed-mustard is about 0.41 m ha with a production of 0.42 m t (sharing 5.1% of the national production) during 2010-11 (Anonymous b, 2012). However, the country and the state West Bengal in particular have remained deficit in the production since long.

For getting higher yield of mustard, irrigation and fertilizer management are two important agronomic practices. Application of increased level of irrigation significantly increases the plant height, number of siliquae per plant, seed yield and straw yield of mustard (Piri *et al.*, 2011). In addition, irrigation at critical growth stages is very much important in increasing the seed yield (Mahapatra *et al.*, 1992). Sulphur is the fourth major nutrient in crop production (Singh *et al.*, 2000) and plays a vital role in the yield of mustard. Sulphur is involved in the synthesis of chlorophyll and is also required in cruciferae for the synthesis of volatile oil (Manaf and Hassan, 2006). Sulphur increased dry matter in plant and thus it is effective on growth analyses (Piri *et al.*, 2011). Irrigation and sulphur application in mustard directly influence the seed yield, a polygenic trait involving a number of genes contributing in it and their interaction with environment (Hassan *et al.*, 2013). It is more desirable that the structure of yield is probed through breeding techniques. It is important to measure the mutual relationship between various plant attributes and determine the component characters, on which selection procedure can be based for direct and indirect genetic improvement of crop yield. Seed yield is influenced by several yield contributing traits. These components are related among themselves and also with yield either positively or negatively. However, sometimes breeders obtain measures on a number of observed variables and wish to develop a smaller number of artificial variables (principal components) which will account for most of the variance in the observed variables. The principal components may then be used as predictor or criterion variables in subsequent analyses. Actually, it is a variable reduction procedure and useful when breeders have obtained data on a number of variables (possibly a large number of variables), and believe that there is some redundancy in those variables. In this case, redundancy means some of the variables are correlated with one another, possibly because they are measuring the same construct (Jupp, 2006). Hence, the purpose of this study was to determine the importance of traits associated with seed yield of mustard along with their inter-relationship and to cluster them using PCA analysis.

MATERIALS AND METHODS

The present experiment was carried out during *rabi* (winter) season of 2010-11 and 2011-12 at Jaguli Instructional Farm of Bidhan Chandra Krishi Viswavidyalaya, West Bengal located at 22°56′ N latitude and 88°32′ E longitude with the altitude of about 9.75 m above mean sea level. The experimental soil was clay loam in texture with pH 6.21, EC 0.104 ds/m, oxidizable organic carbon 0.43%, available N 393.54 kg/ha, available P_2O_5 52.6 kg/ha, available K_2O 154.0 kg/ha and available S 14.3 ppm at the start of the study. The treatments comprised of three irrigation schedules on the basis of critical growth stages [I_1 – one irrigation at flower initiation stage (30 DAS), I_2 – one irrigation at siliquae development stage (60 DAS) and I_3 – two irrigations, one at flower initiation stage (30 DAS) and another at siliquae development stage (60 DAS)] in the main plot and four sulphur levels [S_0 – no sulphur, S_1 – 30 kg S/ha, S_2 – 45 kg S/ha and S_3 – 60 kg S/ha] in the sub plots replicated thrice, and were laid out in split-plot design. Bentonite clay (elemental S) was applied about 30 days before sowing of mustard as the elemental S i.e. S^0 takes about one month to be oxidized to SO_4^{2-} and becomes available to plants. The recommended dose of fertilizer i.e. 80:40:40 kg N : P_2O_5 : K_2O/ha were applied through urea, DAP and MOP, respectively while all agronomic management was done as per recommended package of practices. Seeds of Indian mustard var. 'varuna (T-59)' were sown at a rate of 7 kg/ha on 3rd October with 45cm x 10cm spacing. Thinning was done to maintain a uniform plant population in each plot at three weeks after sowing. Crop in both the years were sown after a pre-sowing irrigation. Metasystox at 0.2% was sprayed thrice at 10 days interval during pod development stage to protect the crop from aphids. The crop from the net plot area was harvested by cutting at ground level and allowed for sun drying in doughing seed. After sun-dry, the weight of the seed yield from the net plot was recorded. In this experiment, observations on plant height and dry matter accumulation (DMA) in plant shoot were recorded at 40, 75 and at 110 DAS. However, data on number of primary branches per plant, number of siliquae per plant, number of seeds per siliqua and test weight (1000 seed weight) were recorded at the time of harvest. Other growth parameters were recorded as per the formula given below:

$$\text{Leaf Area Index (LAI)} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Land area (cm}^2\text{)}} \text{..........................(1)}$$

(Watson, 1947)

$$\text{Crop Growth Rate (CGR) (g/m}^2\text{/day)} = \frac{w_2\ w_1}{T_2\text{-}T_1} \text{ ....(2)}$$

Watson, 1952)

$$\text{Relative Growth Rate (RGR) (mg/g/day)} = \frac{\log_e w_2 - \log_e w_1)}{T_2 - T_1}$$

....(3) (Blackman, 1919)

Where, W_1 and W_2 are dry weight of plant in g at times T_1 and T_2.

$$\text{Net Assimilation Rate (NAR) (mg/m}^2\text{/day)} = \frac{w_2\text{-}\ w_1)\ \text{x}\ \log_e L_2\text{-}\ \log_e L_1)}{T_2 - T_1)\ \text{x}\ (L_2 - L_1)}$$

....(4) (Evans, 1982)

Where, L_1 and L_2 are total leaf area of plant at times T_1 and T_2.

Pooled data of both the two years for the above variables were estimated for further analysis. Firstly, Pearson correlation coefficients were worked out (Al-Jibouri *et al.*, 1958). The component extraction was done using principal component method and the criterion of eigen value (≥1) or characteristic root was utilized for deciding the number of factors to be retained (Bharathiveeramani and Prakash, 2012). The varimax rotation was used to make each factor uniquely defined as a distinct cluster of inter-correlated variables. The observed variables were standardized in the course of analysis and the standardized variables had been distributed with zero mean and unity variance. For standardizing the data, Z score was calculated by using the following formula (Etzkorn, 2012):

$$Xi, 1\sigma = \frac{X1\ \text{-}X2}{\sigma xs} \text{...(5)}$$

Where,

xi = Each data point i

$\overline{x}s$ = The average of all the sample data points

σxs = The sample standard deviation of all sample data points

$x_{i,1\sigma}$ = The data point i standardized to 1ó, also known as Z-Score

Principal Component Analysis (PCA) which has been used in the analytical part of this article is a statistical method that transforms an original set of variables into a smaller set of uncorrelated linear variables retaining the most of the information in the original set of variables. Statistically, first few principal components usually account for most of the variation in the original set of data. The total variance is simply the sum of variances of these variables. As they have been standardized to have a variance of one, each observed variable contributes one unit of variance to the total variance in the dataset. The total variance of the dataset is equal to nineteen. The array of communality, the amount of the variance of a variable accounted by the common factors together, was estimated by the highest correlation coefficient in each array as suggested by Seiller and Stafford (1985). Factor loadings were estimated for determining the correlation of a variable with a factor. The highest value of the loading of a particular variable in a particular factor among the extracted factors plays the important role to churn out the factor. However, the naming of factors is a subjective process. It is done by examining the variables with high loadings on the factor and selecting a name that summarizes the content of these variables.

To study the relationship and the sensitivity between different variables and seed yield, Cobb-Douglas production function was applied and was expressed as follow (Mohammadi and Omid, 2010):

$$Y = f\,(x)\,\exp\,(u) \text{.. (6)}$$

We can express it like the following –

$$Y = ax_1\ b^1\ x_2\ b^2 \text{ ....} x_n{}^{bn} e \text{.. (7)}$$

Where,

x_1, x_2...and x_n are different variables;

Table 1: Correlation matrix for different yield attributing characters in Indian mustard (pooled data of 2 years)

	PL1	PL2	PL3	LAI1	LAI2	CGR1	CGR2	RGR1	RGR2	NAR1	NAR2	DM1	DM2	DM3	NBP	NSP	NSS	TW	SUS	SY
PL1#	1	.509**	.750**	.654**	.440**	.496**	.512**	.619**	.651**	.351*	.343*	.523**	.276	.710**	.631**	.794**	.407*	.064	.782**	.140
PL2		1	.647**	.381*	.314	.332*	.329	.431**	.612**	.190	.248	.347*	.159	.470**	.501**	.577**	.274	-.073	.629**	.019
PL3			1	.481**	.512**	.451**	.336*	.541**	.763**	.146	.271	.395*	.161	.582**	.599**	.690**	.359*	-.046	.644**	.050
LAI1				1	.408*	.377*	.467**	.650**	.487**	.426**	.363*	.421*	.448**	.661**	.580**	.706**	.404*	.208	.675**	.282
LAI2					1	.201	.261	.237	.546**	.029	.114	.392*	-.015	.330*	.383*	.503**	.239	-.201	.355*	-.155
CGR1						1	.549**	.722**	.235	.629**	.590**	.610**	.546**	.569**	.293	.568**	.654**	.461**	.607**	.550**
CGR2							1	.684**	.226	.739**	.695**	.489**	.539**	.720**	.188	.572**	.766**	.554**	.730**	.586**
RGR1								1	.267	.796**	.801**	.518**	.786**	.766**	.411*	.695**	.786**	.645**	.810**	.725**
RGR2									1	-.106	.004	.242	-.096	.420*	.665**	.682**	.179	-.351*	.543**	-.267
NAR1										1	.885**	.428**	.865**	.701**	.085	.418*	.785**	.886**	.657**	.907**
NAR2											1	.329*	.827**	.679**	.144	.407*	.778**	.857**	.631**	.892**
DMA1												1	.301	.432**	.336*	.610**	.472**	.163	.486**	.244
DMA2													1	.597**	.184	.322	.670**	.869**	.586**	.902**
DMA3														1	.382*	.661**	.603**	.510**	.831**	.555**
NBP															1	.695**	.185	-.115	.514**	-.003
NSP																1	.523**	.113	.800**	.222
NSS																	1	.684**	.688**	.724**
TW																		1	.404*	.987**
SUS																			1	.480**
SY																				1

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at 0.05 level (2-tailed); # Here PL 1, 2 and 3 are plant height at 40, 75 DAS and at harvest; LAI 1 and 2 are Leaf Area Index at 40 and 75 DAS, respectively; CGR 1 and 2, RGR 1 and 2 and NAR 1 and 2 are Crop Growth Rate, Relative Growth Rate and Net Assimilation Rate at 40 - 75 DAS and 75 – 110 DAS, respectively; DMA 1, 2 and 3 are Dry Matter Accumulation at 40 DAS, 75 DAS and 110 DAS, respectively; NBP is number of primary branches per plant; NSP is number of siliquae per plant; NSS is number of seeds per siliqua; TW is test weight; SUS is sulphur uptake in seeds and SY is seed yield

'a' is constant;

'e' is the error term;

b_1, b_2...........and b_n are output elasticity of production factors (or inputs) which measures the response of output to a change in the levels of any one of the input. For example if b_1 = 0.30, a 1% increase in input x_1 would lead to approximately a 0.30% increase in output keeping other inputs constant or unchanged. Further, $b_1 + b_2 + \ldots\ldots\ldots + b_n$ = Return to scale (Ghasemi *et al.*, 2010).

If, $b_1 + b_2 + \ldots\ldots\ldots + b_n = 1$, the production function has constant return to scale (CRTS). That is, if x_1, x_2................and x_n are increased by 30%, then production also increases by 30%.

However, if $b_1 + b_2 + \ldots\ldots\ldots + b_n < 1$, there are decreasing return to scale (DRS), and if $b_1 + b_2 + \ldots\ldots\ldots + b_n > 1$, there are increasing return to scale (IRS).

The final log-transformed linear equation can be expressed explicitly in the following form:

$$\ln Y_i = a + b_1 \ln X_1 + b_2 \ln X_2 \ldots\ldots\ldots\ldots + b_n \ln X_n + e_i \text{ Where } i = 1, 2, 3 \ldots\ldots\ldots\ldots n \quad (8)$$

Where,

'Y_i' denotes the yield of ith treatment combination,

'X_1, X_2, X_3..... X_n' are the quantity of inputs used in the production process,

'a' the constant term,

'b_1, b_2, b_3....b_n' represent coefficients of inputs which are estimated from the model and

'e_i' is the error term.

Equation 8 was estimated by ordinary least square (OLS) method (Pishgar *et al.*, 2011).

Sensitivity analysis was done by using the marginal physical productivity (MPP) technique which indicates the change in the output with a unit change in the input factor remaining all the other factors constant at their geometric mean level (Ghahderijani *et al.*, 2013).

The MPP value was estimated by using the '$\acute{a}_j$' of different variables as follow (Pishgar *et al.*, 2011; Singh *et al.*, 2004):

$$MPP_{xj} = \frac{GM(Y) \times a_j}{Gm(x_j)} \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where,

'MPP_{xj}' is marginal physical productivity of jth input,

'$\acute{a}_j$' the regression coefficient of jth input,

GM(Y), geometric mean of yield and

GM(X_j), geometric mean of jth variable.

To examine the presence of auto-correlation in the residuals of regression analysis and to measure the likelihood of prediction of the future outcome by the model, Durbin-Watson statistics were used (Ghasemi *et al.*, 2010).

Entire statistical calculations and estimations were carried out on pooled data of two years study by using SPSS (ver

18.0) software.

RESULTS AND DISCUSSION

Correlation study

Result of correlation coefficients between the studied variables and seed yield showed that crop growth rate (CGR) and net assimilation rate (NAR) at 40 - 75 and at 75 -110 DAS, relative growth rate (RGR) at 40 - 75 DAS, dry matter accumulation (DMA) at 75 and 110 DAS, number of seeds per siliqua (NSS), test weight (TW) and uptake of sulphur in seeds (SUS) were positively correlated at 1% level of significance with seed yield (Table 1). All these variables were observed to have significant correlations among themselves. Test weight had the highest positive correlation (0.987**) with seed yield followed by NAR at 40 - 75 DAS (0.907**) and DMA at 75 DAS (0.902**), respectively. However, leaf area index (LAI) at 75 DAS and number of primary branches (NBP) were negatively correlated with seed yield. Among the different independent variables, highest correlation (0.886**) existed between test weight and NAR at 40 - 75 DAS immediately followed by the correlation between NAR at 40 - 75 DAS and the same at 75 - 110 DAS (0.885**) and that between test weight and DMA at 75 DAS (0.869**). Though test weight was highly correlated with seed yield, it had negative association with plant height at 75 and 110 DAS, LAI at 75 DAS, RGR at 75 - 110 DAS and NBP. The effect of irrigation and sulphur levels were highly significant on test weight, NAR at 40 - 75 DAS and DMA at 75 DAS. Irrigation might have facilitated higher uptake of sulphur which, in turn, resulted in building new tissues and thereby enhancing the vegetative growth and photosynthetic activities of plants (Piri *et al.*, 2011). This ensures the increase in weight of thousand seeds, dry matter at reproductive phase and also the increase in net photosynthetic gain over respiratory losses from peak vegetative phase to peak reproductive phase and ultimately the seed yield. However, both LAI at 75 DAS and NBP are important yield contributing traits but here these two have very low or even negative correlation with other variables which might be the reason of negative correlation between the above two traits and seed yield. Once the plant enters its reproductive stage, vegetative growth of the plant contributes very little to the seed yield and sometimes the excess vegetative growth during peak reproductive stage poses even negative impact in the partitioning of photosynthates to the heterotrophic organs (sink) due to more transport of the same in the autotrophic organs (source). This clearly defines the negative correlation of LAI at peak reproductive stage (75 DAS) and NBP at harvest with different yield attributes and yield. In the present experiment, plant height was found to have very low association with seed yield. A plant with excessive stature may suffer from intra-plant competition (Reddy and Reddy,

Table 2: Total variance explained for each factor based on different yield attributing characters in Indian mustard (pooled data of 2 years)

Factor	Total	% of Variance	Cumulative %
1	9.85	51.838	51.838
2	3.91	20.578	72.416
3	0.94		
4	0.76		
5	0.72		
6	0.54		
7	0.46		
8	0.40		
9	0.30		
10	0.24		
11	0.18		
12	0.16		
13	0.15		
14	0.11		
15	0.11		
16	0.07		
17	0.06		
18	0.04		
19	0.02		

Table 3: Principal factor matrix after varimax rotation for different yield attributing characters of Indian mustard (pooled data of 2 years)

Parameters	Unit	Factor		Communalities
		1	2	
Plant height at 40 DAS	cm	0.313	0.821	0.773
Plant height at 75 DAS	cm	0.141	0.704	0.515
Plant height at 110 DAS	cm	0.152	0.847	0.741
LAI at 40 DAS	-	0.399	0.645	0.575
LAI at 75 DAS	-	-0.015	0.651	0.424
CGR at 40 - 75 DAS	g/m^2/day	0.657	0.376	0.573
CGR at 75 – 110 DAS	g/m^2/day	0.746	0.338	0.671
RGR at 40 - 75 DAS	mg/g/day	0.827	0.447	0.884
RGR at 75 – 110 DAS	mg/g/day	-0.136	0.900	0.829
NAR at 40 - 75 DAS	mg/m^2/day	0.970	0.046	0.944
NAR at 75 – 110 DAS	mg/m^2/day	0.919	0.100	0.855
DMA at 40 DAS	g/m^2	0.401	0.491	0.402
DMA at 75 DAS	g/m^2	0.899	0.019	0.808
DMA at 110 DAS	g/m^2	0.682	0.545	0.762
Number of primary branches/plant	-	0.047	0.776	0.604
Number of siliquae/plant	-	0.376	0.838	0.843
Number of seeds/siliqua	-	0.827	0.254	0.748
Test weight (1000 seed weight)	g	0.933	-0.274	0.863
Sulphur uptake in seed	kg/ha	0.676	0.638	0.946

#Number in bold are those with factor loadings greater than 0.5

Table 4: Econometric estimation and sensitivity analysis of mustard production with respect to seed yield (pooled data of two years)

Sl. No.	Independent variable		Co-efficient	Standard error	t-Ratio	MPP
Model: $Y = (-)\ 12.748 + \acute{a}_1 \ln (X_1) + \acute{a}_2 \ln (X_2) \ldots\ldots\ldots\ldots + \acute{a}_{19} \ln (X_{19})$						
Constant	(-) 12.748					
1.	Plant height at 40 DAS	cm	- 1.665	1.536	-1.084	-53.93
2.	Plant height at 75 DAS	cm	- 0.027	0.797	-0.033	-0.36
3.	Plant height at 110 DAS	cm	3.215	2.655	1.211	32.13
4.	LAI at 40 DAS	-	1.380	0.575	2.402[b]	2420.25
5.	LAI at 75 DAS	-	- 0.428	0.467	-0.915	-327.30
6.	CGR at 40 - 75 DAS	g/m²/day	0.497	0.438	1.136	150.58
7.	CGR at 75 – 110 DAS	g/m²/day	- 0.594	0.545	-1.089	-724.55
8.	RGR at 40 - 75 DAS	mg/g/day	- 4.688	2.662	-1.761	-319.10
9.	RGR at 75 – 110 DAS	mg/g/day	- 0.721	0.703	-1.026	-118.25
10.	NAR at 40 - 75 DAS	mg/m²/day	2.468	0.590	4.183[a]	992.05
11.	NAR at 75 – 110 DAS	mg/m²/day	0.238	0.287	0.829	134.40
12.	DMA at 40 DAS	g/m²	- 0.394	0.978	-0.402	-2.84
13.	DMA at 75 DAS	g/m²	1.437	2.635	0.545	5.47
14.	DMA at 110 DAS	g/m²	- 1.296	3.250	-0.399	-4.44
15.	Number of primary branches/plant	-	2.203	1.020	2.160[b]	430.59
16.	Number of siliquae/plant	-	1.878	3.094	0.607	9.06
17.	Number of seeds/siliqua	-	1.055	1.438	0.734	126.74
18.	Test weight (1000 seed weight)	g	0.585	1.254	0.466	189.05
19.	Sulphur uptake in seed	kg/ha	- 0.527	0.993	-0.530	-48.76
Durbin-Watson		1.824				
R^2		0.963				
Return to scale		6.051				

[a] Significant at 1% level; [b] Significant at 5% level; Co-efficient values in bold are those with significant t-ratio

2013). This competition between the shoot and the economic portion (seed) might be cause of low association between plant height and seed yield.

Eigen values and percent variance accounted

Eigen values and corresponding proportions of variance extracted along with cumulative percentage of total variance explained is presented in Table 2. We find that the first principal component explains 51.84% of the total sample variance and 20.58% of variance is explained by the second principal component. At the same time, first two components containing the eigen values greater than 1 have been retained for the study. Thus first two components explain the variance of the sample reasonably. The correlation of variables to the different principle components can be seen from the corresponding factor loadings (Table 3). Two factors have been extracted. The first factor consists of CGR and NAR at both periods of observation, RGR at 40 - 75 DAS, DMA at 75 and 110 DAS, number of seeds per siliqua, test weight, and sulphur uptake in seed. While, second factor consists of plant height and LAI at all dates of observation, RGR at 75 – 110 DAS, DMA at 40 DAS, number of primary branches per plant and number of siliquae per plant.

Scree-plot test also gave a clear-cut visual aid for justification of retaining two components effectively (Figure 1). From table 2, it is clear that only the first two components accounted for meaningful amount of variance, so only these two were retained, interpreted, and used in subsequent analysis. Here the characters like CGR and NAR at two periods of observations, RGR at 40 - 75 DAS, DMA at 75 and 110 DAS, NSS, test weight and sulphur uptake in seed showed highest loadings in PC 1. It was evident that the first PC was associated with traits having high and positive correlation with seed yield. So, they can be named as "reproductive component". On the other hand, PC 2 showed highest loadings of plant height and LAI at all dates of observation, RGR at 75 – 110 DAS, NBP and NSP. All these variables in PC 2 were observed to have association with the 'reproductive component' and thus can be named as 'vegetative component'. The first component extracted in this PCA accounts for a maximal amount of total variance in the observed variables. However, the second component accounted for a maximal amount of data set that was not accounted for by the first component. The percent of variance in any observed variable that is accounted for by the retained components has been presented by the communality. Thus uptake of sulphur in seed displayed the highest communality as because it loaded heavily on the first component and the same reason also reflects the lowest communality in case of DMA at 40 DAS. In the experiment,

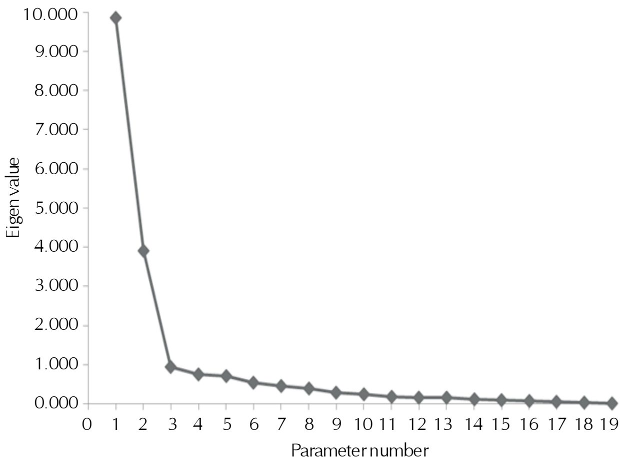

Figure 1: Scree-plot for different characters influencing seed yield of Indian mustard (pooled data of 2 years)

application of irrigation twice at 30 and 60 DAS and sulphur dose upto 60 kg/ha significantly increased the variables extracted in component 1 and 2 (data not shown). The more availability of water with two irrigations might have enhanced the leaf area and DMA with an increase in turgidity, cell division and meristematic activity (Piri *et al.*, 2012). On the other hand, sulphur has an important role in amino acid (particularly methionine) synthesis and it is involved in Fe metabolism thereby increasing the synthesis of chlorophyll. Besides, sulphur has similarity with N in improving meristematic activity. Being a constituent of succinyl coenzyme A, it is involved in chlorophyll formation. Kumar *et al.* (2011) reported an increase in mustard yield with increasing supply of sulphur. However, the different variables in PC 1 having high correlation with mustard yield were significantly influenced by sulphur levels. Increased application of sulphur also augmented the CGR (Kumar and Kumar, 2008), RGR (Saha and Mandal, 2000), NAR (Yadav, 1999), NSS (Kumar *et al.*, 2011), SUS (Sharma *et al.*, 2009) which were very much associated with the seed yield.

Econometric estimation and sensitivity analysis

As yield of mustard is the function of different yield attributing traits, the Cobb-Douglas production function was used for estimating the relationship between different yield attributes and yield. From the results in table 4, it can be revealed that NAR at 40 to 75 DAS had significant impact ($p \leq 0.01$) on mustard yield. Other variables which play significant positive role in determining the yield of mustard are LAI at 40 DAS and number of primary branches per plant ($p \leq 0.05$).

For examining the auto-correlation, Durbin-Watson test was done and value was 1.824. The R^2 value and return to scale were calculated as 0.963 and 6.051, respectively for the model presented in table 4. The last column belonged to MPP value to study the sensitivity of different variables. The MPP value was highest for LAI at 40 DAS followed by NAR at 40 - 75 DAS and NBP, respectively. To find the relationship between different variables and seed yield, Cobb-Douglas production function was applied. From the model, it is clear that 10% increase in NAR at 40 - 75 DAS, NBP and LAI at 40 DAS may lead to 24.68, 22.03 and 13.80% increase in the seed yield of mustard (Table 4). So, there are much scope to augment the seed yield by increasing the LAI at peak vegetative stage i.e. at 40 DAS, NAR at 40 - 75 DAS and NBP. In regression analysis, R^2 defines the percentage of data set explained by the model (Shabani *et al.*, 2012). For heteroscedasticity test, auto-correlation was tested by Durbin-Watson value for the model which was 1.824 indicating that there was no auto-correlation in the model.

The return to scale in table 4 also signifies that the production function had increasing return to scale (IRS). The MPP values indicate that additional use of one unit LAI, 1 mg/m²/day NAR at 40 - 75 DAS and one unit NBP can increase 2420.25, 992.05 and 430.59 kg of seed yield per hectare. Increase of 1cm height at 40 and 75 DAS, 1 unit LAI at 75 DAS, 1 g/m²/day CGR at 75 – 110 DAS, 1 mg/g/day RGR at 40 - 75 DAS and also at 75 – 110 DAS, 1 g/m² DMA at 40 DAS and at harvest and 1 kg/ha sulphur uptake in seed can decrease 53.93, 0.36, 327.30, 724.55, 319.10, 118.25, 2.84, 4.44 and 48.76 kg/ha seed yield.

The present experiment has shown the effect of irrigation schedules and sulphur levels on seed yield of mustard and its components. The study has shown the correlation of different yield components with seed yield. Among the different components, test weight, NAR at 40 - 75 DAS and DMA at 75 DAS were highly correlated with seed yield. However, these three variables were also significantly correlated among themselves. On the other, the study points out the multiple correlations among the yield attributing variables. Principal Component Analysis, in this study, had been so used to reduce the complex and large dataset into a smaller data set with few new variables, in turn, interpret different yield attributes easily and conveniently. The analysis helps to identify the major factors responsible for seed yield. Two factors had been extracted from this analysis namely "reproductive factor" and "vegetative factor", respectively. The production function analysis to identify the important variables reveals that NAR at 40 to 75 DAS, NBP and LAI at 40 DAS had the significant coefficient values which imply the opportunity to augment the seed yield through enhanced use of these attributes. The positive or negative MPP values of the variables also indicate the change in the mustard yield with a unit change in those variables keeping all the other variables constant.

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