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Principal component analysis of yield associated traits under abiotic stress conditions in Indian mustard (*Brassica juncea*) genotypes

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Abstract

A study was carried out using 80 different genotypes and five check varieties, viz., NRCHB-101, RH-749, Giriraj, RH-406 and Kranti of Indian mustard in augmented randomized complete block design, for two *Rabi* seasons during 2020-22, under timely sown, drought and terminal heat stress conditions to determine the selection criteria among yield related traits. The cluster analysis, revealed that the first seven principal components (PC) in all three trials had eigenvalues more than 1 and contributed around 74, 75 and 72 % of variability in timely sown, drought and late sown conditions, respectively. The maximum contribution towards variation in timely sown condition was exhibited by biological yield, yield per hectare, plant height and yield per plant. The maximum contribution towards variability under drought sown condition was exhibited by number of siliquae per plant, number of secondary branches and plant height. Biological yield, yield per plant and plant height contributed maximum towards variability under late sown condition. Thus, the aforementioned traits should be considered for improving yield per plant under different conditions studied.

Keywords: *Drought, heat stress, Indian mustard, principal component*

Introduction

Indian mustard [*Brassica juncea* (L.) Czern & Coss] is an allopolyploid species of the family Brassicaceae. It is a popular *Rabi* oilseed crop grown majorly in Northern and Eastern India. Of the total 73.84 million metric tonnes of rapeseed-mustard produced over 37.81 million hectares globally during 2021-22, India produced about 11 million metric tonnes from an area of 8.2 million hectare with a productivity of 1.3 metric tonnes per hectare (Anonymous, 2022). In the global market, India is the third largest producer of rapeseed-mustard after Canada and China. However, India continues to be a net importer of vegetable oils, with imports accounting for roughly 40 % of the country's annual edible oil requirements. To meet the current demand of our country, the Government has imported 136 lakh tonnes of edible oil for approximately Rs. 75,000 crores in the year 2019-20 (Anonymous, 2021).

The primary goal of any breeding programme is to maximise the yield. Yet, many high-yielding varieties fail to realize their full yield potential due to biotic and abiotic stresses caused by changes in climatic conditions (Srivastava and Srivastava, 2020). Drought and heat are the two most important abiotic factors that limit crop growth and yield. Drought has resulted in reduced yield of crop by 17-94 % annually (Srivastava *et al*., 2021). Water stress during flowering and siliqua development stage results in a drop in seed yield by 30.3 % and 20.7 %, respectively (Ghobadi *et al*., 2006). According to Sodani *et al*. (2017), water stress has great impact on seed yield during the pollen development, anthesis and fertilization stages. Seed yield per plant was reduced by 15 % when plants were subjected to heat stress during bud formation stage, while heat stress during the flowering and pod development stages reduced yield by 58 % and 77 %, respectively (Gan *et al*., 2004).

Drought stress has a significant impact on plant height, leaf area and number of lateral stems and also leads to loss in pigments and disorganisation of thylakoid membranes resulting in lowered chlorophyll content and reduced photosynthesis (Dogra *et al*., 2018). Singh *et al*. (2016) suggested that heat stress is most damaging during seedling, blooming, and terminal stages. Although, C_3 plants have an efficient photosynthetic response at 15-20°C, the global temperature rise of 0.2°C per decade is raising concerns about crop productivity and food security. For suitable seedling germination and establishment, an ideal mean temperature of 26°C is required (Lallu, 2008), but the average surface soil temperature may reach up to 45°C causing seedling mortality (Ram *et al.*, 2016). The sowing of Indian mustard should be completed by first fortnight of October, but due to the late harvesting of previous crop (Sharma and Sardana,2016), sowing gets delayed, exposing the crop to heat stress. This affects inter-molecular interactions at the tissue and cellular level leading to altered growth and development such as flower abortion, significant seed yield losses, decrease in cell water content and cellular membrane disruptions (Tirkey and Srivastava, 2022).

Hamman (1972) suggested that multivariate approaches have the potential to reduce numerous phenotypic measurements in large populations to fewer, more interpretable, and easily displayable dimensions. Karl Pearson invented Principal Component Analysis, or PCA, in the early twentieth century. It is a dimensionality-reduction approach for reducing dimensions of large data sets by reducing a large collection of variables into a smaller one retaining the majority of information in the large set. Therefore, the present study was undertaken to envisage a small number of independent linear combinations (PC) of a set of variables that captures all possible variation found in the original variables, for timely sown, drought and heat stress conditions separately.

Materials and Methods

The experimental material consisted of 3 sets of 80 genotypes of Indian mustard and five check varieties, namely NRCHB-101, RH-749, Giriraj, RH-406, and Kranti. The experimental field was laid in an augmented randomized completely block design, at agricultural research farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, during the *Rabi* seasons of 2020-21 and 2021-22. The field was divided into three sections, each with five blocks for the three trials viz., timely, drought (under protected structure), and late (for inducting terminal heat stress on test genotypes). For each trial, one set of material was line sown in a plot with three rows for each genotype of 5 m length, at a spacing of 30 × 10 cm, with all checks replicated in each block. Irrigation was withheld in drought trials, resulting in a water stress condition. The genotypes were sown late in heat stress trials so as to subject them to terminal heat stress at the end of season. The sowing for timely sown and drought stress was done on 23rd October and late sown trial was sown on 17th November for two consecutive years i.e. 2020-2021 and 2021-22. The weather condition at BHU, Varanasi for both the years has been depicted in Fig. 1.

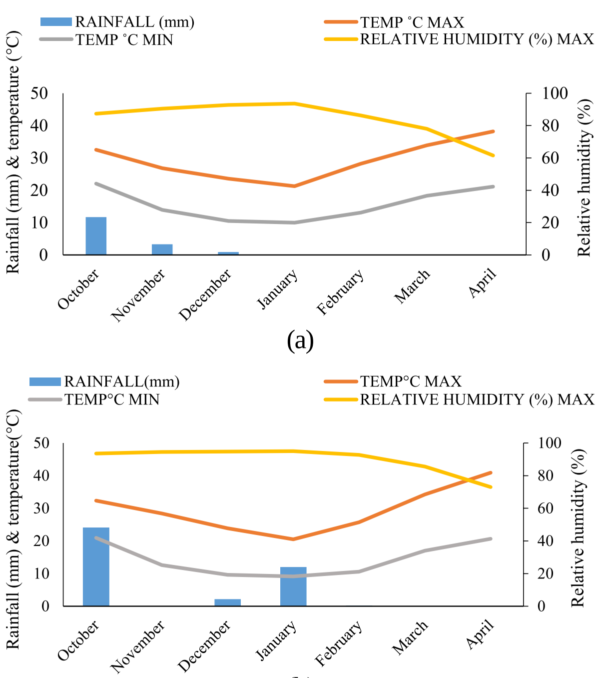

Fig. 1: Meteorological parameters observed during the study 2020-21 (a) and 2021-22 (b)

The texture of soil was sandy clay loam with bulk density ranging from 1.35-1.75 g/cm^3 and EC values of 0.15-0.33 dS/m. The availability of nitrogen in the soil was low and available phosphorus ranged from 23.6 to 34.2 kg/ha. The available potassium was 185-252 kg/ha and available zinc was 6.4 ppm in the soil. All the recommended package and practices were followed to raise a healthy crop. Observations were recorded for 20 different morpho-physiological characters. Five plants were randomly selected from each plot to record the data on plant height, number of primary branches, number of secondary branches, number of silique per plant, siliqua length, number of seeds per siliqua, main raceme length, number of silique on main raceme, test weight, biological yield and yield per plant. Days to 50 % flowering and days to maturity were recorded on plot basis. The pollen viability test was performed using 1 % aceto-carmine solution. The fertile and sterile pollens observed under microscope were counted and pollen viability percent was calculated. The relative water content and membrane thermo-stability index were determined by the method described by Barrs and Weatherley (1962) and Sairam (1994), respectively. The chlorophyll content at flowering stage and siliqua formation stage was determined using SPAD 502 Chlorophyll meter. The data obtained was used to conduct PCA. Uncorrelated data were used to analyse simple sums of squares and sums of products; and matrix A was produced. Once the vector's components were stable, the vectors were created through an iterative process. The un-standardized vector-I was divided into its individual components using a common divider, which was determined by taking the square root of sum of the squares of each component. The first primary component had the highest element from the previous iteration. The first PC, the i[th] element, and the j[th] element of vector I were added together to create matrix B, which was then subtracted from the (i,j)[th] element of matrix A. The same iteration method was used to calculate the second PC. Then, the reduced matrices were generated until the cumulative value exceeded 80 %. The formula for contribution of variation by 1[st] PC is as follows:

$$\text{Contribution of PC1} = \frac{\text{(Highest element of last iteration) x100}}{\text{Total sum of square of uncorrelated data}}$$

Results and Discussion

The eigenvalues obtained under the three situations *viz*. timely sown, drought and heat stress conditions are presented through the scree plot below (Fig. 2, 3 and 4). The scree plot in PCA is used to visually assess the components explaining most of the variability in the data (Venujayakanth *et al*., 2017). The scree plot graph showed that, the line changes its nature from a steep curve to flat or horizontal line from the seventh PC onwards. This indicated that each successive component accounted for smaller and smaller amounts of the total variance.

The first seven PC had eigenvalues greater than 1 under timely sown, drought and heat stress conditions (Table 1, 2 and 3). Therefore, first seven PC were retained as remaining components explained only a small portion of total variability. The cumulative variability for the timely sown condition from first seven axes was 74 % (Table 1). The first PC PC1 had eigenvalue of 4.92 which represented 25 % of entire variability. The value for PC1 exhibited that biological yield (0.38) contributed the greatest followed

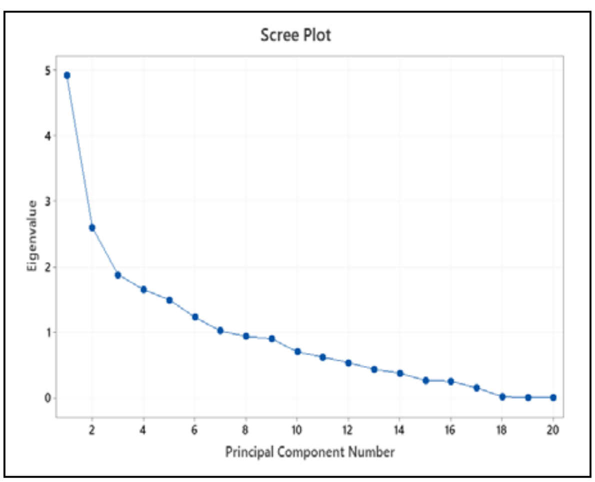

Fig. 2: Scree plot for timely sown condition

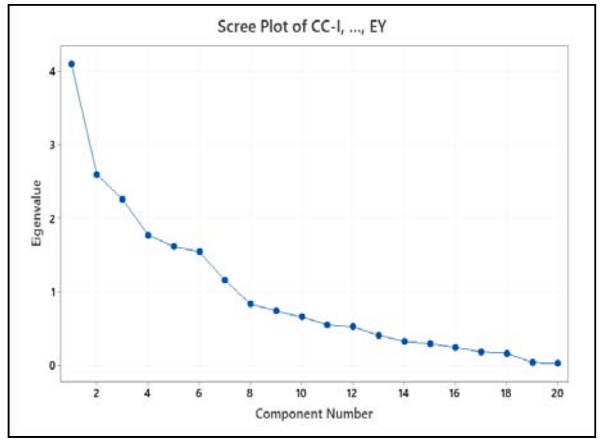

Fig. 3: Scree plot of different parameters under drought condition

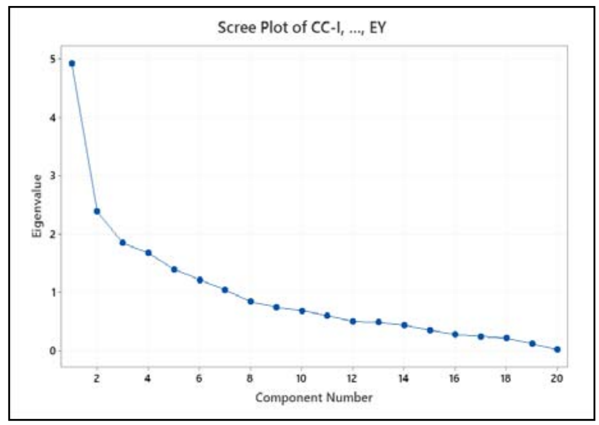

Fig. 4: Scree plot of different parameters under heat stress condition

by seed yield/ha (0.33) and plant height (0.33). PC2 had eigenvalue of 2.60 and explained 13 % of entire variability. The major contributors to PC2 were main raceme length (0.44) and siliqua length (0.43). The eigenvalue for PC3 was 1.88 explaining 9 % of entire variability. Days to maturity (0.09) followed by relative water content (0.06) contributed maximum towards PC3. The eigenvalue recorded for PC4 was 1.65 that explained 8 % of entire variability. Number of secondary branches (0.30) followed by number of silique per plant (0.26) contributed highest towards variation for PC4. The eigenvalue of PC5 was 1.50 governing 8 % of the entire variability and the highest variability was contributed by relative water content (0.28) followed by siliqua length (0.27). PC6 had eigenvalue of 1.23, which contributed 6 % of entire variability. The major contributors towards PC6 were pollen viability (0.53) and siliqua length (0.34). The eigenvalue of PC7 was 1.02, which contributed to 5 % of the entire variability. Number of siliquae per plant (0.50) and days to maturity (0.36) contributed maximum variability towards PC7.

Table 1: Eigen analysis and eigen vectors of the correlation matrix for timely sown condition

PCs	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16	PC17	PC18	PC19	PC20
Eigenvalue	4.92	2.60	1.88	1.65	1.50	1.23	1.02	0.93	0.90	0.70	0.62	0.54	0.44	0.38	0.27	0.25	0.15	0.02	0.00	0.00
Proportion	0.25	0.13	0.09	0.08	0.08	0.06	0.05	0.05	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
Cumulative	0.25	0.38	0.47	0.55	0.63	0.69	0.74	0.79	0.83	0.87	0.90	0.93	0.95	0.97	0.98	0.99	1.00	1.00	1.00	1.00
CC-I	-0.08	-0.29	-0.43	0.03	-0.02	0.10	0.35	0.00	-0.11	-0.23	-0.26	0.08	-0.20	0.59	-0.13	0.04	0.19	-0.03	0.00	0.00
CC-II	-0.08	-0.31	-0.44	0.09	0.01	-0.05	0.28	0.09	-0.06	-0.25	0.22	0.18	0.01	-0.56	0.28	0.12	-0.21	0.02	0.00	0.00
DM	0.19	0.12	0.09	-0.36	-0.39	0.02	0.36	0.07	-0.10	-0.20	-0.21	-0.02	0.08	-0.33	-0.54	-0.15	0.00	-0.06	0.00	0.00
DTF	-0.07	0.16	-0.05	-0.12	-0.67	0.06	-0.05	0.26	0.00	0.09	0.28	-0.06	-0.14	0.13	0.19	0.48	0.14	0.12	0.00	0.00
MRL	-0.27	0.44	-0.11	-0.01	0.20	0.06	0.20	0.15	0.01	0.01	0.09	0.02	-0.02	0.02	-0.04	-0.03	-0.01	0.01	-0.65	-0.43
MSI	0.03	-0.19	-0.10	-0.55	0.20	-0.19	0.11	0.20	0.00	0.12	0.15	-0.27	0.60	0.21	0.13	0.06	0.01	-0.01	0.00	0.00
NPB	0.15	0.25	-0.13	0.06	-0.03	-0.40	-0.17	0.29	-0.31	0.06	-0.60	0.27	0.13	-0.02	0.24	0.09	-0.04	0.04	0.00	0.00
NSB	0.27	0.05	-0.08	0.30	-0.18	-0.22	-0.06	0.28	-0.07	-0.09	0.49	0.25	0.16	0.28	-0.16	-0.44	-0.16	-0.05	0.00	0.00
NSMR	-0.34	0.31	-0.19	0.02	0.09	-0.19	0.07	-0.04	-0.15	0.06	0.10	-0.16	-0.06	-0.01	-0.14	-0.03	-0.05	0.00	0.68	-0.39
NSP	0.16	0.04	-0.09	0.26	-0.16	-0.08	0.50	-0.32	0.17	0.65	-0.04	0.13	0.20	0.00	0.02	0.05	0.01	0.02	0.00	0.00
PH	0.33	0.17	0.06	-0.14	-0.04	0.10	0.24	-0.14	-0.24	-0.05	-0.01	-0.35	-0.30	0.16	0.42	-0.19	-0.49	0.01	0.00	0.00
PVT	0.03	-0.14	-0.08	0.13	0.09	0.53	-0.11	0.22	-0.64	0.38	0.04	-0.08	0.09	-0.10	-0.17	0.00	0.02	0.04	0.00	0.00
RWC	0.18	-0.19	0.06	-0.29	0.28	-0.30	0.08	0.30	0.04	0.37	0.13	0.16	-0.60	-0.06	-0.17	0.05	0.03	0.04	0.00	0.00
SL	-0.07	0.43	0.04	-0.04	0.27	0.34	0.29	0.32	0.19	-0.06	0.04	0.24	0.04	0.04	0.11	0.00	0.04	0.02	0.25	0.51
SPS	-0.33	0.15	-0.22	0.04	-0.02	-0.35	-0.05	-0.18	-0.24	0.08	0.10	-0.28	-0.08	-0.02	-0.20	-0.04	-0.07	-0.01	-0.23	0.64
TGW	-0.01	0.13	-0.15	-0.47	-0.02	0.11	-0.19	-0.50	-0.23	0.03	0.18	0.58	0.01	0.07	0.06	-0.04	-0.01	0.02	0.00	0.00
Yield	0.33	0.14	-0.27	0.06	0.17	0.09	-0.19	-0.06	0.19	-0.06	0.01	-0.04	0.06	0.09	-0.39	0.54	-0.47	-0.08	0.00	0.00
HI	-0.20	-0.05	-0.37	-0.17	-0.23	0.20	-0.26	0.17	0.37	0.29	-0.22	-0.03	-0.08	-0.05	0.06	-0.36	-0.23	-0.38	0.00	0.00
BY	0.38	0.20	-0.21	0.04	0.10	-0.03	-0.03	-0.09	-0.08	-0.06	0.13	-0.17	-0.07	-0.13	0.12	0.04	0.52	-0.63	0.00	0.00
EY	0.31	0.14	-0.43	-0.04	0.04	0.07	-0.17	-0.04	0.20	0.00	-0.02	-0.21	-0.04	-0.12	-0.01	-0.24	0.28	0.66	0.00	0.00

Where, (PC)= Principal component, (PH)=Plant height(cm), (DTF) =Days to 50% flowering, (NPB)=No. of primary Branches, (NSB)=No. of secondary branches, (NSP)=No. of silique per plant, (SL)=siliqua length(cm), (SPS)=seeds per siliqua, (MRL)=main raceme length(cm), (NSMR)=No. of silique on main raceme, (TGW)=test weight(g), (BY)=biological yield (g), (Y)=seed yield per hectare, (DM)= days to maturity, (RWC)= relative water content, (MSI)= membrane stability index, (CC-I)= chlorophyll content at flowering stage, (CC-II)= chlorophyll content at siliqua formation stage, (PVT)= pollen viability test, (EY)= seed yield per plant(g), (HI)= Harvest Index.

Table 2: Eigen analysis and eigen vectors of the correlation matrix for drought condition

PCs	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16	PC17	PC18	PC19	PC20
Eigenvalue	4.11	2.59	2.26	1.77	1.61	1.54	1.16	0.83	0.74	0.65	0.55	0.52	0.41	0.32	0.29	0.24	0.18	0.16	0.04	0.02
Proportion	0.21	0.13	0.11	0.09	0.08	0.08	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0	0
Cumulative	0.21	0.34	0.45	0.54	0.62	0.69	0.75	0.79	0.83	0.86	0.89	0.92	0.94	0.95	0.97	0.98	0.99	1.00	1.00	1.00
CC-I	-0.14	-0.28	0.20	0.46	0.06	0.12	-0.16	-0.02	0.15	-0.18	0.16	-0.27	-0.18	-0.20	-0.03	0.53	0.13	-0.30	-0.06	0.04
CC-II	-0.04	-0.22	0.21	0.55	-0.02	0.05	-0.27	-0.04	0.05	-0.07	-0.04	-0.08	0.19	0.20	0.04	-0.65	0.02	0.09	0.05	-0.01
DM	0.12	-0.12	0.01	0.05	0.46	0.48	0.15	0.06	0.03	-0.13	-0.25	0.17	-0.11	-0.03	0.52	0.08	-0.02	0.32	-0.04	-0.02
DTF	0.18	0.04	0.09	-0.01	0.47	0.28	-0.03	-0.38	0.02	0.34	0.46	0.13	0.02	0.11	-0.37	-0.02	-0.10	-0.03	0.04	0.02
MRL	0.09	-0.14	0.10	-0.11	-0.35	0.45	-0.35	0.15	-0.08	0.31	-0.29	0.01	0.24	0.33	-0.14	0.31	-0.08	0.05	0.00	-0.07
MSI	0.01	-0.39	-0.32	-0.09	0.04	-0.18	-0.27	0.12	0.42	0.16	0.01	0.21	-0.25	-0.03	-0.10	-0.07	-0.07	0.15	-0.51	0.07
NPB	0.20	-0.18	0.03	0.22	0.28	-0.36	0.32	0.05	-0.03	-0.06	-0.47	-0.06	-0.01	0.26	-0.42	0.18	-0.23	0.08	0.10	-0.02
NSB	0.38	0.02	0.15	0.05	0.09	-0.27	-0.08	0.05	-0.01	0.30	-0.04	0.14	0.01	0.17	0.47	0.01	-0.10	-0.60	-0.08	0.02
NSMR	0.30	0.14	-0.19	0.02	-0.25	0.15	-0.14	-0.20	0.04	-0.49	0.11	0.04	-0.48	0.39	-0.01	-0.02	-0.26	-0.07	0.08	-0.01
NSP	0.39	-0.01	0.19	0.03	-0.13	-0.25	-0.04	-0.21	-0.04	0.09	0.09	-0.06	-0.13	0.15	0.09	0.15	0.64	0.41	-0.05	-0.13
PH	0.35	-0.15	-0.18	-0.10	-0.02	0.27	0.05	-0.12	-0.08	-0.12	-0.35	0.04	-0.03	-0.35	-0.28	-0.26	0.40	-0.38	-0.02	0.05
PVT	-0.03	-0.47	-0.38	-0.09	-0.01	-0.10	-0.05	-0.07	0.10	0.13	0.12	0.04	0.02	0.01	0.16	0.05	0.05	-0.01	0.73	-0.08
RWC	-0.04	-0.37	-0.31	-0.02	-0.07	0.02	0.25	-0.30	-0.44	-0.06	0.16	-0.29	0.25	0.20	0.17	0.03	-0.07	-0.04	-0.40	0.04
SL	-0.19	0.20	-0.23	0.33	-0.11	0.06	0.02	-0.22	-0.23	0.53	-0.26	-0.14	-0.50	-0.13	0.06	-0.05	-0.07	0.06	0.02	-0.01
SPS	-0.31	-0.12	0.10	0.11	-0.02	-0.13	-0.13	-0.19	-0.40	-0.15	-0.06	0.76	-0.03	0.01	-0.06	0.12	0.09	-0.05	-0.02	-0.04
TGW	-0.10	0.02	0.06	0.13	-0.35	0.11	0.49	-0.40	0.56	0.08	-0.09	0.23	0.17	0.08	0.07	0.05	0.01	-0.06	-0.05	0.00
Yield	0.13	-0.15	-0.01	0.23	-0.21	0.17	0.46	0.59	-0.15	0.13	0.36	0.20	-0.20	0.08	-0.12	-0.09	0.09	-0.03	0.00	-0.02
HI	0.02	0.31	-0.47	0.29	0.14	0.01	-0.09	0.10	0.09	-0.05	0.03	0.07	0.27	0.05	-0.03	0.10	0.13	-0.09	-0.11	-0.65
BY	0.38	-0.15	0.17	0.08	-0.24	-0.06	-0.02	-0.12	-0.10	-0.01	0.09	0.06	0.09	-0.57	0.02	0.02	-0.47	0.20	-0.01	-0.34
EY	0.26	0.24	-0.33	0.34	-0.06	-0.04	-0.11	0.04	-0.03	-0.01	0.06	0.15	0.31	-0.14	0.02	0.18	-0.01	0.17	0.06	0.65

Where, (PC)= Principal component, (PH)=Plant height(cm), (DTF) =Days to 50% flowering, (NPB)=No. of primary Branches, (NSB)=No. of secondary branches, (NSP)=No. of silique per plant, (SL)=siliqua length(cm), (SPS)=seeds per siliqua, (MRL)=main raceme length(cm), (NSMR)=No. of silique on main raceme, (TGW)=test weight(g), (BY)=biological yield (g), (Y)=seed yield per hectare, (DM)= days to maturity, (RWC)= relative water content, (MSI)= membrane stability index, (CC-I)= chlorophyll content at flowering stage, (CC-II)= chlorophyll content at siliqua formation stage, (PVT)= pollen viability test, (EY)= seed yield per plant(g), (HI)= Harvest Index.

Avtar *et al*. (2017) observed eight PC having eigen values greater than 1 explaining 70.41 % of the total variation in which the PC1 explained 16.21 % of the total variation. Neeru *et al*. (2016) showed 11 PCs that explained approximately 75% of the variance. PC1 represented 13.19 % of overall morphological variability, PC2 represented 10.07 % of total morphological variability, and PC3 represented 8.56 % of total morphological variability. Shekhawat *et al*. (2020) reported that five axes accounted for 74.87 % of the overall variability in which PC1 explained about 25.32 % of overall variability and parameters, viz., days to 50 % flowering, days to maturity, plant height and siliqua length contributed maximum towards PC1. Similarly, Yadav *et al.* (2022) identified four PC that explained 86 % of the variance. PC1 alone explained 36.19 % of the overall variation.

The cumulative variability from first seven axes under drought stress was 75 % (Table 2). The eigenvalue of PC1 was 4.11 explaining 21 % of the entire variability. The eigenvalue of PC2 was 2.59 which explained 13 % of the entire variability. The eigenvalues of PC3, PC4, PC5, PC6 and PC7 was 2.26, 1.77, 1.61, 1.54 and 1.16 respectively, each contributing around 11, 9, 8, 8 and 6 % of total variability, respectively. The greatest contribution towards PC1 was by number of silique per plant (0.39), followed by number of secondary branches (0.38) and plant height (0.35). Major contributors to PC2 were harvest index (0.31) and yield per plant (0.24). Chlorophyll content at siliqua formation stage (0.21) contributed highest to the variation in PC3, followed by chlorophyll content at flowering stage (0.20) and the major contributors to PC4 were also the same aforementioned traits. The highest contribution towards PC5 was by days to 50 % flowering (0.47) and days to maturity (0.46). The highest contribution to variability explained by PC6 was by days to maturity (0.48) and main raceme length (0.45). The major contributors to PC7 were test weight (0.49) and yield (0.46). Thus, the study indicated that the traits viz., number of silique per plant, number of secondary branches and plant height; which, contributed greatest towards variability under drought stress can be used as a selection parameter under drought stress. Kashyap *et al.* (2023) did a cluster analysis and observed that the variables can be grouped into two clusters with PC eigenvalues greater than one accounting for 53.2 % and 31.6 % of the total variability in the germination and seedling datasets respectively, under drought stress. Gunasekera *et al*. (2006) investigated the effect of environment and crop-environment interaction on crop growth and yield under stress condition characterized by low rainfall, high temperature and late sowing. The PCA revealed that the first two PC accounted for 88 % of the total variation.

The cumulative variability under heat stress from first seven axes was 72 % (Table 3). The eigenvalue of PC1 was 4.93 which explained 25 % of entire variability. The eigenvalue of PC2 was 2.38, which contributed 12 % towards total variability. Similarly, eigenvalues of PC3, PC4, PC5, PC6 and PC7 were 1.84, 1.67, 1.40, 1.22 and 1.04 with contribution of 9, 8, 7, 6 and 5 % respectively, towards total variability. Major contributors to PC1 were biological yield (0.37) followed by yield per plant (0.34) and plant height (0.34). In PC2, the major contributing parameter was number of silique per plant (0.17). Days to maturity (0.33) followed by number of secondary branches (0.29) and days to 50 % flowering (0.23) contributed maximum towards PC3. The maximum variability in PC4 was contributed by number of primary branches (0.29) followed by days to 50 % flowering (0.23) and number of secondary branches (0.17). The major contributors to PC5 were membrane stability index (0.46) followed by relative water content (0.46) and pollen viability (0.38). Number of primary branches (0.37) followed by membrane stability index (0.32) contributed maximum to PC6. And, the maximum variability in PC7 was contributed by test weight (0.62) followed by number of primary branches (0.45) and number of secondary branches (0.35). Thus, traits contributing the most towards variability under drought stress viz., seed yield per plant, biological yield, yield per plant and plant height can be used selection parameters under heat stress. Chugh *et al.* (2020) conducted a PC analysis under heat stress condition and found that PC1 and PC2 contributed around 67.1 % and 3.1 % towards total variation, respectively. The genotypes under study were divided into 4 groups based on the cluster analysis. Kashyap *et al.* (2023) performed a cluster analysis to identify potentially tolerant genotypes at the germination and seedling stage, under heat stress. The first two PC having eigenvalue greater than 1, accounted for 58.7% and 89.2% of the total variability at germination and seedling stages, respectively.

Breeders use the traits contributing highest towards variability to determine selection criteria and select superior genotype under a particular condition. The study indicated the importance of different traits for improvement of yield under timely sown, drought and heat stress conditions. Thus, the identified traits can be used to devise selection indices in crop improvement programmes.

Conclusion

Seven principal components were observed in 80 genotypes and five check varieties of Indian mustard to have eigen values greater than 1 in timely sown, drought and terminal heat stress conditions. The maximum contribution towards variation in timely sown condition

Table 3: Eigen analysis and eigen vectors of the correlation matrix for late sown condition

PCs	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16	PC17	PC18	PC19	PC20
Eigenvalue	4.93	2.38	1.84	1.67	1.4	1.22	1.04	0.84	0.75	0.69	0.6	0.5	0.48	0.43	0.35	0.28	0.24	0.21	0.12	0.02
Proportion	0.25	0.12	0.09	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0
Cumulative	0.25	0.37	0.46	0.54	0.61	0.67	0.72	0.77	0.80	0.84	0.87	0.89	0.92	0.94	0.96	0.97	0.98	0.99	1.00	1.00
CC-I	-0.15	-0.45	-0.10	0.09	-0.08	0.08	-0.02	0.33	0.08	0.03	0.30	0.12	0.02	-0.59	-0.31	0.17	-0.11	-0.21	-0.01	-0.03
CC-II	-0.18	-0.44	0.05	0.03	0.01	0.18	0.02	0.39	0.26	0.02	0.09	-0.17	0.15	0.30	0.26	-0.13	0.34	0.34	0.22	0.05
DM	0.23	-0.31	0.33	0.11	-0.21	-0.21	-0.20	0.08	0.15	0.13	-0.17	0.04	0.01	0.13	-0.02	-0.04	-0.19	0.16	-0.66	-0.10
DTF	0.16	-0.32	0.23	0.23	-0.24	-0.35	-0.02	-0.10	-0.36	0.16	-0.06	-0.09	-0.16	0.19	-0.08	0.32	0.05	-0.11	0.47	0.07
MRL	0.25	0.01	-0.37	0.01	0.19	-0.18	-0.13	-0.05	0.39	0.08	0.11	-0.14	0.30	0.36	-0.53	0.13	0.00	-0.08	0.07	-0.02
MSI	0.00	-0.30	0.06	-0.10	0.46	0.32	-0.11	-0.32	0.05	0.37	-0.08	0.01	-0.52	0.02	-0.16	-0.15	0.08	-0.03	-0.01	0.00
NPB	0.13	-0.21	-0.01	0.29	-0.14	0.37	0.45	-0.33	0.11	0.12	-0.20	0.25	0.41	0.06	0.09	-0.09	-0.08	-0.25	0.04	-0.03
NSB	0.22	-0.02	0.29	0.17	0.13	0.10	0.35	0.10	0.22	-0.58	-0.02	-0.40	-0.31	0.02	-0.13	-0.02	-0.08	-0.16	0.01	-0.04
NSMR	0.32	-0.06	-0.15	0.09	0.22	-0.25	-0.22	0.15	0.06	0.15	-0.17	-0.27	0.10	-0.27	0.42	-0.31	0.07	-0.44	0.06	0.06
NSP	0.32	0.17	0.05	0.07	0.07	0.28	0.04	0.06	-0.06	0.28	-0.22	-0.37	0.18	-0.37	-0.05	0.31	-0.06	0.48	0.08	-0.04
PH	0.34	-0.04	-0.01	0.09	0.06	-0.20	-0.10	-0.10	0.25	-0.30	-0.14	0.54	-0.09	-0.26	-0.04	-0.18	0.12	0.38	0.29	0.07
PVT	0.04	-0.06	-0.36	0.14	0.38	-0.12	0.35	0.46	-0.31	0.02	-0.29	0.25	-0.14	0.19	0.01	0.13	-0.12	0.08	-0.14	-0.02
RWC	0.04	-0.34	0.04	-0.09	0.46	-0.04	-0.12	-0.33	-0.32	-0.37	0.26	-0.05	0.35	-0.02	0.19	0.17	-0.12	0.13	-0.12	0.00
SL	-0.06	-0.19	-0.52	-0.09	-0.26	-0.04	0.01	-0.27	0.30	-0.12	-0.14	-0.14	-0.31	-0.03	0.37	0.39	-0.11	0.07	-0.07	-0.04
SPS	-0.26	-0.19	-0.28	0.08	-0.18	-0.15	0.07	-0.20	-0.27	-0.15	-0.31	-0.33	0.07	-0.15	-0.34	-0.46	0.11	0.20	-0.07	0.04
TW	0.11	-0.03	0.04	-0.27	0.03	-0.42	0.62	-0.12	0.10	0.30	0.39	-0.08	-0.04	-0.13	0.07	-0.15	0.02	0.17	-0.05	0.00
Yield	0.28	-0.13	-0.12	-0.38	-0.20	0.21	-0.07	0.15	-0.14	-0.02	0.08	-0.02	-0.05	0.15	-0.01	-0.31	-0.63	0.06	0.24	0.15
HI	-0.08	-0.12	0.22	-0.61	0.05	-0.07	0.11	0.06	0.11	-0.07	-0.47	0.04	0.18	-0.08	-0.12	0.22	0.13	-0.16	-0.01	0.38
BY	0.37	0.01	-0.19	0.07	-0.19	0.22	0.01	0.00	-0.21	-0.05	0.26	0.01	-0.11	0.04	-0.03	0.04	0.40	-0.02	-0.30	0.60
EY	0.34	-0.10	-0.09	-0.38	-0.17	0.13	0.01	0.07	-0.22	-0.11	-0.02	0.05	0.00	0.02	-0.05	-0.01	0.41	-0.11	-0.03	-0.66

Where, (PC)= Principal component, (PH)=Plant height(cm), (DTF) =Days to 50% flowering, (NPB)=No. of primary Branches, (NSB)=No. of secondary branches, (NSP)=No. of silique per plant, (SL)=siliqua length(cm), (SPS)=seeds per siliqua, (MRL)=main raceme length(cm), (NSMR)=No. of silique on main raceme, (TGW)=test weight(g), (BY)=biological yield (g), (Y)=seed yield per hectare, (DM)= days to maturity, (RWC)= relative water content, (MSI)= membrane stability index, (CC-I)= chlorophyll content at flowering stage, (CC-II)= chlorophyll content at siliqua formation stage, (PVT)= pollen viability test, (EY)= seed yield per plant(g), (HI)= Harvest Index.

was exhibited by biological yield, yield per hectare, plant height and yield per plant. The maximum contribution towards variability under drought sown condition was exhibited by number of silique per plant, number of secondary branches and plant height. Biological yield, yield per plant and plant height contributed maximum towards variability under late sown condition. The traits showing maximum variation under different conditions are more suitable for targeted crop improvement under respective conditions. Furthermore, the correlation and path coefficients can help to discern the association of aforementioned traits with yield traits for crop improvement through correlated response to selection.

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