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Heat stress tolerance study in eggplant based on morphological and yield traits

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ABSTRACT

High temperature has detrimental effects on growth and yield of any crops. A total of 62 two eggplant genotypes were evaluated for growth and yield traits at two growing season during summer season (March-July) and *kharif* season (July-November). Average of three replications was used for each trait in statistical analysis involving one way analysis of variance (ANOVA), Principal Component Analysis (PCA) and Agglomerative Hierarchial Clustering (AHC) using SAS ver. 9.3 and R package. Analysis of variance indicated high variability for all the traits among the eggplant genotypes. Highest yield per plant was recorded in Guhala Chatua Local (1.8 kg) in summer season whereas in *kharif* season, yield per plant was maximum in Swarnamani Black (5.97 Kg). The mean yield per plant (1.83 kg) was more in *kharif* season as compared to summer season (0.09 kg). The percentage yield reduction in summer season was more than 90% in almost all the genotypes and the lowest yield reduction (22.11%) was found in Guhala Chatua Local followed by DBL-21 and DBL-08. In summer season, the first principal component (PC1) and second principal component (PC2) could explain 48% and 14% of total variance, respectively where yield per plant contributed positively to PC1. In *kharif* season, first principal component (PC1) and second principal component (PC2) could explain 33% and 20% of the variance, respectively where total number of fruit weight per plant, fruit diameter and yield per plant traits contributed positively to PC1. The Hierarchical cluster analysis revealed five clusters based on the similarities among the genotypes in both summer and *kharif* season but the clustering pattern was different among season. Based on the study, promising heat-tolerant genotypes (Guhala Chatua Local, DBL-21 and DBL-08) have been identified which could be novel source for heat tolerance gene (s) for utilizing in breeding programme.

Key words: *Solanum melongena*, brinjal, hot set.

INTRODUCTION

The growth and development of crop plant depends on the surrounding environment wherein atmospheric temperature plays a prominent role. In tropical countries, an increased temperature creates heat stress to plant and affects its growth and development. The increase in temperature has become a major curtailing factor for declining growth and yield of plant and also determines the geographical spread of plants (Mittler *et al.,* 12). Due to heat stress (HS), changes occur at morpho-anatomical, physiological, biochemical process in plants. In almost all the annual crops, exposure to intense heat stress leads to extreme yield loss (Tesfaendrias *et al.,* 20). Abnormal flower development, dehiscence and poor production of pollen, low pollen viability, bud drop, decline in the level of carbohydrate and reproductive anomalies are the reasons for reduced fruit set at elevated temperature (Hazra *et al.,* 9).

Brinjal or eggplant (*Solanum melongena* L.) is one of the most important non-tuberiferous solanaceous crop in India. It has great significance in South East, Central and South Asia and in African countries (Koundinya *et al*., 10; Bhanushree *et al*., 4). Wide range diversity is available in India, thereby it is known as king of vegetables in India (Daunay, 7). West Bengal, Orissa, Gujarat, Madhya Pradesh, Bihar, Chhattisgarh, Karnataka and Andhra Pradesh are the major states where eggplant is grown over an area of 0.66 million hectare with average production and productivity of 12.4 million tonnes and 18.78 t/ha, respectively (Anonymous, 1). A moderately warm and long growing season is desirable for its cultivation. Ideal temperature for growth is 20-30°C but during summer month when temperature goes beyond 35°C, it affects plant growth, development and subsequently yield (Dhatt and Kaur, 8). The optimum temperature requirement for fruit set is 18-21°C and most of the varieties are gown as *kharif* season and fruits are harvested during autumn-winter season (Nath *et al.*, 14). During summer season, eggplant can be grown as off season vegetable in Northern plains which can fetch premium price in the market. When the day and night temperature exceeds 35°C, there is drastic reduction in fruit set with lower fruit weight

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(Ansari *et al.,* 2). Mohanty and Prusty (13) have reported yield reduction with high day (33-39 ºC) and night (33-39 ºC) temperature. Pandit *et al.* (15) observed low yield in summer-rainy season which is due to decline in fruit weight and size in eggplant. The capability of plant to grow under high temperature is taken as an indicator factor for heat tolerance. To overcome the heat stress effect, crop varieties that perform well in heat stress condition is need of day especially in northern plains where extreme temperature prevails during May to June. Intrinsic variation for high temperature tolerance might exist in promising eggplant genotypes that need to be explored. One of the ways to study the effects of heat stress is to transplant crops in March which ensures high temperature window (>40°C) during fruiting stage. Generally commercially grown varieties are poor yielder in prevailing high temperature which affects fruit set (Singh and Kalda, 17). This factor and the changing climate scenario made necessary to develop heat tolerant varieties which perform well in heat stress conditions. The present study was, therefore, undertaken to screen eggplant genotypes under high temperature conditions.

MATERIALS AND METHODS

Plant materials

A total of sixty two eggplants genotypes (Table 1) comprising commercial varieties, advanced breeding lines, land races were grown in the research farm of Division of Vegetable Science, ICAR- Indian Agricultural Research Institute, New Delhi. The genotypes were maintained as true homozugous lines through selfing.

Growing of crops in outdoor experiment

All the genotypes were grown in the field during summer (March-June) and in *kharif* (July to November) season. In case of summer season crop, sowing was done during mid-week of February and the seedlings were transplanted during mid-March. In *kharif* season sowing was done during mid-June and the seedlings were transplanted in the main field in mid-July. A total of 20 plants in each genotype were grown in both the season. The seedlings were planted in randomized block design with 3 replications at spacing of 75 × 75 cm. Recommended cultivation practices was followed to raise the crop. Well rotten cowdung manure was applied @ 25 tonnes per hctare during field preparation along with 50 kg N, 80 kg P, 60 kg K per hectare. Another dose of 25 kg N was applied 30 and 60 days after transplanting All other management practices were followed as per Singh and Kalda (17).

Observations on morphological traits

For measuring plant height in both the season, observations were recorded from five randomly selected plants per line. The data were pooled and averaged.

Table 1. List of eggplant genotypes used for evaluation in summer and *kharif* season.

Code	Genotypes	Code	Genotypes	Code	Genotypes	Code	Genotypes
G1	Pusa Ankur	G18	DBGR-32	G35	Khashi Sandesh	G52	DEB- 3709
G2	Pusa Anupam	G19	NDB-25	G36	Panipat Gole	G53	Debjuri Hajari
G3	Pusa Bindu	G20	129-5	G37	Pant Rituraj	G54	Boulder
G4	DBL-02	G21	190-10-12	G38	Pant Samrat	G55	DBL-08
G5	Pusa Purple Cluster	G22	Br-112	G39	Punjab Barsati	G56	DBR-32
G6	Pusa Purple Long	G23	Punjab Sadabahar	G40	Guhala Chatua Local	G57	DBR-203
G7	Pusa Purple Round	G24	DBL-100-1-10	G41	Keonjhar Local	G58	DBGR-181
G8	DBL-21	G25	DBL-09	G42	BB-7	G59	Kushpada Local
G9	Pusa Upkar	G26	DBL-17	G43	Arka Nidhi	G60	DBL-128
G10	Pusa Uttam	G27	DBPR-23	G44	Arka Neelkanth	G61	DBR-184
G11	Pusa Hara Baingan 1	G28	DBPR-43	G45	Arka Keshav	G62	Pusa Bhairav
G12	Pusa Safed Baingan 1	G29	DBL-60	G46	Manjari Gota		
G13	DBGL-164	G30	DBR-92	G47	IC -112991		
G14	DBGL-225-2-5-17	G31	DBSR-94	G48	IC-112992		
G15	DBWL-22-1-11	G32	DBGR-131	G49	Bangar Begoon		
G16	DBWL-50-7-14	G33	DBL-160	G50	Nabanita (Lukri Begoon)		
G17	DBWR-190-44	G34	Swarnamani Black	G51	Kalo Solia		

Observations on yield traits

Fruit length (cm) and fruit diameter (cm) were recorded in each of the five fruits taken from each of five randomly selected plants from each genotype in each replication. Digital weighing balance was used to record average fruit weight (g). Yield per plant (kg) was calculated by multiplying average fruit weight with total number of fruits per plant in each genotype.

Statistical analysis

Average of three replications was used for each trait in statistical analysis involving one way analysis of variance (ANOVA), principal component analysis (PCA) and Agglomerative Hierarchial Clustering (AHC). The analysis was done in SAS ver. 9.3 and R package. A dendrogram was made for genotypes using SAS ver. 9.3 to obtain a two-dimensional projection of the similarity or dissimilarity of all the genotypes.

RESULTS AND DISCUSSION

The 62 eggplant genotypes were screened during summer season, when the temperature exceeds 40°C with peak during May-June, and the mean annual temperature was 24°C. The maximum and minimum temperature during the crop growing season (March-December, 2018) is given in Fig. 1. The analyses of variance for all the traits is mentioned in Table 2 and the perusal of the table showed high variability among the eggplant genotypes because of high significance of mean sum of square. Plant height was measured in both summer and *kharif* season crop, which showed a significant reduction alongwith leaf chlorosis and scorching in summer season. The plant height varied from 17.00 cm (DBWL-22-1-11) to 61.83 cm (DBL-60) in summer season. In *kharif* season, the highest plant height was observed in DBR-92 (78.33 cm) and lowest in Punjab Sadabahar (27.33 cm) (Table 3). During heat stress condition, the vegetative growth of the plant is restricted with limited foliage as reported by (Solankey *et al.,* 19). Similarly in our study we found that plant height was less in summer season as compared to *kharif* season due to unfavourable growing conditions is contrary to the previous reports of Dhatt and Kaur (8) and Pandit *et al.* (15).

The average fruit weight ranged from 0 to 146 g (DBR-92) with a mean value of 19.31 g in summer season. The average fruit weight was maximum in DBGR-131(820 g) and minimum in DBL-60 (31.67 g) with mean value of 115.47 g in *Kharif* season (Table 3). Significant decrease in average fruit weight was recorded in summer season but reduction was maximum in the plants which are susceptible to heat stress. Dahal *et al.* (5) reported that high temperatures during flowering and fruiting period severely affect the fruit weight. Yield potential of individual genotypes also depends on fruit weight which declined due to heat stress (Singh *et al*., 18).

Table 2. Analysis of variance for morphological and yield traits in eggplant.

Character	Mean sum of squares			LSD (5%) Season	LSD (5%) Genotype	CV (%)
	Season (1)	Genotypes (6)	Error (246)			
Plant height (cm)	6987.93	658.25**	27.28	1.06	5.93	11.82
Fruit length (cm)	11089.91	49.05**	4.10	0.41	2.30	21.14
Fruit diameter (cm)	976.50	15.03**	0.58	0.15	0.86	22.49
Fruit weight (g)	855376.21	19533.63**	735.32	5.53	30.83	40.31
Yield/plant (Kg)	276.52	1.75**	0.19	0.09	0.50	46.49

*Significant at 5% level; **Significant at 1 per cent level values in parenthesis indicating degrees of freedom

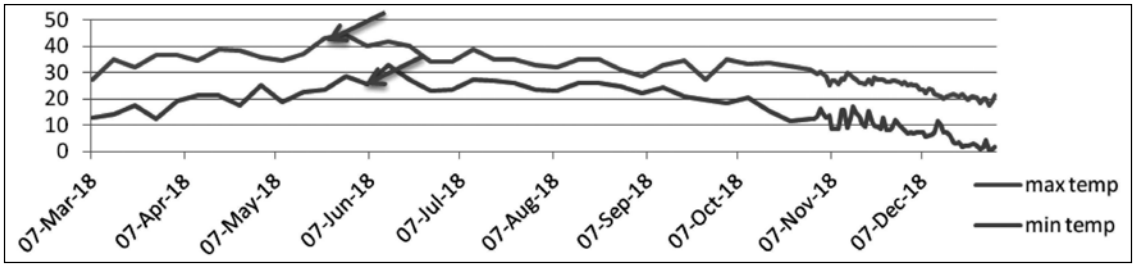

Fig. 1. Maximum and minimum temperature during the crop growing season (March, 2018-December, 2018), X-axis: Date, Y-axis: Temperature.

Table 3. Morphological and yield related parameters in 62 eggplant genotypes under summer (off season) and *kharif* season (normal season) crops, Mean values with different letters in a vertical column are significantly different (P < 0.05) from each other.

Genotype	Plant height (cm)		Fruit weight (g)		Fruit length (cm)		Fruit diameter (cm)		Yield/plant (Kg)		Per cent yield reduction in summer (%)
	Summer	*Kharif*	Summer	*Kharif*	Summer	*Kharif*	Summer	*Kharif*	Summer	*Kharif*	
Pusa Ankur	41.67	49.00	35.33	88.00	6.07	12.26	3.37	6.54	0.37	1.78	79.44
Pusa Anupam	39.33	52.33	15.67	80.67	7.53	18.86	2.23	3.91	0.02	1.99	98.96
Pusa Bindu	38.67	46.00	21.17	42.00	7.83	11.54	4.57	6.43	0.03	0.72	95.76
DBL-02	20.00	32.00	0.00	70.00	0.00	12.62	0.00	3.90	0.00	1.64	100.00
Pusa Purple Cluster	37.00	41.67	27.67	36.67	9.47	13.61	1.57	2.78	0.11	0.99	89.16
Pusa Purple Long	33.67	37.67	0.00	38.00	0.00	16.43	0.00	1.85	0.00	0.63	100.00
Pusa Purple Round	46.67	56.67	0.00	135.00	0.00	11.93	0.00	5.83	0.00	1.46	100.00
DBL-21	39.67	49.67	51.33	58.33	8.50	18.50	2.90	3.33	0.80	1.97	59.62
Pusa Upkar	32.67	42.67	0.00	193.33	0.00	11.10	0.00	7.73	0.00	2.37	100.00
Pusa Uttam	29.33	39.33	15.33	118.67	7.23	12.27	2.63	6.23	0.02	0.98	98.43
Pusa Hara Baingan 1	33.33	41.33	62.67	153.33	11.93	15.00	4.33	7.14	0.08	2.44	96.54
Pusa Safed Baingan 1	37.67	44.33	0.00	84.33	0.00	8.87	0.33	4.43	0.00	2.08	100.00
DBGL-164	47.50	55.33	0.00	67.00	0.00	17.33	0.00	3.33	0.00	0.93	100.00
DBGL-225-2-5-17	39.00	63.17	0.00	46.67	0.00	16.40	0.00	2.50	0.00	0.58	100.00
DBWL-22-1-11	17.00	28.67	60.88	51.33	9.73	15.80	3.13	3.13	0.14	1.03	86.25
DBWL-50-7-14	31.67	38.33	39.67	43.00	9.40	11.90	3.03	3.30	0.10	0.97	89.68
DBWR-190-44	43.33	47.00	0.00	91.67	0.00	11.30	0.00	5.40	0.00	1.54	100.00
DBGR-32	38.00	44.67	0.00	122.33	0.00	15.67	0.00	5.03	0.00	1.84	100.00
NDB-25	31.67	36.67	35.67	118.00	7.63	17.23	2.53	4.53	0.05	2.95	98.30
129-5	42.00	57.67	0.00	45.00	0.00	16.97	0.00	2.43	0.00	0.65	100.00
190-10-12	29.83	32.33	0.00	116.67	0.00	10.27	0.00	6.63	0.00	1.96	100.00
Br-112	38.67	51.67	0.00	81.33	0.00	12.03	0.00	5.00	0.00	1.31	100.00
Punjab Sadabahar	20.33	27.33	0.00	108.67	0.00	11.07	0.00	5.87	0.00	1.38	100.00
DBL-100-1-10	31.33	37.67	0.00	97.67	0.00	20.17	0.00	3.53	0.00	1.31	100.00
DBL-09	49.67	61.33	14.67	49.67	6.97	18.83	3.40	2.50	0.02	1.26	98.07
DBL-17	47.67	54.33	19.33	116.33	8.33	14.70	3.07	5.07	0.02	1.77	98.91
DBPR-23	47.67	60.57	0.00	137.67	0.00	12.97	0.00	6.80	0.00	2.03	100.00
DBPR-43	49.33	63.00	0.00	115.00	0.00	10.50	0.00	6.23	0.00	1.61	100.00
DBL-60	61.83	70.67	0.00	31.67	0.00	15.20	0.00	2.23	0.00	0.43	100.00
DBR-92	61.00	78.33	146.67	151.33	14.97	15.70	7.13	6.23	0.20	2.22	91.06
DBSR-94	51.67	51.33	0.00	96.67	0.00	13.20	0.00	4.60	0.00	1.28	100.00
DBGR-131	42.67	62.33	0.00	820.00	0.00	13.93	0.00	9.20	0.00	3.26	100.00
DBL-160	32.33	56.33	15.67	241.67	7.43	14.80	2.50	6.80	0.02	3.29	99.32
Swarnamani Black	57.67	71.00	15.00	272.33	5.80	13.60	4.60	8.77	0.03	5.97	99.50
Khashi Sandesh	38.33	44.67	0.00	169.67	0.00	11.60	0.00	6.93	0.00	4.03	100.00
Panipat Gole	60.33	74.67	21.67	433.67	8.00	13.03	5.77	9.27	0.02	3.88	99.44
Pant Rituraj	45.67	59.33	68.83	60.33	4.07	13.18	1.53	5.80	0.09	1.25	92.74

Genotype	Plant height (cm)		Fruit weight (g)		Fruit length (cm)		Fruit diameter (cm)		Yield/plant (Kg)		Per cent yield reduction in summer (%)
	Summer	*Kharif*	Summer	*Kharif*	Summer	*Kharif*	Summer	*Kharif*	Summer	*Kharif*	
Pant Samrat	53.00	63.33	41.33	66.33	12.98	19.27	1.23	3.83	0.76	2.05	62.65
Punjab Barsati	46.57	54.67	0.00	93.00	0.00	13.97	0.00	6.70	0.00	2.36	100.00
Guhala Chatua Local	37.33	40.33	94.67	96.00	8.83	14.00	9.07	8.73	1.80	2.31	22.11
Keonjhar Local	33.33	36.67	20.00	138.00	11.40	15.87	4.53	6.23	0.02	2.03	99.02
BB-7	33.33	42.33	0.00	67.00	0.00	12.33	0.00	4.53	0.00	0.16	100.00
Arka Nidhi	36.67	45.33	48.67	144.33	3.03	21.00	0.70	4.57	0.05	0.77	93.68
Arka Neelkanth	41.00	46.00	32.67	84.33	7.60	19.23	2.33	3.80	0.05	1.41	96.51
Arka Keshav	36.00	46.67	0.00	83.33	0.00	16.93	0.00	3.90	0.00	1.39	100.00
Manjari Gota	55.50	61.33	24.67	66.00	6.43	15.30	3.77	4.13	0.03	0.94	96.49
IC -112991	29.33	35.33	23.67	95.67	4.50	14.03	2.17	4.47	0.03	1.85	98.36
IC-112992	53.33	55.33	18.33	65.33	4.90	13.63	1.50	4.20	0.03	1.21	97.88
Bangar Begoon	32.00	41.00	18.00	108.67	8.50	16.35	2.60	5.07	0.02	2.38	99.24
Nabanita (Lukri Begoon)	27.33	30.00	29.00	129.00	8.23	16.33	3.23	5.67	0.07	3.01	97.75
Kalo Solia	24.00	38.33	18.67	175.67	5.27	16.03	4.53	6.43	0.02	3.39	99.30
DEB- 3709	29.00	33.33	25.00	72.00	5.73	15.93	4.20	3.80	0.04	1.44	97.15
Debjuri Hajari	37.00	44.67	0.00	66.33	0.00	18.73	0.00	3.47	0.00	1.52	100.00
Boulder	25.67	32.33	0.00	118.00	0.00	15.43	0.00	5.47	0.00	2.32	100.00
DBL-08	41.67	46.00	52.73	110.67	10.27	19.80	2.98	3.80	0.65	1.83	64.57
DBR-32	43.00	45.67	66.00	170.00	4.93	13.43	3.37	6.77	0.08	4.21	98.10
DBR-203	43.33	53.00	0.00	86.67	0.00	19.07	0.00	4.00	0.00	2.61	100.00
DBGR-181	52.07	57.33	16.33	94.00	12.00	15.48	4.77	4.43	0.02	1.56	98.95
Kushpada Local	52.00	56.67	0.00	85.33	0.00	18.87	0.00	3.53	0.00	1.19	100.00
DBL-128	45.67	45.67	0.00	55.33	0.00	16.10	0.00	3.37	0.00	1.23	100.00
DBR-184	41.00	49.67	0.00	67.67	0.00	16.30	0.00	4.10	0.00	1.57	100.00
Pusa Bhairav	36.00	43.33	0.00	37.00	0.00	18.07	0.00	4.53	0.00	0.63	100.00
Mean	39.85	48.47	19.31	115.47	4.12	15.03	1.77	5.01	0.09	1.83	95.05
CV (%)	6.98	5.87	1.43	0.96	1.08	0.19	1.19	0.35	2.94	0.57	0.13
CD (0.05)	10.36	8.69	6.99	28.25	1.13	0.71	0.53	0.45	0.07	0.26	3.24

The fruit length ranged from 0 to 14.97 cm with the mean value of 4.12 cm. The longest fruit was observed in genotype DBR-92 (14.97). In *kharif* season, the range of fruit length ranged from 8.87 to 21.00 cm with mean value of 15.07 cm, whereas Arka Nidhi had longest fruit (21.0 cm) and the smallest was in Pusa Safed Baigan 1 (8.87 cm) (Table 3). Fruit diameter ranged from 0 to 9.07 cm (Guhala Chatua Local) with a mean value of 1.77 cm in summer season. In *kharif* season fruit diameter ranged from 9.27 cm (Panipat Gole) to 1.85 cm (Pusa Purple Long) with a mean value of 5.01 (Table 3). The genotypes which had highest fruit length and diameter may not have highest average fruit weight sometimes because of puffy fruits that also exist due to improper pollination during heat stress. Our finding was found to be in line with those of Solankey *et al.* (19). There was significant decline in fruit length and diameter in summer season as compared to *kharif* season as also reported by of Dahal *et al.* (6).

Yield is the major component in selection of desirable genotypes under heat stress condition which is ultimately important parameter of selection. Highest yield per plant was recorded in Guhala

Chatua Local (1.8 kg) in summer season whereas in case of *kharif* season yield per plant was maximum in Swarnamani Black (5.97 Kg). The mean yield per plant (1.83 kg) was more in *kharif* season as compared to summer season 0.09 kg (Table 3). The highest fruit yield obtained during *kharif* season was due to high fruit weight, fruit set and more number of fruits per plant. Dhatt and Kaur (8) found more yield per plant during *kharif* season as compared to summer season in eggplant. The performance of all the morphological traits is found to reduce during *kharif* season than the summer season. In May-June, the minimum temperature ranged from 20°C to 33°C and maximum was from 35°C to 45°C during fruiting period which was higher than the optimum temperature for flowering and fruiting and this was found to be reason for poor performance of morphological and yield related traits. Heat stressed plants decrease their photosynthetic function which is vital for maintaining plant growth under stressful conditions (Kaushal *et al*., 11; Awasthi *et al.,* 3). The highest fruit yield obtained during rainy season may be due to high fruit weight, increase in fruit set and more number of fruits per plant due to high pollen viability. While the lower fruit yield recorded during summer season may be due to vice-versa effects as explained by Dhatt and Kaur (8). The percentage yield reduction in summer season was more than 90% in almost all the genotypes except DBL-21, Guhala Chatua Local and DBL-08. The lowest percentage of yield reduction (22.11%) was found in Guhala Chatua Local followed by DBL-21 and DBL-08. Our observations clearly depict that Guhala Chatua Local, DBL-21 and DBL-08 are the most prominent heat tolerant genotypes.

On subjecting the data obtained on various traits from 62 eggplant genotypes to Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA), one can visualize underlying structure in experimental data and relationship between eggplant genotypes and various traits studied. In summer season, the scree plot is presented in Fig. 2 which showed the variance explained by the principal components. It was observed that maximum variance (84%) could be explained by four principal components. Based on the factor loadings of the PCA, the 62 eggplant genotypes were grouped. The first principal component (PC1) and second principal component (PC2) could explain 48% and 14% of variance, respectively. The yield per plant contributed positively to PC1. It was observed that line Guhala Chatua Local had more yield per plant. Based on the

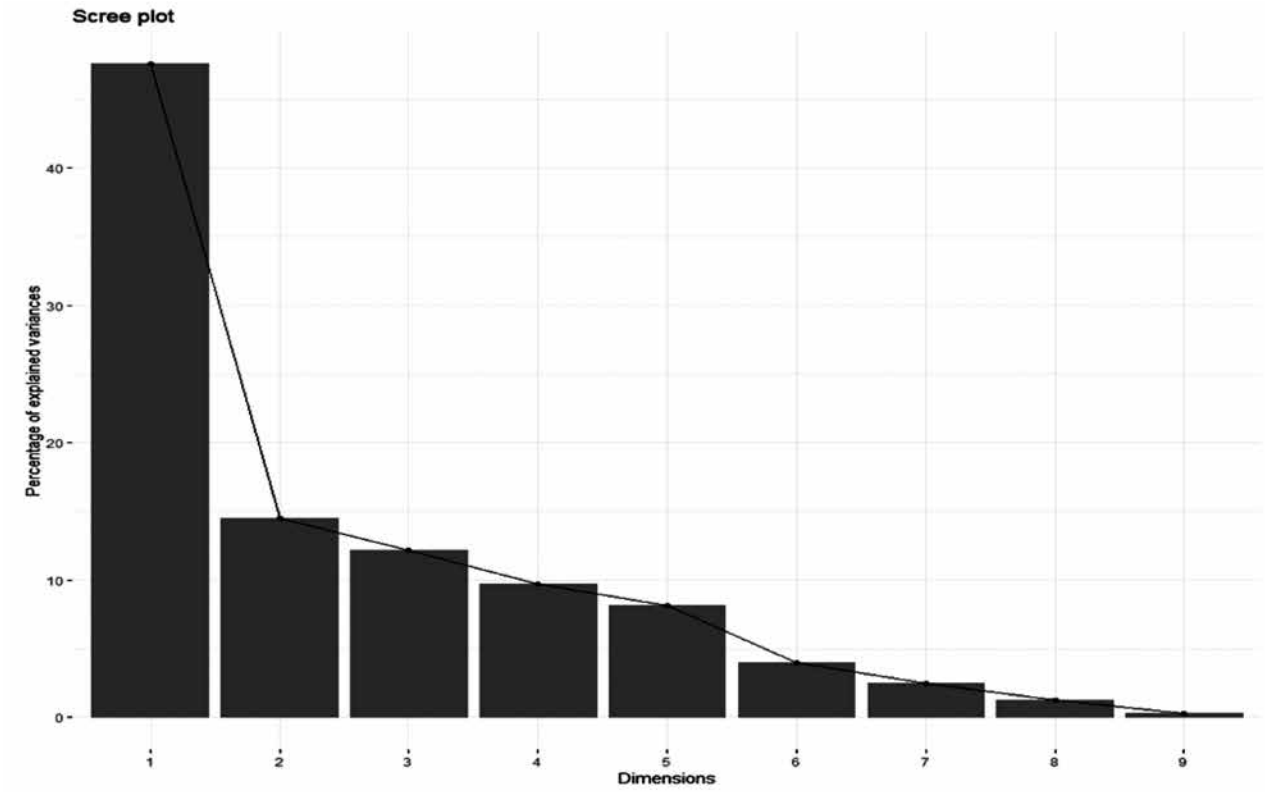

Fig. 2. Principal Component Analysis (PCA) – Scree plot of 62 eggplant genotypes in summer season.

similarities among the 62 genotypes, five clusters were formed (Fig. 3). Cluster I was comprised of 23 genotypes namely Kushpada Local, IC-112992, DBPR-23, DBL-60, DBGL-225-2-5-17, Debjuri Hajari, Pusa Purple Cluster, Boulder, Punjab Sadabahar, DBL-100-1-10, BB-7, Pusa Upkar, 190-10-12, Pusa Purple Round, 129-5, DBGL-164, DBR-32, DBR-184, DBR-43, Punjab Barsati, DBR-128, BR-112 and DBGR-131. Cluster II had five genotypes viz., Guhala Chatua Local, Pant Samrat, Pusa Ankur, DBL-21 and DBL-08. The cluster III had 8 genotypes, namely DBWL-22-1-11, DBL-02, DBSR-94, Arka Keshav, DBR-203, Pusa Bhairav, Pusa Safed Baingan-1 and Khashi Sandesh. The cluster IV had 6 genotypes, namely DBL-09, DBGL-17, Manjari Gota, DBGR-181, Swarnamani Black and Panipat Gole. The cluster V had 20 genotypes, namely NDB-25, IC-112991, DEB-3709, Pusa Uttam, Pusa Anupam, DBL-160, Bangar Begoon, Nabanita (Lukri Begoon), Pusa Bindu, Keonjar Local, DBR-92, Pusa Hara Baingan 1, DBWL-50-7-14, DBWL-190-44, Kalo Solia, Arka Nidhi, Pant Rituraj, DBR-32, Pusa Purple Cluster and Arka Neelkanth.

For *kharif* season, Fig. 4 showed the scree plot and the variance explained by the principal components. It was observed that maximum variance (77%) could be explained by four principal components. The first principal component (PC1) and second principal component (PC2) could explain 33% and 20% of the variance, respectively. The traits which contributed positively to PC1 were fruit weight per plant, fruit diameter and yield per plant. It was observed that genotypes Swarnamani Black had more yield per plant. The Hierarchical cluster analysis performed on 62 eggplant genotypes is illustrated as dendrogram in Fig. 5. Based on the similarities among the genotypes, five clusters were formed. Cluster I was comprised of 13 genotypes, namely Khashi Sandesh, Punjab Barsati, DBWL-50-7-14, DBL-02, Pusa Safed Baingan 1, Guhala Chatua Local, Nabanita (Lukri Begoon), DBR-32, 190-10-12, Keonjar Local, IC-112991, Bangar Begoon, and Boulder. The cluster II had 3 genotypes, namely DBGR-131, Swarnamani Black and Panipat Gole. The cluster III was comprised of 16 genotypes, namely which includes Pusa Upkar, Pusa Uttam, Punjab Sadabahar, Pusa Ankur, Pant Rituraj, IC-112992, Pusa Bindu, DBWL-160-44, BR-112, DBL-160, DBR-32, DBGL-17, Pusa Purple Round, DBPR-43, DBPR-23 and DBR-92. The cluster IV had 12 genotypes, namely NDB-25, Kalo Solia, Pusa Purple Cluster, DEB-3709, DBL-128, Pusa Anupam, Debjuri

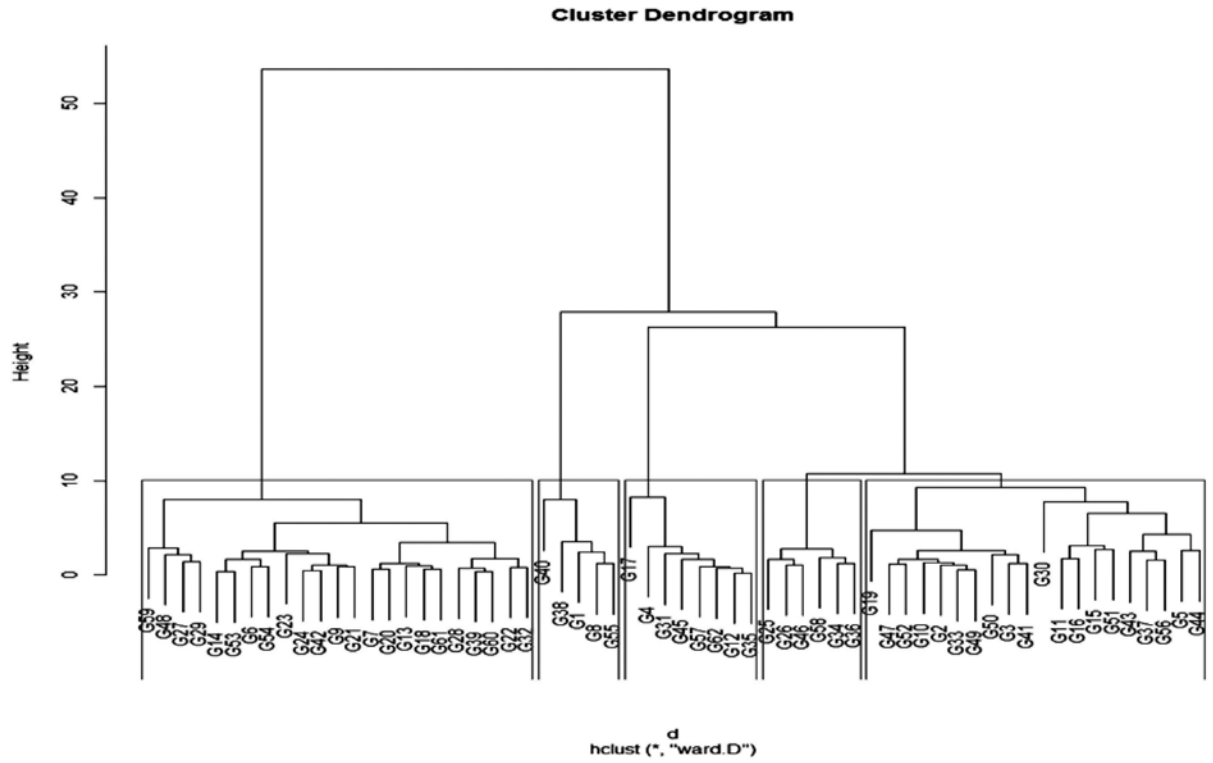

Fig. 3. Hierarchical Cluster Analysis (HCA) of 62 eggplant genotypes based on morphological and yield data in summer season.

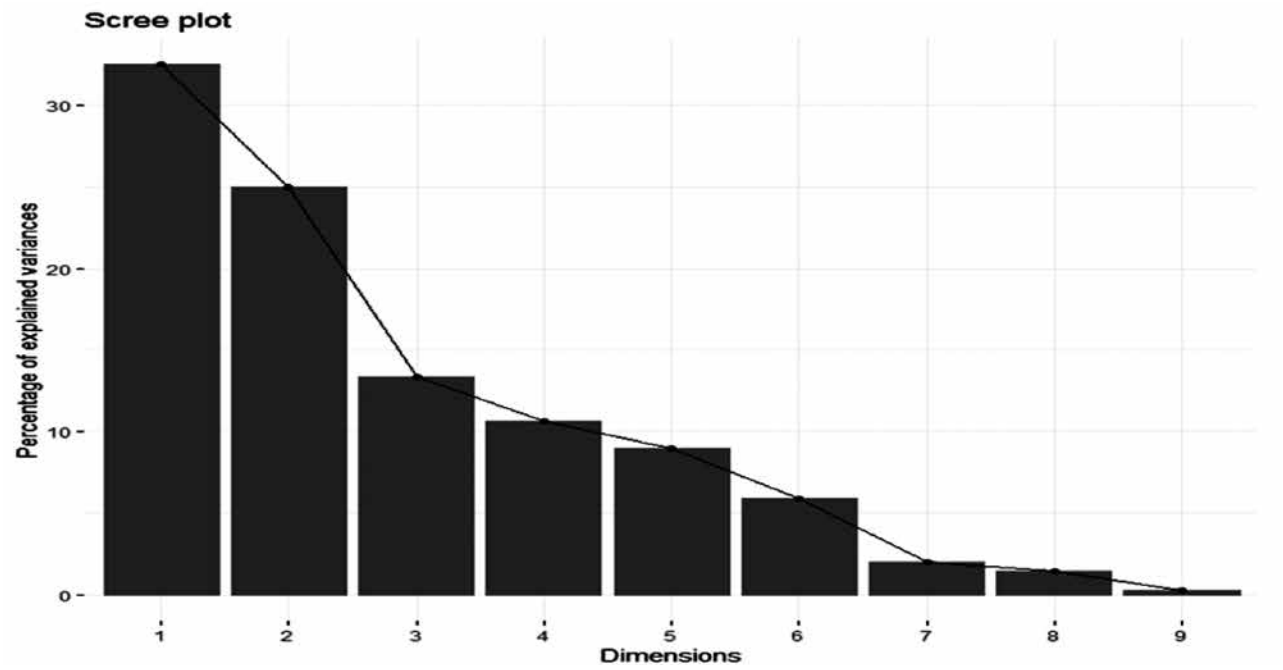

Fig. 4. Principal Component Analysis (PCA) – Scree plot of 62 eggplant genotypes in *kharif* season.

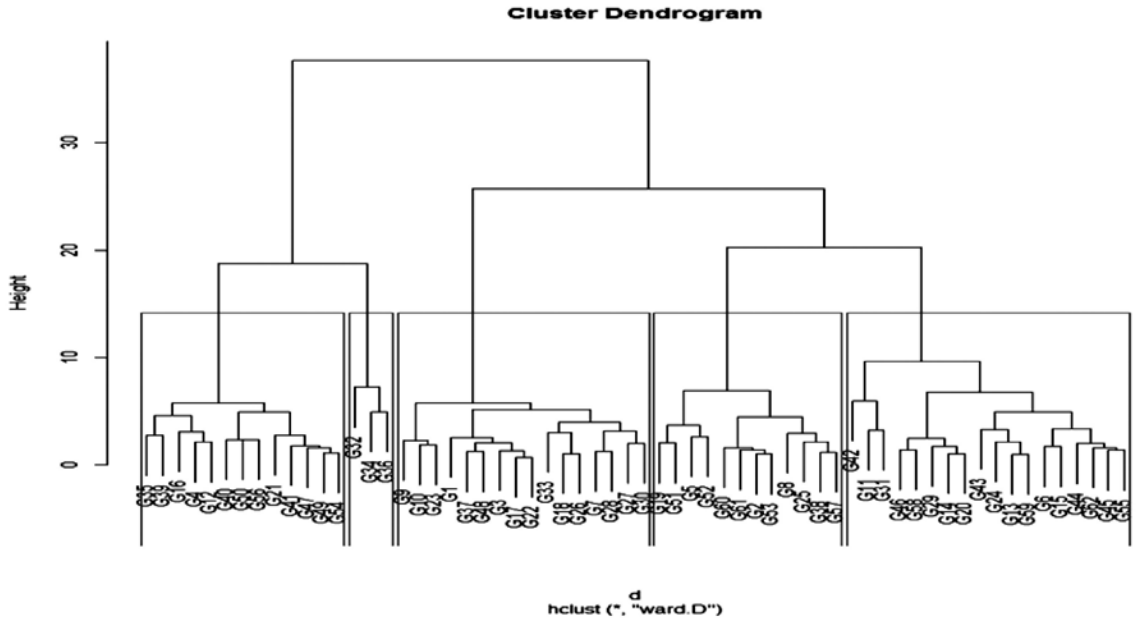

Fig. 5. Hierarchical Cluster Analysis (HCA) of 62 eggplant genotypes based on morphological and yield data *kharif* season.

Hajari, DBL-21, DBL-09, Pant Samrat and DBR-203. The cluster V had 18 genotypes namely, BB-7, Pusa Hara Baingan 1, DBSR-94, Manjari Gota, DBGR-181, DBL-60, DBGL-225-2-5-17, 129-5, Arka Nidhi, DBL-100-1-10, G-164, Kushpada Local, Pusa Purple Long, DDWL-160-44, Arka Neelkanth, Pusa Bhairav, Arka Keshav and DB-8. The clustering patterns among the season are different which might be due to seasonal variability. The principal component analysis depicted that among the significant descriptors that contributing to the first principal component, yield per plant contribute to the total variation. Along with this trait, fruit weight and length also contributed to total variation and the results corroborated with Rajput *et*

al. (16). The HCA revealed that in summer season, all the heat tolerant genotypes were clubbed together in cluster II whereas all the heat susceptible genotypes were clubbed in cluster I. The HCA analysis in both the seasons was different because of the fact that the performance of the genotypes varies due to high temperature effect on the morphological and yield related traits.

The present study showed that temperatures (>40^{o}C) during summer season crop had detrimental effect on growth and yield parameters of crop. Significant variation was found for heat tolerance among the eggplant elite genotypes. The genotypes Guhala Chatua Local, DBL-21 and DBL-08 were found to have high heat tolerance. These heat tolerant varieties can be further evaluated and incorporated in breeding programme for heat tolerance in brinjal which is important in changing climatic scenario.

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