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Multivariate analysis of fruit quality traits in brinjal

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ABSTRACT

An experiment was conducted to study the differences of various fruit quality parameters between the Spring-Summer (February-June) and Autumn-Winter (September-March) seasons and the extent of variation contributed by the fruit quality parameters with 40 eggplant germplasm with the help of Principal Component Analysis (PCA). Two factorial ANOVA showed highly significant differences for total sugars, vitamin-A, anthocyanin in the peel, total phenols and DPPH free radical scavenging capacity for the two factors *viz.*, genotypes (G) and season (S) and their interaction (G X S). Paired t-test also confirmed the seasonal differences for all the fruit quality traits. First four Principal components (PCs), cumulatively contributing 74.4% of total variation, were selected. The first PC contributed 27.9% of total variation and was highly loaded with total phenols, vitamin-C and DPPH free radical scavenging capacity. TSS and total sugars; total phenols and DPPH free radical scavenging capacity; and moisture content and vitamin C were significantly positively correlated pairs. Vitamin-C had a significant negative association with total phenols and DPPH free radical scavenging capacity. Anthocyanin in the peel and phenol based DPPH free radical scavenging capacity were also negatively correlated. No outlier was found and the genotypes *Kalo Makra*, BCB-123 and KS-8103 had the maximum distance from the centroid indicating their diverse nature.

Key words: *Solanum melongena*, seasons, biochemical, correlations, principal components.

INTRODUCTION

Vegetables are commonly known as “Protective food” as they supply essential amino acids, nutrients and vitamins to the human body and also fight against several diseases like diabetes, hypertension, cancer, which are associated with ageing by supplying antioxidants. Among these vegetables, brinjal or aubergine or eggplant [*Solanum melongena* L.] is an important vegetable crop growing mainly in Asian, European and African countries. Eggplant is mainly cultivated for its immature fruits consumed as a vegetable. Fruits are widely used in various culinary preparations *viz.,* sliced *baji,* stuffed curry, *bartha*, chutney, pickles, etc. Eggplant fruit is reported to be a rich source of ascorbic acid and phenolics, both of which are powerful antioxidants. Presence of phenolic compounds like Caffeic, p-coumaric, ferulic, gallic, protocatechuic and p-hydroxybenzoic acids (Kowalski and Kowalski, 10) and anthocyanin compounds supply a good amount of antioxidants to the human body (Chanasut and Rattanapanone, 1) They help in binding of the free ion radicals, thereby, protects the body tissues from damage and ageing associated diseases like cancer, rheumatism and heart attack.

Moreover, it fetches good prices in the market and supports the grower economically rather than any other vegetable. Its consumption keeps us healthy and cultivation keeps us wealthy. Most of the present day, high yielding varieties and hybrids are very low in their nutrient content and quality aspects. India is the primary centre of diversity of eggplant and is rich in several indigenous varieties grown in different states of the country. Therefore, evaluation of these genotypes for fruit quality characters may provide better options for selecting suitable genotypes as suitable parents in further breeding programmes. Keeping these points, an experiment was undertaken to study the genotype and seasonal variations in various fruit quality parameters and to see the extent of variation contributed by these fruit quality parameters in the lower Gangetic plains of West-Bengal, India.

MATERIALS AND METHODS

Eggplant crop was grown in the AB District Seed Farm, BCKV, Kalyani Simanta (Latitude 22°58´ N and Longitude 88°32´ E), West Bengal for four consecutive seasons, spring-summer (February-June) 2012-13 and 2013-14 and autumn-winter (September-March) 2013-14 and 2014-15. The study site is flat and is located at an altitude of 9.75 m above mean sea level. The experimental material was comprised of 40 eggplant germplasm, including local cultivars of West-Bengal and breeding lines/ varieties obtained from other parts of the country.

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The experiment was laid out in a Randomized Block Design (RBD) with two replications. In each replication, each genotype was grown on a plot of 3 × 2.25 m size, accommodating 12 plants with the row-to-row spacing of 75 cm and plant-to-plant spacing of 75 cm. The seeds were sown in a raised nursery bed and the seedlings were transplanted to the main field when they were four weeks old.

Various fruit quality parameters were estimated for all the genotypes for all the seasons. A randomly selected 5 fruits from each genotype in each replication were collected in the morning hours at the time of different harvestings and were immediately taken to the laboratory for the analysis. TSS was determined by digital refractometer and expressed in °Brix. Total sugars were estimated as per (Dubois *et al.,* 3). The moisture content was estimated by weight loss (%) method after drying the fresh fruit. TSS and total sugars were analysed by collecting the fully grown marketable fruits from each genotype and each replication from the first harvesting of the crop, while moisture content was estimated from the fourth harvesting of the crop.

Anthocyanin content in the peel of the fruit was estimated spectrophotometrically by taking peel tissue (Srivastava and Kumar, 19). Fresh fruits numbered 5 of harvestable maturity were collected from the third harvesting of the crop from each genotype in each replication. A sample of 10 g of the peel of the fresh eggplant fruits was weighed and blended it with 10 ml of EthanolicHCl and the volume was made up to 100 ml in a flask. The flask was kept in the refrigerator at 4°C overnight. Next day the sample was filtered through the filter paper. Optical Density (O.D.) was measured at 535 nm spectrophotometrically. Total O.D./100g was measured as (O.D. × Volume made up × 100)/(Weight of the sample), which was again divided by 98.2 to get total anthocyanin in the peel (mg/100g).

For estimation of vitamin C, the procedure proposed by Sadasivam and Balasubraminan (16) was followed. Fresh fruits numbered 5 of harvestable maturity were collected from the third harvesting of the crop from each genotype in each replication. A fresh sample of about 5 g weight was taken and it was crushed in metaphosphoric acid (3%) and the volume was made up to 30 ml. One ml standard ascorbic acid was taken and added in 9.0 ml metaphosphoric acid (3%). Then 5 ml solution was taken from prepared 10 ml solution and titrated with Dye (2, 6-dichlorophenol- indophenols). Thus, the Dye Factor Value (DFV) reading was found. Five ml extract was taken in a beaker and then titrated with Dye. The appearance of pink colour was marked as the end point and the reading on the burette was noted. /Vitamin-C (mg/100g) content was measured as (Dye Factor Value × Titrate Value × Volume make up × 100) / (Aliquot took ×Weight of the sample), where, Dye Factor Value = 0.5/ Titrate reading (ml).

For analysis of Vitamin A content, the homogenised eggplant pulp from the fresh sample was utilised to determine the amount of β carotene content spectrophotometrically (Srivastava and Kumar, 19). The fruit samples used for Vitamin C were also used for the estimation of Vitamin A. A fresh sample of 2 g weight was taken and 20 ml of 80% acetone was added to it. The mixture was kept overnight in a refrigerator. Next day, the sample was filtered to get the clear extract. From this, 2 ml of filtered extract was taken in a separating funnel and 8 ml of petroleum ether and Na_2SO_4 was added and well shaken. Out of two layers formed in the separating funnel, the lower layer was discarded and the upper layer was collected in 100 ml volumetric flask and the volume was made up to 100 ml with petroleum ether. Absorbance was measured at 452 nm spectrophotometrically. Blank solution was made up by mixing 9.7 ml pet ether and 0.3 ml acetone.

$$\beta\text{-carotene } (\mu g/100g) = \frac{\text{O.D. X 13.9 X Dilution factor X } 10^6}{560 \text{ X } 1000}$$

$$\text{Dilution factor} = \frac{\text{Volume of extract X Volume of final sample}}{\text{Weight of sample X Volume taken for extraction}}$$

Vitamin-A (I.U/100g) = β-carotene (μg/100g) ÷ 0.6

Total phenolic contents were determined using Folin–ciocalteu reagent and expressed as Gallic Acid Equivalents (GAE) (Singleton and Ross, 18). The fruit samples numbered five were obtained from the fourth harvesting of the crop from each genotype in each replication. The sample was prepared by Sun drying the fresh fruit and grinding the dry sample into powdered form. A sample of 0.1 g was weighed and 15 ml of 1.2 N Methanoloic HCl was added to it. Then, it was boiled in a water bath at 72-80°C for 2 hours and cooled to room temperature. After cooling, it was centrifuged @ 10000 rpm for 30 min. The supernatant was collected in 25 ml graduated tube. The final volume was made up to 25 ml by adding 1.2 N Methanoloic HCl. The sample prepared by mixing 0.2 ml aliquot, 2.8 ml H_2O and 0.5 ml FCR in a test tube, besides, 2 ml of 10% Na_2CO_3 was added to the sample after 3 min and was shaken well. The same was kept in a water bath for 8-10 min at 50-60°C and cooled to room temperature. Absorbance was measured at 650 nm by using a spectrophotometer. Total phenol content was measured by using the standard curve.

The phenol-based antioxidant capacity of the dry fruit was estimated as DPPH (2,2-diphenyl-lpicryl hydrazyl) free radical scavenging capacity and expressed in Trolox equivalents (Leong and Shui, 13). From the extracted phenols solution, an aliquot of 150 µl was taken in a test tube and 2850 µl DPPH solution was added. The same was kept in the dark for 30 min at room temperature. The absorbance was measured at 517 nm by using a spectrophotometer. The absorbance of 1.2 N Methanoloic HCl was used as a control. The difference in absorbance was measured as $A_{control}$ – A_{sample}. DPPH free radical scavenging capacity was expressed in Trolox Equivalent (TE) units from the standard graph.

The analysis of variance in two factorial RBD fashion for different characters was carried out, in order to assess the variability among the genotypes and across the seasons as given by (Cochran and Cox, 2). Paired t-test was also done to know that the seasonal differences were at a significant level or not. The Principal Components (PCs) were calculated from the correlation matrix by using the mean values as input (Hotelling, 5). The software employed for calculating the Paired t-statistic, Principal Components and preparation of loading, scoring and outliers plot is MINITAB v. 16.

RESULTS AND DISCUSSION

Two factorial analysis of variance of RBD (Table 1) showed that all the genotypes had significant differences among themselves (G), across the seasons (S) and had significant G × S interactions for the traits like total sugars, vitamin A, anthocyanin in the peel, total phenols and DPPH free radical scavenging capacity. The genotypes, however, did not significantly differ and did not interact with season significantly in terms of moisture content. On the country, Hanson *et al.* (4) reported significant year and genotype interaction for moisture content. This controversy was probably due to the differences in the genetic materials studied. Though significant genotype and seasonal differences were observed for TSS and vitamin C, significant G × S interactions were not found for these characters. Total protein content differed among the genotypes significantly, but not over the seasons. Obviously, there was no significant G × S interaction for total protein content.

Paired t-test takes each genotypes performance in both the seasons (in pairs) into consideration and explains whether any significant difference is there between the two seasons (spring-summer and autumn-winter) or not. Paired t-test calculated values for each trait were tested against the null hypothesis i.e. there was no significant difference between both the seasons by comparing the t-calculated value with the t-table value at 5% level of significance and 38 degree of freedom. These results showed significant differences between both the seasons for all the traits (Table 1). From the above results, ANOVA and paired t-test, one can say that the seasonal differences in eggplant performance in terms of fruit quality are true.

The total soluble solids (TSS) of immature tender eggplant fruits were measured with a digital refractometer and expressed in °Brix units (Table 2). The mean TSS values were found high during spring-summer (5.7 °Brix) than autumn-winter (5.4 °Brix). The cultivars *Lal Lamba* (6.8, 6.4 °Brix), Local Collection-1 (6.7, 6.4 °Brix) and *Mukta Mala* (6.7, 6.4 °Brix) recorded the high TSS values in both spring-summer and autumn-winter. During spring-summer the cultivar *Sada Makra* (4.4 °Brix) followed by KS-6308 (4.5 °Brix) and *Heera* (4.8

Table 1. Mean sum of squares of ANOVA and paired t-test of fruit quality traits.

		TSS (°Brix)	Moisture content (%) #	Total Protein (%) #	Total Sugars (%) #	Vitamin C (mg/g)	Vitamin A (IU/g)	Anthocyanin in Peel	Total Phenols (mg GAE/ g DW)	DPPH FRSC (mg TE/g DW)
Source of Variation	d.f.	Mean Sum of Squares (MSS)								
Season (S)	1	2.937*	0.337	0.001	0.062*	0.001*	0.003*	91.543*	1.807*	667.081*
Genotype (G)	39	1.01*	0.015	0.004*	0.011*	0.001*	0.002*	696.904*	0.396*	1,998.28*
S × G	39	0.248	0.007	0.001	0.008*	0.0001	0.001*	5.386*	0.186*	425.909*
Error	79	0.185	0.107	0.002	0.001	0.00006	0.00025	2.305	0.025	40.143
Paired t-test										
Spring-summer (Mean)		5.7	88.0	1.7	1.57	0.108	0.205	12.03	2.18	83.7
Autumn-winter (Mean)		5.4	89.7	1.68	1.44	0.113	0.213	13.55	1.97	75.7
Paired t-test (d.f.-38)		3.58*	6.77*	1.14*	2.85*	81.8*	2.60*	4.36*	3.15*	2.57*

*Significant at 5% level of significance; # MSS are square root transformed values

Table 2. Mean performance of brinjal germplasm for TSS, Moisture content, Total sugar and Vitamin C content.

S. No.	Genotypes	TSS (°Brix)			Moisture content (%)			Total Sugar (%)			Vitamin C (mg/g)		
		SS	AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean
1	Lamba Kuli	5.5	5.4	5.4	87.0 (9.38)	88.1 (9.44)	87.6 (9.41)	1.57 (1.60)	1.48 (1.57)	1.52 (1.59)	0.105	0.110	0.107
2	Muktamala	6.7	6.4	6.5	88.0 (9.43)	88.6 (9.46)	88.3 (9.45)	1.89 (1.70)	1.62 (1.62)	1.76 (1.66)	0.105	0.110	0.107
3	Samrat	6.1	5.8	6.0	88.6 (9.46)	91.3 (9.61)	89.9 (9.54)	1.73 (1.65)	1.61 (1.62)	1.67 (1.63)	0.103	0.108	0.106
4	Makra	5.6	5.3	5.4	84.6 (9.25)	87.5 (9.41)	86.1 (9.33)	1.56 (1.60)	1.42 (1.55)	1.49 (1.58)	0.101	0.106	0.103
5	Makra Midlong	6.3	5.8	6.0	86.3 (9.35)	87.3 (9.40)	86.8 (9.37)	1.78 (1.67)	1.53 (1.59)	1.65 (1.63)	0.105	0.110	0.107
6	Kalo Makra	6.2	5.5	5.8	87.7 (9.42)	89.9 (9.53)	88.8 (9.48)	1.78 (1.67)	1.49 (1.58)	1.64 (1.62)	0.094	0.099	0.096
7	Lal Lamba	6.8	6.4	6.6	88.9 (9.47)	91.2 (9.59)	90.1 (9.53)	1.61 (1.61)	1.94 (1.72)	1.78 (1.67)	0.112	0.118	0.115
8	BCB-123	5.8	6.2	6.0	87.5 (9.40)	90.0 (9.54)	88.7 (9.47)	1.74 (1.66)	1.81 (1.68)	1.77 (1.67)	0.110	0.116	0.113
9	Muktakeshi Lal	6.2	5.7	5.9	85.6 (9.31)	89.3 (9.50)	87.5 (9.40)	1.56 (1.60)	1.52 (1.59)	1.54 (1.59)	0.106	0.111	0.109
10	Gol Makra	6.5	5.1	5.8	85.9 (9.31)	90.4 (9.55)	88.2 (9.43)	1.73 (1.65)	1.46 (1.57)	1.59 (1.61)	0.109	0.114	0.112
11	Muktakeshi	5.8	5.8	5.8	88.5 (9.46)	91.1 (9.59)	89.8 (9.53)	1.75 (1.66)	1.57 (1.60)	1.66 (1.63)	0.110	0.116	0.113
12	Panna	6.2	5.5	5.8	87.5 (9.41)	91.1 (9.60)	89.3 (9.50)	1.58 (1.61)	1.19 (1.48)	1.38 (1.54)	0.120	0.126	0.123
13	Lal Kuli	5.6	6.0	5.8	87.5 (9.40)	88.9 (9.48)	88.2 (9.44)	1.80 (1.67)	1.01 (1.42)	1.40 (1.55)	0.108	0.113	0.111
14	Mala	6.1	5.9	6.0	87.6 (9.41)	91.4 (9.61)	89.5 (9.51)	1.83 (1.68)	1.34 (1.53)	1.59 (1.61)	0.116	0.121	0.119
15	Muktazuri	6.0	5.9	5.9	88.1 (9.43)	89.2 (9.49)	88.6 (9.46)	1.70 (1.64)	1.62 (1.62)	1.66 (1.63)	0.108	0.113	0.110
16	Heera	4.8	4.9	4.8	88.3 (9.45)	93.2 (9.71)	90.8 (9.58)	1.25 (1.50)	1.54 (1.59)	1.40 (1.55)	0.124	0.130	0.127
17	Sada Makra	4.4	4.9	4.6	88.5 (9.45)	89.7 (9.52)	89.1 (9.49)	0.90 (1.38)	1.62 (1.62)	1.26 (1.50)	0.108	0.113	0.110
18	Nandini	4.9	5.2	5.1	89.3 (9.50)	93.0 (9.70)	91.1 (9.60)	1.26 (1.51)	1.65 (1.63)	1.46 (1.57)	0.118	0.123	0.120
19	BCB-320	5.4	4.9	5.1	89.3 (9.50)	91.4 (9.61)	90.3 (9.56)	1.45 (1.57)	1.19 (1.48)	1.32 (1.52)	0.115	0.120	0.117
20	KS-8407	5.1	5.0	5.0	90.4 (9.56)	91.9 (9.64)	91.2 (9.60)	1.39 (1.55)	1.46 (1.57)	1.42 (1.56)	0.103	0.108	0.106
21	KS-8102	5.7	5.4	5.6	88.9 (9.48)	89.7 (9.52)	89.3 (9.50)	1.64 (1.62)	1.45 (1.57)	1.54 (1.59)	0.106	0.111	0.109
22	KS-7848	5.7	5.2	5.4	88.0 (9.42)	88.8 (9.47)	88.4 (9.45)	1.66 (1.63)	1.29 (1.51)	1.48 (1.57)	0.108	0.113	0.110
23	KS-8317	5.3	5.2	5.2	87.8 (9.42)	90.0 (9.54)	88.9 (9.48)	1.43 (1.56)	0.97 (1.40)	1.20 (1.48)	0.103	0.108	0.106
24	Kerala collection-1	5.5	4.7	5.1	88.8 (9.47)	91.9 (9.64)	90.3 (9.56)	1.51 (1.58)	1.36 (1.54)	1.43 (1.56)	0.103	0.108	0.106
25	KS-7812	4.9	5.3	5.1	88.5 (9.45)	89.1 (9.48)	88.8 (9.47)	1.30 (1.52)	1.31 (1.52)	1.31 (1.52)	0.115	0.120	0.117
26	KS-2011-1	5.1	4.0	4.5	87.9 (9.43)	92.4 (9.66)	90.1 (9.55)	1.33 (1.53)	1.08 (1.44)	1.21 (1.59)	0.108	0.113	0.110
27	H-8	5.0	5.4	5.2	87.9 (9.43)	89.5 (9.51)	88.7 (9.47)	1.26 (1.50)	1.16 (1.47)	1.21 (1.59)	0.109	0.114	0.112
28	KS-5144	5.5	4.6	5.1	89.5 (9.50)	87.2 (9.39)	88.3 (9.44)	1.58 (1.61)	1.15 (1.47)	1.36 (1.54)	0.121	0.127	0.124
29	BR-112	5.9	4.7	5.3	89.7 (9.52)	88.5 (9.46)	89.1 (9.49)	1.63 (1.62)	1.36 (1.54)	1.50 (1.58)	0.112	0.118	0.115
30	KS-6308	4.5	5.6	5.0	87.0 (9.38)	88.0 (9.43)	87.5 (9.40)	1.71 (1.65)	1.28 (1.51)	1.49 (1.58)	0.098	0.104	0.101
31	KS-8329	5.9	5.2	5.6	87.8 (9.43)	89.2 (9.50)	88.5 (9.46)	1.56 (1.60)	1.40 (1.55)	1.48 (1.58)	0.117	0.122	0.119

S. No.	Genotypes	TSS (°Brix)			Moisture content (%)			Total Sugar (%)			Vitamin C (mg/g)		
		SS	AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean
32	KS-9503	6.3	5.7	6.0	87.8 (9.42)	88.4 (9.45)	88.1 (9.43)	1.79 (1.67)	1.49 (1.58)	1.64 (1.63)	0.094	0.099	0.096
33	KS-8805	5.0	4.8	4.9	88.3 (9.45)	92.6 (9.68)	90.4 (9.56)	1.25 (1.50)	1.30 (1.53)	1.29 (1.51)	0.108	0.113	0.110
34	KS-8105	6.0	5.4	5.7	87.7 (9.42)	88.8 (9.48)	88.2 (9.45)	1.70 (1.64)	1.45 (1.57)	1.58 (1.61)	0.117	0.122	0.119
35	KS-9010	5.7	5.5	5.6	88.5 (9.46)	88.1 (9.44)	88.3 (9.45)	1.81 (1.68)	1.56 (1.60)	1.68 (1.64)	0.108	0.113	0.110
36	KS-9504	6.2	5.9	6.1	87.4 (9.40)	87.5 (9.41)	87.5 (9.41)	1.27 (1.51)	1.58 (1.61)	1.42 (1.56)	0.108	0.113	0.110
37	KS-8103	5.6	5.3	5.4	87.5 (9.40)	87.1 (9.38)	87.3 (9.39)	1.55 (1.60)	1.43 (1.56)	1.49 (1.58)	0.094	0.099	0.096
38	KS-9501	5.9	5.8	5.8	88.1 (9.44)	88.8 (9.48)	88.5 (9.46)	1.62 (1.62)	1.57 (1.60)	1.60 (1.61)	0.112	0.117	0.114
39	Local collection-1	6.7	6.4	6.6	89.0 (9.49)	89.7 (9.52)	89.4 (9.51)	1.81 (1.68)	1.82 (1.68)	1.82 (1.68)	0.107	0.112	0.109
40	Mukta Hasi	6.2	5.7	5.9	88.8 (9.47)	89.5 (9.51)	89.2 (9.49)	1.41 (1.55)	1.56 (1.60)	1.49 (1.58)	0.103	0.108	0.106
Mean		5.7	5.4		88.0 (9.43)	89.7 (9.52)		1.57 (1.60)	1.44 (1.56)		0.108	0.113	
		S	G	G X S	S	G	G X S	S	G	G X S	S	G	G X S
S.E (m)		0.048	0.215	0.304	0.04	0.16	0.23	0.004	0.018	0.025	0.001	0.004	0.006
C.D.		0.136	0.607	N/A	N/A	N/A	N/A	0.011	0.05	0.07	0.003	0.011	N/A

*Figures in the parenthesis are square root transformed ($\sqrt{x+1}$) values

SS-Spring-summer; AW-Autumn-winter

°Brix) recorded low TSS while the genotype KS-2011-1 (4.0 °Brix) followed by KS-5144 (4.6 °Brix) and Kerala Collection-1 (4.7 °Brix) recorded low TSS during autumn-winter. The TSS of eggplant fruits was previously measured by Kaur *et al.* (9) and they found relatively wide variation in TSS content (7.17 to 27.86 mg/100 g) than the present study.

The moisture content in the present study did not show any significant difference among the genotypes irrespective of the seasons and the same trend was reflected in G × S interaction. However, the mean moisture content in fruits was ranged from 84.6% (*Makra*) to 90.4% (KS-8407) with a grand mean value of 88% during spring-summer while during the autumn-winter it was ranged from 87.1% (KS-8103) to 93.2% (*Heera*) with a grand mean value of 89.7% (Table 2). Previously Hanson *et al.* (4), Nisha *et al.* (15) and Karak *et al.* (7) calculated the moisture content of eggplant fruits and found a moderate to wide range of values. Some research workers like Kaur *et al.* (9) found a significant difference in fruit dry matter content. These findings vouch that there was a significant difference in the moisture content of fruits that agree well with the present findings.

Total sugar content (Table 2) was observed to be high during spring-summer (1.57%) than autumn-winter (1.44%). The cultivar *Sada Makra* followed by *Heera* and KS-8805 had low total sugar content while *Mukta Mala* followed by *Mala* and Local Collection-1 had high total sugar content during spring-summer. KS-8317, *Lal Kuli* and KS-2011-1 recorded low total sugar content while *Lal Lamba*, Local Collection-1 and BCB-123 had high total sugar content during autumn-winter. Appreciably high sugar content in eggplant fruits ranging from 18-44 g/100g with a mean value of 28 g/100g was observed by Hanson *et al.* (4); they also found the significant year and genotype interaction for sugar content. On the other hand, low amount of total sugar (1.42-3.95%) was found by Karak *et al.* (7) corroborated with the present findings.

High vitamin C content were analysed during autumn-winter (0.113 mg/g) than spring-summer (0.108 mg/g). The same trend was observed among the genotypes for vitamin C content in both the seasons (Table 2). The genotypes, namely *Kalo Makra* (0.094, 0.099 mg/g), KS-9503 (0.094, 0.099 mg/g) and KS-8103 (0.094, 0.099 mg/g), recorded low vitamin-C content in both spring-summer and autumn-winter seasons respectively. *Heera* (0.124, 0.130 mg/g), KS-5144 (0.121, 0.127 mg/g) and *Panna* (0.120, 0.126 mg/g) had high vitamin C content in both the seasons. Significant difference in vitamin C content has been reported to the tune of 0.56 to 1.29 mg/g (DW basis) by Hanson *et al.* (4), 0.099 to 0.146 mg/g FW during *Kharif* (Rainy) season by Kumar *et al.* (11).

Vitamin A content (Table 3) was high during autumn-winter (0.205 IU/g) than spring-summer (0.213 IU/g). The highest amount of vitamin A was found in *Lamba Kuli* (0.271 IU/g) followed by *Mala* (0.223 IU/g) and *Mukta Mala* (0.260 IU/g) and the lowest amount of vitaminA was found in KS-8105 (0.140 IU/g) during spring-summer. *Mukta Mala* (0.270 IU/g) topped in the amount of vitamin A followed by BCB-320 (0.266 IU/g) and *Lamba Kuli* (0.252 IU/g) during autumn-winter and the least were in KS-8105 (0.161 IU/g). The high Vitamin A content during autumn-winter might be due to more favourable weather conditions than spring-summer.

Total protein content in this experiment ranged from 1.41 to 1.89 % with a grand mean value of 1.70% during spring-summer and 1.46 to 1.86% with a grand mean value of 1.68% during autumn-winter (Table 3). The genotypes *Mala* (1.46%), KS-6308 (1.5%) and *Heera* (1.52%) were having lowest total protein content during autumn-winter and BR-112 (1.41%), *Sada Makra* (1.46%), KS-9010 (1.46%) had the lowest total protein content during spring-summer. The highest total protein content was observed in KS-8317 (1.86%) followed by H-8 (1.85%) and KS-8102 (1.82%) during autumn-winter and in BCB-123 (1.89%), *Gol Makra* (1.84%) and KS-9501 (1.83%) during spring-summer. The considerable lower range of protein content in eggplant fruits 0.69 to 1.66% was earlier estimated by Nisha *et al.* (15). Karak *et al.* (7) found the range of protein content was 1.17-1.87%, almost similar to the present experiment.

Anthocyanin content in the peel of the brinjal fruits (Table 3) was measured spectrophotometrically by using Ethanolic HCL as solvent at 4°C extraction temperature in the refrigerator. The anthocyanin content in the peel of eggplant fruits was found high during autumn-winter than spring-summer.

It was obvious that purple coloured fruits had more anthocyanin content in peel than the green and white coloured fruits. The purple coloured fruits had 21.43 and 24.22 mg/g anthocyanin in peel while green coloured fruits had 2.92 and 3.11 mg/g anthocyanin in peel and the white coloured fruits were noted to have 1.18 and 1.56 mg/g of anthocyanin in peel on an average during spring-summer and autumn-winter respectively. The highest peel anthocyanin content was recorded in BCB-123 (44.72, 54.89 mg/g), which indicates to its dark purple to black coloured fruits and it was followed by KS-7812 (38.8, 45.2 mg/g) during spring-summer and autumn-winter, respectively.

Among the purple coloured fruits low peel anthocyanin content was recorded in KS-8105 (10.02 to 10.06 mg/g) which was correlated with its light

Table 3. Mean performance of brinjal germplasm for Vitamin A, Total protein, anthocyanin, total phenol and DPPH fruit quality traits.

S. No.	Genotypes	Vitamin A (IU/g)			Total protein (%)			Anthocyanin in peel (mg/g)			Total Phenol (mg GAE/g DW)			DPPH FRSC (mg TE/g DW)		
		SS	AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean
1	Lamba Kuli	0.271	0.252	0.261	1.59 (1.61)	1.65 (1.63)	1.62 (1.62)	02.51	03.09	02.80	2.31	2.23	2.27	81.4	70.4	75.9
2	Muktamala	0.260	0.270	0.265	1.69 (1.64)	1.65 (1.63)	1.67 (1.63)	11.81	13.73	12.77	2.15	2.12	2.14	72.4	71.2	71.8
3	Samrat	0.235	0.241	0.238	1.80 (1.67)	1.64 (1.62)	1.72 (1.65)	11.76	12.90	12.33	2.23	2.50	2.37	91.4	116.5	104.0
4	Makra	0.260	0.241	0.251	1.69 (1.64)	1.61 (1.62)	1.65 (1.63)	04.11	05.35	04.73	1.96	2.64	2.30	78.1	101.7	89.9
5	Makra Midlong	0.190	0.226	0.208	1.81 (1.68)	1.72 (1.65)	1.76 (1.66)	03.34	04.30	03.82	2.09	2.06	2.08	71.2	69.1	70.2
6	Kalo Makra	0.186	0.213	0.200	1.64 (1.62)	1.65 (1.63)	1.64 (1.63)	36.31	42.85	39.58	2.53	2.38	2.46	79.4	47.4	63.4
7	Lal Lamba	0.209	0.237	0.223	1.69 (1.64)	1.56 (1.60)	1.62 (1.62)	19.54	22.50	21.02	2.14	1.36	1.75	72.7	43.3	58.0
8	BCB-123	0.180	0.186	0.183	1.89 (1.70)	1.77 (1.66)	1.83 (1.68)	44.72	54.89	49.80	1.92	1.38	1.65	76.6	70.7	73.7
9	Muktakeshi Lal	0.193	0.200	0.197	1.78 (1.67)	1.58 (1.61)	1.68 (1.64)	10.25	12.16	11.21	2.21	1.61	1.91	75.0	85.6	80.3
10	Gol Makra	0.207	0.229	0.218	1.84 (1.69)	1.68 (1.64)	1.76 (1.66)	02.56	02.36	02.46	1.78	1.97	1.88	60.3	88.0	74.2
11	Muktakeshi	0.194	0.221	0.208	1.78 (1.67)	1.70 (1.64)	1.74 (1.66)	23.58	23.72	23.65	2.45	1.47	1.96	88.0	53.6	70.8
12	Panna	0.217	0.187	0.202	1.80 (1.67)	1.81 (1.68)	1.81 (1.68)	20.97	23.30	22.13	2.43	2.44	2.44	93.5	116.7	105.1
13	Lal Kuli	0.211	0.192	0.202	1.53 (1.59)	1.57 (1.60)	1.55 (1.60)	25.58	27.84	26.71	2.63	1.85	2.24	88.5	52.7	70.6

S. No.	Genotypes	Vitamin A (IU/g)			Total protein (%)			Anthocyanin in peel (mg/g)			Total Phenol (mg GAE/g DW)			DPPH FRSC (mg TE/g DW)		
		SS	AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean	SS	AW	Mean
14	Mala	0.223	0.244	0.233	1.51 (1.58)	1.46 (1.57)	1.48 (1.58)	03.80	03.52	03.66	2.19	1.88	2.04	76.3	55.5	65.9
15	Muktazuri	0.238	0.215	0.226	1.50 (1.58)	1.57 (1.60)	1.53 (1.59)	13.33	15.04	14.19	2.04	2.01	2.03	69.9	78.4	74.2
16	Heera	0.212	0.221	0.216	1.49 (1.58)	1.52 (1.59)	1.51 (1.58)	03.11	03.14	03.12	2.00	1.89	1.95	81.8	66.9	74.4
17	Sada Makra	0.176	0.226	0.201	1.46 (1.57)	1.56 (1.60)	1.51 (1.58)	03.50	03.93	03.71	1.80	1.72	1.76	65.2	62.0	63.6
18	Nandini	0.213	0.221	0.217	1.65 (1.63)	1.71 (1.65)	1.68 (1.64)	19.21	22.79	21.00	1.83	1.12	1.48	61.4	68.4	64.9
19	BCB-320	0.247	0.266	0.256	1.68 (1.64)	1.65 (1.63)	1.66 (1.63)	17.11	19.36	18.23	2.19	1.29	1.74	58.8	42.4	50.6
20	KS-8407	0.223	0.220	0.222	1.81 (1.68)	1.81 (1.68)	1.81 (1.68)	01.87	01.48	01.67	1.65	2.18	1.92	86.2	75.9	81.1
21	KS-8102	0.156	0.188	0.172	1.80 (1.67)	1.82 (1.68)	1.81 (1.68)	04.06	03.90	03.98	2.47	2.01	2.24	89.6	75.8	82.7
22	KS-7848	0.180	0.217	0.198	1.69 (1.64)	1.79 (1.67)	1.74 (1.65)	11.60	11.08	11.34	2.55	1.56	2.06	93.2	30.7	62.0
23	KS-8317	0.205	0.199	0.202	1.82 (1.68)	1.86 (1.69)	1.84 (1.69)	01.57	01.68	01.63	2.07	2.32	2.20	90.0	118.4	104.2
24	Kerala collection-1	0.187	0.201	0.194	1.78 (1.67)	1.81 (1.68)	1.80 (1.67)	01.90	01.66	01.78	2.15	2.59	2.37	74.5	92.2	83.4
25	KS-7812	0.214	0.202	0.208	1.78 (1.67)	1.68 (1.64)	1.73 (1.65)	38.80	45.21	42.00	2.30	1.66	1.98	74.3	61.8	68.1
26	KS-2011-1	0.224	0.229	0.226	1.72 (1.65)	1.72 (1.65)	1.72 (1.65)	11.34	12.72	12.03	1.77	1.51	1.64	58.9	55.5	57.2
27	H-8	0.226	0.244	0.235	1.77 (1.66)	1.85 (1.69)	1.81 (1.68)	11.77	13.22	12.50	1.93	1.59	1.76	66.7	64.8	65.8
28	KS-5144	0.176	0.194	0.185	1.74 (1.65)	1.79 (1.67)	1.77 (1.66)	37.40	41.13	39.27	1.97	1.32	1.65	67.1	69.0	68.1
29	BR-112	0.163	0.196	0.180	1.41 (1.55)	1.54 (1.59)	1.47 (1.57)	17.98	18.48	18.23	1.81	1.72	1.77	79.6	79.1	79.4
30	KS-6308	0.199	0.212	0.205	1.72 (1.65)	1.50 (1.58)	1.61 (1.61)	01.03	01.49	01.26	2.40	1.77	2.09	91.1	68.2	79.7
31	KS-8329	0.199	0.205	0.202	1.72 (1.65)	1.66 (1.63)	1.69 (1.64)	02.11	02.26	02.18	1.93	1.53	1.73	68.0	49.0	58.5
32	KS-9503	0.171	0.196	0.184	1.66 (1.63)	1.71 (1.65)	1.69 (1.64)	03.17	03.32	03.25	2.26	2.01	2.14	88.5	75.9	82.2
33	KS-8805	0.185	0.200	0.193	1.76 (1.66)	1.71 (1.65)	1.74 (1.65)	01.12	01.18	01.15	2.85	2.37	2.61	152.0	128.2	140.1
34	KS-8105	0.140	0.161	0.151	1.78 (1.67)	1.74 (1.66)	1.76 (1.66)	10.02	10.06	10.04	2.18	1.70	1.94	76.4	64.7	70.6
35	KS-9010	0.228	0.209	0.218	1.46 (1.57)	1.62 (1.62)	1.54 (1.59)	03.78	03.89	03.84	2.39	2.72	2.56	133.8	111.5	122.7
36	KS-9504	0.198	0.187	0.193	1.79 (1.67)	1.65 (1.63)	1.72 (1.65)	27.52	30.55	29.04	2.03	1.96	2.00	70.2	73.2	71.7
37	KS-8103	0.193	0.190	0.191	1.56 (1.60)	1.62 (1.62)	1.59 (1.61)	01.39	02.02	01.70	2.85	2.83	2.84	163.0	155.2	159.1
38	KS-9501	0.211	0.201	0.206	1.83 (1.68)	1.78 (1.67)	1.81 (1.68)	03.71	04.14	03.93	2.17	2.05	2.11	70.2	54.9	62.6
39	Local collection-1	0.211	0.216	0.214	1.81 (1.68)	1.77 (1.66)	1.79 (1.67)	29.36	35.16	32.26	2.27	2.63	2.45	91.0	67.7	79.4
40	Mukta Hasi	0.187	0.164	0.176	1.60 (1.61)	1.68 (1.64)	1.64 (1.63)	01.66	01.68	01.67	2.39	2.74	2.57	120.2	97.3	108.8
Mean		0.205	0.213		1.70 (1.64)	1.68 (1.64)		12.03	13.55		2.18	1.97		83.7	75.7	
		S	G	G × S	S	G	G × S	S	G	G × S	S	G	G × S	S	G	G × S
S.E (m)		0.002	0.007	0.01	0.01	0.02	0.03	0.17	0.76	1.07	0.02	0.08	0.11	0.71	3.17	4.48
C.D.		0.005	0.021	0.029	N/A	0.061	N/A	0.48	2.14	3.03	0.05	0.22	0.31	1.99	8.93	12.63

*Figures in the parenthesis are square root transformed ($\sqrt{x+1}$) values
SS-Spring-summer; AW-Autumn-winter

purple fruit colour. High anthocyanin content of fruits (peel + flesh) was found in in purple coloured big size fruits (0.756 ± 0.040 mg/100 g) and low content was registered in long green fruits (0.048 ± 0.023 mg/100g) earlier studies by Nisha *et al.* (15). The anthocyanin contents in various parts of eggplant fruits were previously estimated by Jung *et al.* (6) by using Methanolic HCl solvent and it was observed to be highest in peel (138.05 ± 0.67 mg/100g) followed by the calyx (135.94 ± 0.66 mg/100g) and the pulp (2.29 ± 0.60 mg/100g).

Total phenol content (Table 3) was high during spring-summer 2.18 mg GAE/g dry weight (DW) with a range from 1.65 to 2.85 mg GAE/g DW than autumn-winter 1.97 mg GAE/g DW with a range from 1.12 to 2.83 mg GAE/g DW. The highest total phenol content was observed in KS-8103 (2.83 mg GAE/g DW) followed by *Mukta Hasi* (2.74 mg GAE/g DW) and KS-9010 (2.39 mg GAE/g DW) and the lowest in *Nandini* (1.12 mg GAE/g DW) followed by BCB-320 (1.29 mg GAE/g DW), KS-5144 (1.97 mg GAE/g DW) and *Lal Lamba* (2.14 mg GAE/g DW) during autumn-winter. Again KS-8103 (2.85 mg GAE/g DW) and KS-8805 (2.85 mg GAE/g DW) were found to have high in phenol content during spring-summer followed by *Lal Kuli* (2.63 mg GAE/g DW) and the lowest was noted in KS-8407 (1.65 mg GAE/g DW) followed by KS-2011-1 (1.77 mg GAE/g DW) and *Gol Makra* (1.78 mg GAE/g DW). Several other workers Kaur *et al.* (9), Kowalski and Kowalski (10), Karak *et al.* (7), Kumar *et al.* (11) and Sultana *et al.* (20) have estimated the total phenol content of eggplant fruits and reported significant variation among the germplasm studied. Hanson *et al.* (4) showed a significant year and genotype interaction for total phenol content of fruits. Jung *et al.* (6) mentioned that the highest total phenol content was present in peel followed by the calyx and the pulp. The interesting thing revealed during reviewing the literature was that all the authors from temperate regions of the world reported a higher amount of total phenol content as compared to the reports from the Indian subcontinent even with the same extraction protocol and expression units. This could be due to differences in the genetic architecture of eggplant germplasm in different parts of the world.

Antioxidant capacity of different eggplant genotypes was estimated through DPPH Free Radical Scavenging Assay of total phenols and expressed in mg Trolox Equivalent /g DW (Table 3). This is a qualitative measurement while the estimation of phenols is a quantitative measurement. Almost all the genotypes followed the similar trend of total phenol content with few exceptions. This might be attributed to the fact that eggplant genotypes contain large amounts of phenolic compounds and thus have more ability to donate the hydrogen ion, ultimately increasing the free radical scavenging activity of the extract. This was in agreement with Sultana *et al.* (20). DPPH free radical scavenging capacity was found high during spring-summer (83.7 mg TE /g DW) than autumn-winter (75.7 mg TE /g DW). The genotypes, KS-8103 (163, 155.2 mg TE /g DW) followed by KS-8805 (152, 128.2 mg TE /g DW), KS-9010 (133.8, 111.5 mg TE /g DW) and *Mukta Hasi* (120.2, 97.3 mg TE /g DW) were able to donate more hydrogen ions and neutralise maximum free radicals in both the seasons. During autumn-winter, KS-7848 (30.7 TE /g DW) followed by BCB-320 (42.4 TE /g DW) and *Lal Lamba* (30.7) and during spring-summer, BCB-320 (58.8 mg TE /g DW) followed by KS-2011-1 (58.9 mg TE /g DW) and *Gol Makra* (60.3 mg TE /g DW) converted the low amount of DPPH to DPPH-H. Prior to present study Nisha *et al*. (15) observed significant differences among phenol based eggplant fruit DPPH activity. Jung *et al.* (6) found high DPPH free radical scavenging capacity in peel followed by calyx and pulp through IC50 values. Sultana *et al.* (20) studied antioxidant potential of two different fruit shaped eggplant varieties and mentioned that round-fruited varieties (55.3-70.1% DPPH free radical scavenging capacity) of eggplant were having higher antioxidant components and potential as compared to the long fruited varieties (50.0-64.5% DPPH free radical scavenging capacity).

The pooled mean values of the 40 eggplant genotypes were subjected to the Principal Component Analysis (PCA) and the Principal Components (PCs) were computed from the correlation matrix. Out of the nine PCs, the first four PCs were selected from the scree plot. The first PC with Eigen value 2.5141 contributed 27.9% variation to the total variability among the 40 genotypes for various fruit quality traits. The second PC (1.9677) was responsible for 21.9% variation followed by the third PC (1.2961), which generated 14.4% variation. Finally, the fourth PC (0.9162) created 10.2% variation. Thus, these four PCs cumulatively contributed 74.4% to the total variability present in the eggplant germplasm for the nine fruit quality parameters (Table 4). Kaur *et al.* (8) also applied the total phenols, flavanoids and antioxidant capacity values of eggplant accessions to the PCA.

The first PC had contributed the maximum variation, hence, undoubtedly, the fruit quality attributes associated with this PC *viz*., total phenols, vitamin C and DPPH free radical scavenging capacity, had a high amount of variation. Likewise, the quality parameters associated with the PC2 were TSS, total

Table 4. Eigen values, proportion of variance and character loadings of four Principal Components (PC).

PC	Eigen value	Proportion of variance (%)	Cumulative variance (%)	Characters associated
1	2.5141	27.9	27.9	Total phenols (-0.5415), Vitamin C (0.4664), DPPH free radical scavenging capacity (-0.4442)
2	1.9677	21.9	49.8	TSS (0.5891), Total sugars (0.5601), Anthocyanin in the peel (0.4105)
3	1.2961	14.4	64.2	Vitamin-A (0.6694), Total protein (-0.6216)
4	0.9162	10.2	74.4	Moisture content (0.7940)

sugars and anthocyanin content in the peel. Total protein and vitamin A were correlated with the third PC and the moisture content was loaded with the fourth PC (Table 4). Similarly, Milivojević *et al.* (14) also found that glucose, fructose, total sugars, ellagic acid, total phenolics and total antioxidant capacity were loaded with PC1 in different berries. Kumar *et al.* (12) also observed that total phenol content was one of the factors created the highest variation among the eggplant germplasm.

The loading plot reflected the Pearson correlations among the fruit quality traits. On loading plot of the character loadings, TSS and total sugars fall near to each other revealing their high significant positive correlation (0.812). The second highest significant positive correlation was between total phenols and DPPH free radical scavenging capacity (0.764) and it was observed on the graph as they fall near in the same direction. Moisture and vitamin C contents were also correlated positively (0.377). Vitamin C had a significant negative association with total phenols (-0.535) and DPPH free radical scavenging capacity (-0.367) as it was laid on the graph in opposite direction to these traits. Equally, the negative correlation of anthocyanin in the peel with DPPH free radical scavenging capacity (-0.322) was also seen on the graph. Shinde *et al.* (17) reported the negative association between total sugars and total phenols in eggplant. Significant positive correlation between total phenol content DDPH free radical scavenging capacity was previously observed by Jung *et al.* (6) and Kaur *et al.* (8).

The scoring plot of the genotype scores of the PC1 and PC2 displayed that there was no difference between the two groups of genotypes, *viz.,* local cultivars and breeding lines/varieties in respect to fruit quality parameters. Both the local cultivars (L-red colour squares) and the breeding lines/varieties (G-black colour dots) scattered on the graph randomly. From this observation, it could be said that it is difficult to differentiate the local cultivars and breeding lines/varieties based on these fruit quality parameters. The genotypes, KS-7848, KS-7812, *Nandini* and BR-112 were near to the PC1 suggesting that these genotypes were having high values for PC1 than the PC2. Therefore, it could be said that these genotypes were highly loaded with PC1. Similarly, the genotypes, KS-9501, *Gol Makra*, KS-9504 *Lal Kuli* and *Panna* were having high loading values for PC2. On scoring plot of PC1 and PC2, we could see that the genotypes, KS-8103, KS-8805, *Lal Lamba* and BCB-123 were fallen distantly from others owing to their diverse PC scores.

The outliers plot showcases the Mahalanobis distances such as the distance from the centroid and between each pair of points. The outlier is a genotype, which is having genetic distance from the centroid more than the critical distance. In the present experiment, all the genotypes were having a genetic distance lesser than the critical distance (4.461), thus, no outlier was found. Hence, the data in the present experiment was not influenced due to the absence of the extreme values. The genotypes *Kalo Makra*, BCB-123, KS-8103 had the maximum distance from the centroid indicating their diverse nature.

Significant differences for total sugars, vitamin-A, anthocyanin in the peel, total phenols and DPPH free radical scavenging capacity indicated the variation among the genotypes and between the two seasons for these traits. Total phenols, vitamin C and DPPH free radical scavenging capacity were the traits that contributed to the maximum variation. TSS and total sugars; total phenols and DPPH free radical scavenging capacity; and moisture content and vitamin C were significantly positively correlated suggesting the selection for one trait will improve another trait. The genotypes Kalo Makra, BCB-123 and KS-8103 were diverse for these fruit quality traits from other genotypes.

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