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EVALUATION OF EGGPLANT ACCESSIONS BASED ON THEIR QUANTITATIVE AND QUALITATIVE TRAITS PERFORMANCE UNDER TROPICAL CLIMATE

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ABSTRACT

Agro-morphological genetic variation on yield and yield-related traits plays an important role in varietal development in eggplant. The present study assessed different genetic variations of 27 eggplant accessions using yield and yield-related morphological traits. The experiment was laid out in a randomized complete block design with three replications. All collected data on nine qualitative and eleven quantitative traits were subjected to analysis of variance using SAS 9.4 software, while variance components were estimated. All the studied traits (quantitative) exhibited high significant variation ($p \leq 0.01$). The quantitative traits such as number of primary branches per plant, fruit diameter, fruit length, fruit girth, average fruit weight, number of fruits per plant, fruit length to width ratio, and fruit yield per plant can be exploited through selection as these traits have high PCV, GCV, h^2B and GAM. Considering diversity patterns and other agronomic traits, the accessions BB1 from group I, accessions BT13, BM9, BB26, BB31, BM5 from group II, BB23 from group III, BT17 from group IV, BB12 and BT6 from group V and BT15 from group VI was taken into consideration as better parents for an effective hybridization program.
Keywords: Eggplant, Genetic diversity, Principal component analysis, Phenotypic correlation and Qualitative traits

Introduction

Eggplant (*Solanum melongena* L.), which belongs to the Solanaceae family, is ranked third in harvested area and production after tomato and potato production. The area harvested for potato and tomato is almost ten times and three times greater than eggplant (FAOSTAT 2019). The literature survey found that eggplant is used for medicinal purposes for different illnesses such as immune system, gastrointestinal, and cardiovascular ailments in different regions (Meyer *et al*., 2014). It also has potential value in making pickle and dehydration industry. Furthermore, it has specific medicinal properties, such as white colour fruit is beneficial for diabetic patients. Eggplant is usually eaten after being fried as a single dish of food or as an ingredient of mixed vegetables. Besides, a specific spicy smell exists in eggplant fruit. Today, eggplant is widely cultivated and common in the street market of less developed countries and the supermarket in developed countries. Genetic variability within a population is essential for yield and yield-related traits in new varietal development. Usually, morphological characteristics are recognized visually (such as growth habits, flower colour, and seed shape etc). The major limitation of morphological markers is limited in number and influenced by the environment (Kordrostami and Rahimi, 2015). Despite these limitations, plant breeders extensively use morphological markers due to their inexpensive, rapid and easy scoring method (Sulaiman *et al*., 2020). Morphological markers are the primary move to explore genetic variation in eggplant (Sulaiman *et al*., 2020). The eggplant descriptor of IBPGR (International Board for Plant Genetic Resources, 1990) has been widely used to characterize this crop as breeding materials. It is costly and time-consuming to create variation by mutation, hybridization, and other biotechnological methods. As a result, plant breeders are interested in studying genetic diversity based on different quantitative and qualitative traits as these traits are easily distinguished from each other (Uddin *et al*., 2021). A right selection approach can save time, money, and resources in breeding programs. Moreover, genetic variation provides the genetic base for crop advancement of yield, environmental adaptation and disease resistance (Husnudin *et al*., 2019). Therefore, variability assessment of eggplant is a prerequisite for an effective breeding program (Onyia *et al*., 2020). The total variability is grouped into two parts, i.e. heritable and non-heritable components which are important to obtain a thorough intimation of the characters' genetic variation. Heritability is an important index through which characters are transmitted from parents to offspring (Falconer and Mackey, 1996). The heredity of agronomic traits is significant for plant breeders to make proper breeding strategies for advancing any crop. The selection criteria of specific characters depend on the amount of heritability and genetic advance as a percentage of the mean of that character. The highest contributing traits of total variation at every axis of differentiation are determined by PCA (principal component analysis) (Al-Hubaity and Teli, 2013). Hence, this research's main objective was to determine the morphological variability among the existing genotypes and identify and classify the accessions.

Materials and Methods

Experiment location and design

The research was conducted from mid-March to mid-August 2019 at ladang15, Faculty of Agriculture in Universiti Putra Malaysia. The location is geographically situated between 2°59´north latitude and 101°43´east latitude with 55 m altitude. This experiment was laid out in a randomized complete block (RCBD) along with three replications.

Planting materials

Selected twenty-seven eggplant accessions used in this study were collected from three countries (namely Bangladesh, Malaysia and Thailand). The accessions name, source code, selection criteria and origin are presented in Table 1. The seeds were placed in a germinating tray filled with peat moss soil and kept until three leaves developed (Fig 1a).

Transplantation and management of seedlings

Seeds were kept on a germination tray filled with peat moss soil and watered daily. Twenty-one-days old seedlings were kept from tray to polybag, and the polybags were contained with soil and peat moss in a ratio of 2:1 and kept in the net house for two weeks before transplanting in the field (Fig 1a & b). Seedlings were planted in the field after 35 days at one seedling per hole at 60 cm and 80 cm within and between rows. All recommended cultural procedures were followed according to the package of practices to raise a healthy crop. The transplanting date was considered as day 'zero'.

Table 1: List of studied accessions

Sl No	Accession code	Source code	Collection country	Selection Criteria
1	BB1	China 3	Bangladesh	Fruit diameter and fruit girth
2	BB3	MuktaJhuri	Bangladesh	Fruit yield per plant
3	BB4	MuktaKeshi	Bangladesh	Average fruit weight
4	BB5	Chinese Macra	Bangladesh	Average fruit weight
5	BB6	BARI Eggplant 2	Bangladesh	Fruit yield per plant
6	BB8	Pahuja seed co.	Bangladesh	Fruit yield per plant
8	BB16	BARI Eggplant 7	Bangladesh	Fruit length
9	BB17	BARI Eggplant 8	Bangladesh	Fruit length
10	BB18	BARI Eggplant 9	Bangladesh	Number of fruits per plant
11	BB19	BARI Eggplant 10	Bangladesh	Fruit length
12	BB20	220	Bangladesh	Average fruit weight
13	BB22	253	Bangladesh	Average fruit weight
14	BB23	222	Bangladesh	Average fruit weight
15	BB26	288	Bangladesh	Fruit length
16	BB31	338	Bangladesh	Fruit length
17	BB36	357	Bangladesh	Fruit yield per plant
18	BM5	330, White	Malaysia	Number of fruits per plant and fruit colour
19	BM7	428, Nyonya	Malaysia	Fruit length
20	BM9	312, Super Naga	Malaysia	Fruit length
21	BM10	MTe2	Malaysia	Average fruit weight
22	BT2	01387/2552	Thailand	Number of primary branches per plant
23	BT6	969/2560	Thailand	Number of primary branches per plant
24	BT8	914/2558	Thailand	Number of primary branches per plant
25	BT13	1745/2560	Thailand	Number of fruits per plant
26	BT15	548/2558	Thailand	Number of fruits per plant
27	BT17	548/2556	Thailand	Average fruit weight andfruit size

Note: BB: Brinjal Bangladesh, BM: Brinjal Malaysia, and BT: Brinjal Thailand

Fig. 1 : Different stage of eggplant seedlings a) 21 days seedlings in germination tray b) Seedlings in polybag for two weeks before transplanting

Data Recorded

Data were taken from five plants for each accession in every replication for yield and yield-related traits. Fruits were harvested at the proper maturity stage. All data were adapted as per the descriptor of IBPGR. Qualitative (9 traits) and quantitative (11 traits) data were recorded as in the previous chapter described in Table 2 and Table 3. All quantitative characters were measured based on a metric scale in which qualitative traits were recorded on an arbitrary scale.

Table 2 : Description of the measured qualitative characters from selected genotypes

Sl No	Traits	Method of evaluation
1	Plant growth habit	Scale from 1 (upright) to 3 (prostrate)
2	Leaf blade length	Scale from 3 (short) to 7 (long)
3	Leaf blade lobing	Scale from 1 (very weak) to (9) very strong
4	Leaf blade tip angle	Scale from 1 (very acute) to 9 (very obtuse)
5	Corrolla colour	Scale from 1 (greenish-white) to 9 (bluish violet)
6	Fruit shape	Scale from 1(long) to 5 (others)
7	Fruit colour	Scale from 1 (green) to 9 (black)
8	Seed size	Scale from 3 (small) to 7 (large)
9	Flowering habit	Scale from 3 (cluster flowering) to 7 (solitary flowering)

Table 3: Measurement method of quantitative traits of eggplants

Traits	Method of evaluation
Fruit length (FL, cm)	The average length from top to bottom of 10 marketable fruits per plant was taken
Fruit diameter (FD, cm)	The central part of 10 fruits per plant was measured by using Caliper and lastly, the average value (mm) was converted into centimetre (cm)
Fruit girth (FG, cm)	The central part of fruit (10 harvestable) per plant was measured by measuring tape and the mean value was taken
Fruit length to width ratio (FLWR, ratio)	The value of fruit length was divided by the diameter of its fruit of individual plant
Average fruit weight (FW, g)	The average weight value of ten edible fruit per plant was taken
Fruit yield per plant (YPP, g)	The total number of fruits taken from each selected plant in each replication and harvest was weighted and averaged.
Number of primary branches (PB, no)	The number of primary branches was recorded at 90 DAT (Days after Transplanting)
Days to first flowering (DF, days)	Days was recorded from transplant to first flower opening of every plant of each accession is
Days to fifty percent flowering (DFF, days)	Days was taken from transplant to first flower opening of fifty percent plant of every accession
Number of fruits per plant (NF, no)	Total number of fruits harvested from individual plant
Plant height (PH, cm)	A ruler was used to measure the length of the main stem from the base to tip at 90 DAT (Days after Transplanting)

Data Analyses Software

ANOVA (analysis of variance), mean comparison and simple phenotypic correlation coefficient were analyzed using SAS software (9.4 versions). NTSYS-PC (version 2.1) software was used for analyzing diversity. The different genetic parameters, such as the genotypic variance and phenotypic variance, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad-sense heritability ((h_B^2) and genetic advance as a percentage of the mean (GAM), were calculated using the following formula given by Myint *et al.* (2019).

a) Phenotypic Coefficient of Variation (PCV)

$$PCV\ (\%) = \frac{\sqrt{\sigma^2 p}}{\overline{X}} \times 100$$

[Where, phenotypic variance i.e. σ^2p and X is the traits mean]

b) Genotypic Coefficient of Variation (GCV),

$$GCV(\%) = \frac{\sqrt{\sigma^2 g}}{\overline{X}} \times 100$$

[Where, σ^2g is genotypic variance and X is expressed as a traits mean.]

PCV and GCV were divided into as low (0-10%), medium (10-20%) and high (> 20%) by (Sulaiman *et al.,* 2020)

c) Heritability in broad sense (h_B^2),

$$h_B^2(\%) = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Heritability was divided into three types i.e. low (0 to 30%), moderate (30 to 60%) and high (≥ 60%) as described by (Sulaiman *et al.,* 2020).

d) Genetic Advance of Mean (GAM),

$$GAM(\%) = h_B^2 \times \frac{\sqrt{\sigma^2 p}}{\overline{X}} \times k \times 100$$

Here, k is constant value (2.06 at 5% selection intensity), x is the mean of a specific trait. GAM is also grouped into low (i.e. 0 to 10%) moderate (10 to 20%) and high (≥ 20%) (Sulaiman *et al.,* 2020). Cluster analysis was used for analyzing diversity using NTSYS-PC (version 2.1) software. Genetic relationship among eggplant accessions was measured based on UPGMA (unweighted pair group method with arithmetic mean) algorithm and Sequential, Agglomerative, Hierarchic and Non-overlapping (SAHN) method. Principal component analysis (PCA) was also performed to produce 2D plots.

Results

Qualitative traits

Nine qualitative traits with their specification are presented in Table 4.

Plant growth habit

Three growth habits were found, namely upright, intermediate and prostrate. Among these three types, the most frequent was a prostrate type (51.85%) followed by upright (29.63%) and intermediate (18.52%) (Table 4).

Leaf-blade length

The leaf blade length varied from ~10 cm to ~30 cm. Most of the genotypes had a short leaf blade (74.07%), whereas the intermediate type was recorded in 22.22% of genotypes, and one genotype had a long (3.70%) leaf blade (Table 4).

Leaf blade lobing

Out of 27 genotypes, 14 genotypes (51.85%) had intermediate type lobing, whereas 13 genotypes had strong leaf blade lobing (48.15%) (Table 4).

Leaf blade tip angle

The highest percentage of leaf blade tip angle was recorded for acute type and obtuse type (29.63%), followed by very acute (22.22%) and intermediate (18.52%) (Table 4).

Corolla colour

Three types of corolla colour were recorded from all the studied accessions. The most frequent colour was bluish-violet (55.55%), followed by light violet (33.33%) and white (11.11%) (Table 4).

Fruit shape

Based on shape, five types of fruits were recorded from all accessions, namely long (37.04%), round (25.92%), oblong (22.22%), oval (7.41%), and others (7.41%) (Table 4 and Fig 2).

Fruit colour

All the studied genotypes fell into five type's fruit colour, namely purple (51.85%), green (18.52%), milky white (22.22%), purple-black (3.70%), and light purple (3.70%) (Table 4 and Fig 2).

Seed size

Two types of seed were recorded for all genotypes. The most frequent type was the intermediate size of seed (92.59%), followed by small size (7.41%) (Table 4).

Flowering habit

The flowering habit in eggplant was axillary and borne in three patterns: solitary, cluster (cyme), and mixed type (both solitary and cluster). Most of the accessions had a solitary flowering habits (44.44%) followed by cluster (29.63%) and both types (25.92%) (Table 4 and Fig 3).

Table 4: Predominance character of nine qualitative descriptors in selected eggplant accesssions

Traits	Specification	No of genotypes	Percentage
Plant growth habit	Upright (3)	8	29.63
	Intermediate (5)	5	18.52
	Prostrate (7)	14	51.85
Leaf blade length	Short (3) = ~10 cm	20	74.07
	Intermediate (5) = ~20 cm	6	22.22
	Long (7) = ~30 cm	1	3.70
Leaf blade lobing	Very weak (1)	0	0
	Weak (3)	0	0
	Intermediate (5)	14	51.85
	Strong (7)	13	48.15
	Very strong (9)	0	0
Leaf blade tip angle	Very acute (1) = ($<15^0$)	6	22.22
	Acute (3) = ($\sim 45^0$)	8	29.63
	Intermediate (5) = ($\sim 75^0$)	5	18.52
	Obtuse (7) = ($\sim 110^0$)	8	29.63
	Very obtuse (9) = ($>160^0$)	0	0
Corolla colour	Greenish white (1)	0	0
	White (3)	3	11.11
	Pale violet (5)	0	0
	Light violet (7)	9	33.33
	Bluish violet (9)	15	55.55
Fruit shape	Long (1)	10	37.04
	Round (2)	7	25.93
	Oblong (3)	6	22.22
	Oval (4)	2	7.41
	Others (5)	2	7.41

Fruit colour	Green (1)	5	18.52
	Milky White (2)	6	22.22
	Deep yellow (3)	0	0
	Fire red (4)	0	0
	Scarlet red (5)	0	0
	Lilac grey (6)	0	0
	Purple (7)	14	51.85
	Purple black (8)	1	3.70
	Black (9)	0	0
	Light purple (10)	1	3.70
Seed size	Small (3) = ~2 mm	2	7.41
	Intermediate (5) = ~3 mm	25	92.59
	Large (7) = ~4 mm	0	0
Flowering habit	Solitary (7)	12	44.44
	Cluster (3)	8	29.63
	Mixed (5)	7	25.92

Fig. 2: Different shapes and colours of fruits

Fig. 3 : Different types of flowering habits

Quantitative traits

In this investigation, all quantitative traits revealed a significantly significant (P ≤ 0.01) difference between the accessions (Table 5). The table also showed no significant difference in genetic variation for most of the traits among replications except plant height and fruit girth. This means that only these two traits have significant genetic variation among replications. The mean performance of studied quantitative traits is also shown in Table 5. The highest ruit length was recorded from the accession BM9 (16.11 cm), and the shortest was for BT15 (3.67 cm). BB1 produced the highest fruit diameter and fruit girth with 7.71 cm and 21.77 cm, respectively. The lowest fruit diameter and fruit girth were recorded from BB17 the accession (2.07 cm) and BT15 (7.28 cm), respectively. The highest value for fruit length to width ratio (FLWR) was recorded for BT13 (6.62, ratio), and the lowest value was 1.59 (BT15). The accession BB1 recorded the highest fruit weight (236.48 g), whereas BT15 recorded the lowest fruit weight (6.34 g), respectively. But the average fruit weight was recorded at 99.46 g (Table 5). The fruit yield per plant ranged from 206.78 (BB4) to 1659.37 g (BB12). The trait number of primary branches per plant is 10.44 (BT6) and 3.67 (BB23), respectively, indicating the highest and the lowest numbers. The earliest flower-bearing accession was BT6 (38.33 days), whereas; the late flowering accession was BM10 (65.67 days) (Table 6). The trait days to fifty percent flowering (DFF) of the plant was varied from 44.33 days (BT6) to 69 days (BB36). The tallest plant (129.35 cm) was recorded for the accession BB16, but BB23 was the shortest (52.13 cm) plant; both are reported from Bangladesh accession. On the other hand, the number of fruits per plant ranged from 1.33 (BB4) to 153.78 (BT15) (Table 6).

Table 0: Mean squares of different morphological traits

Sl no.	Trait	Mean sum of Squares		
		Accessions	Replication	Error
1	Fruit length (cm)	37.39**	0.68ns	0.44
2	Fruit diameter (cm)	6.88**	0.02ns	0.073
3	Fruit girth (cm)	68.96**	7.24**	1.42
4	Average fruit weight (g)	11647.12**	6.50ns	94.21
5	Fruit length to width ratio	9.04**	0.004ns	0.1
6	Fruit yield per plant (g)	270495.95**	1135.25ns	853
7	Number of primary branches per plant (no)	6.67**	0.08ns	0.17
8	Days to first flowering (day)	173.57**	141.34ns	59.99
9	Days to fifty percent flowering (day)	148.54**	88.75ns	61.74
10	Number of fruits per plant (no)	3517.22**	3.27ns	3.05
11	Plant height (cm)	750.56**	59.23**	7.93

'*' Significant at 0.05, '**' Significant at 0.01 and 'ns' Non-significant

Table 6: Mean performance of different quantitative characters of eggplant

Accession Name	FL (cm)	FD (cm)	FG (cm)	FW (g)	FLWR (ratio)	YPP (g)	PB (no)	DF (days)	DFF (days)	NF (no)	PH (cm)
BB1	12.31	7.71	21.77	236.48	1.60	1031.8	5.22	50.00	56.33	4.22	87.83
BB3	10.85	3.28	9.75	37.61	3.33	531.63	5.89	53.00	58.67	11.11	82.63
BB4	8.00	3.4	9.52	119.28	2.35	206.78	5.00	62.33	65.33	1.33	76.83
BB5	12.83	5.7	15.91	200.02	2.25	500.32	5.45	54.00	59	1.67	72.22
BB6	9.96	3.6	10.38	99.68	2.80	315.86	5.00	56.00	60.33	2.00	79.41
BB8	11.70	2.45	10.71	43.35	4.77	509.07	4.11	48.33	52.67	8.00	82.96
BB12	7.72	3.21	10.19	31.95	2.41	1659.37	7.89	45.00	48.67	43.44	87.33
BB16	15.67	4.49	11.88	95.73	3.52	632.53	6.45	52.33	57	9.56	129.35
BB17	14.11	2.07	12.93	55.02	6.82	894.56	6.44	49.33	53.33	10.67	100.33
BB18	11.3	4.71	18.10	105.69	2.41	949.02	6.44	50.67	56.33	9.78	82.56
BB19	13.45	3.76	13.38	67.68	3.62	595.05	7.00	50.00	55.67	6.00	91.56
BB20	12.3	5.12	16.68	98.53	2.4	722.56	7.00	53.33	58.00	5.00	84.70
BB22	13.57	6.87	19.00	188.94	1.97	632.7	7.56	59.67	62.67	2.67	86.00
BB23	13.68	3.18	11.00	207.41	4.31	441.37	3.67	45.67	50.33	4.33	52.13
BB26	15.38	3.26	10.79	108.17	4.71	860.73	4.67	62.33	65.67	7.00	76.22
BB31	15.82	3.57	10.83	84.04	4.44	713.85	6.44	44.33	50.00	5.67	92.33
BB36	11.13	4.32	16.23	160.78	2.58	726.02	5.89	65.33	69.00	5.33	74.68
BM5	15.09	2.48	9.16	140.52	6.09	931.85	4.00	58.67	63.67	5.89	69.63
BM7	13.03	3.28	17.07	96.52	3.98	543.38	6.66	42.00	47.33	4.89	88.06
BM9	16.11	3.31	10.08	110.89	4.87	676.54	6.67	59.67	63.67	4.89	59.52
BM10	11.37	5.26	12.49	155.61	1.97	449.09	5.00	65.67	68.00	3.89	64.63
BT2	4.45	2.33	7.28	8.98	1.92	790.93	8.44	41.00	46.33	70.22	79.45
BT6	5.56	2.44	7.38	8.36	2.32	1344.99	10.44	38.33	44.33	91.44	87.89
BT8	15.41	4.08	10.71	82.83	3.78	838.4	7.44	49.33	54.67	12.22	109.45
BT13	15.66	2.36	7.53	46.3	6.62	806.66	7.11	48.67	54.33	17.67	103.56
BT15	3.67	2.33	7.28	6.34	1.59	871.45	6.44	40.67	44.67	153.78	85.83
BT17	12.23	5.95	15.79	88.66	2.06	862.09	4.89	55.00	60.67	9.00	64.28
Mean	11.94	3.87	12.36	99.46	3.40	742.17	6.19	51.88	56.54	18.95	83.38
LSD	1.09	0.44	1.95	15.9	0.52	47.85	0.68	12.69	12.87	2.86	4.61
CV (%)	5.58	7.10	9.65	9.76	8.97	3.93	6.67	14.93	13.9	9.21	3.38

Note: FL: Fruit length, FD: Fruit diameter, FG: Fruit girth, FLWR: Fruit length to width ratio, FW: Average fruit weight, YPP: Fruit yield per plant, PB: Number of primary branches per plant, DF: Days to first flowering, DFF: Days to fifty percent of flowering, NF: Number of fruits per plant, PH: Plant height, LSD: Least significant difference

Genetic Variation Estimation

The phenotypic variances (σ^2p) for all characters were higher than the genotypic variance (σ^2g) (Table 7). Therefore, both PCV and GCV are also necessary equipments for selecting superior traits. The value of PCV was also greater than the value of GCV. PCV and GCV ranged from 16.84-180.84% and 9.51-180.61%, respectively (Table 7). The PCV value was the highest for the trait number of fruits per plant (180.84%), followed by the number of primary branches per plant (88.36%) and average fruit weight (63.15%). Similarly, GCV was maximum (180.61%) for the trait number of fruits per plant (85.08%), followed by the number of primary branches per plant (85.08%) and average fruit weight (62.39%). The lowest value of PCV and GCV was recorded from the trait days to fifty percent flowering with the value of 16.84% and 9.51%, respectively (Table 7).

Table 7: Estimated value of different genetic parameters of eggplant accessions

Sl No	Trait	σ^2g (%)	σ^2p (%)	PCV (%)	GCV (%)	h^2B (%)	GAM (%)
1	FL (cm)	12.32	12.76	29.91	29.39	96.60	59.21
2	FD (cm)	2.27	2.34	40.27	39.64	96.90	79.98
3	FG (cm)	22.51	23.93	39.58	38.39	94.10	76.33
4	FW (g)	3850.97	3945.18	63.15	62.39	97.60	126.37
5	FLWR (ratio)	2.98	3.08	49.44	48.63	96.80	98.05
6	YPP (g)	89880.98	90733.99	40.59	40.40	99.10	82.42
7	PB (no)	2.17	2.34	88.36	85.08	92.70	167.96
8	DF (days)	37.86	97.85	19.07	11.86	38.70	15.12
9	DFF (days)	28.93	90.67	16.84	9.51	31.90	11.02
10	NF (no)	1171.39	1174.44	180.84	180.61	99.70	369.77
11	PH (cm)	247.54	255.47	19.17	18.87	96.90	38.08

Note: σ^2p = Phenotypic variance, σ^2g = Genotypic variance, PCV: Phenotypic coefficient of variation, GCV: Genotypic coefficient of variation, h^2_B = Heritability in broad sense, GAM: Genetic advance of mean, FL: Fruit length, FD: Fruit diameter, FG: Fruit girth, FLWR: Fruit length to width ratio, FW: Average fruit weight, YPP: Fruit yield per plant, PB: Number of primary branches per plant, DF: Days to first flowering, DFF: Days to fifty percent of flowering, NF: Number of fruits per plant, and PH: Plant height

Genetic advance as percentage of mean and Heritability

Estimation of heritability in a broad sense (h^2_B) and genetic advance as a percentage of the mean (GAM) are presented in Table 7. Heritability and GAM values ranged between 31.90-99.70% and 11.02-369.77%. Heritability values were high (> 60%) for most of the studied traits, such as plant height (96.90%), number of primary branches per plant (92.70%), fruit length (96.60%), fruit diameter (96.90%), fruit girth (94.10%), fruit length to width ratio (96.80%), average fruit weight (97.60%), number of fruits per plant (99.70%) and fruit yield per plant (99.10%) except days to the first flowering of the plant and days to fifty percent flowering of the plant (Table 7). These two traits have moderate heritability, 38.70% and 31.90%, respectively. Estimates of GAM are also high for the majority of the traits such as plant height (38.08%), number of primary branches per plant (167.96%), fruit length (59.21%), fruit diameter (79.98%), fruit girth (76.33%), fruit length to width ratio (98.05%), average fruit weight (126.37%), number of fruits per plant (369.77%) and fruit yield per plant (82.42%) (Table 7). The moderate GAM was recorded for the traits of days to first flowering (15.12%) and days to fifty percent flowering (11.02%) (Table 7).

Coefficient of Correlation

Simple correlation coefficients among 11 phenotypic traits are shown (Table 8). Extent knowledge among yield and yield-related traits is one of the important factors because yield is a complicated trait. It depends on the interaction of other traits with their surrounding environment. The correlation coefficient determines how closely two traits are related. Fruit yield per plant (YPP) is directly correlated with the number of primary branches per plant (PB) and the number of fruits per plant (NF). The correlation levels of fruit yield per plant with these two traits are 0.43-0.50 (Table 5.6). The highest correlation value (0.98) is found from the trait between days to first flowering and days to fifty percent of flowering of plants. The second highest correlation value is 0.82, which is recorded between fruit diameter (FD) and fruit girth (FG). Days to first flowering (-0.29), days to fifty percent flowering (-0.27) and average fruit weight (-0.32), these three traits showed a negative correlation with fruit yield per plant. Besides this, plant height (0.20), fruit length (0.20), fruit width (0.05), fruit girth (0.05), and fruit length to width ratio (0.17) showed no significant relation with fruit yield per plant (Table 8).

Table 8 : Phenotypic correlation among different studied quantitative traits

	PB	DF	DFF	FL	FD	FLWR	FG	FW	NF	YPP
PH	0.44**	-0.24*	-0.22*	0.15ns	0.02ns	-0.01ns	0.09ns	-0.35**	0.10ns	0.20ns
PB		-0.34**	-0.33**	-0.33**	-0.09ns	-0.04ns	-0.06ns	-0.51**	0.46**	0.50**
DF			0.98**	0.26*	0.25*	0.14ns	0.16ns	0.40**	-0.45**	-0.29**
DFF				0.29**	0.27*	0.15ns	0.17ns	0.40**	-0.46**	-0.27*
FL					0.14ns	0.02ns	0.16ns	0.41**	-0.72**	-0.20ns
FD						0.28*	0.82**	0.61**	-0.36**	-0.05ns
FLWR							-0.30**	0.11ns	-0.07ns	-0.17ns
FG								0.55**	-0.35**	0.05ns
FW									-0.58**	-0.32**
NF										0.43**

Note: '*' Significant at 0.05, '**' Significant at 0.01 and 'ns' Non- significant, FL: Fruit length, FD: Fruit diameter, FG: Fruit girth, FLWR: Fruit length to width ratio, FW: Average fruit weight, YPP: Fruit yield per plant, PB: Number of primary branches per plant, DF: Days to first flowering, DFF: Days to fifty percent of flowering, NF: Number of fruits per plant, PH: Plant height

Cluster analysis

Genetic divergence analysis is required to estimate the extent of diverse nature existing among accessions, which eventually leads to select parents. Therefore, accurate and specific information on the genetic variability level is important to select parents and reduce the crossing number (Yatung *et al.*, 2014). The morphological data were standardized and utilized to calculate Euclidean distances among the 27 eggplant accessions and UPGMA dendrogram constructed in Figure 4 using NTSYS -pc software (version 2.1) for cluster analysis. The dendrogram was grouped into six major clusters at the 3.85 similarity coefficient level (Fig 4). According to the cophenetic value's grouping, this point is used to cut the tree for convenient discussion. This point is also best fit for the genetic similarity ranging from 1.20 to 6.51 according to Jaccard's correlation coefficient (Fig 4). The list of accessions with their countries is presented in Table 9. Cluster I had one accession from Bangladesh, while cluster II had 20 accessions from Bangladesh, Malaysia, and Thailand. Cluster III had only one accession from Bangladesh. Cluster IV and VI had one and two accessions, respectively, from Thailand. But cluster V consisted two accessions from two countries, namely Bangladesh and Thailand (Table 9).

Table 9: Cluster of eggplant accessions according to their origin

Group	No of genotypes	Name of genotypes	Origin
I	1	BB1	Bangladesh
II	20	BB3, BB4, BB5, BB6, BB8, BB16, BB17, BB18, BB19, BB20, BB22, BB26, BB31, BB36, BM5, BM7, BM9, BM10, BT8, BT13	Bangladesh, Malaysia, Thailand
III	1	BB23	Bangladesh
IV	1	BT17	Thailand
V	2	BB12, BT6	Bangladesh, Thailand
VI	2	BT2, BT15	Thailand

Note: BB: Brinjal Bangladesh, BM: Brinjal Malaysia, and BT: Brinjal Thailand

The mean values of all clusters for all traits are presented in Table 10. The first cluster had the highest mean values for some traits like plant height (87.83 cm), fruit diameter (7.71 cm), fruit girth (26.77 cm) and fruit weight (236.48 g) (Table 10). On the other hand, cluster III had the highest fruit length (13.68 cm) and the highest value (4.31, ratio) of the fruit length to width ratio. Flowering traits like days to first flowering and days to fifty percent of flowering had the highest values for cluster IV. The highest yield (1502.18 g) is recorded from cluster V with the highest number of primary branches per plant (9.16, no) (Table 10). Group VI reported the highest number of fruits per plant (112, no) with the lowest values of days to first flowering and days to fifty percent flowering (Table 10). Besides, Cluster II reported the second-best number of fruit lengths (13.14 cm) with moderate average fruit weight (104.86 g) (Table 10).

Table 10: Mean value of quantitative traits each cluster

Cluster	FL	FD	FG	FW	FLWR	YPP	PB	DF	DFF	NF	PH
I	12.31	7.71	21.77	236.48	1.60	1031.80	5.22	50.00	56.33	4.22	87.83
II	13.14	3.87	12.66	104.86	3.78	651.83	6.01	54.25	58.77	6.76	85.33
III	13.68	3.18	11.00	207.41	4.31	441.37	3.67	45.67	50.33	4.33	52.13
IV	12.23	5.95	15.79	88.66	2.06	862.09	4.89	55.00	60.67	9.00	64.28
V	6.64	2.82	8.78	20.15	2.36	1502.18	9.16	41.66	46.50	67.44	87.61
VI	4.06	2.33	7.28	7.66	1.75	831.19	7.44	40.835	45.50	112.00	82.64

Note: FL: Fruit length, FD: Fruit diameter, FG: Fruit girth, FW: Average fruit weight, FLWR: Fruit length to width ratio, YPP: Fruit yield per plant, PB: Number of primary branches per plant, DF: Days to first flowering, DFF: Days to fifty percent of flowering, NF: Number of fruits per plant, PH: Plant height

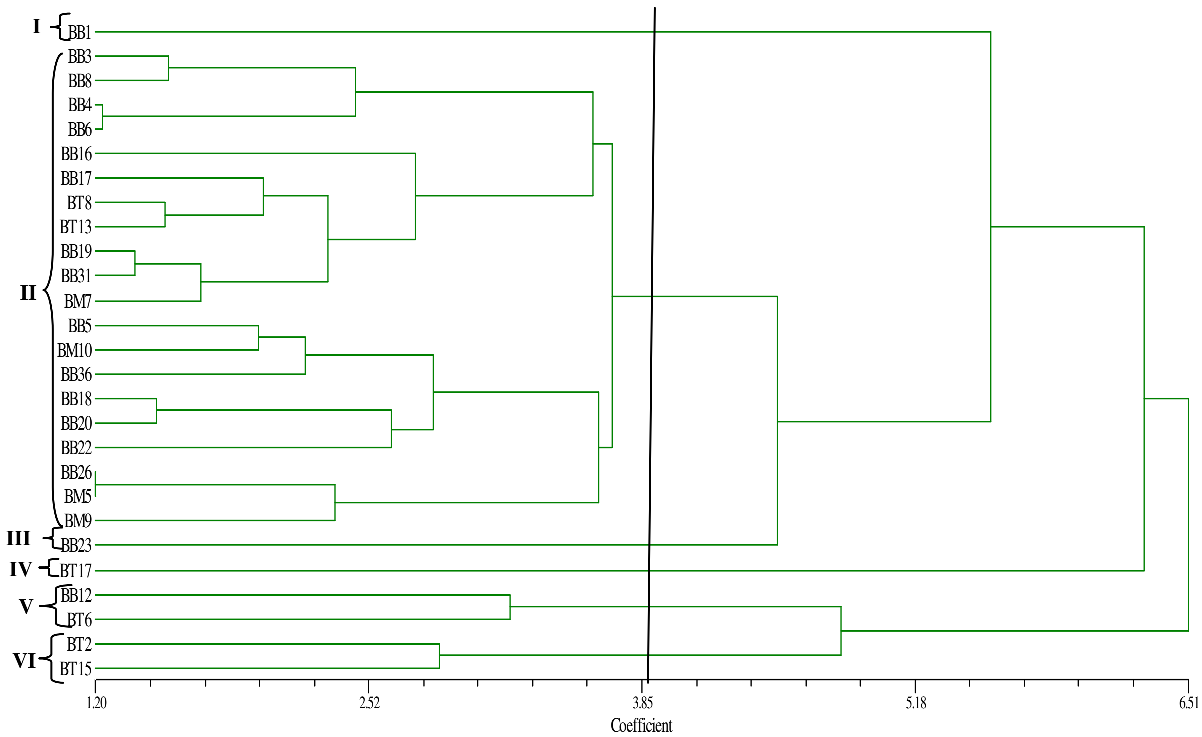

Fig. 4 : Dendrogram of 27 eggplant accessions based on quantitative traits

Analyze the Principal Components

Principal component analysis (PCA) was done on 11 quantitative characters of eggplant accessions. The two-dimensional (2D) graphical illustration is shown in Fig. 5, which describes that most of the accessions were located at close distance, but only a few were located at more distances. PCA mostly confirms the clustering. The first four principal components comprise 82% cumulative variation for all quantitative traits. Eigen vector analysis also reported that the first four principal components could narrate 38%, 21%, 15%, and 8% variation of all characters (Table 11). The percentage of the total variation for the first principal component was 38%, the highest percentage value. The major contributing traits for representing first principal component (PC1) were days to first flowering (DF) followed by average fruit weight (FW) and days to fifty percent of flowering (DFF) while negatively major contributed traits were the number of fruits per plant (NF) and the number of primary branches per plant (PB). The highest positively contributing traits for PC2 (principal component) were fruit diameter (FD) and fruit girth (FG), and negatively contributing trait was fruit length to width ratio (FLWR) (Table 11). In case of PC3, the traits plant height (PH) and fruit length (FL) were the major contributing traits. In PC4, the major contributing trait was fruit yield per plant (YPP) with a value of 0.671. The second contributing trait was negatively correlated days to fifty percent of flowering (DFF) (Table 11).

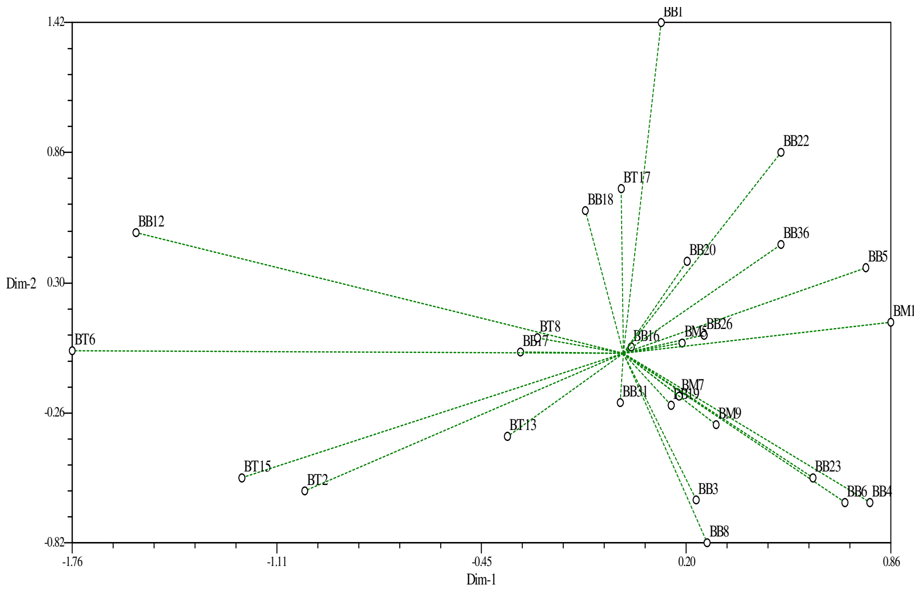

Fig. 0 : Principle component analysis (PCA) of 27 eggplant accessions based on quantitative traits.

Table 11: Eigenvalues, variability, cumulative variability and principal component axes for different traits

Parameters and characters	Eigenvectors			
	PC1	PC2	PC3	PC4
Eigenvalue	4.52	2.55	1.76	0.97
Variation (%)	0.38	0.21	0.15	0.08
Cumulative (%)	0.38	0.59	0.74	0.82
FL	0.277	-.107	0.543	0.221
FD	0.213	0.536	-.029	0.078
FG	0.184	0.501	0.052	0.268
FW	0.385	0.186	-.052	0.195
FLWR	0.083	-.488	0.383	0.260
YPP	-.254	0.118	0.022	0.671
PB	-.331	0.175	0.114	0.028
DF	0.393	-.010	-.119	-.196
DFF	0.360	-.0464	-.028	-.278
NF	-.381	-.012	-.307	-.009
PH	-.186	0.191	0.543	-.258

Note: FL: Fruit length, FD: Fruit diameter, FG: Fruit girth, FW: Average fruit weight, FLWR: Fruit length to width ratio, YPP: Fruit yield per plant, PB: Number of primary branches per plant, DF: Days to first flowering, DFF: Days to fifty percent of flowering, NF: Number of fruits per plant PH: Plant height

Discussion

Qualitative traits

Three types of growth habits could be found: upright or erect (meaning that strong and stiff stem), intermediate or semi-spreading, and prostrate (spreading or decumbent habit). This type of variation was also reported by Gramazio *et al.* (2019), Tiwari *et al.* (2016) and Cercicola *et al.* (2013). The shape of fruit was recorded to be varying from long to oval. Similar variation was also found in Khan and Singh (2014) and Tiwari *et al.* (2016). Colour development in eggplant fruits appeared to be a manifested character in which all of the accessions expressed fruit colouration. Besides, the intensity of purple colour fruit varied with the genotypes, presumably because of different types of chlorophyll and anthocyanin present in fruits. Different types of fruit colour variations were also found from the reporter Prohens *et al.* (2005), Khan and Singh (2014), and Tiwari *et al.* (2016). It is important to categorize the eggplant genotypes as having wide adaptability and better acceptance according to local preferences. Different varieties, local cultivars, wild types, and stable breeding lines should be characterized for different quantitative and qualitative characteristics for the next breeding program. The characters of eggplant that govern quality viz., fruit shape, fruit colour, less seed inside fruit, solitary fruiting habit, and erect growth habit should be considered for further improvement of eggplant in the future.

Quantitative traits

The quantitative traits used for this study exhibited a highly significant difference ($p \leq 0.05$) among 27 accessions. These variations occur among the studied accessions that might be due to their genetic constitutions. Phenotypic variation exists among all eggplant accessions studied by different researchers for different traits. Similar findings were also reported by Ullah *et al.* (2014) and Kumar *et al.* (2016). The GCV value is slightly smaller than the PCV value for all of the characters. The same result is also reported by Mili *et al.* (2014). The environmental influence on the expression of these traits is regulated by the difference between the phenotypic and genotypic coefficient of variation. The low difference value between PCV and GCV means more appearance of genetic influence; on the other hand, a big difference indicates a heavily environmental effect on the expression of these traits. All of the traits under study reveal a small difference, meaning that the menifestation of these traits has more genetic influence. It also suggests that future breeding projects could benefit from selection based on these traits. The PCV and GCV values are both high, were recorded for the trait number of primary branches per plant (PB), fruit length (FL), fruit length to width ratio (FLWR), fruit diameter (FD), fruit girth (FG), fruit weight (FW), number of fruits per plant (NF) and fruit yield per plant (YPP). A similar result is also found by several researchers like Pujer *et al.* (2017) and Mili *et al.* (2014). The medium PCV and GCV values were reported from the trait days to first flowering (DF) and days to fifty percent (DFF). Similar finding was also recorded by Jirankali *et al.* (2019). All of the studied characters showed high heritability. This result is related to Jirankali *et al.*'s findings (2019). The high value of GAM was recorded for plant height (PH), number of primary branches per plant (PB), fruit length (FL), fruit girth (FG), fruit diameter (FD), fruit length to width ratio (FLWR), average fruit weight (FW), number of fruits per plant (NF) and fruit yield per plant (YPP). Similar results observation was reported by Jirankali *et al.* (2019) and Arunkumar *et al.* (2013). Both traits days to first flowering (DF) and days to fifty percent flowering (DFF) have moderate GAM value. Similar type of result reported by Jirankali *et al.* (2019) and Vandana *et al.* (2014) for DF and DFF, respectively. In this study, high heritability with high genetic advance as percentage of mean was reported for the traits plant height (PH), number of primary branches per plant (PB), fruit length (FL), fruit diameter (FD), fruit girth (FG), fruit length to width ratio (FLWR), average fruit weight (FW), number of fruits per plant (NF) and fruit yield per plant (YPP) meaning that these traits mainly depend on genetic factors and selection can be done through these characters in crop improvement program. High heritability associated with high genetic advance as a percentage of the mean is also recorded by Yadav *et al.* (2016) and Rad *et al.* (2015) in eggplant. On the other side, the traits with low heritability and genetic advance meant that non-additive genes regulated these traits. So it is important to select those traits which have high genotypic coefficient of variation, heritability and genetic advance (Weaver and Awade, 1986). Selection is effective when environmental effects are smaller than additive effects (Usman *et al*., 2014). One of the important criteria for parental selection is the analysis of genetic divergence. Here all accessions are grouped into six clusters at a coefficient level 3.85. Group VI, which has two accessions may have different genes as compared to other groups for controlling traits. Analysis of diversity for morphological traits indicated the most similar genotypes which are in same group hybridization among these accessions will not be fruitful because accessions in the same group have more or less same genetic constituent. But hybridization between two different group members will be meaningful, as these accessions were being distinctive. Group II had three types of accessions which were collected from Bangladesh, Malaysia and Thailand. It is reported that geographical dispersion is not correlated with genetic variation (Li *et al*., 2010). Multivariate analysis of PCA helps to light up cluster analysis result. The outcome of PCA supports cluster analysis output for more accurate and precise data confirmation. Strong diversity present among 27 accessions in this research and these were also further confirmation by PCA. PC1 to PC4, these four principal components were presented from the initial data analysis table with eigen values >1 are considered meaningful reported by Kaiser (1960). The total variation is reported 76.59% for the first three principal axes for ten morphological characters among 26 eggplant genotypes (Karim and Quamruzzaman, 2016) which is more or less similar findings with this research (74%). The researcher Sunseri *et al.* (2010) studied genetic diversity determination using PCA, who also got the same result i.e., 74% total variance among seventy accessions of eggplant. Perception of correlations among different characters is very important for an effective crop breeding program. It shows that one character's change can lead to another's change and how such types of characters are linked (Hussain, 2014). Galton was the first to introduce correlation concept (1889). Fisher (1918) and Wright (1921) expanded on it afterwards. The majority of economic characteristics (including yield) are complicated traits. So, direct selection based on yield might be complicated because yield is inherited and highly influenced by the environment and interaction between two factors, genotype and environment. So indirect selection is more preferable to direct selection for the traits. The trait fruit girth ($r = 0.61$) and fruit diameter ($r = 0.55$) positively correlated with average fruit weight. Praneetha *et al*. (2011) and Dash *et al.* (2017) also reported this type of association in eggplant. On the other hand, the trait days to first flowering, days to fifty percent flowering and average fruit weight negatively correlate with fruit yield per plant. Besides, the trait average fruit weight is negatively significant with the trait number of fruits per plant ($r = -0.58$). This result is conformity with the result of Kumar and Arumugam (2013). Here, the number of fruits was greatly varied according to the accession tested. Some accessions had small size but high number of fruits. Some accessions had large size but few numbers of fruits. The trait number of primary branches per plant (PB) and number of fruits per plant (NF) are positively and significantly correlated with fruit yield per plant (YPP). It indicates that if primary branches per plant increase, fruit bearing also increases, which ultimately increases fruit yield per plant. So these characteristics could be exploited to create superior genotypes.

Conclusion

The performance of individual eggplant genotype is important for selecting as the best cultivar in varietal development. Twenty-seven eggplant genotypes varied with respect to their quantitative and qualitative traits performance. Extension of genetic variation indicated that they might come from diverse origins meaning their different source. The quantitative traits such as PB, FL, FD, FG, FW, FLWR, NF and YPP can be exploited through selection as these traits with high PCV, GCV, h^2B and GAM. Considering diversity patterns and other agronomic traits, the accessions BB1 from group I, accessions BT13, BM9, BB26, BB31, BM5 from group II, BB23 from group III, BT17 from group IV, BB12 and BT6 from group V and BT15 from group VI was taken into consideration as better parents for an effective hybridization program

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