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Research Article

Assessment of Diversity among Important Brinjal (*Solanum melongena*) Cultivars Using Morphological Markers

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Background. *Solanum melongena* is a medicinally important vegetable crop that belongs to the family *Solanaceae*, which is cultivated worldwide. *Methodology*. In the present study, 22 eggplant varieties from the different ecogeographical regions were evaluated for nine quantitative and twenty-two qualitative morphological characters. A significant divergence was observed in all characters and wide regional variations for plant characteristics, flower, and fruit characteristics. Principle component analysis (PCA) was performed using PAST3 software to determine the relationship among eggplant accessions. *Results*. The principal component analysis showed that the first two principal component axes explained 97.17% of the total multivariate variation. Cluster analysis using the Unweighted Pair Group Method of Arithmetic Means (UPGMA) grouped the 22 eggplant accessions into two main clusters based on similarities in morphological characteristics. The study showed that the *Solanum melongena* accessions belonging to Pakistan and other geographical regions of the world possess marked variation in fruit weight, fruit shape, fruit color, leaf spine, number of locules in fruit, plant height, and flower color. *Conclusion*. Based on morphological diversity, the best cultivars of eggplant that show better yield can be selected for farmers.

1. Introduction

Brinjal, also called eggplant or aubergine, belongs to the nightshade family of "*Solanaceae*", [1]. The family of *Solanaceae* contains approximately 2450 species appropriated in 95 genera cultivated all over the world [2, 3]. *Solanum incanum* is wild African species, thought to be an ancestor relative of *Solanum melongena* that emerged from the Indo-Burmese district [4]. However, the latest DNA sequencing elucidated that eggplant emerged from Africa [5]. The history of cultivation of *Solanum melongena* started in Asia. That is, in India, the cultivation of *Solanum melongena* started in the 3rd century while in China it started in the 4th century and spread to another geographic region of (African countries) in the 9th century [6, 7]. The eggplant comprised 5th position in vegetable production in Asia and the Mediterranean region [6]. The countries with leading eggplant production in world aggregate are China (58%), India (25%) Egypt, Turkey, and Iran. In Pakistan, the annual production of eggplant is 88,140 tons under an area of 9000 hectares. The eggplant cultivars grown in Pakistan are ISD006, BL114, BL095, KB9, Pusa Purple Long, KP10, BB1, Mistasa, Abar,

Parat, EG 2003, Mara, Acc 612, Nepali, Neelum, Sigatoka Beauty, Sitara, Chayat, Greek, Local Gool, Violetta, Prospera, Dilnasheen, Hybrid Shilpa, Black Pearl, etc. [8]. The common name of brinjal in other geographic regions is quizi in Chinese, gaji in Korean, garden egg in Nigeria, gauta, igbo, and yaruba in Sri Lanka, batu in Sinhala, and kaththiri in Tamil [9]. The eggplant fructification cycles are complete in three months. Being warm-season plant eggplant needs a 10–12 hr photoperiod and 23°C–26°C temperature for normal growth [7]. The low temperature 10°C–12°C influenced the growth of flowering and fruit sets [10].

Eggplant has a solid and taproot system. The eggplant stem thickness varies from herbaceous in the early growth phase to woody in the older stage along with spiny or spineless stem and erect or pendent growth pattern. Plant height varies from 0.4 to 1.5 m in height, with branched and broad leaves [11]. The leaves vary in size and may have a large or small leaf with dense hair. The arrangement of leaf on the stem is alternate and leaf shape varies in eggplant varieties as ovate, simple, lanceolate, and lobulated whereas the leaf margin is acute or obtuse [12]. The flower of eggplant is hermaphrodite or male, complete, actinomorphic, star-shape, hypogynous or epigenous, solitary, or clustered of 3–5 flowers, and flower size varies from 3 cm to 5 cm in diameter. In eggplant, calyx ranges from 5 or 7 sepals, tubular spiny, woolly, and persistent, and calyx aestivation is campanulate or tubular. The corolla ranges from 5 to 7 in number, gamopetalous, white or purplish-white, or purplish-violet colored [13]. The anthers are pentamerous to heptamerous [13]. The stamen is bicelled and fused into cone shapes of varying lengths. The ovary is bilobed, style is simple, and stigma is capitate. The size of style depends on its position related to stamen and stigma position.

The flower is having long-style with a stigma present at the same level or above stamens, while a short-style flower has a stigma position below the stamens. Eggplant fruit seed content varies from many to seedless (Parthenocarpic). The seeds are white or yellow and may keep their viability up to six years [7]. Eggplant is rich in chemical constituents such as iron, calcium, phosphorous, potassium, vitamin B, water, proteins, fiber, fat, minerals, and carbohydrates [14]. The leaves of African eggplant are abundant in folic acid, ascorbic acid, and riboflavin whereas the fruit is low in sodium, and cholesterol is not found in fruit. Eggplant is the 5th important crop of *Solanaceae* after potato, tomato, pepper, and tobacco. In China, the eggplant is used as a vegetable for a long period, and in the Middle East region, the dry eggplant is used as an important ingredient in soup and sauces [15, 16]. Fruit of eggplant is eaten boiled, steamed, cured, and stewed with different meats while eggplant fruits were eaten as a salad component with vine and sugar [17]. The extracts obtained from different plants organs of *Solanum melongena* are used to treat diabetes, sickness, gonorrhea, cholera, bronchitis, dysuria, loose bowels, asthenia, and hemorrhoids whereas chlorogenic acid has anticancerous, cardio defensive, against corpulence, pain-relieving, lowering the blood cholesterol, and free radical scavenging [18, 19]. The various molecular markers, morphological markers, and biochemical markers are used to explore the diversity of eggplant. The molecular markers are the second-generation PCR-based markers such as AFLP, SSR, ISSR, and RAPD that are used to check diversity in eggplant [20]. The molecular markers are used in QTL (Qualitative trait loci) mapping, DNA fingerprinting, and using marker-assisted selection [21]. The molecular markers are highly informative, highly reproducible, and transferable genetic markers [22]. Morphological markers are physical plant parameters that can be seen through the naked eye and were traditionally used for diversity analysis between interspecific and intraspecific species. The eggplant belonged to the same ecogeographical distribution and exhibited variation in morphological features of plant characteristics and leaf characteristics such as plant height, stem color, leaf size, leaf tip, and leaf midrib color [23]. The eggplant native to regions revealed morphological variation in fruit characteristics and flower characteristics such as fruit size fruit shape, fruit color, fruit yield, fruit quality, fruit taste, presence or absence of spine on the calyx, number of the corolla, and position of stamen [11, 23]. The fruit taste, fruit length, and fruit diameter parameters are taken as morphological markers [24, 25]. The common insects that attacked different physical plant parameters are *Leucinodes orbonalis*, *Euzophera perticella*, *Eublemma olivacea*, *Epilachna vigintioctopunctata*, *Aphis gossypii*, *Bemisia tabici*, *Thrips palmi*, and *Amrasca biguttula* [8].

2. Material and Methods

The present experiment was conducted in the botany Lab of the Department of Biology, Allama Iqbal Open University, Islamabad, from October 2018 to October 2019. Seeds of 22 different varieties of eggplant (*Solanum melongena* L.) were collected from the Horticulture Research Institute (HRI) of National Agriculture Research Center, Islamabad (NARC) (Table 1). In the present study, diversity analysis of 22 eggplant accessions was carried out based on morphological markers during one growing season of the crop. The qualitative and quantitative characters used for eggplant characterization are shown in Table 2.

2.1. Data Scoring and Analysis. Data was recorded for 31 plant parameters which included 22 qualitative characters and 9 quantitative characters among 22 eggplant accessions. For qualitative parameters, the percentage range of variations was recorded, and the average mean, coefficient of variance, standard deviation, and range of variation were calculated for quantitative data. Cluster analysis was carried out based on similarity coefficient among samples, using UPGMA; the dendrogram was generated for Euclidean distance and multivariate ordinate analysis for principle component analysis (PCA) using PAST 3.22 [26].

3. Results and Discussions

In the present study, twenty-two qualitative and nine quantitative characters characterized a high level of morphological diversity among 22 eggplant accessions belonging to the different geographical regions of the world.

Table 1: *Solanum melongena* (L) accessions used for diversity analysis.

Sr #	Variety name	Accession number	Origin
1	Black king	018500	India
2	PP-long	018502	India
3	004467 (17)	019326	Pakistan
4	Mk-95	025913	Pakistan
5	Xiangzue-6	025914	China
6	White egg	025915	Pakistan
7	A-58	025916	Unknown
8	004464 (07)	025919	Pakistan
9	BARI-1	028377	Bangladesh
10	004729 (01)	028379	Pakistan
11	Badanjan	030859	Iran
12	Viserba	030862	Italy
13	PI 606711	030874	USA
14	Grif-13962	033834	Exotic
15	PI-362727	033835	Exotic
16	PI-371849	033836	Exotic
17	PI-379545-A	033837	Exotic
18	PI-381288-A	033839	Exotic
19	PI-381288-B	033840	Exotic
20	7655 (4)	036681	Pakistan
21	7657 (6)	036692	Pakistan
22	036690	036690	Pakistan

Table 2: Qualitative and quantitative traits for diversity analysis among eggplant varieties.

Morphological characterization		
Sr #	Qualitative characters	Quantitative characters
1	Plant branching	Plant height
2	Stem thickness	Leaf length
3	Stem spine/prickles	Leaf width
4	Stem color	Petiole length
5	Stem hairiness	Flower size
6	Leaf lobe	Fruit length
7	Leaf blade color	Fruit width
8	Leaf spine	Fruit weight
9	Petiole color	Seed weight
10	Leaf hairness	
11	Flower bud size	
12	Flower bud color	
13	Flower bud spine	
14	Flower size	
15	Flower color	
16	Fruit color	
17	Fruit shape	
18	Fruit curvature	
19	Fruit brightness	
20	Fruit firmness	
21	Number of locules in fruit	
22	Seed abundance	

Morphological traits recorded were grouped accordingly under plant characteristics, leaf characteristics, fruit characteristics, inflorescence, and flower characteristics. The diversity of eggplant was checked on the basis of both vegetative and reproductive characters.

3.1. Plant Characteristics. The plant characteristics varied considerably among 22 eggplant accessions. Morphological markers such as plant height ranged from small to intermediate and large height. In the present study, plant height was observed as a highly variable characteristic among 22 eggplant accessions that ranged from 10.1 cm to 72.1 cm, and the average mean valve of plant height was noted as 35.5 cm. In a previous study performed by [27], the plant height of eggplant in Spain ranged from 69.7 cm to 111.7 cm. The significant difference in plant height in both studies may be due to differences in the climatic condition of the country. In Spain, the climatic condition may favor large height plants but in Pakistan climatic conditions favored intermediate height plants. Similarly, in the present study, the percentage range of variation was observed in plant characteristics including plant branching, stem thickness, stem spines, stem color, and stem hairs. The previous study performed by [11] which was compared to the present study showed similar results. The closed similarities in plant characteristics may due to similar environmental conditions. In the present study, it was observed that the eggplant varieties having spines on the stem were resistant to insect attack while it was also noted that insect attack was more prevalent on the green stem as compared to stem with purple-green color and no such clue was present in the previous study. The mean value and standard deviation of nine quantitative characters are shown in Table 3.

3.2. Leaf Characteristics. In the present study, the percentage range of variation in leaf characteristics such as leaf blade color, leaf spines, leaf hairs, petiole color, and several leaf lobes among 22 eggplant accessions is shown in Figure 1. Previously, [28, 29] observed variation in the leaf characteristics and they observed dark green leaf blade color was dominant over green which showed an opposite result to the present study. Our present study was conducted in Pakistan where climatic conditions favored green leaf blade color while a previous research study was attempted in Kenya where the warm condition may have favored dark leaf blade color [28]. In comparison to leaves at higher elevations, leaves in warm, lower elevation sites exhibited lower leaf mass per area and reflected less light in the near-infrared range [30, 31]. Leaves will become darker and absorb more of the light that strikes them if their near-infrared reflectance decreases [32]. Leaf characteristics varied depending on elevation even within a single location, demonstrating how easily trees can adjust to modest changes in temperature. The higher temperatures may actually cause leaves to turn a darker shade, reflecting less light [33].

Similarly, the distinctive morphological character such as the presence of leaf spine on leaf blade was also observed in some eggplant accessions. Similarly, leaves with many hairs were dominant (50%) as compared to leaves with no hairs (31.8%) or with intermediate hairs (18.2%). A similar finding was observed by [29] in the study on eggplant, they also find that a leaf with no spines has a dominant character followed by the presence of a spine on a leaf in eggplant accessions, and intermediate leaf hairiness has a dominant character followed by a few leaf hairiness. Another important trait in our investigation was leaf lobing which

Table 3: The mean value and SD taken for 9 quantitative descriptors of 22 eggplant accessions.

Sr #	Acc. no	Variety name	Plant height (cm)	Leaf blade length (cm)	Leaf blade width (cm)	Petiole length (cm)	Flower size (cm)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Seed wt. 100 seed (g)
1	018500	Black king	50.2	8.5	4.8	1.6	3.4	4.7	3.6	17.7	0.43
2	018502	PP-long	30.6	10.0	6.4	2.4	2.4	6.3	2.5	66.0	0.19
3	019326	004467 (17)	40.8	8.3	4.9	2.7	3.3	7.4	4.1	26.0	0.27
4	025913	Mk-95	20.8	7.4	4.3	0.9	2.4	6.1	4.8	13.5	0.28
5	025914	Xiangzue-6	38.3	11.3	10.1	5.4	3.6	7.0	2.9	26.1	0.32
6	025915	White egg	28.3	11.6	8.1	1.3	2.2	5.4	4.3	35.8	0.11
7	025916	A-58	40.8	15.2	11.4	5.1	2.4	7.3	3.1	30.6	0.35
8	025919	004464 (07)	32.2	7.9	5.1	1.2	2.2	5.1	4.3	20.0	0.20
9	028377	BARI-1	39.1	9.4	5.8	2.3	2.3	3.9	2.3	11.7	0.20
10	028379	004729 (01)	62.1	12.1	5.9	5.7	2.6	6.1	6.0	96.2	0.41
11	030859	Badanjan	24.4	4.9	3.7	3.5	2.3	7.9	4.3	65.5	0.31
12	030862	Viserba	32.1	11.4	8.8	3.7	3.1	5.8	2.4	20.4	0.48
13	030874	PI606711	48.7	10.6	7.3	8.2	3.3	7.3	7.1	154.1	0.18
14	033834	Grif-13962	51.2	7.5	4.2	4.3	2.5	9.0	3.9	64.1	0.27
15	033835	PI-362727	27.7	13.8	9.2	6.0	2.9	7.9	3.4	36.5	0.16
16	033836	PI-371849	33.8	10.4	6.8	5.5	2.3	7.9	1.8	13.6	0.12
17	033837	PI-379545-A	33.1	6.6	3.2	1.6	2.6	5.7	1.8	19.6	0.40
18	033839	PI-381288-A	30.9	8.4	4.6	1.3	2.4	9.1	3.5	43.7	0.49
19	033840	PI-381288-B	20.8	8.1	5.4	6.2	3.2	6.3	3.0	29.3	0.43
20	036681	7655 (4)	29.9	6.1	3.2	5.5	4.6	9.2	2.5	27.7	0.30
21	036692	7657 (6)	35.2	10.2	6.9	2.4	2.3	8.3	3.1	35.0	0.36
22	036690	036690	29.1	6.7	7.0	2.1	2.4	8.1	2.6	11.2	0.17
Mean			35.45	9.4	6.2	3.6	2.76	6.9	3.5	39.27	0.29
Standard deviation			10.3	2.6	2.2	2.1	0.6	1.5	1.3	33.53	0.12

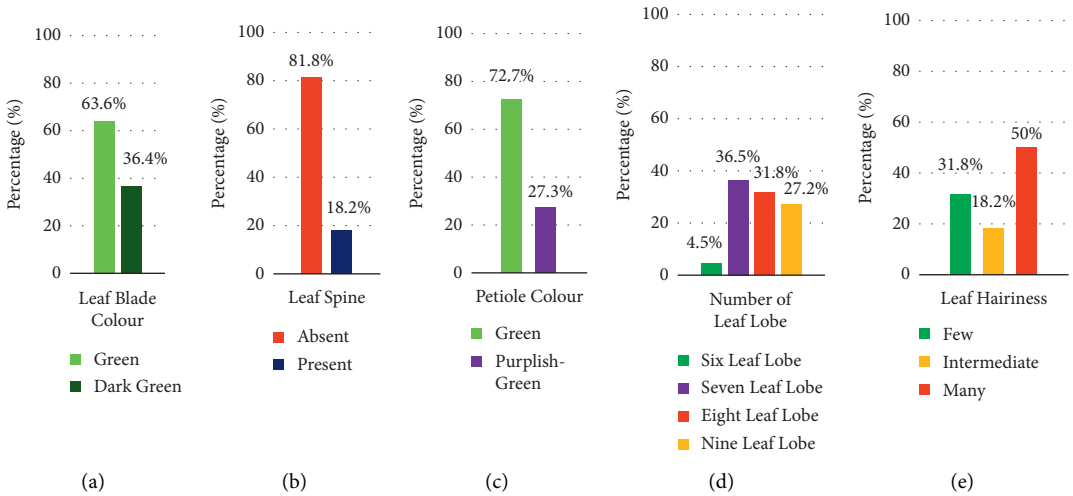

Figure 1: The percentage range of variation in morphological leaf parameters. (a) Leaf blade color. (b) Leaf spine. (c) Petiole color. (d) Number of leaf lobe. (e) Leaf hairiness.

ranged from 5 to 11 lobed among 22 eggplant accessions, and most of the varieties had strong lobing in leaves. Our results are contradictory to the results of [29]. In past, a study conducted by [29] on different varieties of eggplant revealed the range of leaf blade length as 11.20 cm–37.0 cm and leaf width as 4.70 cm–29.78 cm. Comparing the result of both studies, the range of variation in leaf blade length and width was more diverse in the study attempted at Mauritius as

compared to the present study. The climatic condition in Mauritius favored large leaf blade length and width, but in Pakistan, the climatic condition favored intermediate leaf blade length and width. Environmental factors have a significant impact on plant development and geographic dispersion (where a plant may grow). A plant's development is restricted by unfavorable climatic conditions, especially when it comes to leaf size [34–36].

In the same way, in our present study, other leaf traits such as petiole length ranged between 0.9 cm and 8.2 cm, the average mean petiole length was 3.6 cm which was compared with a studied attempt by [11] where the average mean of petiole length was 7.36 cm, and the range varied between 2.90 cm and 10.61 cm (Table 3). Comparing the result of both studies, there is a large difference in petiole length. In our study, petiole length was comparatively small as compared to [11] in which the petiole length was large. The difference in petiole length may be due to the selection of different eggplant accession, just as the green-colored petiole was more dominant (63.6%) than purple-green (36.4%) in our study (Figure 1).

3.3. Flower and Inflorescence Characteristics. The 22 eggplant accessions showed more diversity in inflorescence and flower characteristics as shown in Tables 3 and 4. In addition to leaf traits mentioned earlier, the most significant characters in the present study were flower and fruit characters compared to various studies earlier performed by [11, 28, 37]. The flower color ranged from purplish to light purplish and white (Table 4). In the present study, variation in flower color showed approximately similar findings to [37]. In our present study, the flower character that was observed in our study was the spine of the flower bud. The flower bud with no spine comprised 68.2% and with a spine 31.8% (Table 4). In the present study, it was noticed that eggplant varieties in which spines were present on flower buds were more resistant to insects followed by spines present on the leaf and then on the stem. The spines of a plant may be a key component for defense against herbivorous insects by limiting their capacity to move and extending the time it takes them to reach feeding grounds. This may lead to prolonged developmental times as well as greater sensitivity or apparency to predators [38, 39]. In the previous studies conducted by [11, 28], no such clue was present. The diversity in the number of petals of a flower was also observed among eggplant accessions, and the number of petals varied from five to seven among eggplant accessions studied as shown in Figure 2. The variation was also observed in the margin of the petal. It was observed that the corolla may have been rounded, pointed, or slightly concave (Figure 2). In our study, the percentage range of variation in flower and bud size showed that small bud size was dominant (68.2%) over large flower bud size (18.2%) and intermediate flower bud size (13.6%) (Table 4). 77.3% of flower bud was green in color and the rest of all with purple-green in our study. In addition to flower color in our present research, the flower with small size was a dominant character with 63.6% over the large flower with 36.4%.

3.4. Fruit Characteristics. In the present study, it was observed that the eggplant varieties show marked variation in fruit characteristics as well. In the present study, 22 different eggplant accessions showed marked variation in the fruiting stage as shown in Figure 3. The diverse variation was observed in fruit color, fruit shape, fruit curvature, fruit glossiness, fruit length, and width (Figure 4). In the present study, the average fruit length ranges from 3.9 cm to 9.2 cm in eggplant accessions (BARI-1 and 7655 (4)) whereas the maximum average fruit weight was observed in eggplant variety PI606711, followed by 004729 (01) and PP-Long (154.1 g, 96.2 g, and 66.0 g, respectively). The variation in fruit length in fruit width showed a small variation to an earlier research study by [40]. In the current research, the fruit shape ranged from lengthy to ovoid and round shape with a wide range of color diversity which included light purple, dark purple, green, yellow, white, grey, black-purple, purple-green, purple white, and whitish-green fruit. The fruit shape in the earlier study of [11] ranged from round, egg-shaped, and elongated, and fruit colors ranged from white, green, purple-red, purple-black, and dark purple-black in different varieties. In our present study, fruit with lengthy shapes was more dominant (54.54%) followed by a round and ovoid shapes (22.73%) each (Figure 4). In an earlier study, [11] found 40.1% round fruits followed by 31.8% elongated and 27.3% egg-shaped fruits. Our present study showed the opposite result in fruit curvature and fruit glossiness to the previous study of [29], and it was observed that the variation in qualitative traits might be due to differences in climatic conditions. The maximum weight of 100 seeds was 0.49 g in eggplant variety PI-381288A and the minimum weight was 0.11 gm in white egg with an average mean weight of 100 seeds being 0.29 gm. The average fruit weight in our study was 39.27 g with a range of variation from 11.7 g to 154.1 g which was compared with the previous research study of [40] in which the fruit weight ranged between 30.77 and 275 g, with an average of 98.75 g. The fruit weight in our study was comparatively less as compared to [40].

3.5. Principle Component Analysis (PCA) and Cluster Analysis. To fully reflect the various factors that played a principal role in the comprehensive indicators, PCA was carried out on nine quantitative traits and twenty-two qualitative traits. The eigenvalues, variance, and accumulative variance were calculated for 9 quantitative and 22 qualitative traits among 22 eggplant accessions as shown in Table 5. Phylogenetic dendrogram based on genetic distance using Unweight Pair Group Method of Arithmetic Means (UPGMA) indicated the segregation of 22 genotypes of eggplant into "out-group" and "main cluster" (Figure 5). The clustering pattern of eggplant varieties obtained in the dendrogram was further investigated through PCA to determine the relationship between plant traits and eggplant accessions. It indicated a set of traits that caused clustering of eggplant accessions into specific groups and the most effectively discriminated between eggplant accessions. The first major out-group had only one eggplant variety PI 606711 placed in G1, and secondly, the main cluster

Table 4: Morphological variation in flower traits of 22 eggplant varieties.

Sr. no	Accession number	Variety name	Flower color	Flower size	Flower bud color	Flower bud spine	Flower bud size
1	018500	Black king	Purple	Large	Green	Absent	Small
2	018502	PP-long	Light purple	Small	Green	Absent	Small
3	019326	004467 (17)	Purple	Large	Green	Absent	Large
4	025913	Mk-95	Light purple	Small	Green	Absent	Small
5	025914	Xiangzue-6	Light purple	Large	Purplish-green	Present	Small
6	025915	White egg	Light purple	Small	Green	Absent	Small
7	025916	A-58	Light purple	Small	Purplish-green	Present	Intermediate
8	025919	004464 (07)	Purple	Small	Green	Absent	Small
9	028377	BARI-1	Purple	Small	Green	Absent	Small
10	028379	004729 (01)	Light purple	Small	Green	Present	Small
11	030859	Badanjan	White	Small	Green	Absent	Small
12	030862	Viserba	Purple	Large	Purplish-green	Absent	Intermediate
13	030874	PI 606711	Light purple	Large	Green	Present	Large
14	033834	Grif-13962	White	Small	Green	Absent	Small
15	033835	PI-362727	Light purple	Small	Green	Present	Small
16	033836	PI-371849	Purple	Small	Purplish-green	Present	Large
17	033837	PI-379545-A	Purple	Small	Purplish-green	Present	Large
18	033839	PI-381288-A	Purple	Small	Green	Absent	Small
19	033840	PI-381288-B	Light purple	Large	Green	Absent	Small
20	036681	7655 (4)	Light purple	Large	Green	Absent	Small
21	036692	7657 (6)	Purple	Small	Green	Absent	Intermediate
22	036690	036690	Light purple	Small	Green	Absent	Small

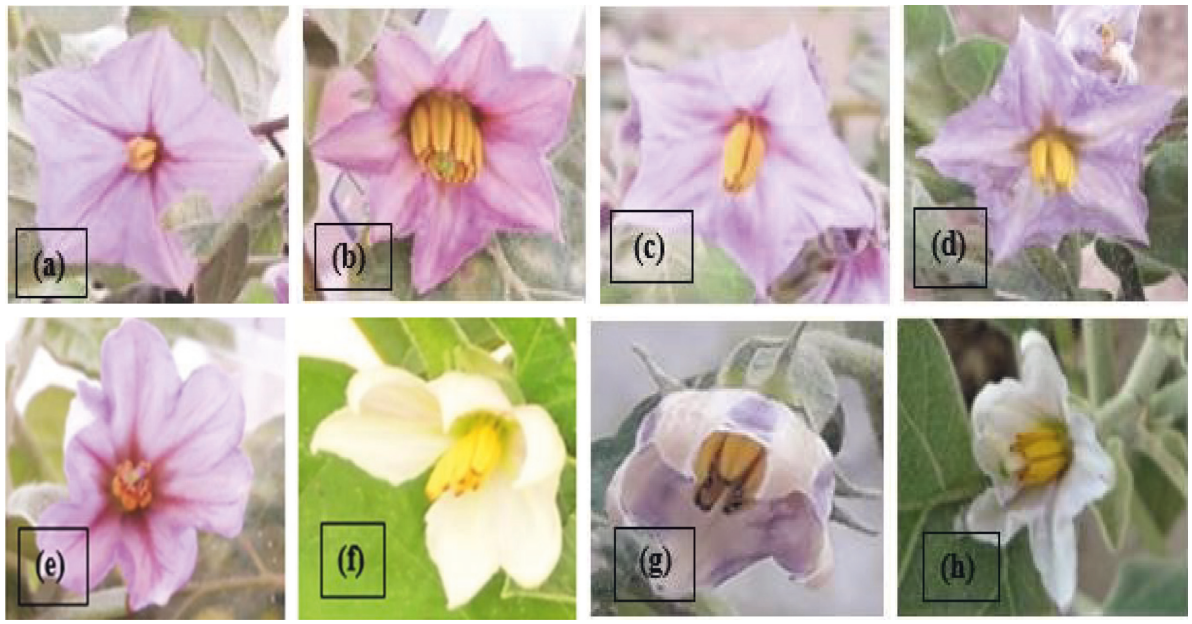

Figure 2: Morphological variation in flower color, number of corollas, and corolla margin among 22 eggplant accessions. (a) Eggplant variety PI-321018 having a light purple colored flower with 5 winged petals. (b) Eggplant variety BARI-1 having a dark purple colored flower with 7 pointed petals. (c) Eggplant variety PI-381288-A having a light purple colored flower with 5 pointed petals. (d) Eggplant variety PI371849 having a light purple colored flower with 5 pointed petals. (e) Eggplant variety PI-606711 having a light purple colored flower with 6 rounded petals. (f) Eggplant variety PI-251506 having a white colored flower with 6 pointed petals. (g) Eggplant variety Xiangzue-6 371849 having a light purple colored flower with 5 pointed petals. (h) Eggplant variety white egg having a white colored flower with 5 pointed petals.

contained twenty-one eggplant genotypes. The main cluster was divided into two clusters (A and B) in which cluster A had four eggplant genotypes placed in G2 including eggplant variety 004729 (01), PP-Long, Badanjan, and Grif-13962. Cluster B consisted of seventeen eggplant genotypes. Cluster B was subdivided into further two subclusters (B1 and B2) in which subcluster B1 had eleven eggplant genotypes which were further placed into two groups (G3 and G4). G3 contained four eggplant varieties including 004467 (17), Xiangzue-6, A-58, and black king whereas G4 had seven eggplant accession including 004464 (07), PI-379545-A, Viserba, Bari-1, PI-371849, 036690, and Mk-95. Subcluster

Figure 3: Continued.

Figure 3: Fruiting stage of 22 eggplant accessions.

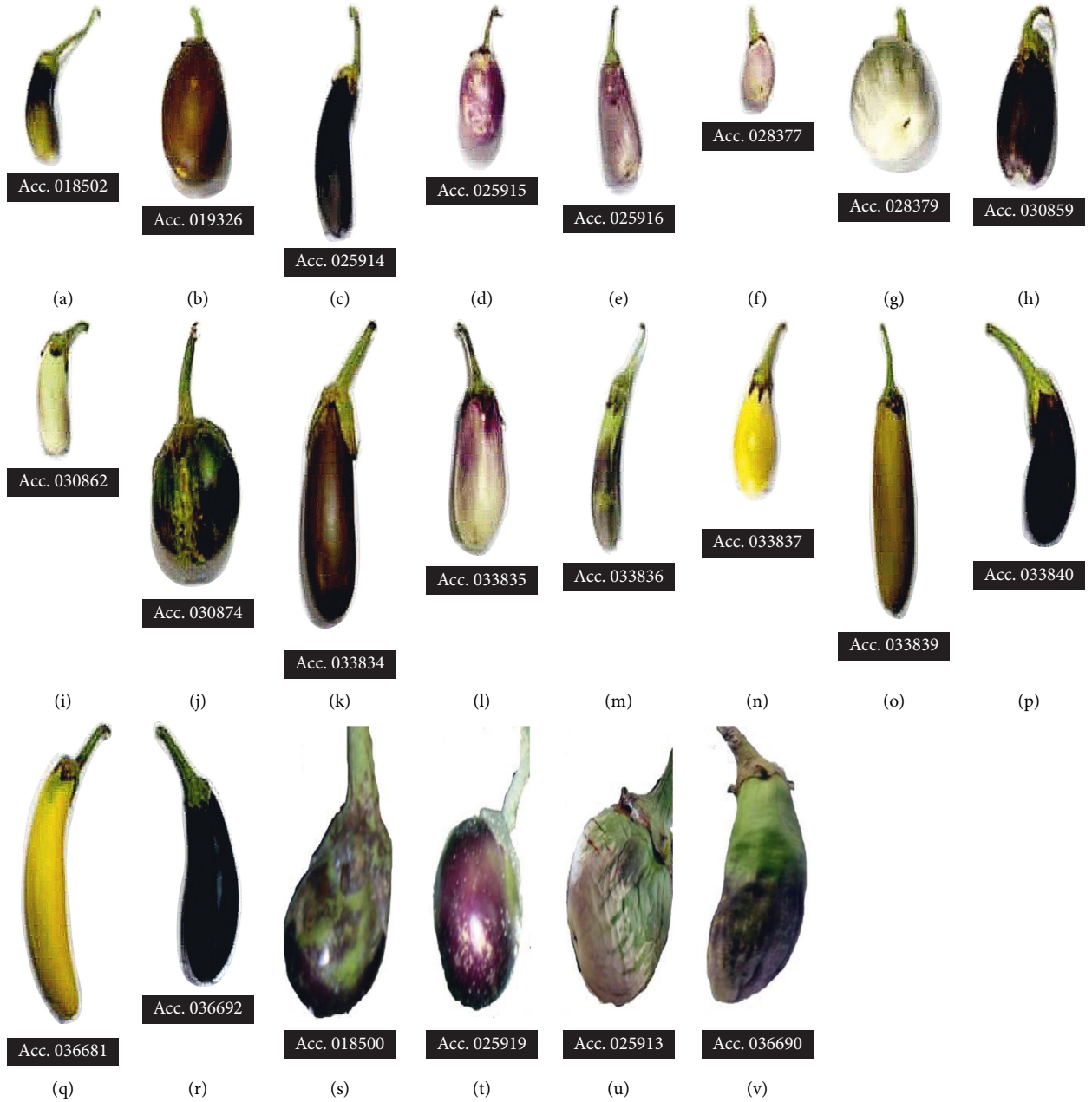

Figure 4: The variation in morphological characters among 22 different eggplant accessions. (a) Eggplant PP-Long (Acc. No 018502). (b) Eggplant variety 004467(17) (Acc. No 019326). (c) Eggplant Xaiangzue-6 (Acc. No 025914). (d) Eggplant white egg (Acc. No 025915). (e) Eggplant A-58 (Acc. No 025916). (f) Eggplant BARI-1 Acc. (No 028377). (g) Eggplant variety 004729 (01) with (Acc. No 028379). (h) Eggplant Badanjan (Acc. No 030859). (i) Eggplant Viserba (Acc. No 030862). (j) Eggplant variety PI 606711 (Acc. No 030874). (k) Eggplant Grif-13962 (Acc. No 033834). (l) Eggplant variety PI-362727 (Acc. No 033835). (m) Eggplant variety PI-371849 (Acc. No 033836). (n) Eggplant variety PI-379545-A (Acc. No 033837). (o) Eggplant variety PI-381288-A (Acc. No 033839). (p) Eggplant variety PI-381288-B (Acc. No 033840). (q) Eggplant variety 7655(4) (Acc. No 036631). (r) Eggplant variety 7657 (6) (Acc. No 036692). (s) Eggplant Black king (Acc. No 018500). (t) Eggplant variety 004464 (07) (Acc. No 025919). (u) Eggplant Mk-95 (Acc. No 025913). (v) Eggplant variety 036690.

B2 had six eggplant accessions including white egg, PI-362727, 7657 (6), PI 381288-A, P1 381288-B, and 7655 (4) which was a group to G5. Multivariate PCA analysis revealed that the first two principle components cumulatively contained 97.174% of the total variance. The highest multivariate variation was observed for PC 1 (90.758%) followed by PC 2 (6.419%). In the present study, every multivariate variation was significant as PC 1 analyzed with any of the principle component axes from PC 2 to PC 21 gave a variance greater than 70%. The PC 2 analyzed with other PC including (PC 3 to PC 21) resulted in nonsignificant multivariate variation except for PC 1 because the variance calculated was less than 70%. The PC 1 contained the highest eigenvalue (1155.07) and percentage variance (90.758%) for plant traits such as

Table 5: Loading score, eigenvalue, percentage variance, and accumulative variance for 9 quantitative and 20 qualitative traits among 22 eggplant accessions.

	PC1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14	PC 15	PC 16	PC 17	PC 18	PC 19	PC 20	PC 21
Plant height	0.155	0.98173	−0.07032	−0.00477	0.017615	−0.04175	−0.04057	0.009888	−0.0216	0.028001	−0.03036	0.015748	0.01487	−0.00315	−0.00273	−0.00181	−0.00788	−0.00298	0.001008	0.006683	−0.00886
Plant branching	0.01383	0.0057849	−0.10066	−0.06062	−0.04623	0.10209	0.099342	0.3229	0.094487	0.13713	0.16702	0.33789	−0.18304	−0.23077	−0.10146	0.028235	−0.12625	−0.40893	0.074271	−0.1725	0.13709
Stem thickness	0.006531	0.020888	0.023635	0.016143	0.051781	0.10646	0.097057	−0.00595	0.25088	0.31793	0.22943	−0.00687	0.097869	−0.22529	−0.03305	0.23391	−0.18739	0.26258	−0.14749	0.032286	0.062521
Stem spine	−0.00179	−0.015175	−0.03649	0.044421	−0.02602	0.003248	−0.03148	−0.11198	−0.03532	0.015122	−0.08877	0.23678	0.067369	−0.012328	−0.03909	0.18569	0.061774	−0.11977	0.15729	0.64243	−0.13991
Stem color	−0.00551	0.012255	−0.00128	0.007607	0.060179	0.056235	0.08448	0.29486	−0.2842	−0.24641	−0.2154	−0.08356	−0.09187	0.22518	0.020389	−0.14249	0.17067	−0.01814	−0.10148	0.017846	0.49005
Stem hairness	0.007502	0.0015029	−0.0177	0.037283	0.29305	0.051448	0.36606	−0.0493	−0.02244	0.29181	−0.16673	−0.23717	0.049281	0.10869	−0.00772	0.072564	−0.01479	−0.02606	−0.05741	−0.0816	−0.02615
Leaf blade color	−0.00068	0.0085899	0.009559	0.040683	−0.05674	0.03223	0.17486	−0.11356	0.013249	0.005701	−0.0281	0.090871	0.06333	−0.05068	0.57787	0.21967	−0.30277	−0.09664	0.26926	−0.15564	0.31645
Leaf lobe	0.00426	−0.038645	−0.032314	0.020568	0.21063	−0.00576	−0.20437	0.096753	0.21005	0.14123	−0.40166	0.021374	0.50611	−0.32885	0.14307	−0.31895	0.1632	−0.22632	−0.04862	0.016051	0.077101
Leaf length	0.01221	0.077923	0.57491	0.26184	−0.17915	0.38746	0.044655	−0.141641	−0.00807	−0.14667	0.090616	−0.34188	−0.06146	−0.34564	0.07499	−0.17668	0.085746	−0.02924	0.13255	0.063858	−0.01221
Leaf width	0.001112	0.024514	0.5491	0.20285	−0.00061	0.15936	−0.117561	0.078078	0.13076	0.26575	−0.17494	0.43357	0.061592	0.44285	−0.11759	0.1098	0.070505	0.00328	−0.10007	−0.16749	0.041351
Leaf spine	−0.00238	−0.228084	−0.02133	−0.01002	−0.04945	0.084123	0.004982	−0.04961	−0.12169	0.030528	−0.16657	0.26622	−0.03319	−0.06111	−0.11071	0.099297	−0.07283	0.068788	0.007556	0.42783	0.19561
Petiole color	−0.00336	0.0057486	0.031241	0.080202	0.001843	0.00649	0.04379	0.18851	0.054689	−0.11422	−0.25695	−0.10095	0.03877	0.33801	0.17713	−0.1207	−0.19661	0.14042	0.097217	0.252251	−0.13097
Petiole length	0.032717	0.0045837	0.22358	0.21569	0.66615	−0.17765	0.10917	−0.12964	−0.16593	−0.28442	0.29924	0.25695	−0.01187	−0.10379	−0.17054	−0.11694	−0.1087	−0.05881	−0.09759	0.015341	0.041662
Leaf hairness	0.007502	0.0015029	−0.0177	0.037283	0.29305	0.051448	0.36606	−0.0493	−0.02244	0.29181	−0.16673	−0.23717	0.049281	0.10869	−0.00772	0.072564	−0.01479	−0.02606	−0.05714	−0.00816	−0.02615
Flower bud size	0.003503	0.010846	0.008134	0.014206	0.10901	.013106	−0.00926	0.45286	0.27689	−0.30047	0.13623	0.000959	0.37579	−0.06284	−0.03056	0.17549	−0.07743	0.18688	−0.07437	−0.05195	−0.17432
Flower bud color	−0.00351	0.0089068	0.044116	0.061204	0.028217	−0.01801	0.090574	0.18989	0.075729	−0.05904	−0.01467	0.031384	0.13479	0.15797	0.15884	−0.11836	−0.1603	0.12038	0.050993	0.29929	−0.01335
Flower bud spine	0.00439	0.012537	0.057557	0.063207	0.036401	0.003689	0.089871	0.15433	−0.12191	−0.07534	0.14423	−0.0065	0.13706	0.044399	0.093765	0.15668	−0.15972	−0.0914	0.3211	0.031246	0.17914
Flower size	0.001069	0.0056793	−0.01271	0.048745	0.17133	−0.06795	0.060502	−0.22811	0.16602	0.09852	0.05393	0.088413	0.046265	0.16777	0.15585	0.2992	0.53934	−0.012536	0.35565	−0.06608	−0.017572
Flower color	0.008012	−0.020404	−0.00089	0.044897	0.030866	−0.10929	−0.02871	−0.1264	−0.16092	0.34064	0.053755	0.20034	0.079536	−0.10658	−0.01311	−0.39198	−0.02955	0.41743	0.32122	−0.04607	0.14509
Fruit color	0.022461	−0.011648	−0.51912	0.56228	0.002092	0.55876	0.011283	−0.1503	0.049952	−0.06775	0.029842	0.1117	0.02553	0.08581	−0.0404	−0.08336	0.033614	0.032033	−0.09133	−0.03642	0.036698
Fruit length	0.008351	−0.036357	−0.06551	0.32249	0.24711	−0.14057	−0.65216	0.17188	−0.00866	0.21148	0.11617	−0.29368	−0.14101	0.070112	0.057964	0.15926	−0.01748	−0.03211	0.19111	0.024094	0.14506
Fruit width	0.028671	0.0046997	−0.0026	−0.16414	−0.11169	0.044751		−0.15927	−0.33539	−0.10398	0.052946	0.44872	−0.05927	0.45368	0.2601	0.12886	−0.02812	0.003799	−0.20384	−0.35694	0.10921
0.24286																					
Fruit shape	0.002272	−0.002086	−0.07583	−04.16286	−0.00625	0.17419	0.17541	0.24594	−0.0701	0.096611	0.29907	0.055921	0.10956	0.10669	0.02421	−0.30972	0.32326	−0.12618	0.27093	0.037406	−0.06629
Fruit curvature	−0.00329	−9.11E-05	0.022745	0.033297	0.051808	−0.11044	0.024256	−0.04882	0.15527	−0.1962	−0.1761	0.11017	−0.15056	−0.18344	0.29786	0.11852	0.19834	0.056142	−0.30355	0.034715	0.23052
Fruit brightness	0.001192	−0.000971	0.05288	−0.0457	−0.03626	0.065771	0.08796	0.13596	0.001223	0.098336	0.062612	−0.25093	0.073821	−0.08798	−0.40343	0.29292	0.20372	−0.02641	0.068678	0.19233	0.36995
Fruit firmness	−0.00346	−0.00059	−0.08452	−0.0584	−0.05673	−0.00111	−0.01578	−0.16313	−0.0674	−0.2656	−0.14438	0.045706	0.33485	−0.03202	−0.25622	0.16136	0.053153	0.38756	0.24424	−0.26413	0.18744
Av. fruit weight	0.98576	−0.15537	0.00859	−0.00201	−0.03981	−0.0238	0.013119	0.015221	−0.00134	−0.00845	−0.02651	−0.00843	−0.00665	0.002135	0.001237	0.009642	0.002457	0.006223	0.006231	−0.00149	−0.01316
No of locule	0.031566	0.0053395	0.044079	−0.57674	0.39897	0.5448	−0.26712	−0.09607	0.086938	−0.0361	−0.04805	0.03235	−0.21985	0.054093	0.091383	0.005943	−0.05363	0.13323	0.085814	0.038544	0.048815
Seed Weight (100 seed)	−0.00021	0.0025502	−0.00515	0.003371	0.001102	−0.00959	0.011854	−0.01708	0.039551	−0.01035	0.023257	−0.03648	−0.06142	0.059764	0.084533	0.012119	−0.07393	0.12525	−0.02153	0.095487	−0.010297
Seed abundance	0.009342	0.017685	−0.0258	0.014566	−0.0217	−0.18784	0.13502	0.004151	0.55273	0.032934	0.2394	0.012158	−0.22577	0.060072	0.067384	−0.19614	0.25161	0.24901	−0.02954	0.13694	0.30172
Insect attack	0.000479	0.014482	−0.01157	−0.03097	−0.01026	−0.07141	0.004462	−0.26966	0.47492	−0.18216	−0.14643	−0.12328	0.005003	0.19281	−0.34815	−0.20461	−0.34477	−0.31884	0.24053	0.013736	0.14611
Eigenvalue	1155.07	81.7029	13.958	6.47008	3.81658	3.28145	1.94754	1.18424	1.1161	0.930796	0.742969	0.613688	0.156757	0.373451	0.260828	0.230084	0.167371	0.099952	0.078799	0.046873	0.030798
Variance	90.758	6.4197	1.0967	0.50838	0.29988	0.25784	0.15303	0.09305	0.087696	0.073136	0.062307	0.04822	0.040603	0.029343	0.020494	0.018079	0.013151	0.007854	0.006192	0.003683	0.00242
Accum variance	90.78	97.1747	98.2714	98.77978	99.07966	99.3375	99.49053	99.358	99.67128	99.74441	99.80672	99.85494	99.22489	99.92489	99.44538	99.66346	99.97661	99.88446	99.99066	99.99434	99.99769

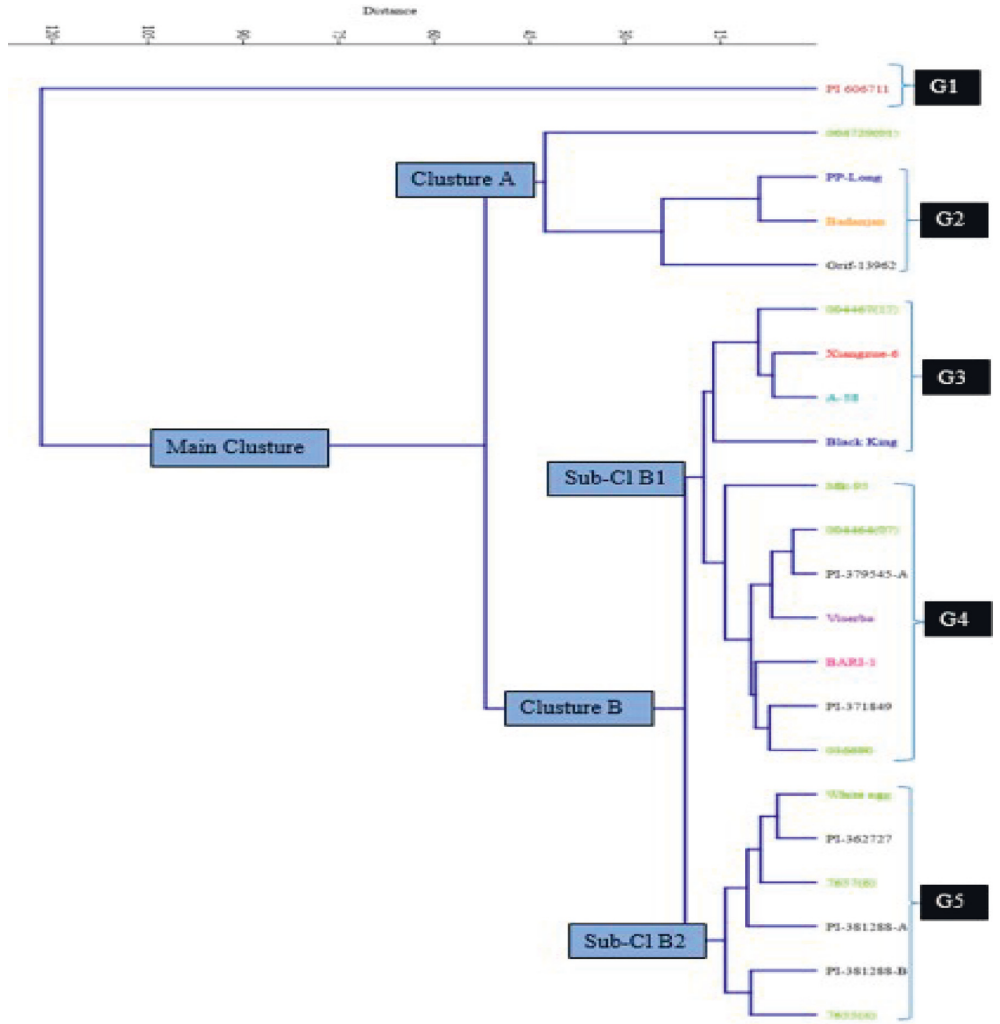

Figure 5: UPGMA dendrogram constructed from morphological data showing a genetic relationship among 22 eggplant genotypes.

average fruit weight, plant height, and leaf length. The PC 2 had an eigenvalue of 81.70 and percentage variance (6.419%) for plant traits including plant height, flower bud size, and stem color. The PC 3 had less eigenvalue (13.958) and percentage variance (1.096%) for plant traits such as leaf length, leaf width, and petiole length. The PC 4 was comprised of an eigenvalue of 6.470 and a low percentage variance (0.508%) characterizing morphological traits including fruit color, fruit length, and leaf length. The PC 5 contained a low eigenvalue (3.816) along with percentage variance (0.299%),and plant traits such as petiole length, number of locules, and stem hairiness. Similarly, the PC 6 consisted of a low eigenvalue (3.281) with less percentage variance (0.257%) and accounted for fruit color, number of locules, and leaf length. The eigenvalue was less than 3 for PC 7 to PC 21 with the least accumulative percentage variance of approximately 0.5% for various plant traits. Similarly, in the present study, the multivariate variation using PCA and clustering analysis used for the construction of dendrogram among 22 eggplant accession were done. Similarly, [41] worked on 40 eggplant accessions, and they also studied multivariate analysis using PCA, and in the present research study, a significant percentage variance was observed for PC 1 (90.758%) and PC 2 (6.419%) having the highest eigenvalue of 1155.07 and 81.70 while the previous study performed by [41] showed percentage variance for PC 1 (17.07%) and PC 2 (13.53%) having eigenvalue of 5.292 and 4.195. By comparing the results of both studies, it was observed the present study had significant percentage variation with the highest eigenvalues as compared to the previous study.

3.6. Scatterplot Analysis. The two-dimensional scattered plot was constructed between PC 1 and PC 2 in which PC 1 was plotted on the *x*-axis and PC 2 on the *y*-axis as shown in Figure 6. In the present study, based on nine quantitative and twenty-two qualitative characters, 22 eggplant accessions were distributed in the same group. The five groups assigned for 22 eggplant varieties were Group 1, Group 2, Group 3, Group 4, and Group 5.

Group 1: the eggplant accession PI 606711 belonged to the USA ecogeographical area and was allotted into a separate group and it was observed that PI 606711 had distinguishing features from other eggplant accessions.

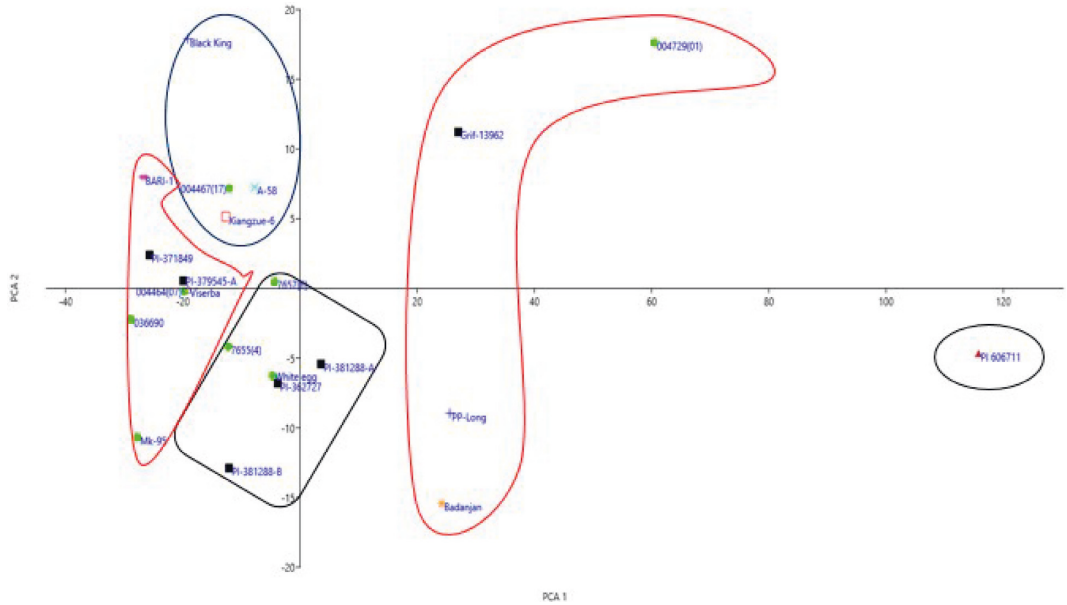

Figure 6: First (*X*-axis) and (*Y*-axis) principle components (90.758% and 6.419% of total variation explained, respectively) among 22 eggplant accessions (Pakistani and foreign eggplant accessions).

Among 22 eggplant varieties, PI 606711 has distinguished features such as the highest average fruit weight, highest petiole length, spiny flower bud, flower color, fruit color, fruit shape, number of locules (11), and the fruit width approximately equal to fruit length.

Group 2: the eggplant varieties including 004729 (01), Grif-13962, PP-Long, and Badanjan were placed into the same group because they possessed nearly identical morphological features. The eggplant accessions having similarities in morphological parameters are small flower, petiole length, stem color, petiole color, flower bud color, flower bud size, fruit brightness, and seed abundance (many).

Group 3: the eggplant accession belonged to different ecogeographical areas including A-58, 004467 (17) (Pakistan), black king (India), and Xuangzue-6 (China) was placed in the same group on the basis of morphological parameters. These parameters included fruit length, less average fruit weight, seed weight, seed abundance (many), spineless leaf blade, and spineless stem. The morphological parameters which allotted them into the same group (G1 and G2) were opposite to G3.

Group 4: the eggplant varieties from the different ecogeographical regions having similar morphological features were placed in the same group including Mk-95, 036690, Viserba, 004464 (07), PI-379545-A, PI-371849, and BARI-1. The similar morphological features in them are stem color, lowest average fruit weight, flower color, and small flower size.

Group 5: the exotic eggplant varieties including 7657 (6), 7655 (4), white egg, and Pakistani eggplant varieties PI-362727, PI-381288-A, and PI-381288-B were assigned to the same group on the basis of similar agromorphological traits. These included open plant branching, flower bud color, flower bud size, fruit width, average fruit weight, petiole length, and spineless leaf blade.

4. Conclusion

In the present research work, the diversity in local and foreign eggplant varieties was carried through nine quantitative and twenty-two qualitative traits in which wide variation is present in plant, leaf, flower, and fruit characteristics. However, morphological data along with molecular data can be used for the precise characterization of *Solanum melongena* germplasm resources. Such studies can help farmers and plant breeders to select the best cultivars.

Data Availability

All the data used to support the findings of the study are available within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

All the authors contributed equally.

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