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Agro-morphological characterization and genotypic diversity of chilli (*Capsicum. frutescens*) landraces of Bangladesh

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Abstract

Samples of 82 chilli (*Capsicum* spp.) genotypes grown during the Rabi season of 2016-17 were characterized based on 28 qualitative and 7 quantitative agro-morphological markers. The genotypes were collected and conserved in the Plant Genetic Resources Centre (PGRC) of the Bangladesh Agricultural Research Institute (BARI). The Chi-square (χ^2) tests and the Shannon Diversity Index (H´) were used for the genetic diversity study. All the characters under study were distributed independently except cotyledon leaf shapes and leaf pubescence density. The values of H´ of the genotypes varied widely, the maximum values being observed for the cotyledon leaf shape, leaf density, and anthocyanin leaf spot on the fruit. In contrast, the lowest values were recorded for pigmentation of node and leaf color. The estimated coefficient of variation was the highest while it was the lowest for one thousand seed weights. No variation was observed for calyx annular constriction of fruit. Analytical functions of DIVA-GIS (Geographic Information System) mapping localized the accessions into 10 districts and marked the areas of insufficient collection. Accession AMA-248 belonging to Mymensingh was almost round fruit. Accessions RAI-232 and RAI-80 belonging to Chattogram, AMA-335 belonging to Sherpur, AMA-361 belonging to Jamalpur, RAI-80 belonging to Chattogram, and AHI-01 belonging to Jhenaidah were elongated fruit. Germplasms collected from Chattogram showed the maximum variation in traits of cotyledon leaf color and stem color at the seedling transplanting age. The variation observed in different characters could be important characters in selecting parents for breeding programs.

Keywords: Bangladesh; *Capsicum*; Chi-square test; Diversity; Characterization; Chilli

1. Introduction

Chilli (*Capsicum annum* L.) is an important spice in Bangladesh because of its widespread culinary usage among Bangladeshis and its nutritional value. It is one of the income-generating crops for farmers, grown in both summer and winter. The crop belongs to the genus *Capsicum* which includes 31 species of which 26 are wild and five are cultivated, the latter species being *Capsicum annuum* L, *C. frutescens* mill, *C. baccatum, C. chinense and C. pubescens* [1]. It is self-pollinated and the occurrence of cross-pollination leads to the development of variants to adapt to versatile climatic conditions [2]. These well-adapted local populations are under threat of extinction due to the release and cultivation of modern varieties. Disappearing of landraces from the geographic regions, termed as genetic erosion of local varieties *in*

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situ causes the irreversible loss of genes responsible for the expression of unique agronomic traits such as adaptability, resistance, and/or tolerance to diseases and abiotic stresses [3]. Regarding the effect of genetic erosion of crops and crop varieties *in situ*, the Bangladesh Agricultural Research Institute (BARI), has collected local crop varieties for *ex-situ* conservation where they are used to develop patented varieties and are then released for cultivation in the country. The Plant Genetic Resources Centre (PGRC) acts as the germplasm storehouse of BARI. *S*ince its inception in 1983, PGRC has collected 11083 germplasm of 83 crops. Among the collections, chilli germplasm constituted about 355 [4]. Standard morphological characterization of germplasms is being routinely carried out at PGRC to identify germplasm to enhance crop improvement programs and efficient management of the genebank. Qualitative characters are controlled by a single or a few major genes and exhibit distinct phenotypic variations, showing no intermediate forms. Unlike qualitative characters, quantitative characters are influenced by multiple genes and environmental factors, making their inheritance more complex. The present investigation was therefore designed to identify the gaps in chilli germplasm conservation and fill them up at PGRC, characterize new germplasm for various morphological and agronomic traits, and identify diverse trait-specific accessions. A total of 28 qualitative and 14 quantitative traits were recorded for this study.

2. Materials and Methods

The experiment was conducted in the Plant Genetic Resources Centre (PGRC) of the Bangladesh Agricultural Research Institute (BARI), Gazipur, during the Rabi season of 2016-17. Analytical functions of the DIVA-GIS (Geographic Information System) computer program were used to localize the accessions to administrative boundaries (Districts). Grids of approximately 20x20 km were marked on a DIVA-GIS-generated map along the longitude and latitude division/degrees. All grids, which accommodate candidate germplasm were then identified and the number of germplasm was determined per grid. The grids were then coded by alphabetic sequence along the longitude started by A up to M and along the latitude by numeric sequence started by 01 up to 15. Details of the localities (districts) along with geographical notations are presented in Table 1 and in Fig. 1. For the field experiment, seedlings of representative germplasm were raised in the seedbeds and 35-day-old seedlings were transplanted in the well-prepared land on 23 October 2016. The plot size was 3x2.1 m^2. Each germplasm was planted in a plot of three rows having five pits in each. A spacing of 70x60 cm was provided between row to row and plant to plant. Recommended doses of manures and fertilizer were applied following standard application methods. Weeding, mulching, and plant protection measures were done as and when necessary. Harvesting of chilli was done at the mature green stage when a few fruits changed color from green to red. Morphological data (28 qualitative and 14 quantitative traits) were recorded using the standard descriptors for characterization [5]. Qualitative traits were used to evaluate the diversity of the germplasm.

2.1. Data analysis

Qualitative morphological characters were assessed through frequency distribution while in the case of quantitative agro-morphological characters, frequency distribution, and descriptive statistics analysis of germplasm were performed for all the characters. Descriptive statistics, the Shannon Weaver Diversity Index (H'), and frequency distribution were employed to estimate and analyze the diversity via MS Excel.

2.2. Chi-square (χ2) tests

The chi-square test (χ2) was used to compare the observed and the expected frequencies for each character [6]. To calculate the expected frequencies for a uniform distribution, the total of the observed frequencies was divided by the number of categories. The critical value (χ2c) at 95 % level of significance was determined based on the degree of freedom (df) and the inference was made under the following decision: Reject H0 if χ2 *> χ2c (χ2 * is the calculated value, df = k-1 where k is the number of categories).

2.3. Shannon-Weaver index of diversity

Phenotypic diversity for both qualitative and quantitative traits was determined by using the Shannon-Weaver Diversity Index (H′). H′ ranges from 0 to 1, where 1 indicates the maximum diversity. H'= -Pilog2Pi

In the above formula, Pi indicates the proportion of the total genotypes belonging to the i^{th} class. The exact descriptor states define the classes for the qualitative characters while the classes for quantitative characters are defined according to the procedure suggested by Yu Li et al. (1996) [7] where each H' value was standardized. MS Excel Package program was used to determine the H′ value. The H′ for each character was calculated using MS Excel. Test statistic H0: H'=0. H' classifies as high when ≥ H ´0 .66, moderate when H´= 0.34- 0.66 and low variation when H´< 0.33 [2].

3. Results and Discussion

3.1. Location and Collection sites

Analytical functions of the DIVA-GIS (Geographic Information System) computer program based on the grid mapping technique have localized accessions into 10 administrative units (Districts). Superimposing the grids of 20x20 km squares on the DIVA-GIS- map has visualized the collection sites and their ecological affinities (Fig. 1). It appears from the GIS map the maximum number of germplasms belonged to Mymensingh, Chattogram, and Jamalpur districts. Out of 82, only two germplasms belong to Jhenaidah and three to each Gazipur, Nilphamari, Tangail, and Thakurgoan (Table 1). Some germplasm collection sources belonged to several districts but, there exist close ecological relationships between them. Even though some germplasm collection sources belong to a district, there is no strong ecological relationship between them due to the existing geographical distances between them. Several studies have shown that contrasting ecological conditions may have a strong influence on the genetic differentiation of local populations [8]; [9]. Early reports also imply that distance-induced climate heterogeneity of sites accounts for shaping the genetic variation of plants [9]; [10]; [11]. Environmental changes with geographical gradients may also influence plant genetic diversity. Evidence is accumulating that environmental changes with geographical gradients (e.g., temperature and precipitation), influence plant genetic diversity [12]. The GIS map reveals that Mymensingh, Jamalpur, and Sherpur are nearby although each of them is administratively considered as separate units. The results are the evidence of prevailing environments and ecology of these three districts that plants can detect and respond to are likely to be homogenous as compared to that of Chattogram [13]. It is to be noted that, the climate of Bangladesh ranges from tropical to sub-temperate but due to frequent seasonal changes and latitude-longitude differences, weather variations are evident from time to time and region to region.

Table 1 Details of location for each genotype and code information (Corresponded to Fig. 1)

Sl. No.	District	Grid on GIS Map (Nos)	Total grid	Number of germplasm	CV%	Germplasm code (Collector's Number)
1	Chattogram	J-5, J-6, K-4, K-5, K-6, L-4	6	15	28.87	RAI-115, RAI-80, RAI-95, RAI-100, RAI-156, RAI-160, RAI-190, RAI-232, RAI-83, RAI-67, RAI-145, RAI-188, RAI-205, RAI-228
2	Gazipur	G-9	1	3	19.18	MAH-29, MAH-40, MAH-41
3	Jamalpur	E-12, F-11, F-12, G-11	4	10	18.03	AMA-285, AMA-320, AMA-325, AMA-343, AMA-349, AMA-358, AMA-361, AMA-361/1, AMA-344, AMA-361/3
4	Jhenaidah	C-8	1	2	8.39	AHI-1, AHI-6
5	Mymensingh	G-10, G-11, H-10	3	27	22.95	AMA-187, AMA-191, AMA-225, AMA-226, AMA-240, AMA-246, AMA-254, AMA-112, AMA-118, AMA-128, AMA-146, AMA-153, AMA-174, AMA-203, AMA-56, AMA-73, AMA-74, AMA-75, AMA-90, AMA-95, AMA-139, AMA-163, AMA-164, AMA-175, AMA-199, AMA-248, AMA-283
6	Narayanganj	G-8	1	7	17.60	MAH-18, MAH-36, MAH-11, MAH-38 MAH-39, MAH-42, MAH-43
7	Nilphamari	C-13, C-14	2	3	6.56	RAI-292, RAI-259, RAI-258
8	Sherpur	E-12, F-11	3	9	31.48	AMA-297, AMA-335, AMA-415, AMA-296, AMA-307,

						AMA-333, AMA-391, AMA-408, AMA-416
9	Tangail	E-9, F-9	2	3	20.60	AMA-37, AMA-51, AMA-23
10	Thakurgaon	A-14, B-14	1	3	-	RAI-261, RAI-260, RAI-263
		Total=	23		82	

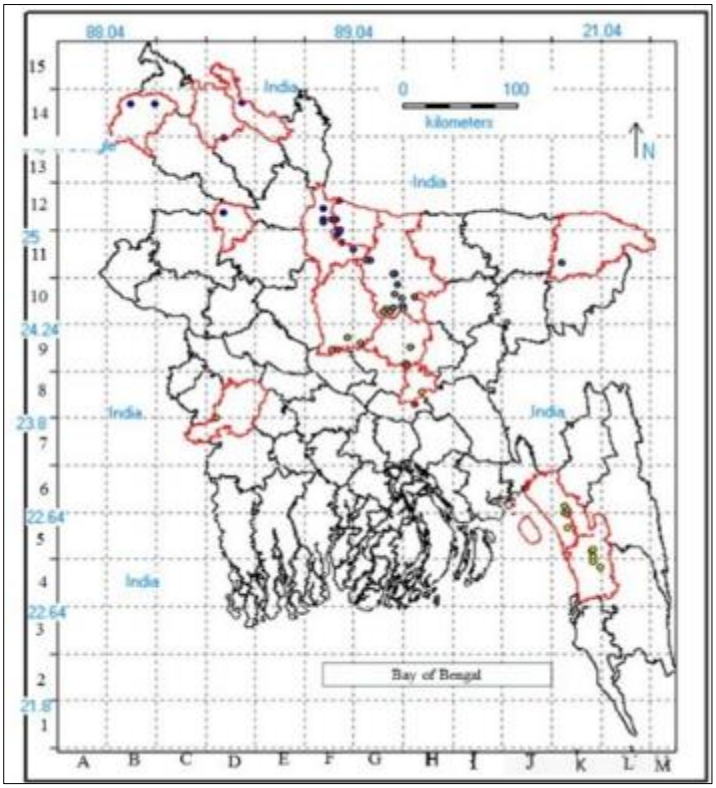

Figure 1 Collection sites of germplasm under study (population code corresponds to those given in Table 1

3.2. Morphological characterization

There are several procedures of characterization which include morphometric, biochemical, cytological, and molecular methods. Initially, morphological markers were used for diversity analysis and are still in use. It is a direct method, inexpensive, easy does not require expensive technology, and can be done based on both qualitative and quantitative traits. Qualitative traits are more stable than quantitative ones, help in determining the distinctiveness of a particular genotype under different agroclimatic conditions, and have profound effects on plant value and utilization. Quantitative traits on the other hand are measurable, economically important phenotypes and do not show clearcut differences. Scoring qualitative traits is an alternative to molecular techniques to assess genetic variation in plant germplasm. Considering the aforesaid facts the germplasms were characterized based on 28 qualitative traits. Descriptive statistics, Chi-square Tests (χ^2), and Shannon Diversity Indices (H') were used to show the extent of variability.

- ***Cotyledon leaf characteristics:*** Cotyledon is the first part of a plant to emerge from the seed in epigeal germination. It is the primary leaf in the embryo of higher plants and functionally similar to leaves. Cotyledon provides nutrients to developing embryos. As this reserve is used up, cotyledon turns green and begins photosynthesis. Five (5) observed phenotypic classes of cotyledon leaf shape and leaf color indicated cotyledon leaves were polymorphic. Distributions of each phenotype of cotyledon were independent except for cotyledon leaf shape. Two categories of cotyledon leaf shapes as described (1) ovate and (2) lanceolate were documented in the germplasms (Table 2). An early report on diversity analysis of 60 chilli genotypes of Bangladesh also documented equal distribution of ovate and lanceolate cotyledon-shaped were equally distributed [14].
- ***Stem characteristics at transplanting age:*** Eight phenotypic classes indicating polymorphism of stem of seedlings at transplanting age. The observed phenotypes were stem color described as (a) green (b) green with

purple strips and (c) purple; stem pubescence density as (a) spares, (b) intermediate, and (c) dense; pigmentation types at nodes as (a) green (b) purple. A higher frequency was observed for stems with green purple strip, sparse stem pubescence, and green pigmentation at the node (Table 2). Stem pigmentation is genetically controlled and develops possibly in response to abiotic stresses [15]. The presence of anthocyanin or any pigmentation at the stem in chilli was reported before as the response of plants to abiotic stresses such as drought, low temperature, and ultraviolet radiation [16]. Pubescence consists of the layer of hairs (trichomes) extending from the epidermis of the above-ground plant parts including the stem and occurs in several forms such as straight, spiral, stellate, hooked, and glandular [17]. Variations of stem pubescence among the genotypes in chilli were reported earlier as a defensive organ against insect pests and pathogens [18].

Table 2 Qualitative traits of cotyledons leaf and seedlings at transplanting age

Descriptor	Observed phenotype	Frequency (n=82)	Expected	Value of χ^2	χ^2 – test
Cotyledons leaf shape	Ovate	39 (47.56)	41	0.2NS	0.65
	Lanceolate	43 (52.44)	41		
Cotyledons leaf color	Light green	54 (65.85)	27.34	44.94	00
	Green	23 (28.05)	27.34		
	Purple	5 (6.10)	27.34		
Stem color	Green	9 (10.98)	27.34	105.51***	00
	Green with purple strips	71 (86.59)	27.34		
	Purple	2 (2.44)	27.34		
Stem pubescence density at transplanting	Sparse	40 (48.78)	27.34	09.97*	0.006
	Intermediate	17 (20.73)	27.34		
	Dense	25 (30.59)	27.34		
Pigmentation at node	Green	3 (3.66)	41	119.28***	00
	Purple	79 (96.34)	41		

(within the parenthesis, the percent of observed values)

- ***Leaf characters:*** Three categories of leaf shape viz deltoid, ovate, and lanceolate were observed in the genotype. Lanceolate leaf shape dominated while deltoid occurred very less in the genotypes. In a report of previous study on morphological characterization of fifteen (15) chilli accessions also observed lanceolate leaf shape was dominating in the genotypes [19]. Variations were also observed in leaf-anthocyanin pigmentation; leaf pubescence density and leaf margin (Table 3). Distributions of germplasm for each character were independent as compared to the expected number of their equal distribution of each character. Earlier it has also been reported that the dark green color of leaves is generally due to the presence of high chlorophyll content in the leaves which ultimately leads to increased yield hence, it becomes a good criterion for the selection of elite cultivars [20].

Table 3 Distribution of germplasm based on leaf character

Descriptor	Observed phenotype	Frequency	Expected	Value of χ^2	χ^2 –test
Leaf shape	Deltoid	1 (1.22)	27.34	130.74***	00
	Ovate	5 (6.10)	27.34		
	Lanceolate	76 (92.68)	27.34		
Leaf color	Green	79 (96.34)	41	119.28***	00
	Variegated	3 (3.66)	41		

Leaf pubescence density	Sparse	67 (81.71)	27.34	87.22***	00
	Intermediate	11 (13.41)	27.34		
	Dense	4 (4.88)	27.34		
Leaf margin	Entire	59 (71.95)	41	15.80***	0
	Undulate	23 (28.05)	41		
Leaf density	Sparse	27 (32.93)	27.34	0.90 ns	0.52
	Intermediate	24 (29.27)	27.34		
	Dense	31 (37.80)	27.34		

- ***Branching plant growth habit:*** Branching habits and plant growth habits develop the canopy structure and height of the plant. Three types of branching habits described as (a) sparse (b) intermediate and (c) dense were observed in the genotypes where the intermediate type was found to dominate while sparse branching was shown by very less genotypes. Three types of plant growth habits were described as (a) prostrate (b) intermediate and (c) erect types where erect type growth was shown by maximum genotypes while prostrate and erect type growth was shown by very less genotypes (Table 4). Different studies of the past reported that okra accessions erect plants with intermediate or erect-type growth habits with medium or strong branching lead to higher yields [8]; [21]. The growth habit could also be subject to different cultivation procedures in the traditional cropping system [22].

Table 4 Growth habit of chilli landraces under study

Descriptor	Observed phenotype	Frequency	Expected	Value of χ^2	χ^2 –test
Branching habit	Sparse	9 (10.98)	27.34	36.02***	00
	Intermediate	52 (63.41)	27.34		
	Dense	21(25.61)	27.34		
Plant growth habit	Prostrate	3 (3.66)	27.34	114.58***	00
	Intermediate	73 (89.02)	27.34		
	Erect	6 (7.32)	27.34		

Table 5 Flower morphology of chilli landrace

Descriptor	Observed phenotype	Frequency	Expected	Value of χ^2	χ^2 –test
Flower position	Pendant	21 (25.61)	27.34	13.63**	0.001
	Intermediate	43 (52.44)	27.34		
	Erect	18 (21.95)	27.34		
Corolla color	Light yellow	76 (92.68)	27.34	130.00***	00
	Yellow	2 (2.44)	27.34		
	Purple	4 (4.88)	27.34		
Anther color	Pale blue	32 (39.02)	41	3.95*	0.004
	Blue	50 (60.98)	41		
Filament color	Yellow	73 (89.02)	27.34	114.87***	00
	Light purple	2 (2.44)	27.34		
	Purple	7 (8.54)	27.34		
Stigma position	Inserted	13 (15.85)	27.34	20.95*	0.0004

	Same level	23 (28.05)	27.34		
	Exerted	46 (56.10)	27.34		
Calyx margin shape	Entire	4 (4.88)	41	66.78***	00
	Intermediate	78 (95.12)	41		
Calyx pigmentation	Absent	78 (95.12)	41	66.78***	00
	Present	4 (4.88)	41		

- ***Flower characteristics:*** The flower itself comprises most of the evolutionary innovations of flowering plants. Polymorphism in flower form and size of species and even population foster interaction with novel kinds of pollinators, enemies, and abiotic stresses [23]; [24]. We studied 7 qualitative traits of flower morphology. Two or more forms and sizes of each of the 7 traits indicate the presence of high polymorphism in flower traits. Altogether, we observed 18 distinct phenotypic flower forms with the highest discriminant values (Table 5). The results are in support of the report of a scholar [25] who studied and reported that the flower and its position in the axile were the characters with the highest discriminant values which could be used to establish genetic differences between groups.
- ***Fruit characteristics****:* Fruits of chilli plant are the economic parts and undergo human selection and discriminating variability within a collection. The accessions showed phenotypic variations concerning fruit pigmentation, fruit shape, and color at the intermediate stage and mature stage. The purple characteristic of fruits indicates the presence of phenolic compounds called anthocyanin in their tissues [26]. These compounds have several biological functions including attracting pollinators and preventing photo-oxidative damage [27]. From a human physiological standpoint, phenolic compounds are vital in defense responses, such as anti-aging, anti-inflammatory, antioxidant, and anti-proliferative activities [28]; [29]. We recorded, four categories of fruit shape namely (a) elongated (b) almost round (c) triangular, and (d) blocky fruit which were distributed independently. Germplasm with a higher percentage of elongated fruits were observed. Variabilities were also observed at peduncle attachments, shape at the blossom end of the fruits, neck marker at the base, and phenotypes of the cross-section of fruits (Table 6). Almost similar results in fruit phenotypes of chilli genotypes were reported by many scholars [16]. Attractive fruit color, lesser fruit pubescence, and smooth fruit texture are the factors that determine the consumer acceptability of chilli. Therefore, these traits have become a good selection criterion for a breeder.

Table 6 Descriptor states of the fruits and their distribution

Descriptor	**Observed phenotype**	**Frequency**	**Expected**	**Value of χ^2**	**χ^2 –test**
Anthocyanin pigmentation	Absent (green)	45 (54.88)	41	0.78ns	0.37
	Present	37 (45.12)	41		
Fruit color at the intermediate stage	Green	46 (56.10)	27.34	32.66***	0
	Deep purple	4 (4.88)	27.34		
	Green with blackish bluish	32 (39.02)	27.34		
Fruit color at the mature stage	Light red	58 (70.73)	41	14.10***	0
	Red	24 (29.27)	41		
Fruit shape	Elongate	66 (80.49)	20.5	140.15***	0
	Almost round	1 (1.22)	20.5		
	Triangular	14 (17.07)	20.5		
	Blocky	1 (1.22)	20.5		
Shape at peduncle attachment	Acute	51 (62.20)	27.34	30.75***	0
	Obtuse	16 (19.51)	27.34		
	Truncate	15 (18.29)	27.34		

Shape at blossom end	Pointed	63 (76.83)	20.5	122.98***	0
	Blunt	15 (18.29)	20.5		
	Sunken	2 (2.44)	20.5		
	Sunken and pointed	2 (2.44)	20.5		
Neck at base of fruit	Absent	19 (23.17)	41	23.61***	0
	Present	63 (76.83)	41		
Cross-section corrugation	Slightly corrugated	78 (95.12)	41	66.78***	0
	Intermediate	4 (4.88)	41		
Fruit surface sinuate	Smooth	2 (2.44)	27.34	101.05***	0
	medium	70 (85.37)	27.34		
	strong (Wrinkled)	10 (12.20)	27.34		

3.3. Shannon Diversity Index of qualitative traits (H´)

3.3.1. Qualitative traits

Among the 28 qualitative variables, 27 are found polymorphic while the variable calyx annular is found monomorphic. Shannon Weaver Diversity Index (H') index ranged from 0.22 to 0.99 with a mean value of 0.60 indicating medium diversity is present in the collection of chilli for the qualitative traits (Table 7). According to the earlier studies as the test statistics described, moderate diversity is present in the collection for the qualitative traits [30]. The diversity for the 14 variables was found to be high (H'≥ 0.66), for the 6 variables was moderate (H'=0.34 to 066), and minimal diversity (H'<0.33) was found for the 7 variables. Among the 14 variables with a high diversity index, anthocyanin spots on fruit (H'=0.99), fruit color at intermediate maturity stage (H'= 0.76), fruit color at maturity stage etc., might represent consumer-preferred qualitative traits indicating their potential use in the future breeding programs. Higher values were found in cotyledon leaf shape, leaf density, anthocyanin, another color, stem pubescence density, flower position on the stem, stigma position, fruit color at the mature stage, leaf margin, shape at peduncle attachment, and branching habit while intermediate H' values were found for stem color at transplanting, leaf pubescence density, plant growth habit, fruit shape, shape at the blossom end, fruit surface smoothness. Relatively lower H' values were found for the traits pigmentation at node, leaf shape, leaf color, corolla color, calyx margin shape, and calyx pigmentation. All accessions have calyx annular constriction meaning no diversity with H'=0 (Table 8). H' values of germplasm district-wise were found to range from 0.06 (leaf color in Chattogram) to 0.90 (Cotyledon leaf color in Chattogram). All accessions have calyx annular constriction on fruit meaning no diversity with H'=0 (Table 8). Out of 28 variables, 12 in Jamalpur, 10 each belonging to Narayanganj and Sherpur; one (calyx annular constriction) in Mymensingh and 5 in Chattogram had no variability (H'=0). However, insufficient numbers of representatives of germplasm of Jhenaidah, Gazipur, Nilphamari, Tangail, Thakurgoan, and Tangail regions did not allow for a comprehensive analysis. As stated in an early report by some scholars [11] the variations measured in the germplasm belonging to various districts could be due to specific characteristics of the landraces of the region. These results are also in consonance with the findings of an earlier study by some scholars [26] who estimated diversities among morpho-agronomic characters of chilli ranged from 0.00 to 0.96.

3.3.2. Quantitative traits

Shannon Weaver Diversity Index (H') for all the characters ranged from 0.61 to 0.90 with an average value of 0.77 (Table 8). A higher value of H' for quantitative traits indicates the presence of a higher diversity in studied agro-morphological characters. As suggested in the earlier report on the diversity of the germplasm population of dram wheat [31] diversity is high when ≥ H ´0 .66. Hence, all the characters under study showed a moderate to maximum amount of diversity. The variation observed in different characters could be important characters in selecting parents for breeding programs.

Table 7 Descriptor states and Shannon-Weaver Diversity Index (H') of 28 qualitative traits

Descriptor	All	Chattogram	Jamalpur	Mymensingh	Narayanganj	Sherpur
Cotyledon leaf shape (n=82)	0.99	0.59	0.29	0.59	0.62	0.31
Cotyledon leaf color (n=82)	0.73	0.90	0.55	0.40	0.62	0
Stem color at transplanting	0.41	0.79	0	0.14	0.37	0.48
Stem pubescence density	0.94	0.59	0.60	0.61	0.54	0.52
Pigmentation at node	0.22	0	0	0.31	0	0
Leaf shape	0.26	0.17	0	0.31	0	0.31
Leaf color	0.22	0.06	0	0.14	0	0
Leaf pubescence density	0.52	0.12	0	0.38	0.65	0.48
Leaf margin	0.85	0	0.55	0.57	0.54	0.48
Leaf density	0.99	0.33	0.66	0.66	0.57	0.44
Branching habit	0.80	0.17	0.52	0.53	0.57	0.57
Plant growth habit	0.37	0.25	0.29	0.28	0	0
Flower position on stem	0.92	0.30	0.64	0.66	0.37	0.6
Corolla color	0.28	0.46	0	0.14	0	0
Anther color	0.96	0.59	0.55	0.38	0.37	0.62
Filament color	0.36	0.39	0	0.14	0	0
Stigma position	0.88	0.50	0.62	0.6	0.54	0.54
Calyx margin shape	0.28	0	0	0.14	0.37	0
Calyx pigmentation	0.28	0	0	0.14	0	0
Calyx annular constriction	0	0	0	0	0	0
Anthocyanin spot on fruit	0.99	0.54	0.61	0.82	0.37	0.48
Fruit color at an intermediate stage	0.76	0.39	0.63	0.61	0.37	0.48
Fruit color at a mature stage	0.87	0.62	0.45	0.43	0.37	0.48
Fruit shape	0.42	0.54	0	0.14	0	0.31
Shape at peduncle attachment	0.84	0.61	0.50	0.43	0.37	0.6
Shape at the blossom end	0.50	0.63	0.29	0.22	0.37	0.31
Neck at base of fruit	0.78	0.59	0	0.24	0.54	0.57
Fruit surface smoothness	0.43	0.47	0.29	0.43	0	0
Average	0.60	0.38	0.29	0.37	0.30	0.31
Standard deviation	0.30	0.26	0.27	0.21	0.25	0.25
Minimum	0.99	0.00	0.00	0.00	0.00	0.00
Maximum	0	0.90	0.66	0.82	0.65	0.62
Range	0	0.90	0.66	0.82	0.65	0.62

3.4. Descriptive statistics of fruit attributes and fruit yield

The descriptive statistics employed to assess the magnitudes of genetic variation are presented in Table 8. The coefficient of variation (CV%) ranged from 21 to 72 and the trend of CV% was 1000 seed weight<fruit width <fruit length

<fruit weight< plant height <number of fruits plant^{-1} <yield plant^{-1}. The results indicate that the 1000 seed weight of chilli germplasm is relatively stable while the yield plant^{-1} is unstable and may be influenced by different factors particularly annual climate variation and management practices [16]. Our results also support the findings of many workers [12] who reported environmental factors including precipitation, geographical region, altitude, and longitude contribute to the phenotypic polymorphism and functional traits of crop plants. Climate variables due to environmental gradients increase the genetic variabilities of crop plants [31]. Before, many other scholars similarly reported that changes in environmental gradients correlate with the environmental factors (rainfall temperature, precipitation, soil pH, and nutrients) that contribute to shaping the patterns of genetic diversity of plant species [2].

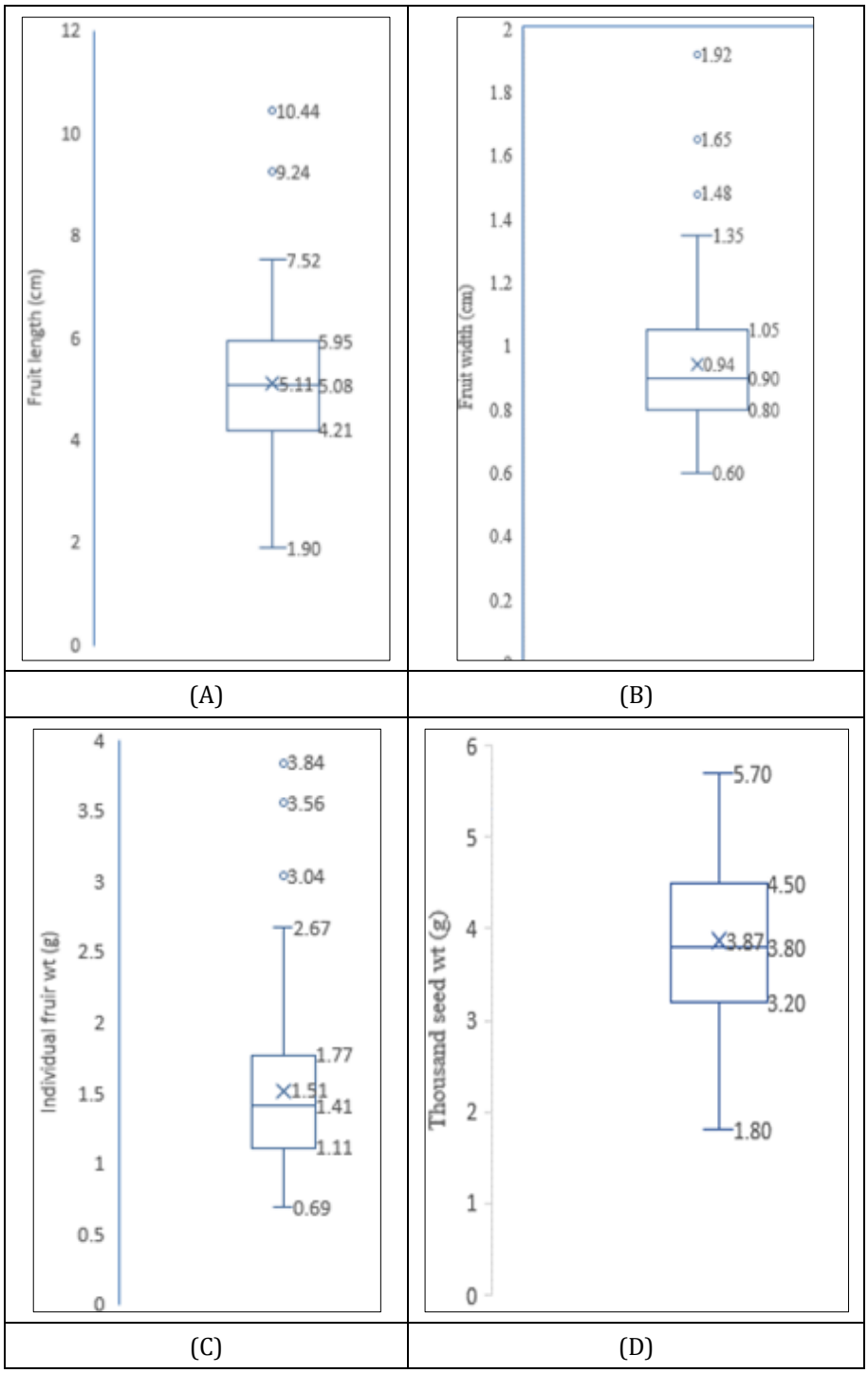

Figure 2 Box and whisker charts showing variation in fruit traits and thousand seed weight: (A) fruit length (cm), (B) fruit width (cm), (C) individual fruit weight (g), and (D) thousand seed weight (g). Box edges show the upper and lower quartile and the median as shown in the middle of the box

3.5. Data Distribution and skewness

In descriptive statistics, a box plot is a type of chart used to show data distribution and skewness. Interquartile range, the median and whiskers length of the boxplot chart highlight that the fruit length, fruit width, individual fruit weight, and thousand seed weight are symmetrical, and normally distributed. However, fruit width and individual fruit weight are skewed positively. The outliers of the boxplot chart of fruit traits and thousand seed weights indicate some values are greater than the means (Fig. 2a to 2d).

Table 8 Descriptive statistics for quantitative traits of fruit traits and yield data

Collector's no.	Fruit length (cm)	Fruit width (cm)	Fruit wt. (g)	Plant height (cm)	No. of fruits/ plant	1000 seed wt. (g)	Yield/plant (g)
AMA-37	4.80	0.80	1.11	89.98	182.93	4.40	202.50
AMA-51	3.46	0.68	1.10	87.14	69.17	3.60	76.42
AMA-56	6.80	1.23	1.84	56.24	36.46	4.00	66.95
AMA-73	5.24	0.85	1.60	66.08	61.50	3.50	98.29
AMA-74	6.22	0.76	1.29	103.68	40.91	2.70	52.76
AMA-75	4.16	0.84	1.00	86.72	62.29	2.40	62.51
AMA-90	5.72	0.86	1.04	60.36	26.22	3.10	27.38
AMA-95	5.72	0.88	1.24	31.96	26.67	4.10	32.97
AMA-112	4.96	0.82	1.06	35.44	28.10	4.00	29.17
AMA-118	4.82	0.82	1.11	24.74	45.00	2.50	50.14
AMA-128	2.12	1.65	1.42	62.34	104.62	4.80	148.69
AMA-139	5.64	0.95	1.46	52.14	47.07	4.80	68.57
AMA-146	5.08	0.88	1.17	38.10	30.80	1.80	36.02
AMA-153	5.48	1.03	1.18	45.54	36.17	3.00	42.51
AMA-163	3.06	0.77	1.22	87.90	23.25	3.20	23.96
AMA-164	5.10	1.04	1.63	63.54	26.75	4.20	27.25
AMA-174	5.08	0.92	0.79	28.08	21.00	5.60	28.69
AMA-175	2.96	0.62	0.69	21.92	23.25	2.90	22.25
AMA-187	5.08	0.64	0.75	22.72	24.00	3.80	23.02
AMA-191	4.30	0.75	0.70	31.98	20.70	4.60	24.41
AMA-199	4.56	0.72	1.07	26.43	28.67	4.00	29.29
AMA-203	4.46	0.77	1.13	26.84	23.40	3.70	25.15
AMA-225	4.58	0.88	1.25	32.96	24.56	3.00	30.64
AMA-226	6.16	0.89	1.36	43.65	28.00	3.60	20.86
AMA-240	3.94	0.95	1.80	30.47	48.75	4.50	87.99
AMA-246	4.70	0.99	1.64	35.24	24.50	4.50	23.73
AMA-248	1.90	1.92	2.67	64.80	27.00	2.80	45.33
AMA-254	5.00	0.94	1.01	37.36	21.43	3.50	21.56
AMA-285	4.78	0.93	1.24	46.02	26.44	3.60	32.87

AMA-296	3.74	0.99	1.06	29.04	20.00	4.80	20.64
AMA-297	4.90	0.86	2.17	23.02	25.00	3.80	20.84
AMA-307	4.10	0.85	0.88	36.08	23.13	4.40	22.74
AMA-320	4.46	0.69	1.16	21.72	23.29	3.70	23.83
AMA-325	5.30	0.79	1.30	38.16	39.55	5.70	51.46
AMA-333	4.16	1.06	1.46	26.46	20.33	4.30	20.49
AMA-335	7.14	0.78	1.45	33.50	24.58	4.60	26.62
AMA-343	6.36	0.86	1.70	44.80	25.25	4.60	42.85
AMA-344	5.94	0.72	0.99	30.14	21.00	2.80	20.87
AMA-349	5.52	0.61	1.48	69.12	58.36	3.20	86.57
AMA-358	4.26	0.84	0.92	40.56	26.13	2.60	23.91
AMA-361	7.08	0.92	1.72	38.46	24.11	3.80	27.05
AMA-361[a]	7.24	0.88	1.51	49.54	28.17	4.40	42.42
AMA-361[b]	5.80	0.68	1.19	39.94	16.20	3.10	27.35
AMA-391	3.30	1.16	2.09	59.36	26.60	3.80	23.77
AMA-408	2.86	0.98	1.68	47.44	21.50	2.80	22.52
AMA-415	2.98	0.91	1.18	34.68	24.60	3.20	27.28
AMA-416	3.92	1.05	1.95	32.22	30.86	2.60	60.18
RAI-67	6.74	1.11	2.33	48.06	21.50	5.30	23.49
RAI-80	7.52	0.95	3.04	54.94	21.54	3.60	24.68
RAI-83	5.32	1.14	1.57	51.12	23.75	5.60	25.89
RAI-95	6.08	0.97	2.15	43.72	26.00	4.90	22.88
RAI-100	5.60	1.16	1.37	38.72	22.90	4.00	23.97
RAI-115	6.26	1.22	2.01	40.82	15.83	4.80	31.85
RAI-145	3.08	0.70	0.70	91.02	24.00	4.20	22.81
RAI-156	5.80	1.14	2.18	38.26	23.50	4.30	27.63
RAI-160	5.94	1.17	2.19	43.88	24.22	5.00	29.26
RAI-188	9.24	0.91	2.15	43.14	20.23	5.00	21.97
RAI-190	5.90	1.48	1.76	42.00	25.58	3.20	45.12
RAI-205	4.50	1.09	3.84	43.80	25.00	3.30	19.21
RAI-231	6.62	1.27	2.13	45.08	24.13	4.60	28.79
RAI-232	10.44	0.82	1.64	58.32	43.00	4.50	70.72
RAI-258	5.98	1.05	1.62	59.86	42.79	3.90	69.10
RAI-259	6.78	1.20	1.79	64.54	53.27	4.80	95.53
RAI-260	5.40	0.92	1.11	50.78	56.86	3.80	62.93
RAI-261	4.76	0.84	0.96	52.20	59.00	3.90	56.35
RAI-263	6.00	0.87	0.79	49.32	51.67	3.70	40.73
RAI-292	6.12	0.90	1.92	51.92	29.42	4.10	56.44

MAH-11	3.80	1.12	1.11	65.50	23.58	3.80	23.97
MAH-18	3.94	0.86	0.77	25.55	21.00	4.10	20.77
MAH-29	5.78	0.90	1.39	26.03	24.00	2.80	25.57
MAH-36	5.32	1.17	1.76	52.88	20.93	3.40	29.19
MAH-38	2.94	0.72	1.17	108.72	22.13	3.50	22.50
MAH-39	4.58	1.25	3.56	103.96	28.33	5.30	29.68
MAH-40	4.16	0.76	1.14	92.25	23.75	3.60	25.64
MAH-41	4.26	0.63	1.73	83.92	30.57	3.80	53.04
MAH-42	4.24	1.35	2.56	87.54	29.00	5.20	23.06
MAH-43	4.22	1.13	2.41	108.90	24.80	4.60	21.59
AMA-23	5.24	1.03	1.44	69.44	23.00	3.70	33.20
AMA-283	4.92	0.70	1.40	85.38	21.07	3.00	21.50
RAI-228	2.86	0.60	0.77	58.47	25.50	2.80	24.26
AHI-01	7.23	0.91	1.73	93.34	25.57	2.70	29.65
AHI-06	6.42	0.80	1.55	57.52	30.00	4.20	46.52
Mean	5.11	0.94	1.51	52.01	32.63	3.87	40.03
St. dev.	1.45	0.23	0.61	22.76	22.07	0.83	29.17
Minimum	1.9	0.6	0.69	21.72	15.83	1.80	19.21
Maximum	10.44	1.92	3.84	108.90	182.93	5.7	202.25
CV %	28.36	24.16	40.40	43.75	67.64	21.45	72.87
H′	0.82 (H)	0.80(H)	0.80 (H)	0.83 (H)	0.61(M)	0.90 (H)	0.68 (H)

*H′= Diversity Index- H indicates high diversity; M indicates Medium Diversity; *CV= Co-efficient of variation

4. Conclusion

Although the result of this report was obtained from a one-year experiment and thus the interaction between environment and genotypes was not measured. The result of the experiment related to morphological traits was equally important to characterize our accession, as it helped to estimate variability that existed in the landraces which was due to the genotype effect between landraces. Further, this study significantly contributes to the knowledge of the conservation of genetic resources and, the breeding of chilli and will be useful for the selection of traits. The maximum number of germplasms under study belong to Mymensingh followed by Chattogram and Jamalpur districts. Future collection should be concentrated in the areas of insufficient collection. Maximum variations (CV%) were observed in the germplasm collected from Sherepur followed by Chattogram, Mymensingh, Tangail, and Gazipur. The lowest variation was observed in the germplasm collected from Nilphamari

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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