

Agro-Morphological Depiction of Lentil Genotypes for Higher Yield and Associated Traits

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Summary

Background: Characterization and genetic diversity is the prerequisite for proper utilization of existing germplasm. Thus, a detailed agro-morphological characterization and genetic diversity need to be evaluated for selection of the superior genotypes which are exploited in lentil breeding program.

Methods: A total 60 lentil genotypes were used under Alpha Lattice design with two replications at the Pulses Research Centre, BARI, Ishurdi, Pabna during 2019-20. Sixteen qualitative traits and fourteen quantitative data were analyzed in this study. Simultaneously, correlation study was done among the studied genotypes based on fourteen quantitative data.

Results: Based on the frequency distribution of the 16 qualitative traits, flower color, testa color, and cotyledon color were identified as the most variable traits among the studied genotypes. The 60 genotypes were grouped into six clusters and the distribution of the genotypes varied from 5 to 15 with the same origin in more than one cluster. Based on the diversity study, the genotypes BLX 09015, Precoz, LR-9-25, LRIL-21-112-1-1-1-1-6, BLX-05002-3, BLX-05002-6, BLX 10001-1, Maitree, BARI Masur-8, and BARI Masur-7 were selected as superior genotypes for future breeding program by the lentil breeders. These selected genotypes belong to Cluster I and Cluster III which showed high genetic diversity based on the maximum inter-cluster distance. The correlation study indicated that filled grains plant⁻¹, hundred seed weight, straw yield plant⁻¹ and harvest index had the significant and positive correlation with the yield; these traits were found to be the major yield contributing traits for the selection of lentil genotypes in a breeding program.

Key words

Lens culinaris Medikus *subsp. culinaris*, genotypes, characterization, genetic diversity, breeding

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Introduction

Lentil (*Lens culinaris* Medikus subsp. *culinaris*) is the most important legume crop for food, feed and is positioned dominantly in the farming systems of Bangladesh. It is the topmost food legume crop in Bangladesh concerning consumer preference and the second in producing area (0.1931 million ha) and production (0.2518 million metric tons) (AIS, 2020). Traditionally, lentil is consumed in various forms of culinary in Bangladesh. A plate of rice and lentil dahl (concentrated soup) is the most popular and eaten by the majority of the people. A mixture of rice and lentil cooked together, known as “*Khichuri*” is another typical dish. Like other pulses, growing lentils within rice-based cropping pattern provides resilient cropping systems. Moreover, lentil is generally grown as a rainfed crop in rotation in cereal-based cropping patterns to break disease and pest cycles, it fixes atmospheric nitrogen and adds carbon and organic matter in the soil thus providing sustainable cropping systems. Lentil grain contains quality protein, carbohydrates, minerals, vitamins, and fiber, which provide a substantial quantity of essential nutrients to maintain human health. Its protein content ranges from 20.6 to 31.40% (Urbano et al., 2007), carbohydrates between 55 to 59% (Frederick et al., 2006), soluble fiber (Brummer et al., 2015), essential macro and micronutrients and vitamins. Its mature vegetative parts and milling wastes are nutrient-rich valued animal feed (Sarker and Erskine, 2006).

Despite the importance of lentil growing, Bangladesh meets only 40% of its domestic demand from local production, and a substantial amount is imported from international markets. To fulfill the deficit, efforts are underway to enhance lentil production through national and international research initiatives. The Pulses Research Centre (PRC) of Bangladesh Agricultural Research Institute (BARI) is engaged in developing improved varieties. With its global mandate in lentil research, the International Centre for Agricultural Research in the Dry Areas (ICARDA) has established fruitful partnerships with BARI to generate suitable high yielding lentil varieties for Bangladesh. To date, about twenty varieties have been released in the country for commercial cultivation, but their potential yield has not been realized in farmers’ fields due to various reasons. The major limitations include lack in optimum yield contributing parameters, disease and other abiotic stress resistance and short duration traits with appropriate phenological adaptation in the context of climate change.

The selection of superior parents as well as knowledge of genetic diversity and description of the available germplasm is the essential prerequisite for introducing a meaningful breeding program (Poonam et al., 2006). Agro-morphological traits along with crop adaptation, agronomic performance, market value and suitability for special uses are the major goals for improving a crop (Saha et al., 2013). However, the Lentil Breeding Program at PRC is employing conventional breeding methodologies for genetic enhancement of the crop. In this context, it is important to identify potential parents from the existing genetic resources available at PRC gene bank through in-depth characterization of agro-morphological and phenological traits and their use in a cross-breeding program. In this endeavor, sixty lentil genotypes consisting of local and exotic germplasm were selected (based on yield contributing traits) from the PRC collection. So, the

objective of this study was to determine the agro-morphological characterization of lentil genotypes collected from local and exotic sources that would contribute to the lentil improvement in Bangladesh.

Materials and Methods

In this experiment, a total 60 lentil genotypes consisting of landraces, breeding lines, released varieties, and exotic germplasm from ICARDA was used (Appendix 1). The experiment was conducted at the research farm of PRC, BARI, Ishurdi, Pabna with 89.05 °E longitudes and 24.03 °N latitude and 16 m altitude above sea level. The soil was clay-loam rich in calcium, of the High Ganges River Floodplain (Agro-ecological Zone: 11) (Banglapedia, 2015). During the growing period, the crop received 960 mm rainfall. The weekly basis meteorological data during the experimentation are given in Fig. 1.

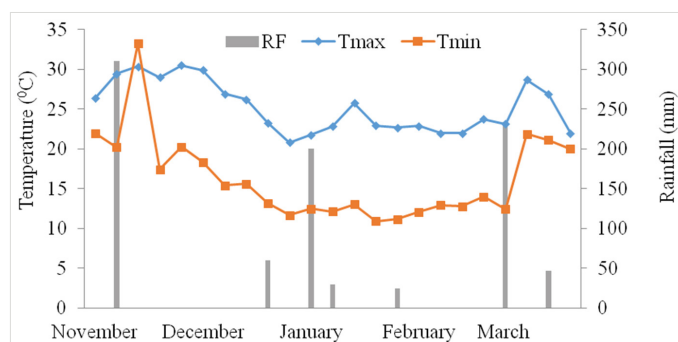


Figure 1. The weekly average temperature (Tmax; maximum, Tmin; minimum) and rainfall (mm) of the crop season during 2019-20 at PRC, Ishurdi, Pabna

Before seed sowing, the land was fertilized with BARI recommended fertilizer doses (Urea 45 kg ha⁻¹, TSP 90 kg ha⁻¹, MOP 35 kg ha⁻¹, Zypsum 52.50 kg ha⁻¹, and Boric acid 8.00 kg ha⁻¹) as basal application during the final land preparation.

The experiment was laid out in Alpha-Lattice design with two replications with the unit plot of 2.5 m long with two rows. The seed sowing date was 7 November 2019 as an optimum sowing date. The seeds were sown by hand in 30 cm row to row distance at 3-5 cm depth from the soil surface with continuous seeding. All crop husbandry measures were undertaken when necessary to achieve good crop growth and plant stand.

A total of 16 qualitative traits were studied following the standard Lentil Descriptors (IBPGR, 1985) (Table 1). For genetic diversity and correlation studies, the fourteen quantitative data were studied, and their detailed description with the measuring scale and procedure is presented in Table 2. Quantitative data were analyzed by the Genstat program for measuring clusters, clusters mean, inter-intra clusters distance; correlation studies of fourteen quantitative data were analyzed using R.3.3.3 statistical software program (R Core Team, 2017).

Table 1. Descriptors used for morphological assessment for 16 qualitative traits of 60 lentil germplasms during 2019-20 crop season at PRC, BARI, Ishurdi, Pabna

Sl. No.	Descriptors	Acronyms	Qualitative traits		
			Definition	Unit	Stage of plant development
1	Seedling stem pigmentation	SSPG	Color at the base of the stem (Hypocotyl color)	0 = Absent + = Present	Seedling stage
2	Leaf pubescence	LP	Recorded on the plot basis	0 = Absent 3 = Slight 7 = Dense	Vegetative stage
3	Leaflet size	LS	Recorded on the plot basis with few plants on lower flowering nodes	3 = Small 5 = Medium 7 = Large	Vegetative stage with fully expanded leaves
4	Tendrill length	TL	Recorded on plot basis of few plants	1 = Rudimentary 2 = Prominent	Pod filling stage
5	Flower ground colour	FGC	Recorded on plot basis of First few flowers	1 = White 2 = White with blue veins 3 = Blue 4 = Violet 5 = Pink 6 = Other	Flowering stage
6	Lodging susceptibility	LSC	Recorded on plot basis	0 = None 3 = Low 5 = Medium 7 = High	Maturity stage
7	Pod pigmentation	PP	Recorded on plot basis of few first pods	0 = Absent + = Present	Pod maturity stage
8	Pod shedding	PS	Recorded on plot basis	0 = None 3 = Low 5 = Medium 7 = High	Harvesting stage
9	Stress susceptibility	SS	Recorded on plot basis	3 = Low susceptibility 5 = Medium susceptibility 7 = High susceptibility	Maturity stage
10	Pest and Disease susceptibility	PDS	Recorded on plot basis (infected plants)	3 = Low susceptibility 5 = Medium susceptibility 7 = High susceptibility	Flowering stage
11	Seed shape	SS	Shape of 100 healthy seeds	1 = Globus 2 = Flattened	Less than 3 months old harvested seeds
12	Seed type	ST	Type of 100 healthy seeds	1 = Macrosperma 2 = Microsperma	Storage stage
13	Ground colour of testa	GCT	Ground colour of Test of 100 healthy seeds	1 = Green 2 = Grey 3 = Brown 4 = Black 5 = Pink	Less than 3 months old harvested seeds
14	Pattern of testa	PT	Pattern of test of 100 healthy seeds	0 = Absent 1 = Dotted 2 = Spotted 3 = Marbled 4 = Complex	Less than 3 months old harvested seeds
15	Color of pattern on testa	CPT	Colour of pattern on testa of 100 healthy seeds	0 = Absent 1 = Olive 2 = Grey 3 = Brown 4 = Black	Less than 3 months old harvested seeds
16	Cotyledon color	CTC	Cotyledon colour of 100 healthy seeds	1 = Yellow 2 = Orange/red 3 = Olive-green	Less than 3 months old harvested seeds

Table 2. List of recorded 12 quantitative traits with recording stage and using scale/measuring procedure at PRC, Ishurdi, Pabna

Sl. No.	Quantitative characters	Acronyms	Data recording stage	Using scale/Measurement procedure
1.	Days to emergence	DE	Just after germination	Recorded days from sowing date just after germination on plot basis.
2.	Days to 50 % flowering	DF	Flowering stage	Counted days from sowing to 50% flowers visible in the plants on plot basis.
3.	Days to maturity	DM	Ripening stage	Counted days from sowing date to 80% physiological maturity or just after turn to straw color of the pods.
4.	Plant height	PH	Maturity stage	Recorded height of 5 plants (cm) of the each plot randomly from ground level to top of the plants.
5.	Canopy temperature before flowering	CTBF	Pre flowering stage	Temperature from each row of upper canopy level of the plants measured by infrared thermometer (°C) (Model: TM-919AL, I.399317 Made in Taiwan). Average of three readings of infrared thermometer was taken.
6.	Canopy temperature after flowering	CTAF	After 50% flowering stage	Temperature from each row of upper canopy level of the plants measured by infrared thermometer (°C) (Model: TM-919AL, I.399317 Made in Taiwan). Average of three readings of infrared thermometer was taken.
7.	Branches plant ⁻¹	BPP	Ripening stage	Calculated average of the randomly selected five plants of each plot.
8.	Canopy width	CWPR	Flowering stage	Recorded canopy width (cm) of the plants randomly selected in three positions of the planted row.
9.	No. of pods plant ⁻¹	PPP	Harvesting stage	Average of randomly selected five plants pods.
10.	No. of seeds pod ⁻¹	SPP	Harvesting stage	Average of randomly selected 10 pods of each plot.
11.	100- seed weight (g)	TSW	After threshing	Weight of 100 seeds (g) from randomly selected five plants at 8-10% (air dry) seed moisture content.
12.	Yield plant ⁻¹	YPP	Before storing	The whole plot yield divided by the total number of final plant stand (g)
13.	Yield hectare ⁻¹	YPH	Before storing	Plot yield was converted into the hectare in kg ha ⁻¹ .
14.	Harvest Index	HI	After threshing	Percentage of yield ratio of the economical yield and biological yield.

Results and Discussion

Qualitative Traits and Their Frequency Distribution

The frequency distribution of 60 lentil genotypes showed a wide range of variations for 16 qualitative traits (Table 3). Regarding this wide range of variations in general, some of the morphological characters were very unique while some others were available and consistently distributed within the genotypes. Characterization of lentil germplasm based on qualitative traits has been recorded by many researchers globally e.g.; Mohammed et al. (2019), Choudhury et al. (2017), Ahamed et al. (2014). Regarding the seedling stem pigmentation (SSPG), the trait was absent in 68.33% and present in 31.67% of genotypes. Similar findings were observed by Mohammed et al. (2019) and Choudhury et al. (2014).

Three categories of Leaf Pubescence (LP) were observed among the studied genotypes and the maximum 48.33% of germplasm had slight LP followed by dense (26.67%), and the rest of 25% germplasm was observed without any LP. Medium size of the leaflet was observed in 58.33%, followed by small (30.00%), and only 11.67% had large leaflet size (Fig. 2). Prominent tendrils

(TL) was observed in 91.67%, and only 8.33% of germplasm had rudimentary TL (Fig. 3). Four categories of flower ground color (FGC) were observed, where violet was the most common (61.67%), followed by blue (15%), white (13.33%), and white with blue veins (10%) (Table 3 and Fig. 4). From this study, white, white with blue veins, blue and violet color petals were observed, and most of genotypes had the violet color petal, which supported the previous study of Gaad et al. (2018), and Mohammed et al., (2019). Several petal colors such as white, pink, purple, light purplish-blue, or pale blue were also recorded by Ahamed et al. (2014).

Lodging susceptibility (LSC) index such as none, low, medium and high was considered based at maturity stage. It was revealed that most genotypes (51.67%) had medium, 23.33% low, 18.33% high, and only 6.67% of the germplasm had no LSC. Among the studied genotypes, most of genotypes (98.33%) had no pod pigmentation (PP), while only one genotype like 'Precoz' (1.67%) had PP. In the case of pod shedding (PS) capability, the greatest number of genotypes (96.67%) had no PS, whereas only two genotypes, LRIL-21-67-1-1-1-1 and BLX-05004-8 (3.33%) had low PS trait.

Table 3. Frequency distribution of 16 qualitative traits assessed in 60 lentil germplasm along with seven check varieties during 2019-20 crop season at PRC, Ishurdi, Pabna

Sl. No.	Descriptors	Descriptor status	Total No. of genotypes	Frequency (%)		
				Breeding lines/ variety/landrace	Foreign germplasm	Total
1	Seedling stem pigmentation	0 = Absent	41	55.00	13.33	68.33
		+ = Present	19	16.67	15.00	31.67
2.	Leaf pubescence	0 = Absent	15	11.67	13.33	25.00
		3 = Slight	29	36.66	11.67	48.33
		7 = Dense	16	21.67	5.00	26.67
3.	Leaflet size	3 = Small	18	20.00	10.00	30.00
		5 = Medium	35	43.33	15.00	58.33
		7 = Large	07	6.67	5.00	11.67
4.	Tendrill length	1 = Rudimentary	05	1.67	6.67	8.33
		2 = Prominent	55	68.33	23.33	91.67
5.	Flower ground colour	1 = White	08	8.33	5.00	13.33
		2 = White with blue veins	06	3.33	6.67	10.00
		3 = Blue	09	10.00	5.00	15.00
		4 = Violet	37	48.33	13.33	61.67
6.	Lodging susceptibility	0 = None	4	6.67	0	6.67
		3 = Low	14	18.33	5.00	23.33
		5 = Medium	31	35.00	16.67	51.67
		7 = High	11	10.00	8.33	18.33
7.	Pod pigmentation	0 = Absent	59	71.66	26.67	98.33
		+ = Present	01	0	1.67	1.67
8.	Pod shedding	0 = None	58	68.34	28.33	96.67
		3 = Low	2	1.67	1.67	3.33
9.	Stress susceptibility	3 = Low susceptibility	56	66.67	26.67	93.34
		5 = Medium susceptibility	02	1.67	1.67	3.34
		7 = High susceptibility	02	1.67	1.67	3.34
10.	Pest and Disease susceptibility	3 = Low susceptibility	31	40.00	11.67	51.67
		5 = Medium susceptibility	18	23.33	6.67	30.00
		7 = High susceptibility	11	6.66	11.67	18.33
11.	Seed shape	1 = Globus	19	18.33	13.33	31.67
		2 = Flattened	41	53.33	15.00	68.33
12.	Seed type	1 = Macrosperma	02	1.67	1.67	3.33
		2 = Microsperma	58	70.34	28.33	98.67
13.	Ground colour of testa	1 = Green	09	13.33	1.67	15.00
		2 = Grey	31	36.67	15.00	51.67
		3 = Brown	05	6.67	1.67	8.33
		4 = Black	04	1.67	5.00	6.67
		5 = Pink	11	15.00	3.33	18.33
14.	Pattern of testa	0 = Absent	06	3.33	6.67	10.00
		1 = Dotted	54	66.67	23.33	90.00
		2 = Spotted	0	0.00	0.00	0.00
		3 = Marbled	0	0.00	0.00	0.00
15.	Colour of pattern on testa	4 = Complex	0	0.00	0.00	0.00
		0 = Absent	03	1.67	3.33	5.00
		1 = Olive	19	13.33	18.33	31.66
		2 = Grey	0	0.00	0.00	0.00
		3 = Brown	01	1.67	0.00	1.67
16.	Cotyledon colour	4 = Black	37	53.33	8.33	61.66
		1 = Yellow	04	3.33	3.33	6.67
		2 = Orange/red	36	41.67	18.33	60.00
		3 = Olive-green	20	25.00	8.33	33.33



Figure 2. Variability in leaflet size



a) Tendril present



b) Tendril absent

Figure 3. Variability in tendril

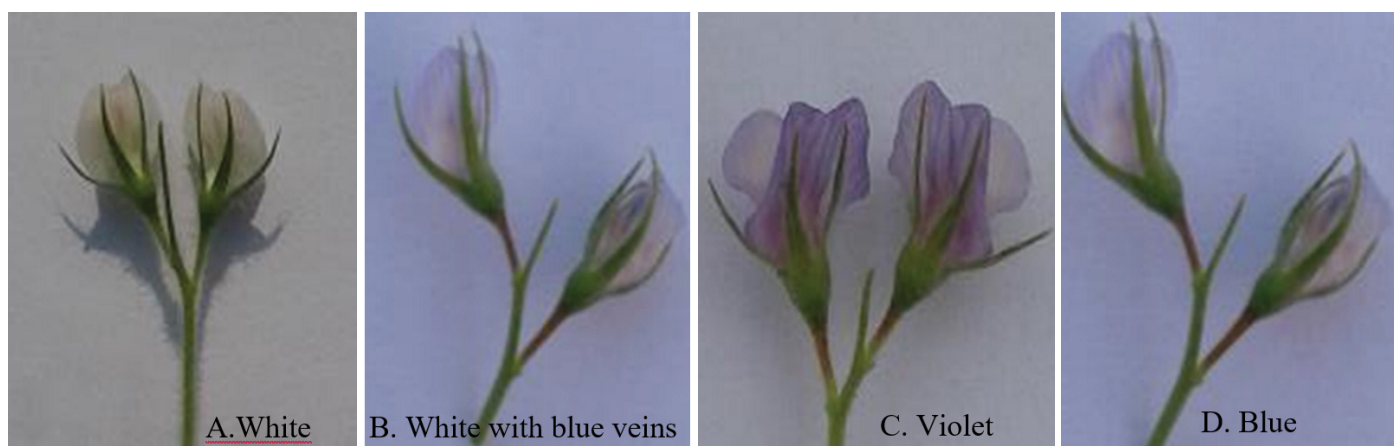


Figure 4. Diversity in Flower Ground Color of lentil germplasm (A, B, C & D)

Concerning the observation of stress susceptibility (SS), low susceptibility was observed in the case of maximum genotypes (93.64%), and most of them were breeding materials or varieties followed by medium (3.33%) and high susceptibility (3.33%). This finding was consistent by Mohammed et al. (2019), who observed the maximum genotypes in low susceptibility to stress. Disease susceptibility was observed in the case of *Stemphylium* blight disease mainly because *Stemphylium* blight is the major disease for lentils in Bangladesh, and among the studied genotypes, most of the breeding lines were identified as low susceptible. These were obtained due to the breeding target done for developing *Stemphylium* blight disease-resistant varieties of lentils. Pest and disease susceptibility (PDS) were observed among 51.67%, followed by 30% medium susceptibility, and 18.33% with high susceptibility.

The maximum percentage of genotypes was recorded as globes seed shape (68.33%), whereas 31.67% of the total genotypes were flattened shaped among two categories of seed shape like globes and flattened. There were two types of seeds, such as var. *macrosperma* and var. *microsperma* observed among them; the *microsperma* was the most common (98.67%) seed type except for only two genotypes (3.33%) viz; 'Precoz' and BLX 09015. Breeding approaches were done for developing the var. *microsperma* seed with red cotyledon color based on Bangladeshi consumer's preference. Toklu et al. (2008) also reported lentil seed as small-seeded (var. *microsperma*) and as large-seeded (var. *macrosperma*), and the var. *microsperma* lentil are widely cultivated in southeast Turkey and south Asia with highly nutritious sources of proteins.

Five categories of the ground color of testa (GCT) such as green, grey, brown, black, and pink (Fig. 5) were found within the studied germplasm. The maximum genotypes (51.67%) were found as grey GCT followed by 18.33% pink, 15% green, 8.33% brown, and 6.67% black. A similar finding was reported by Choudhary et al., (2017) for distinguishing the lentil genotypes based on seed characters. Two types of the pattern of testa were found, and mostly (90%) it was dotted, and only 10% of the total germplasm had no PT on the seed coat. Four categories of the color of pattern on testa (CPT) were observed, and most genotypes (61.66%) had black CPT while 31.66% and 1.67 of the genotypes showed olive

and brown CPT respectively. The rest of 5% had no CPT (Table 3). Regarding cotyledon color (CTC), orange/red color cotyledon (60%) was common among the studied germplasm followed by 33.33% olive-green and 6.67% yellow. A similar finding was observed by Choudhury et al. (2014) from 100 lentil accessions in Bangladesh.

Quantitative Variation

A wide range of variations was revealed among the 14 agronomical characters of 60 lentil genotypes (Table 4, Fig. 6). Grand mean range, standard deviation (SD), standard error (SE), and coefficient of variation (CV %) are presented in Table 4. The maximum DE was recorded during nine days; the minimum was 5 days with an average of 7 days with ± 0.129 SE. The maximum days to flowering were 73 days and minimum 49, where as the mean value were taken 66 days with SE ± 0.148 . The PH was ranged from 38.30 cm to 65.30 cm, and the average was 49.03 cm with ± 0.088 SE. CW was found from 23.67 cm to 35.67 cm with an average of 31.74 cm, and SE was ± 0.093 . CTPF was recorded ranging from 17.22 to 20.92 °C with an average 18.34 °C and SE was ± 0.157 and CTAF was recorded from 18.13 to 22.05 °C and average 19.52 °C with ± 0.168 SE. BPP was found 2 to 6 and average 4 with ± 0.070 SE. The maximum days maturity was recorded 120 and minimum 93 days with a mean performance of 113 days and SE ± 0.186 . FPP was recorded from 24 to 179 with a mean of 102 and SE ± 0.417 . UFPP was obtained 5 to 126 with an average of 19 and SE ± 0.189 . HSW was recorded ranging from 1.430 to 3.400 g, and the average was 2.266 with ± 0.015 SE. The minimum 1.500g and the maximum 5.040 g were recorded in the case of SYP with a grand mean of 3.067 g and SE was ± 0.018 . HI was recorded 18% to 54% with an average of 36% and SE was ± 0.193 . GYP was obtained 0.63 g to 3.65 g with an average yield of 1.649 g for each plant and SE was ± 0.014 .

Genetic Diversity and Cluster Analysis

Significant variation was observed among the fourteen agronomic traits of 60 lentil genotypes indicating the presence of a high degree of variation which demonstrates the possibility of the genotypes to be included in breeding programs.

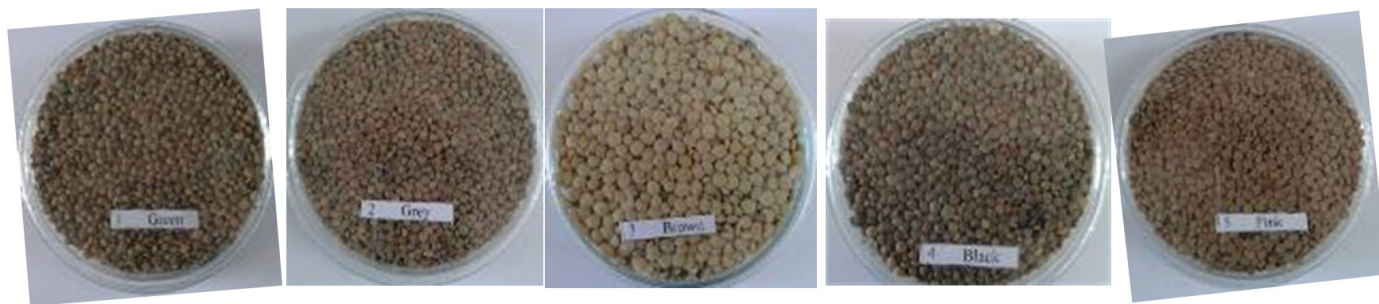


Figure 5. Diversity in Ground Color of Testa in lentil germplasm

Table 4. Range, grand mean, standard deviation (SD), standard error and CV of 15 agronomical traits of 60 lentil genotypes including six varieties

Items	DE	DF	PH	CW	CTPF	CTAF	BPP	DM	FPP	UFPP	HSW	SYP	HI	GYP
Minimum	5	49	38.30	23.67	17.22	18.13	2	93	24	5	1.430	1.5	18	0.63
Maximum	9	73	65.30	35.67	20.92	22.05	6	120	179	126	3.400	5.04	54	3.65
Range	4	24	27	12	3.7	3.92	4	27	155	121	1.970	3.54	36	3.02
Mean	7	66	49.03	31.74	18.34	19.52	4	113	102	19	2.266	3.067	36	1.649
Std. Deviation.	1.002	1.143	0.685	0.719	1.216	1.304	0.542	1.48	3.229	1.461	0.119	0.138	1.498	0.107
Std. error	0.129	0.148	0.088	0.093	0.157	0.168	0.070	0.186	0.417	0.189	0.015	0.018	0.193	0.014
CV%	14.31	1.732	1.397	2.265	6.632	6.681	13.55	1.272	3.166	7.691	5.261	4.506	4.165	6.474

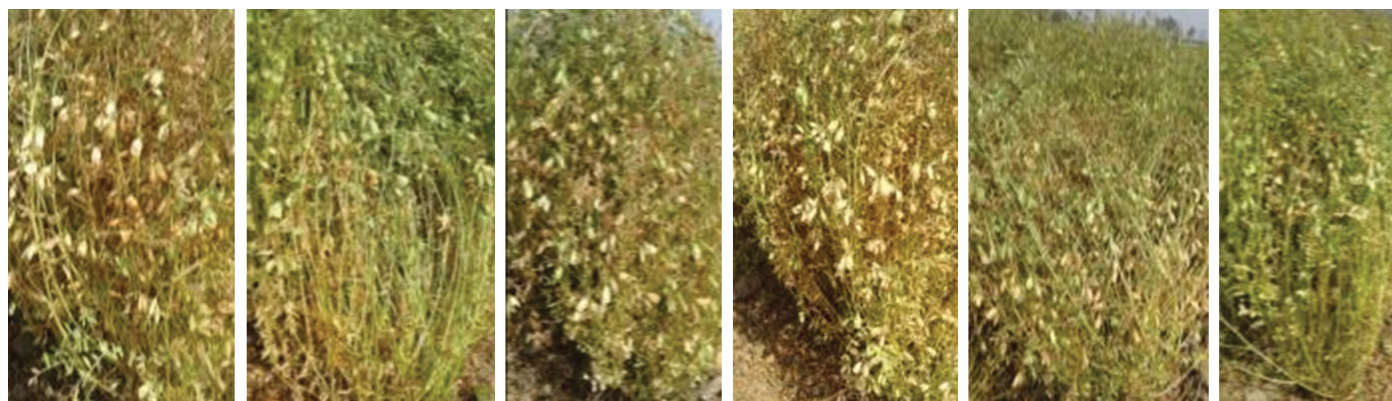


Figure 6. Morphological variability of the studied lentil germplasm

The genetic diversity of existing genotypes was measured by cluster analysis. A total of 60 genotypes were grounded into six different clusters based on D^2 values (Table 5). The maximum number of genotypes (15) was found in Clusters II and IV, and the minimum of 5 genotypes were in Clusters I and III with different origins. Clusters V and VI comprised 9 and 11 genotypes respectively, having diverse origins like BARI-developed varieties, advanced breeding lines, local landrace, and ICARDA-developed breeding lines. All clusters consisted of diverse origins, indicating that there was no relationship between geographical location and genetic diversity. This suggests that genetic diversity is not dependent on the only factor, that of geographical isolation

(Sihag et al., 2004). This also suggests that the degree of ancestral relationship of the genotypes is an important factor within the cluster (Tyagi et al., 2010). However, cluster analysis grouped the genotypes based on greater genetic similarity, not forming the cluster including the genotypes from the same origin (Sultana et al., 2005). Amurrio et al. (1995), and Rabbani et al. (1998) also observed the lack of association between morphological traits and origin in respect of the same clusters. Similar findings were also reported by Singh et al. (2020), Ahmad et al. (2014), and Sirohi et al. (2007). The maximum inter-cluster distance (14.560) was found between Clusters I and III followed by Clusters I and VI, and Clusters I and VI (Table 6), which indicated that these clusters

might be consist of diverse genotypes based on all quantitative traits due to non-allelic interaction and patents should be selected from these clusters in the crop improvement program like hybridization for attaining the maximum genetic variability or getting the heterotic expression of F1s and a wide spectrum of genetic variability in desired transgressive segregates. The lowest inter-cluster distance (2.612) was found between Clusters III & VI followed by Clusters II & IV. The minimum inter-cluster distance was found between Clusters III and VI, which indicates that the genotypes of these clusters were genetically the least diverse and almost of the same genetic architecture (Jeena and Singh 2002). These genotypes can also be exploited in breeding programs for developing bi-parental crosses between the most diverse and nearest groups for the disruption of the unwanted linkages between yield and its related traits (Haddad et al., 2004).

Similarly, the maximum intra-cluster (1.688) distance was observed within Cluster I followed by Cluster III and the lowest intra-cluster (0.721) distance was shown within Cluster IV indicating that the genotypes within the same cluster were more diverged. Similar types of research were conducted by Choudhury et al. (2014) and Sultana et al. (2010). Superior genotypes from the

diverse cluster may be exploited for hybridization due to a better performance of segregates (Ghafoor et al., 2000; Iqbal et al., 2003).

Significant variation was observed among the six clusters with a mean performance of 60 lentil genotypes based on 14 agronomical traits like; days to emergence (DE), days to flowering (DF), plant height (PH), canopy width (CW), canopy temperature before flowering (CTPF), canopy temperature after flowering, branches per plant (BPP), days to maturity (DM), filled pods plant⁻¹ (FPP), unfilled pods plant⁻¹ (UFPP), hundred-seed weight (HSW), straw yield plant⁻¹ (SYP), harvest index (HI) and grain yield plant⁻¹ (GYP) (Table 7). DE was 7 in the case of all Clusters except 6 days found in Cluster I. The maximum days to flowering (68 days) were found in Cluster VIII followed by Clusters IV and V (67 days). The minimum days to flowering (63 days) were recorded in Cluster I. The tallest genotypes were found in Cluster III with 51.40 cm, followed by the genotypes contained in Cluster V (50.74 cm) and Cluster VI (50.23 cm), whereas dwarf type genotypes were found in Cluster I (44.64 cm). The maximum CW was recorded in Cluster III (32.40 cm), and a comparatively narrow width canopy of 27.44 cm was obtained in the genotypes of Cluster I.

Table 5. Distribution of 60 lentil genotypes in six clusters

Cluster no.	No. of genotypes	Genotypes no.	Genotypes name
Cluster I	5	7, 16, 52, 53, 59	BARI Masur-9, Precoz, BLX 10001-1, BLX 10002-15, BLX 09015
Cluster II	15	2, 6, 8, 9, 14, 17, 18, 19, 20, 21, 36, 40, 48, 49, 58	BARI Masur-4, BARI Masur-8, LRIL-21-67-1-1-1-1, LRIL-21-112-1-1-1-1-6, 9945, Flip-2009-52L, BLX-98001-9, BLX-99033-19, BLX-01013-21-5, BLX-01014-9, BLX-05010-3, BLX-12004-5, RL-12-181, BLX 11014-8, and BLX-05002-3.
Cluster III	05	12, 24, 31, 34, 46	ILL-5143, BLX-0200-08-4, BLX-05005-3, BLX-05008-3, and RL-12-171.
Cluster IV	15	4, 22, 23, 26, 30, 32, 33, 37, 38, 41, 43, 45, 50, 54, 56	BARI Masur-6, BLX-02009-11-1, BLX-02009-17-1, BLX-04004-10, BLX-05004-8, BLX-05006-7, BLX-05007-5, BLX-05011-3, BLX-05010-6, BLX-12009-6, L 4717, RL-12-178, BLX 11014-10, BLX 10002-20, and LRIL-22-158.
Cluster V	09	3, 5, 13, 39, 42, 44, 47, 55, 57	BARI Masur-5, BARI Masur-7, 91517, BLX 01013, BLX-12011-6, Bagura Local, Maitree, LRIL-18-102, and LG-198.
Cluster VI	11	1, 10, 11, 15, 25, 27, 28, 29, 35, 51, 60	BARI Masur-3, IRL-22-68-1-1-1-1-0, ILL-8008, LR-9-25, BLX-0200-18-3, BLX-04010-15, BLX-05001-10, BLX-05002-6, BLX-05008-11, BLX 11014-11, and BLX 04005-9.

Table 6. Intra (Bold) and Inter cluster distance among the six clusters of 60 lentil genotypes

	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
Cluster I	1.688					
Cluster II	7.731	0.785				
Cluster III	12.911	5.664	1.129			
Cluster IV	10.168	4.518	3.59	0.721		
Cluster V	14.560	8.697	4.208	4.501	0.884	
Cluster VI	10.384	3.071	2.612	2.668	5.897	0.814

Table 7. Mean performance of 14 agronomical traits in six clusters of 60 lentil genotypes

Cluster no.	DE	DF	PH	CW	CTPF	CTAF	BPP	DM	FPP	UFPP	HSW	SYP	HI	GYP
Cluster I	6	63	44.64	27.44	18.26	19.07	3	104	90	49	2.96	3.98	39.30	2.49
Cluster II	7	66	47.59	32.16	18.41	19.47	5	114	123	17	2.31	3.19	37.40	1.88
Cluster III	7	68	51.40	32.40	18.26	19.23	5	113	121	26	2.08	3.53	25.70	1.15
Cluster IV	7	67	49.23	31.96	18.20	19.56	5	113	79	12	2.33	2.51	40.70	1.62
Cluster V	7	67	50.74	32.35	18.45	19.94	4	114	72	16	2.08	2.47	31.00	1.08
Cluster VI	7	66	50.23	32.03	18.44	19.55	5	115	125	18	2.03	3.51	34.80	1.68

The maximum canopy temperature of 18.45 °C was recorded in the genotypes of Cluster V at the pre-flowering stage, and 19.94 °C was also the maximum in Cluster V at the post-flowering stage. The minimum canopy temperature of 18.20 °C was recorded in Cluster IV at the pre-flowering stage and the minimum canopy temperature of 19.07 °C was in Cluster I at the post-flowering stage. BPP of 5 was recorded in all genotypes of Cluster II, Cluster III, Cluster IV, and Cluster VI except in Cluster I and Cluster V, whereas BPP was recorded 3 and 4, respectively. The maximum DM of 115 days was found in the genotypes of Cluster VI followed by Cluster II and Cluster V with 114 days of maturity, and 113 days of maturity was recorded in genotypes of Cluster III and IV. Comparatively, short-duration genotypes were recorded in Cluster I with 104 DM. The maximum FPP 125 was found in Cluster VI with minimum seed-sized (2.03 g of hundred-seed weight). The maximum UFPP 49 was found in the genotypes of Cluster I with maximum SYP (3.98 g), and maximum GYP (2.49 g). The maximum HI of 40.70% was found in the case of the genotypes in Cluster IV followed by Cluster I (39.30%), and the minimum of 25.70% was found in Cluster III. The maximum GYP (2.49 g) was found in the case of the genotypes in Cluster I with the maximum SYP (3.98 g) and HSW (2.96 g). The genotypes of this cluster could be used in the future breeding program for attaining the maximum yield potential. Significant variation was observed by Sakthivel et al. (2019) consisting of twenty lentil genotypes in respect of fifty percent flowering, days to maturity, plant height, pods plant⁻¹, number of branches plant⁻¹, number of seeds plant⁻¹, biological yield plant⁻¹, seed yield plant⁻¹, harvest index, hundred-seed weight and yield (kg ha⁻¹). Similar variations were reported by Mohammed et al. (2019), consisting of 36 lentil genotypes collected from different sources of diverse origins. Chowdhury et al. (2019) also reported the significant genetic variability among 20 lentil genotypes and revealed that the number of pods plant⁻¹, number of pods plant⁻¹ and number of seeds plant⁻¹ could be the important agronomical traits for the improvement of lentil

genotypes for seed yield. The variability for these traits in lentil germplasm was also reported by Koul et al. (2017), Ahamad et al. (2014), Choudhury et al. (2014). Significant genetic variation of yield and yield contributing characters of lentils based on morphological evaluation also indicates the scope and warranty for utilization in the future breeding program (Khazaei et al., 2016). Seed size directly associates with the seed yield in lentils (Mondal et al., 2007). From this present investigation hundred-seed weight ranged from 1.430 to 3.40 g. Rahman and Ali (2004) also found out a wide range of variations in the case of 100-seed weight, supported by the present study.

Correlation Study

A correlation coefficient study was estimated among the fourteen yield contributing agronomic traits (Table 8). The efficacy of selection in any crop enhancement program generally depends upon the knowledge of association among these traits. Also, correlation coefficient study among the traits is important for the identification of the nature of association among the traits (Sakthivel et al., 2019). From this study, the grain yield had a positive and significant correlation with filled grains plant⁻¹, hundred-seed weight, straw yield plant⁻¹, and harvest index. Still, it had a negative correlation with days to emergence, plant height, canopy width, canopy temperature at and after flowering stage, branches plant⁻¹ and days to maturity. Similar findings were reported by Vanave et al. (2019); Rafiq et al. (2018). Chowdhury et al. (2019) also reported that seed yield plant⁻¹ had positive correlation with the number of primary branches plant⁻¹, pods plant⁻¹, and seeds plant⁻¹, and 100-seed weight. Similar findings were also reported by Ghimire et al. (2020). Seed yield had a significant positive correlation with all the traits (Vanave et al., 2019; Sharma et al., 2018; Pandey et al., 2015) except days to fifty percent flowering and days to maturity (Sakthivel et al., 2019).

Table 8. Estimation of correlation coefficient of 13 yield contributing traits with grain yield per plant of 60 lentil germplasm during 2019-20 crop season at PRC, BARI, Ishurdi, Pabna, Bangladesh

	DE	DF	PH	CW	CTPF	CTAF	BPP	DM	FGP	UFGP	HSW	SYP	HI	GYP
DE	1.00													
DF	0.02 ^{ns}	1.00												
PH	-0.24 ^{ns}	0.13 ^{ns}	1.00											
CW	0.05 ^{ns}	0.28 ^{ns}	0.32 ^{**}	1.00										
CTPF	0.13 ^{ns}	-0.05 ^{ns}	-0.08 ^{ns}	-0.10 ^{ns}	1.00									
CTAF	0.09 ^{ns}	-0.11 ^{ns}	0.05 ^{ns}	0.13 ^{ns}	0.56 ^{**}	1.00								
BPP	0.32 ^{**}	0.15 ^{ns}	0.10 ^{ns}	0.36 [*]	0.03 ^{ns}	0.08 ^{ns}	1.00							
DM	0.29 [*]	0.15 ^{ns}	0.45 ^{**}	0.55 ^{**}	0.08 ^{ns}	0.15 ^{ns}	0.52 ^{**}	1.00						
FPP	0.19 ^{ns}	0.07 ^{ns}	0.07 ^{ns}	0.01 ^{ns}	0.20 ^{ns}	-0.01 ^{ns}	0.49 ^{**}	0.22 ^{ns}	1.00					
UFGP	-0.06 ^{ns}	0.22 ^{ns}	-0.29 [*]	-0.24 ^{ns}	0.02 ^{ns}	-0.17 ^{ns}	-0.15 [*]	-0.51 ^{**}	0.11 ^{ns}	1.00				
HSW	-0.18 ^{ns}	-0.04 ^{ns}	0.06 ^{ns}	-0.31 ^{**}	-0.18 ^{ns}	-0.30 [*]	-0.28 [*]	-0.22 ^{ns*}	-0.03 ^{ns}	0.11 ^{ns}	1.00			
SYP	-0.18 ^{ns}	0.26 [*]	0.12 ^{ns}	-0.19 ^{ns}	0.11 ^{ns}	-0.20 ^{ns}	0.05 ^{ns}	-0.21 ^{ns}	0.59 ^{**}	0.46 ^{**}	0.22 ^{ns}	1.00		
HI	0.12 ^{ns}	-0.43 ^{**}	-0.12 ^{ns}	-0.04 ^{ns}	-0.13 ^{ns}	0.05 ^{ns}	-0.07 ^{ns}	0.11 ^{ns}	-0.14 ^{ns}	-0.30 ^{**}	0.25 ^{ns}	-0.53 ^{**}	1.00	
GYP	-0.05 ^{ns}	-0.23 ^{ns}	0.01 ^{ns}	-0.22 ^{ns}	0.05 ^{ns}	-0.12 ^{ns}	-0.12 ^{ns}	-0.04 ^{ns}	0.41 ^{**}	0.13 ^{ns}	0.51 ^{**}	0.37 ^{**}	0.54 ^{**}	1.00

* Significant at $P \leq 0.05$; **Significant at $P \leq 0.01\%$; nsNon significant at $P \leq 0.05$

Conclusions

Enormous variability was observed among the studied lentil genotypes concerning qualitative and quantitative traits. The parents for hybridization can be selected based on variability and selection of genotypes for desirable traits. The superior genotypes from Cluster I were identified for all the traits, followed by genotypes in cluster Cluster IV. The genotypes BLX 09015, BLX 10001-1, and BLX 10002-15 were identified as donors for seed yield and early maturing genotypes, whereas 'Precoz' was identified as a seed yield donor with late maturity. The genotypes BLX 09015, 'Precoz', BARI Masur-9 from the Cluster I and BARI Masur-5, BARI Masur-7, and 'Maitree' from Cluster V were selected for direct use in yield trials, as well as for exploitation in hybridization program to isolate high yield recombinants since these genotypes have high yield potential, early flowering and maturity, more biological yield, and higher harvest index. Therefore, offspring derived from such diverse crosses are predictable for showing a broad spectrum of genetic variability and a greater choice for quantitative transgressive segregants in the advanced generations. Hence, these genotypes might be exploited in a multiple crossing programs to aggregate useful genes/alleles in a single genotype. Correlation studies also helped to find out the nature of the relationship among the various traits. However, filled grains plant⁻¹, hundred-seed weight, straw yield plant⁻¹, and harvest index were found to be the major traits for the selection of lentil genotypes in a breeding program.

Credit Authorship Contribution Statement

Md. Aktar-Uz- Zaman: Conceptualization, Methodology, Validation, Writing-Original Draft Preparation, Visualization, Supervision, Project Administration. **Ashutosh Sarker, Md. Ashraful Haque, Md. Motiar Rohman:** Validation, Data curation, Writing-Review and Editing. **Md. Ashraful Alam:** Editing, Data analysis. **Md. Omar Ali, Mohd. Mostafa Kamal, Debashish Sarkar, Akbar Hossain:** Validation, Data curation, Writing-Review and Editing

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

References

- Ahamed K. U., Akter B., Islam M. R., Humaun M. R., Alam M. J. (2014). Morphological Characterization and Genetic Diversity in Lentil Germplasm. *Int J Agric Res Innov Tech* 4 (1): 70-76.
- AIS (2020). (Agricultural Information System) Department of Agricultural Extension, Farmgate, Dhaka.
- Amurrio J. M., Ron de A. M., Zeven A. C. (1995). Numerical Taxonomy of Iberian Pea Landraces Based on Quantitative and Qualitative Characters. *Euphytica* 82: 195-205.
- Brummer Y., Kaviani M., Tosh S. M. (2015). Structural and Functional Characteristics of Dietary Fibre in Beans, Lentils, Peas and Chickpeas. *Food Res Int* 67: 117-125.

- Choudhary R., Verma S. K., Panwar R. K., Chourasiya V. K., Pandey D. (2017). Morphological Characterization of Lentil (*Lens culinaris* Medik.) Varieties Based on Six Qualitative Traits. *J Pharm and Phytochem* 6 (5):1611-1615.
- Choudhury R. U., Malek M. A., Sultana M., Sultana D., Ahmed B. (2014). Characterization of Lentil. *Bangladesh Res Pub J* 10 (1): 39-44.
- Chowdhury M. M., Haque M. A., Malek M. A., Rasel M., Ahamed K. U. (2019). Genetic Variability, Correlation and Path Coefficient Analysis for Yield and Yield Components of Selected Lentil (*Lens culinaris* M.) Genotypes. *Fundam Appl Agric* 4 (2): 769-776. doi: 10.5455/faa.21740.
- Frederick M., Cho S., Sarker A., McPhee K., Coyne C., Rajesh P., Ford P. (2006). Application of Biotechnology in Breeding Lentil for Resistance to Biotic and Abiotic Stress. *Euphytica*. 147: 149-165.
- Gaad D., Laouar M., Gaboun F., Abdelguerfi A. (2018). Characterization of Some Algerian and Foreign Lentil Accessions by Qualitative Traits. *Hort Biotech Res* 4: 43-47. doi: 10.25081/hbr.2018.v4.3560
- Ghafoor A. Z., Ahmad M., Afzal, Qureshi A. S. (2000). Influence of Genetic Diversity and Combining Ability in Determining Hybrid Vigor in *Vigna mungo* (L.) Hepper. *J Gen Breed* 54: 125-131.
- Ghimire D., Gurung A., Kunwar S., Paudel A., Poudel R. P., Kohar G. R. (2020). Variability, Correlation and Path Coefficient Analysis for Agro-Morphological Traits in Lentil (*Lens culinaris*). *S. J Agric Res* 7 (3): 480-489.
- Haddad N. I., Boggo T. P., Muchibauer F. J. (2004). Genetic Variation of Six Agronomic Characters in Three Lentil (*Lens culinaris* Medik.) Crosses. *Euphytica*. 31: 113-120.
- IBPGR (International Board for Plant Genetic Resources) and ICARDA (International Centre for Agricultural Research in Dry Areas) (1985). Lentil Descriptors (*Lens culinaris* M.). IBPGR Secretariat, Rome, Italy, 15p.
- Iqbal M. S., Qureshi A. S., Ghafoor A., Qayyum A. (2003). Identification of Superior Genotypes Based on Morphological, Physiological and Agronomic Traits in Local and Exotic Cowpea Germplasm. *Pak J Bot* 35 (1): 69-77.
- Jeena A. S. and Singh I. S. (2002). Genetic Divergence Analysis in Wild Lentils. *Legume Res* 25 (3): 175-179.
- Khazaei H., Caron C. T., Fedoruk M., Diapari M., Vandenberg A., Coyne C.J., Mcgee R., Bett K.E. (2016). Genetic Diversity of Cultivated Lentil (*Lens culinaris* Medik.) and Its Relation to the World's Agro-Ecological Zones. *Front Plant Sci* 7: 1093. doi: 10.3389/fpls.2016.01093.
- Koul M. P., Sharma V., Rana M., Chahota R. K., Kumar S., Sharma T. R. (2017). Analysis of Genetic Structure and Interrelationships in Lentil Species Using Morphological and SSR Markers. *3 Biotech* 7: 83. doi: 10.1007/s13205-017-0683-z
- Mohammed N. A., Refay Y. A., Migdadi H. M., Al-Somain B. H., Muharram A. A., Al-Selwey W. A., Abdela K. A., Alghamdiand S. S., Farooq M. (2019). Agro-Morphological Characterization of Lentil Genotypes in Dry Environments. *International Journal of Agriculture and Biology* 22 (6), 1320-1330. doi: 10.17957/IJAB/15.1204
- Mondal M. M. A., Howlader M. H. K., Akter M. B., Dutta R. K. (2007). Evaluation of Five Advanced Lentil Mutants in Relation to Morpho-Physiological Characters and Yield. *Bangladesh J Crop Sci* 18 (2): 367-372.
- Pandey S., Bhatore A., Babbar A. (2015). Studies on Genetic Variability, Interrelationships Association and Path Analysis in Indigenous Germplasm of Lentil in Madhya Pradesh, India. *Electron J Plant Breed* 6 (2): 592-599.
- Poonam T., Sharma K., Mishra S. K. (2006). Agro-Morphological Characterization of Diverse Germplasm of Lentil (*Lens culinaris* Medik.). *New Botany* 33: 225-235.
- R Core Team (2017). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL: <https://www.R-project.org/>
- Rabbani M. A., Iwabuchi A., Murakami Y., Suzuki T., Takayanagi K. (1998). Phenotypic Variation and the Relationships among Mustard (*Brassica juncea* L.) Germplasm from Pakistan. *Euphytica* 101: 357-366.
- Rafiq M., Kaukab S., Tahir A., Qadir M., Saeed M.S., Hussain B., Riasat G. (2018). Characterization and Correlation Analysis of Economically Important Parameters of Lentil Exotic Germplasm. *J Plant Breed. Crop Sci* 10 (11): 319-323. doi: 10.5897/JPBCS2018.0772
- Rahman M. A., Ali M. O. (2004). The Causes of Decreases in Pulse Production and Its Remedy. *Krishi Biplob* (A Fortnightly Magazine in Bengali). Published on 15 Nov. 2004. Published by M.N. Nabi, 279, East Hazipara, Rampura, Dhaka-1219, Bangladesh, p5.
- Saha C., Sarker A., Chen W., Vandemark J., Muehlbauer J. (2013). Inheritance and Linkage Map Positions of Genes Conferring Agromorphological Traits in *Lens culinaris* Medik. *Int J Agron* 2013: 618926. doi: 10.1155/2013/618926
- Sakthivel G., Jeberson S., Singh N. B., Sharma Ph. R., Kumar S., Jalaj V.K., Sinha B., Singh N.O. (2019). Genetic Variability, Correlation and Path Analysis in Lentil Germplasm (*Lens culinaris* Medik.). *The Pharma Innovation Journal* 8 (6): 417-420.
- Sarker A., Erskine W. (2006). Recent Progress in the Ancient Lentil. *J Agric Sci* 144: 19-29.
- Sharma S. R., Singh S., Gill R. K., Kumar R., Parihar A. K. (2018). Selection of Promising Genotypes of Lentil (*Lens culinaris* Medik.) by Deciphering Genetic Diversity and Trait Association. *Legume Res* 43 (6): 764-769. doi: 10.18805/LR-4056
- Sihag R., Hooda J. S., Vashishtha R. D., Malik B. P. S. (2004). Genetic Divergence in Soybean [*Glycine max* (L.) Merrill]. *Annals of Biology* 20 (1): 17-21.
- Singh M., Kumar S., Basandrai A. K., Basandrai D., Malhotra N., Saxena D. R., Gupta D., Sarker A., Singh K. (2020). Evaluation and Identification of Wild Lentil Accessions for Enhancing Genetic Gains of Cultivated Varieties. *PLoS ONE*. 15 (3): e0229554. doi: 10.1371/journal.pone.0229554
- Sirohi S.P.S., Yadav R., Meenakshi S. (2007). Assaying Genetic Divergence for Morpho-Physiological Traits in Lentil (*Lens culinaris* Medik.). *Plant Archives* 7 (1): 331-333.
- Sultana T., Ghafoor A., Ashraf A.M. (2005). Genetic Divergence in Lentil Germplasm for Botanical Descriptors in Relation with Geographic Origin. *Pak J Bot* 37 (1): 61-69.
- Sultana T., Nadeem S., Fatima Z., Ghafoor A. (2010). Identification of Elite Pure-Lines from Local Lentil Germplasm Using Diversity Index Based on Quantitative Traits. *Pak J Bot* 42 (4): 2249-2256.
- Toklu F., Karaköy, F., Haki E., Bicer T., Brandolini A., Kilian B., Özkan H. (2008). Genetic Variation among Lentil (*Lens culinaris* Medik.) Landraces from Southeast Turkey. *Plant Breeding* 128 (2): 178-186. doi:10.1111/j.1439-0523.2008.01548.x
- Tyagi S. D., Khan M. H. (2010). Genetic Divergence in Lentil. *African Crop Sci J* 18(2): 69-74.
- Urbano G., Porres J. M., Frias J., Vidal-Valverde C. (2007). Chapter 5: Nutritional Value. In: *Lentil: An Ancient Crop for Modern Times*. (Yadav S. S., McNeil D., Stevenson P.C. eds.) Vol. 3. Berlin, Springer, pp. 47-93.
- Vanave P. B., Jadhav A. H., Mane A. V., Mahadik S. G., Pethe U. B., Thaware B. L. (2019). Correlation and Path Analysis Studies in Lentil (*Lens culinaris* Medik.) *Electronic J Plant Breed* 10 (3): 1322-1328. doi: 10.5958/0975-928X.2019.00169.8

Appendix

Appendix 1. List of using 60 lentil genotypes with source of collection, and present status

Sl. No.	Accession code or name	Source/Origin	Status
1	BARI Masur-3	PRC	Popular variety
2	BARI Masur-4	PRC	Variety
3	BARI Masur-5	PRC	Variety
4	BARI Masur-6	PRC	Popular variety
5	BARI Masur-7	PRC	Popular variety
6	BARI Masur-8	PRC	Popular variety
7	BARI Masur-9	PRC	Short duration variety
8	LRIL-21-67-1-1-1-1	ICARDA	
9	LRIL-21-112-1-1-1-1-6	ICARDA	
10	IRLL-22-68-1-1-1-1-0	ICARDA	
11	ILL-8008	ICARDA	
12	ILL-5143	ICARDA	
13	91517	ICARDA	
14	9945	ICARDA	
15	LR-9-25	ICARDA	
16	PRECOZ	ICARDA	Popular variety in Argentina
17	Flip-2009-52L	ICARDA	
18	BLX-98001-9	PRC breeding material	
19	BLX-99033-19	PRC breeding material	
20	BLX-01013-21-5	PRC breeding material	
21	BLX-01014-9	PRC breeding material	
22	BLX-02009-11-1	PRC breeding material	
23	BLX-02009-17-1	PRC breeding material	
24	BLX-0200-08-4	PRC breeding material	
25	BLX-0200-18-3	PRC breeding material	
26	BLX-04004-10	PRC breeding material	
27	BLX-04010-15	PRC breeding material	
28	BLX-05001-10	PRC breeding material	
29	BLX-05002-6	PRC breeding material	
30	BLX-05004-8	PRC breeding material	

Continued. Appendix 1

Sl. No.	Accession code or name	Source/Origin	Status
31	BLX-05005-3	PRC breeding material	
32	BLX-05006-7	PRC breeding material	
33	BLX-05007-5	PRC breeding material	
34	BLX-05008-3	PRC breeding material	
35	BLX-05008-11	PRC breeding material	
36	BLX-05010-3	PRC breeding material	
37	BLX-05011-3	PRC breeding material	
38	BLX-05010-6	PRC breeding material	
39	BLX 01013	PRC breeding material	
40	BLX-12004-5	PRC breeding material	
41	BLX-12009-6	PRC breeding material	
42	BLX-12011-6	PRC breeding material	
43	L 4717	ICARDA	
44	Bagura Local	Bangladesh	Land race
45	RL-12-178	ICARDA	
46	RL-12-171	ICARDA	
47	Maitree	India	Popular variety in West Bengal, India
48	RL-12-181	ICARDA	
49	BLX 11014-8	PRC breeding material	
50	BLX 11014-10	PRC breeding material	
51	BLX 11014-11	PRC breeding material	
52	BLX 10001-1	PRC breeding material	
53	BLX 10002-15	PRC breeding material	
54	BLX 10002-20	PRC breeding material	
55	LRIL-18-102	ICARDA	
56	LRIL-22-158	ICARDA	
57	LG-198	ICARDA	
58	BLX-05002-3	PRC breeding material	
59	BLX 09015	PRC breeding material	
60	BLX 04005-9	PRC breeding material	