A Seminar Paper on

Lentil Breeding for High Yield & Nutritional Quality

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Lentil Breeding for High Yield & Nutritional Quality[1]

by

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ABSTRACT

Lentil is a staple pulse in many developing countries including Bangladesh. It is number one pulse with respect to consumption, among a dozen of pulses grown in the country. It is a rich source of dietary protein and micronutrients for majority the people in the country. The present review discusses the high yielding potentiality of lentil cultivars along with the current ongoing genetic improvement for nutritional quality. Studies revealed that single serving of lentils could provide a significant amount of the recommended daily allowance of micronutrients like Fe (86 ppm) and Zn (60 ppm) found in Barimasur-5 and Barimasur-6 along with protein requirement. Therefore, lentils have been identified as a food legume for biofortification to enhance nutritional quality, which could provide whole food solution to the global micronutrient malnutrition. Significant progress in genetic improvement for yield has been made by using different breeding strategies including molecular marker based precise breeding strategy in lentil. Binamasur-8 was found pioneer followed by Binamasur-5, Barimasur-5, L4717 in respect of seed yield with earliest maturity period. Therefore, it might be possible to increase production and nutrient content of lentil in Bangladesh with popular cultivars utilizing breeding strategies.

Key words: Lentil, land race, marker, nutrition, and yield

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Chapter 1

INTRODUCTION

The lentil plant, *Lens culinaris* ssp. *culinaris* Medikus, is a self-pollinating diploid (2n=2x=14) legume crop with a genome size of about 4 Gbp (Ogutcen *et al.*, 2018). It is an important cool season pulse crop that is grown all over the world in a variety of agroecological conditions. It provides poor people with an affordable source of dietary proteins, minerals, fiber, and carbohydrates, and it plays an important role in alleviating malnutrition and micronutrient deficiencies in developing countries. As it exhibits low glycemic index, it is highly recommended by physicians for the people suffering from diabetes, obesity, and cardiovascular diseases (Srivastava and Vasishtha, 2012). In fact, vegetable protein is gaining preference over the animal protein for consumption by the health-conscious people in the present day. The amino acid composition of lentil protein can impact human health by maintaining amino acid balance for physiological functions and preventing protein-energy malnutrition and other diseases. Therefore, it plays an important role in combating malnutrition and micronutrient deficiencies among developing-country inhabitants, especially those who cannot afford costly animal protein-based diets (Kumar *et al.*, 2016a). Thus, improving lentil protein quality through genetic biofortification, i.e., conventional plant breeding and molecular technologies, is vital for the nutritional improvement of lentil crops worldwide (Salaria *et al.*, 2022).

Among all the food legumes, lentil is one of the oldest and most popular one in Bangladesh. It is a crop with great potential for improving the livelihood of millions of smallholder farmers in tropical developing countries like Bangladesh (Sarker *et al*., 2004). Lentils are used to make an affordable and nutritious split (Dal) all over Bangladesh. They are frequently combined with rice to provide a more complete protein source. Lentil seed is high in protein and a variety of essential micronutrients (Fe, Zn, beta-carotene) (Bhatty, 1988). In Bangladesh, only the red cotyledon type is eaten as food, where it is boiled into a soup-like dhal and eaten with flat bread (roti) or rice. Khichuri is another popular dish made from split lentil seeds and pounded wheat or rice. It provides a valuable and balanced protein source, and its ability to thrive on marginal lands and in adverse environmental conditions has ensured its survival as a crop. More than 52 countries cultivate this crop, which has a 5.5 Mha area and produces 5.63 Mt of grains with a global average productivity of 1038 kg/ha (FAOSTAT, 2022).

In comparison to many major crops, such as cereals, lentil breeding has a relatively short history. Many traditional lentil producing countries still have landraces that are susceptible to a variety of biotic and abiotic factors (Sarker and Erskine, 2006). However, regional breeding programs have now been established around the world, and cultivars that offer significant benefits to farmers are being released. Unfortunately, in many cases, the distribution and adoption of new cultivars continues to limit the potential benefits of breeding in developing countries. Significant progress has been made in overcoming regional obstacles in germplasm diversity since the inception of the ICARDA (International Centre for Agricultural Research in the Dry Areas) breeding program in 1977. The primary goals of these breeding programs are to increase yield through efficient selection from available germplasm, introduce hybrid lines, cross contrasting lines to exploit heterosis, develop biotic and abiotic stress-tolerant cultivars, and induce mutations to generate novel variability using molecular and genomic techniques. Most conventional pulse breeding programs currently employ molecular markers to identify traits of interest. Genetic engineering technology has demonstrated remarkable potential to modify plants for specific breeding objectives. Technological advancements have expanded the possibilities of plant breeding, allowing for the development of specialized breeding programs such as those focused on improving the nutritional quality of crops, which is known as nutritional breeding (Kumar *et al.*, 2020).

By considering the above situations, this review paper is made to satisfy the following objectives:

- To explore higher yielding capacity of lentil
- To evaluate lentil breeding for nutritional improvement

Chapter 2
MATERIALS AND METHODS

The seminar paper is completely a review paper because it is prepared based on the information collecting from secondary sources. During preparation of the manuscript, I studied many corresponding papers, journals, reports, published books, scientific publications etc. I also used the library facilities of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU). I went many websites for collecting latest information such as google, google scholar etc. I got information from Bangladesh Agricultural Research Institute (BARI) and Bangladesh Institute of Nuclear Agriculture (BINA). Maximum necessary supports have been taken from internet searching. I enriched my knowledge with the suggestions and information of our course instructors. My major Professor helped me in many ways for preparing the paper. After collecting enough information, it was sequentially accumulated together for better understanding.

Chapter 3

REVIEW OF FINDINGS

3.1. Nutritional value

Lentil (*Lens culinaris* Medik.) is an essential legume crop that is widely grown in cool seasons worldwide. The grain of leguminous crops contains a variety of nutrients, such as protein, dietary fiber, starch, or oil, which provides energy, macronutrients, micronutrients, vitamins, and various bioactive phytochemicals, including antioxidants, phytoestrogens, phyto-hemagglutinins (lectins), oligosaccharides, saponins, and phenolic compounds, that can have beneficial metabolic effects on human health. Lentils contain primary phenolic compounds such as phenolic acids, condensed tannins, and flavonoids, making them a natural source of macronutrients, micronutrients, and phytochemicals (Thavarajah *et al.*,2011). Several studies have determined the composition of these components in lentil seeds, and their nutritional value has been reported. Johnson *et al.* (2013) showed that consuming 100 g of lentil grain can fulfill 41-113% of the recommended daily allowance (RDA) of Fe, 40-68% of Zn, and 77-122% of Se. Furthermore, lentils are a good source of β-carotene, with concentrations ranging from 2 to 12 µg/g.

Table 1. Different compositions of lentil grain

Elements	Amount
Protein	25%
Carbohydrate	63.35%
Lipid	1.06%
Phenolic Compounds	Quantity (µg/g)
Hydroxybenzoics	5.69
Dihydroxybenzoic acid	3.68
p-hydroxybenzoic acid	1.48
Protocatechuic acid	0.36
2,3,4-trihydroxybenzoic acid	16.9–29.2
Gallic acid	90.9–136.8
Vanillic acid	0.59–3.22
Hydroxycinnamics	3.76
Trans-p-coumaroyl malic acid	10.02
Trans-p-coumaroyl glycolic acid	2.88
Trans-p-coumaric acid	5.74
Sinapic acid	1099–2217
Chlorogenic acid	159–213

Source: Sarker *et al.*, 2021; Amarowicz, 2020; Kamboj & Nanda, 2017; Singh *et al.*,2017

The amino acid proportions in lentil proteins differ among genotypes in the cultivated gene pool. Methionine (Met) and tryptophan (Trp) are limited in quantity compared to other amino acids and are therefore referred to as limiting amino acids. When compared to cereal proteins, lentil protein shows good nutritional complementarity between Met and lysine (Lys), but only to some extent for Trp and threonine (Thr) because cereals are rich in both Met and Trp (Bhatty, 1988). Lentils are deficient in all essential amino acids except for lysine, but they contain a considerable amount of non-essential amino acids. Moreover, lentil proteins lack other S-containing amino acids like cysteine. The essential amino acid content is higher in the albumin fraction of lentils than in the globulin fraction (Bhatty, 1988). New research has shown that the amino acid composition varies among different types of Lens species. A range of differences have been observed in amino acid content between species, including *L. culinaris*, *L. orientalis*, *L. ervoides*, *L. nigricans*, and *L. odemensis*. Higher levels of essential amino acids, such as Phenylalanine (Phe), Met, valine (Val), leucine (Leu), and isoleucine (Ile), have been found in wild species when compared to cultivated lentils. (Table 2; Rozan *et al*., 2001). Similarly, the non-essential amino acid content is also more abundant in wild species than in *L. culinaris*. This suggests that wild species could be a promising reservoir of candidate genes that could enhance protein quality in cultivated lentils.

Table 2. Amino acid concentrations among different *Lens* species

Amino acids	*L. culinaris*	*L. orientalis*	*L. ervoides*	*L. nigricans*	*L. odemensis*
mg amino acids/g of dry seed weight					
Ala	20.42	39.81	16.01	22.47	21.32
Arg	10.61	14.04	12.05	7.48	9.10
Asp	10.96	26.10	17.42	7.68	11.17
Cys	0.40	0.39	0.53	0.47	0.44
Glu	26.55	42.27	32.62	19.95	24.22
Gly	9.77	12.66	11.48	7.89	10.22
His	8.74	3.95	9.75	4.94	6.84
Ile	6.26	9.58	8.59	7.76	5.06
Leu	10.64	15.86	14.07	11.74	8.09
Lys	4.54	12.64	9.48	6.14	5.69
Met	1.49	1.63	1.74	1.22	1.18
Phe	6.70	10.64	9.37	9.46	5.55
Pro	11.11	11.36	11.54	10.52	8.88
Ser	11.38	15.60	14.10	8.70	11.20
Thr	5.57	7.57	6.31	4.56	5.62
Trp	NA	NA	NA	NA	NA
Tyr	6.34	7.53	6.65	6.35	5.05

Source: Rozan *et al*., 2001

3.2. Trends in lentil production & trade

Lentil is a significant dietary element and an essential crop in many countries, including Afghanistan, Bangladesh, India, Nepal, Pakistan, Ethiopia, Morocco, Tunisia, Sudan, Iran, Syria, Turkey, Egypt and Iraq, which are also major producers. Other regions such as Southern Europe, Central Asia, the Caucasus, and Latin America have a lesser extent of production and consumption. Over the last twenty years, lentil cultivation has expanded to developed countries such as Australia, Canada, and the USA, where it has become a valuable agricultural export commodity. Currently, Canada is the second-largest lentil producer globally, after India, and has approximately 700,000 hectares of lentil cultivation (Tullu *et al.*, 2005). However, world lentil production has increased in the last few years from 4.98 million MT in 2010 to 5.61 million MT in 2021(FAOSTAT 2022). Australia, Canada, and Turkey have a stronghold in the international market for small-seeded, red cotyledon lentils, while Canada and the USA lead the market for large-seeded, green lentils. Major importers of red lentils include countries in the Indian Subcontinent, West Asia, and North Africa. Southern Europe and South America import large-seeded green lentils (Sarker & Erskine 2006).

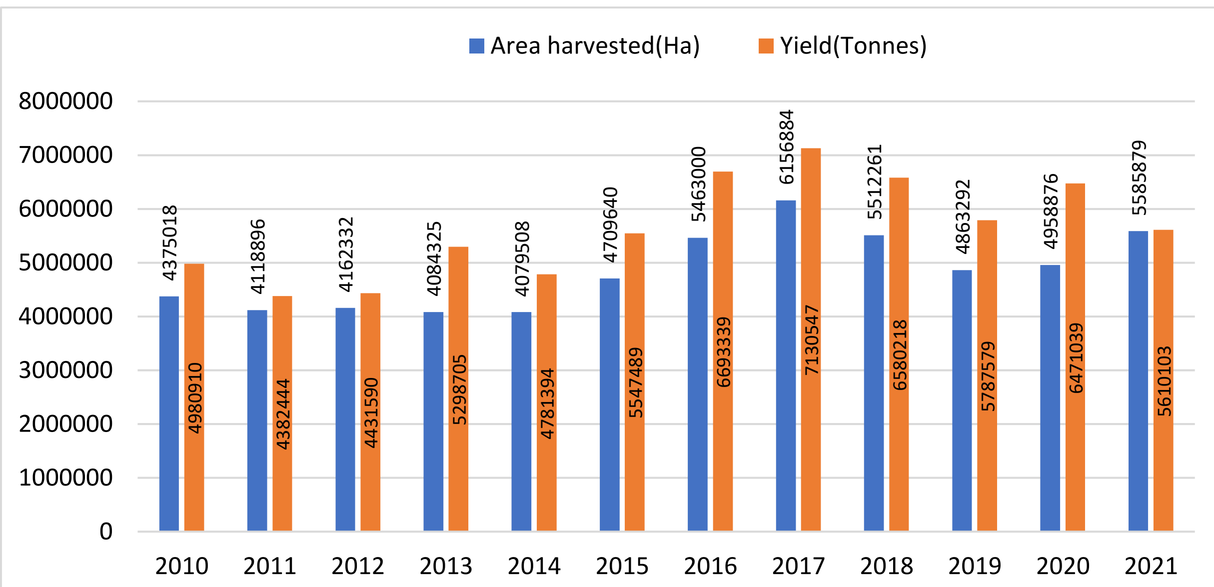

Figure 1. World lentil production (FAOSTAT, 2022)

3.3. Available Genetic Resources and Variation

ICARDA's lentil breeding program is based on the germplasm collection and its effective utilization. This program has conserved a significant number of germplasm accessions under FAO and other organizations' auspices. These accessions are maintained at ICARDA, National Bureau of Plant Genetic Resources in New Delhi, India, Vavilov Institute of Plant Industry in St. Petersburg, Russia, and United States Department of Agriculture (USDA) in the United States. Among these collections, the ICARDA collection is the largest, consisting of 11867 cultivated and 587 wild relatives (Table 3). Out of the cultivated species preserved at the ICARDA, 22% have been created through crossbreeding at the organization and have been provided to national programs via the International Nursery Network.

Table 3. Genetic resources conserved at the ICARDA

Name of taxon	Accessions	Countries of collection
L. culinaris ssp. *culinaris*		
Landraces	11 867	78
Breeding lines (ICARDA)	3358	
L. culinaris ssp. *orientalis*	259	15
L. culinaris ssp. *tomentosus*	21	2
L. culinaris ssp. *odemensis*	66	5
L. ervoides	170	16
L. nigricans	62	8
L. lamottei	10	8

Source: Erskine *et al.*, 2016

In the future, there should be a focus on diversifying and evaluating lentil germplasm through traditional breeding methods to enhance protein quality in response to the growing demand for plant-based protein. Conventional breeding is progressing for lentil crop nutritional improvement, but due to the quantitative nature of these traits, other genomic approaches are required to accelerate the breeding process. Genome-wide association studies combined with conventional plant breeding approaches are appropriate for improving quantitative trait genetic gain by increasing selection accuracy through indirect selection. (Rutkoski, 2019). For example, by selecting diverse parents, increasing selection intensity and accuracy, and decreasing selection cycle duration by increasing the number of generations per year, genetic gain for lentil protein concentration can be achieved. Conventional breeding methods such as pedigree, bulk, and mutation breeding can be used to develop new breeding material from wild species, cultivars, landraces, advanced/elite breeding lines, and genetic stocks (Figure 2). These breeding methods will produce a wide range of germplasm that can be used for phenotyping and genotyping platforms to improve selection accuracy (Xu *et al.*, 2017). However, these conventional methods do not increase the selection intensity due to low heritability, slow progression, and visual phenotypic selection. The development and adoption of genomic resources and tools such as genetic engineering or genome editing may also contribute to the pace of conventional breeding in lentils and eventually lead to breakthroughs in lentil protein improvement programs to ensure nutritional security and improve human health

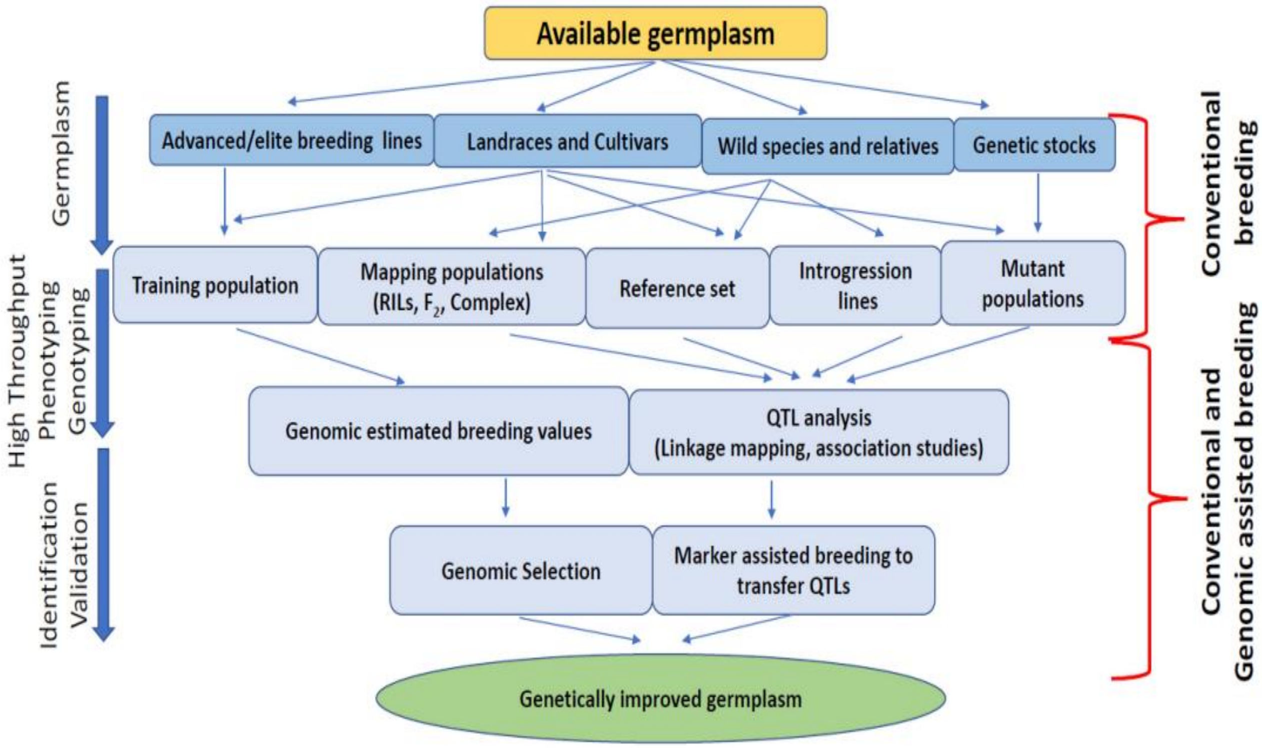

Figure 2. Germplasm improvement process (Salaria *et al*., 2022)

3.4. Potential traits for lentil breeding

Any breeding strategy for developing improved plant types adapted to diverse agro-ecological environments must include genetic variability. ICRADA's core collection revealed enough variation for phenological and morphological traits (Tullu *et al.*, 2005). In this situation, cultivars of lentils can be genetically improved by focusing on several beneficial traits. In this strategy, the region where a target trait is frequently found is used to identify the germplasm for that trait. The method has proven effective in locating genotypes with desirable characteristics like tolerance to biotic and abiotic stresses, superior grain quality and nutritional traits, improved grain size, and early maturity. Thus, after being tested at several locations for useful traits, core sets of diverse origin may be developed and used to increase productivity and yield. Therefore, the above mentioned physiological and biochemical traits can be used in breeding programs to identify superior genotypes.

Table 4. Genetic studies for morphological traits in lentil

Characters	Genetic control	References
Growth habit	Monogenic recessive	Emami and Sharma 1999
Leaflet number	Monogenic dominant	Kumar *et al.*, 2015
Plant height	Monogenic dominant	Tahir *et al.*, 1994
Stipule size	Incomplete dominance	Kumar *et al.*, 2015
Earliness	Monogenic recessive	Sarker *et al.*, 1999
Flower colour	Monogenic dominant	Lal and Srivastava, 1975; Ladizinsky, 1979
Pod size	Incomplete dominance	Kumar *et al.*, 2013
Pod dehiscenc	Monogenic dominant	Ladizinsky 1979
Seed size	Polygenic with partial dominance	Abbo *et al.* 1991
Winter hardiness	Polygenic	Kahraman *et al.* 2010
Early growth vigour	Single recessive and minor genes	Kumar *et al.* 2013

Significant progress has been made in the development of genomic resources in lentil during the past years. Thousands of molecular markers such as Random Amplified Polymorphic DNA (RAPD), Simple Sequence Repeats (SSR), Amplified Fragment Length Polymorphism (AFLP), Restriction Fragment Length Polymorphism (RFLP), Single Nucleotide Polymorphism (SNP), including transcriptome sequences, EST sequences and whole genome sequences have been developed to be used in lentil (Eujayl *et al.*, 1998a; Kumar *et al.*, 2015). However, in recent years, next generation sequencing platforms have accelerated development of SNP markers. The first genetic mapping (linkage analysis) began in lentil in 1984 (Zamir and Ladizinsky, 1984), the first map comprising DNA based markers was produced by Havey and Muehlbauer by (1989). Subsequent molecular maps have been developed in lentil and used for marker trait association analysis (Kumar *et al.*, 2015). Fedoruk et al. (2013), first used the AM in lentil to identify QTL for seed size and seed shape. As the properly designed AM panels have a greater frequency of alleles, encompass the genetic variation of a crop, may facilitate time and cost saving as compared to MAS in lentil. These maps were constructed using RAPD, AFLP, RFLP, ISSR, ITAP resistance gene analogs and morphological markers using RIL populations.

Table 5. Marker-trait association studies conducted in lentil

Trait	Gene/QTL	Marker	Phenotypic variation explained (%)	Reference
Plant structure, growth habit and yield, seed diameter, seed weight	QTL	RAPDs, ISSRs,AFLPs, SSRs	18.2-90.4	Fratini *et al*. 2007
Earliness and plant height	QTL	RAPD, SSR, AFLP	31-46	Tullu *et al.* 2005
Winter hardiness	QTL	RAPD, ISSR	20.5	Kahraman *et al.* 2010
Seed thickness, diameter, seed plumpness, days to 50% flowering	QTL	SSR and seed color loci	8.4-60	Fedoruk *et al.* 2013
Hundred seed weight, plant height, seed diameter	QTL	SSR, SRAP, RAPD	15.3-32.6	Saha *et al.* 2013
Boron tolerance	QTL	SNP	71	Kaur *et al.* 2014
Flowering time	QTL	SSR	57	Kahraman *et al.* 2010
Seed weight and size	QTL	SNP	27.5-48.4	Verma *et al.* 2015
Drought tolerance	QTL	SSR	69.7	Singh *et al.* 2016

3.5. Yield scenario of popular lentil cultivars

According to Sarker *et al.*, 2004 at the farm level, lentil yields are far below the genetic potential of its cultivars. Low yields could be attributed to a lack of available site-specific lentil cultivars and an imbalanced fertilizer application. One of the main disadvantages of existing varieties is their low yield and manufacturability. Giri *et al.* (2021) evaluated 11 cultivars along with a local check variety, in total 12 varieties (Table 6). Among the yield attributes, the highest numbers of branches/plant was recorded in IPL220 (12.40). L-4717 and IPL220 varieties had the highest number of pods plant-1 (43.33) and seeds pod-1 (1.83), respectively. L4717 had the highest test weight (weight of 1000 seeds) (32.03 g), followed by L4727 (27.78 g). The L4717 variety produced the most seed (947.67 kgha-1) followed by the Bari Masoor-5 (892.89 kgha-1) and L4727 (838.67 kgha-

1) varieties. Based on the experimental results, it is possible to conclude that the Bari Masoor-5 lentil variety demonstrated superior growth and yield characteristics, which contributed significantly to its satisfactory seed yield.

Table 6. Yield attributes and yield of different lentil varieties/lines

Treatment	No of primary & secondary branches/plant	No of pods/plant	No of seeds/pod	1000 seed weight (Test Wt) (g)	Seed yield (kg/ha)
Bari Masoor-5	12.40	41.30	1.67	20.51	892.89
Bari Masoor-7	6.30	34.67	1.67	18.63	430.33
Moitri	10.13	41.53	1.67	18.53	515.11
C23E21	9.32	33.17	1.50	17.32	547.00
ILL10802	12.73	32.67	1.58	18.24	487.56
ILL10893	10.98	41.00	1.83	15.10	437.33
IPL220	13.17	38.90	1.83	19.25	655.00
IPL534	11.75	39.17	1.67	26.09	773.33
L4717	9.23	43.33	1.83	32.03	947.67
L4727	7.05	42.73	1.75	27.78	838.67
ILL10961	8.33	40.23	1.25	13.80	711.67
Local Check (WBL77)	2.90	12.00	1.50	19.13	442.33

Source: Giri *et al*., 2021

In most lentil breeding programs, the main target is to achieve a high seed yield. However, there may be situations where other traits are equally or more important. The number of pods per plant and seed yield are highly related, and these traits can be influenced by agronomic practices. The development of improved cultivars can lead to increase lentil production and yields. Despite the potential cultivar yields, lentil production in most regions is typically only half of the maximum yield due to production constraints that limit the realization of the true genetic yield potential. Bicer and Sakar (2010) tested ten lentil (*Lens culinaris* Medik.) genotypes that were grown at Southeast Anatolia region of Turkey (Table 7). Seyran 96, Firat 87, Local Red and Kislik Kirmizi are, high yielding and red cotyledon cultivars, are recommended for winter cultivation in South-east Anatolia in Turkey. Ali Dayi is recommended forspring cultivation in colder central Anatolia in Turkey(Aydin et al., 2003). Ozbek and Kafkas are winter-hardy and high-yielding, cultivars which are recommended for winter cultivation in Central Anatolia

(Sarker et al., 2002). Sakar, was isolated from local populations and registered in 2005, high-yielding, large seeded (4.0 g/100 seed), early maturing and red cotyledon, and recommended for winter cultivation in Southeast Anatolia (Anonymous, 2005). Mut 3 and Mut 10 are mutant lines from Kislik Pul 11.

Table 7. Different yield parameters of 10 Turkey lentil genotypes

Genotypes	Number of pods $plant^{-1}$	Number of seeds $plant^{-1}$	Seed yield $plant^{-1}$, g	1000 seed weight, g	Grain yield, kgha-1
Seyran 96	23.18	31.83	1 056	33.11	1689
Kislik Kirmizi	26.41	38.76	1 349	32.29	2116
Ozbek	21.9	31.19	0.99	32.94	1961
Alidayi	23.14	31.77	1 159	37.37	1969
Kafkas	21.67	29.49	0.97	31.93	1712
Mut 10	16.23	19.22	0.832	45.84	1659
Local red	25.16	33.15	1 142	34.49	1937
Firat 87	29.66	35.71	1 326	34.78	1887
Mut 3	15.85	20.73	0.758	39.1	1484
Sakar	21.15	28.57	1 119	40.85	2050

Source: Bicer and Sakar (2010)

In recent years BINA developed nine lentil varieties (Binamasur-1, Binamasur-2, Binamasur-3, Binamasur-4, Binamasur-5, Binamasur-6, Binamasur-7, Binamasur-8 and Binamasur-9) were tested in Randomized Complete Block Design (RCBD) with three replications to evaluate their morphological and yield contributing characters (Table 8). The performance of Binamasur-8 is the best for maximizing seed yield with short maturity period. Binamasur-8 produced 2.37 t ha-1 yields with 88 maturity days. Primary branch production is more important than plant height in achieving higher seed yield in lentil. More primary branches ensure more pod number which also increase seed number and finally produce more seed yield. Seed size was also responsible for high yield achievement. Among all the BINA developed lentil varieties Binamasur-8 was found pioneer followed by Binamasur-5 in respect of seed yield with earliest maturity period. Therefore, it will be possible to increase lentil production in Bangladesh by cultivating Binamasur-8.

Table 8. Yield attributes of BINA developed lentil varieties

Variety	Pods/plant (no.)	1000 seed weight (g)	Seed Yield (t/ha)
Binamasur-1	105	14.31	1.63
Binamasur-2	102	15.84	1.87
Binamasur-3	67	15.61	1.83
Binamasur-4	83	17.31	1.9
Binamasur-5	103	21.31	2.07
Binamasur-6	67	19.43	2.03
Binamasur-7	76	16.60	2.03
Binamasur-8	109	22.08	2.37
Binamasur-9	88	17.33	2.02

Source: Khatun *et al.*, 2021

3.6. Current status of genetic improvement for target nutritional traits

In the beginning, screening was used in lentils to determine existing natural variation for favorable alleles controlling enhanced concentration for target nutritional traits. This aided in identifying available genetic variability that can be used as a donor for transferring useful genes in the background of cultivated genotypes, as well as directly using it as a biofortified variety if the identified variant is already a high yielding variety. Significant genetic variability in nutrient concentration has previously been observed among lentil land races from various countries, including Turkey, Syria, Canada, and Pakistan (Table 9). Because of their long-term preference in specific growing regions, these land races were adaptive to some specific nutritional traits. As a result, these studies have focused on nutritional characteristics such as folates, macro- and micronutrients. A screening of >1600 lentil accessions for iron and zinc concentration, including local land races, breeding lines, released cultivars, and wild relatives, revealed significant genetic variability ranging from 42-132 ppm for Fe and 23-78 ppm for Zn. Turkish land races also demonstrated a wide range of diversity in macronutrients as well as micronutrients. Breeding lines, varieties, and parental lines of lentil grown under Indian conditions revealed a wide range of variability for macro and micro nutrients. Ca and Mg concentrations in Indian germplasms are much lower than in Turkish germplasm. In addition, Indian genotypes and breeding lines contained more Fe, Zn, and Se than exotic lines.

Table 9. Genetic variability studied for Fe, Zn, and Se concentration among gemplasm lines of lentil

Type of screening material	Number of genotypes	Range of variability			Country
		Fe (mg/kg)	Zn (mg/kg)	Se (µg/g)	
Land races, wild types and breeding lines	1600	43-132	22-78	-	ICARDA, Syria
Lentil germplasm	-	41-109	22-78	-	do
Breeding lines, germplasm and modern high yielding genotypes	900	73-90	44-54	425-673	Canada
Land races, cultivars	46	49- 81	42- 73	-	Turkey
Land races, breeding material, exotic lines	96	37 - 157	26-65	240- 630	India

Source: Kumar *et al*., 2016b

3.7. Harvest plus challenge program towards biofortified lentil

The Bill and Melinda Gates Foundation and other donors officially established the Harvest Plus Challenge Program in 2004. Harvest Plus joined the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH) in 2012. The Consultative Group on International Agricultural Research (CGIAR) has launched the Harvest Plus Challenge Program to develop biofortified lentils high in iron, zinc, and provitamin A. This program has focused on developing high-yielding lentil cultivars with high Fe and Zn concentrations. Initially, efforts were made to identify biofortified lentil varieties through screening of previously released varieties. Under this program, released varieties from various countries (including Bangladesh, Ethiopia, Nepal, Morocco, Turkey, Syria, Lesotho, and Portugal) were screened for Fe and Zn concentration. As a result, a number of released varieties have been discovered to have high iron and zinc concentrations as well as good agronomic performance (Table 3). These varieties or cultivars were developed quickly and are now being used as biofortified lentil varieties in economically poor regions of the world. In Bangladesh, for example, the government has launched a massive dissemination campaign to promote promising lentil varieties (Barimasur 5 and Barimasur 6) with high Fe and Zn levels. Similarly, lentil varieties such as Khajurah 1, Khajurah 2, Sishir, and Shital are rapidly spreading in Nepal's Terai region. Farmers in India's north-west plain agro-climatic zone grow the Fe-rich variety Pusa Vaibhav. More biofortified lentil varieties will be released for general cultivation in various countries in the future.

Table 10. Lentil variety rich in Fe and Zn identified through analysis of released cultivars under the HarvestPlus Challenge Program of CGIAR

Country	Name of variety	Fe (ppm)	Zn (ppm)
Bangladesh	Barimasur -4	86.2	-
	Barimasur -5	86	59
	Barimasur -6	86	63
	Barimasur -7	81	-
Nepal	Sisir	98	64
	Khajurah-2	100.7	59
	Khajurah-1	-	58
	Sital	-	59
	Shekhar	83.4	-
	Simal	81.6	-
India	PusaVaibhav 102 -	102	-
	L 4704 125 74	125	74
Syria/Lebanon	Idlib-2	73	-
	Idlib-3	72	-
Ethiopia	Alemaya	82	66

Source: Kumar et al., 2016a

Chapter 4

CONCLUSION

Indian L4717 variety, Turkish Kislik Kirmizi variety, Alidayi variety, Sakar variety, Bangladeshi Bari Masoor-5, Binamasur-8, Binamasur-5 varieties have shown higher yield potential globally in different studies. The performance of Binamasur-8 is the best for maximizing seed yield with short maturity period. The highest yield was noted in Binamasur-8 which produced 2.37 tha^{-1} followed by Binamasur-5 in respect of seed yield, 2.07 tha^{-1} with earliest maturity period. Kislik Kirmizi (2116 $kgha^{-1}$), Alidayi (1969 $kgha^{-1}$) and Sakar (2050 $kgha^{-1}$) are high yielding varieties in respect of summer and winter season specificity. L4717 variety (947.67 $kgha^{-1}$) followed by Bari Masoor-5 (892.89 $kgha^{-1}$) and L4727 (838.67 $kgha^{-1}$) varieties yielded higher. Form the experimental findings, it can be concluded that also Bari Masoor-5 lentil variety recorded higher growth and yield attributes which significantly contributed towards its satisfactory seed yield.

Essential amino acids like Ala (39.81mg), Arg (14.04 mg), Glu (42.27 mg), Pro (11.54 mg), Ser (15.60 mg), Phe (10.64 mg), Met (1.74 mg), Leu (15.86 mg), and Ile (9.58 mg) concentrations are found significantly higher in different wild species than cultivated lentils. Similarly, the non-essential amino acid content is also higher in wild species than in *L. culinaris*. Such evidence signifies wild species are a potential source of candidate genes that can be harnessed to improve protein quality in cultivated lentils. A screening of lentils including local land races, breeding lines, released cultivars and wild relatives for iron and zinc concentration showed significant genetic variability ranging from 42–132 ppm for Fe and 23–78 ppm for Zn. Nepali Khajurah variety contains 100.7 ppm Fe along with 59 ppm Zn. Barimasur 5 and Barimasur 6 are promising lentil varieties having high Fe (86 ppm) and Zn (~60ppm) that also can be used for further nutritional improvement of lentil breeding.

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