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REGISTRATION

Cultivar

'BARI Masur-8': A high-yielding and biofortified lentil cultivar in Bangladesh

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Abstract

Lentil (*Lens culinaris* Medik.) is a nutritious food for millions of people globally. It plays an important role in Bangladesh as a good source of protein and micronutrients for low-income populations with less access to animal protein. To enhance nutritional security, a nutrient-dense lentil line, LR-9-25, was identified from a Stemphylium blight (SB) screening population developed at The International Center for Agriculture Research in the Dry Areas through a cross between ILLX955-135 and FLIP92-52L. The line LR-9-25 was rigorously evaluated in diverse agro-ecological conditions of Bangladesh and released for commercial cultivation by the Pulses Research Centre, Bangladesh Agricultural Research Institute as 'BARI Masur-8' (Reg. no. CV-35, PI 700306) in 2015. BARI Masur-8 matures in 115–120 d and fits well into existing rice-based cropping patterns. It is a medium-height (35 cm) and medium-seeded (1.94 g 100^{-1} seed) cultivar having a high level of tolerance to SB and root rot diseases. BARI Masur-8 showed high yield potential (1,973 kg ha^{-1}) and high concentrations of Fe (74 mg kg^{-1}), Zn (61 mg kg^{-1}), and Se (325 µg kg^{-1}) in seed. Another desirable trait is the late planting potential, with sowing up to the first week of December after the harvest of long-duration rice (*Oryza sativa* L.) cultivars, which is a major area for lentil production in Bangladesh. The cultivation of this improved cultivar will play an important role for enhancing nutritional security by increasing lentil production in Bangladesh, Nepal, and eastern Indian states in South Asia.

Abbreviations: BADC, Bangladesh Agricultural Development Corporation; BARI, Bangladesh Agricultural Research Institute; ICARDA, The International Center for Agriculture Research in the Dry Areas; PRC, Pulses Research Centre; SB, Stemphylium blight.

1 | INTRODUCTION

Iron (Fe), zinc (Zn), and selenium (Se) are among the most important micronutrients for human health. Both Fe and Zn are essential for the sustenance and optimal physiological function of all life forms on the planet (Bailey et al., 2015). Deficiencies of these nutrients can cause physiological and metabolic disorders. For instance, a shortage of Fe in the blood can lead to a range of serious health problems, including anemia. Zinc deficiency is associated with stunted linear growth and diminished immune function.

Iron and Zn deficiencies are among the most widespread human micronutrient deficiencies and are particularly prevalent in resource-poor countries where there is a heavy dietary reliance on staple crops (Sands et al., 2009). Iron and Zn deficiencies are quite common in all, and women and children are most vulnerable. Nearly one-third and one-fifth of the world's population are Fe and Zn deficient, respectively (De Benoist et al., 2008). In Bangladesh, the national prevalence of Zn deficiency was reported to be 44.6 and 57.3% in preschool-age children (6–59 mo) and nonpregnant, nonlactating women (15–49 yr), respectively (Rahman et al., 2016). The micronutrient-deficient diet causes micronutrient malnutrition, which affects more than one-third of the world's population and is growing to be a global threat from health perspective (Unicef & Micronutritient Initiative, 2004).

Lentil seed is an excellent source of Fe (73–90 mg kg^{-1}), Zn (44–54 mg kg^{-1}), and Se (425–673 μg kg^{-1}) compared with other grain legumes and cereals (Ray et al., 2014; Thavarajah et al., 2011). It is also a good source of protein, vitamins, and dietary fiber. All these benefits increase the importance of lentil in our diet to combat human micronutrient malnutrition globally. Moreover, the higher protein percentage makes lentils an important and more affordable plant-based substitute for animal protein. Production of micronutrient-enriched/biofortified cultivars with resistance to Stemphylium blight (SB) and root rot (the major constraints to lentil production) is considered a promising and cost-effective strategy to increase micronutrients in foods for sustainable and long-term solutions. Here we developed 'BARI Masur-8' (Reg. no. CV-35, PI 700306), a high-yielding, nutrition-dense, and SB-resistant lentil cultivar for enhancing nutritional security in Bangladesh.

2 | METHODS

2.1 | Breeding and selection

The line LR-9-25, designated as BARI Masur-8, was selected from a recombinant inbreed line population (81 lines) derived from a cross between ILLX955-135 and FLIP92-52L at The International Center for Agriculture Research in the Dry Areas (ICARDA), Syria. The parent ILLX955-135 was a high-yielding red lentil breeding line of ICARDA, and FLIP92-52L was a germplasm of ICARDA origin resistance to SB and rust diseases. After confirmation of F_1, the F_2 seeds were advanced to F_7-derived F_8 recombinant inbreed lines by single-seed descent. The populations were used to evaluate resistance to SB disease and for comparative analysis of potential transgressive segregation of agronomic traits at Pulses Research Centre (PRC), Bangladesh Agricultural Research Institute (BARI), Ishwardi, Bangladesh, from the 2004/2005 to the 2007/2008 cropping seasons. Two promising lines—BARI Masur-8 and LR-9-38—were identified as resistant to SB, and the seed was stored in the cool room at PRC for future breeding purposes.

Core Ideas

- High-yielding (1,973–2,500 kg ha^{-1}) lentil cultivar BARI Masur-8 outyielded BARI Masur-7 by 20–25%.
- BARI Masur-8 seed is enriched with Fe (74 mg kg^{-1}), Zn (61 mg kg^{-1}), and Se (325 μg kg^{-1}).
- BARI Masur-8 is tolerant to stemphylium blight and root rot diseases.
- BARI Masur-8 has late planting potential after the harvest of long-duration rice cultivars.

2.2 | Field evaluation

Two experiments were conducted. (a) Yield, yield-contributing traits, and nutritional status of BARI Masur-8 were evaluated. A field experiment was conducted from 2011 to 2014 at Ishwardi (24°9′ N, 89° 4′ E; 19 m asl), Gazipur (22°4′ N, 90°4′ E; 17 m asl), Jessore (23°1′ N, 89°1′ E; 16 m asl), and Jamalpur (24°2′ N, 90°4′ E; 19 m asl) to compare BARI Masur-8 with the commercial check cultivar 'BARI Masur-7' and other promising checks- LR-9-48, BLX-02009-4-1 and BLX-04008-14. (b) The yield performance of BARI Masur-8 in late sown condition was evaluated. BARI Masur-8 was tested for its yield performance in late sowing in a rice-based cropping system at Ishwardi in 2015. In this experiment, five BARI-released lentil cultivars ('BARI Masur-1', 'BARI Masur-3', 'BARI Masur-5', 'BARI Masur-7', and 'BARI Masur-8') were sown on 20 November (optimum sowing) and 10 December (late sowing). All the trials were located on clay loam soil (pH 7.3–7.5). The basal fertilizer was a mix of urea, triple superphosphate, and potassium chloride (muriate of potash) at the rates of

40 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1}. The triple superphosphate, muriate of potash, and half of the urea were broadcast 2 d before lentil sowing, and the rest of urea was topdressed 20 d after sowing. The experiments was conducted in a randomized complete block design with three replications. BARI Masur-8 and the checks were sown in a unit plot of 10 rows × 4 m long with a spacing of 40 cm between rows. Seed was sown in the rows carefully by hand at 3-cm depth and then covered by soil. Post-sowing irrigation was performed to ensure seed germination. Mulching was done, and crusts were broken. Weeding was carried out manually 30 d after crop establishment and when necessary thereafter to keep the plots weed free. The insecticide Dimethoate (Tafgor 40 EC) was sprayed at 2 ml L^{-1} of water twice starting from the flowering stage to control aphids. Total average rainfall at all four locations during the lentil growing season (November–March) was at 44 mm in 2011, 118 mm in 2012, 89 mm in 2013, and 102 mm in 2014.

2.3 | Experimental measurements and statistical analysis

The time (d) from sowing to 50% of plants in a plot coming into flower was recorded, as was the time (d) from sowing to 80% of pods mature in a plot. Plant height, pods $plant^{-1}$, and branches $plant^{-1}$ were taken from 10 randomly selected plants per plot. At harvest, lodging was assessed on a scale of 1–5, with 1 = no plants lodged, 2 = 1–25% plants lodged, 3 = 26–50% plants lodged, 4 = 51–75% plants lodged, and 5 = 76–100% plants lodged (Erskine & Goodrich, 1988). The Fe and Zn concentrations in lentil seed was determined with randomly taken subsamples of 25 g grains from the entire harvested plot of each replicated entry at each location. The samples were oven dried at 70 ˚C for 24 h, and a ground sample of 0.5 g was prepared by a standard HNO_3–H_2O_2 digestion method (Thavarajah et al., 2009) using wet digestion with nitric acid. Concentrations of Fe and Zn concentration was then measured by flame Atomic Absorption Spectrometry (AJ ANOVA 300, Lab Synergy). Measurements of total Fe and Zn were validated using NIST standard reference material 1573a (tomato leaves; [Fe] = 51,610 ± 890 mg kg^{-1} and [Zn] = 352 ± 16 mg kg^{-1}). The concentration of total Se in lentil seeds was determined using the modified HNO_3–H_2O_2 method described by Thavarajah et al. (2008). Grain yield was harvested from eight rows 4-m-long plots, excluding two border rows.

The severity of SB blight disease of lentil was scored under field conditions on a scale of 0–5 (Bakr et al., 2000), where 0 = no infection (highly resistant), 1 = few scattered leaf but no twig blighted (resistant), 2 = 5–10% leaflets infected and few scattered twig blighted (moderate resistant), 3 = 11–20% leaflets infected and 1–5% twig blighted (moderate susceptible), 4 = 21–50% leaflet infected and 6–10% twig blighted (susceptible), and 5 = above 51% leaflet infected and more than 10% twig blighted (highly susceptible). Similarly, root rot severity was scored as in Chatterton et al. (2019) using a scale of 1–7.

The experiment to assay yield potentiality in late sowing was conducted on five BARI released cultivars, including BARI Masur-8, at similar growth conditions and management practices as described above for the yield and nutritional status evaluation experiment. The experimental design was split-plot with three replicate blocks. Main plots were sowing dates (optimum 20 November and late 10 December); cultivars were in sub-plots. Data were recorded as in the yield and nutritional status evaluation experiment.

Data were analyzed using GenStat 16th edition for Windows statistical software (VSN International). Analyses of variance for the traits were performed across locations within years. The LSD test ($P = .05$) was used to compare means for the genotype effects.

3 | CHARACTERISTICS

3.1 | Morphological description

Morphologically, BARI Masur-8 is a distinct cultivar (Figure 1). It is a medium-height (35–40 cm) plant and has many long, ascending branches. The stem is pigmented, most prominently at the basal part. The compound leaves are alternate, with six pairs of oblong-linear leaflets that end in a spine. Leaves are green with clear pubescence. Leaf size is medium with short petiole and rachis that forms prominent tendrils. Two to three pale blue flowers are borne in the axils of the leaves. Seed color is ash, and testa is dotted. Seed has a smooth surface with orange/red cotyledon. The average 100-seed weight is 1.94 g. The recovery percentage of splitted/dehulled quantity from whole seed is 74. BARI Masur-8 requires 16–20 min to cook, which is preferred by consumers. Its seed contains 27.8% protein. BARI Masur-8 is suitable for sole and relay cultivation in all lentil-growing areas in Bangladesh.

3.2 | Agronomical performance

Analysis of variance indicated significant differences ($P < .05$) in agronomic traits between BARI Masur-8 and other test entries (Table 1). Averaged over four locations,

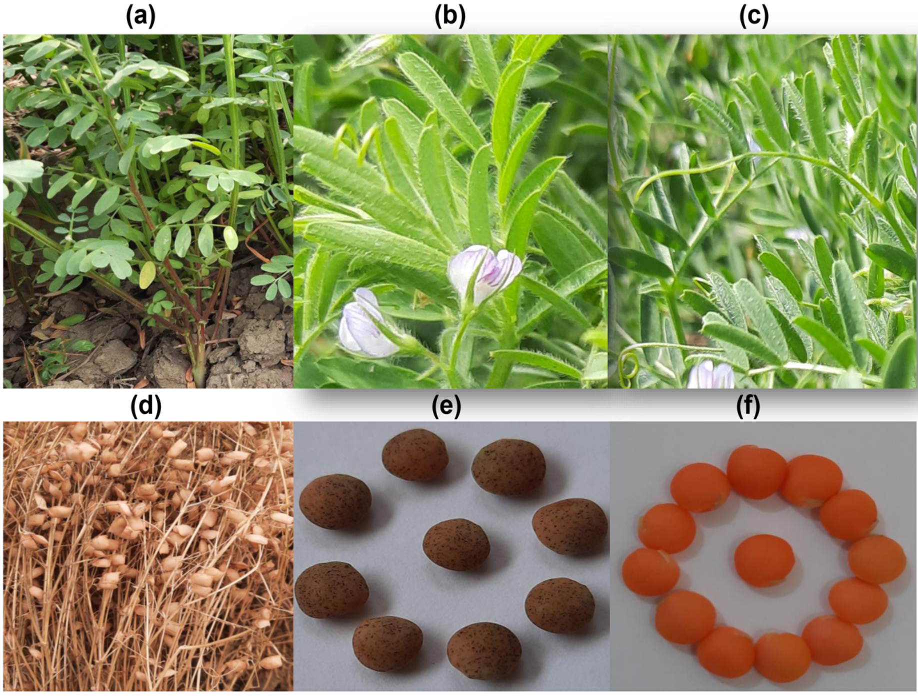

FIGURE 1 Morphological characteristics of BARI Masur-8. (a) Pigmented stem in the basal part of plant; (b) pale blue flowers borne in the axils of the leaves; (c) dark green leaves with clear pubescence and prominent tendrils; (d) mature plant with pods; (e) testa color: ash with black dotted; and (f) Orange/red cotyledons

TABLE 1 Mean performance of yield contributing traits of BARI Masur-8 and check cultivar/genotypes from 2011 to 2014 in different locations (Ishwardi, Gazipur, Jessore, and Jamalpur) of Bangladesh (4 yr; four locations)

Genotype	Time to flower	Time to maturity	Lodging	Plant height	Branches plant^{-1}	Pods plant^{-1}	100-seed wt.
	d		1–5[a]	cm			g
BARI Masur-8	72	119	1.00	35	3.20	255	1.94
LR-9-48	69	118	1.75	36	1.75	180	1.43
BLX-02009-4-1	64	113	1.50	38	2.03	184	1.40
BLX-04008-14	63	110	2.25	33	2.08	177	1.31
BARI Masur-7	61	113	1.00	35	2.83	205	1.42
$LSD_{.05}$	1.8	1.7	0.32	2.2	0.29	16.0	0.11

[a] 1 = no lodging; 5 = 100% plant lodging.

BARI Masur-8 flowered in 72 d, which was similar to LR-9-48 but significantly different from BARI Masur-7 (61 d) and other genotypes. A similar trend was observed for time to maturity, where BARI Masur-8 matured in 119 d, which was about 9 d later than BARI Masur-7 (110 d). The mean lodging score of BARI Masur-8 was 1.0, indicating an erect growth habit. The genotypes BLX-04008-14 tended to lodge at grain filling stage with a lodging score of 2.25, and BARI Masur-7 exhibited the erect plant type with a score of 1.0 over the years and across locations. Mean plant height for BARI Masur-8 (35 cm) was similar to BARI Masur-7 but significantly lower than BLX-04008-14. The highest number of branches per plant (3.2) was found in BARI Masur-8, followed by BARI Masur-7 (2.8). The average number of pods per plant was 255 in BARI Masur-8, which was significantly higher than BARI Masur-7 and other tested genotypes. The mean seed weight of BARI Masur-8 (1.94 g 100^{-1} seed) was significantly greater than BARI Masur-7 (1.42 g 100^{-1} seed) and other genotypes. Regarding yield performance, with the average of four locations and years, BARI Masur-8 produced 1,973 kg ha^{-1}, which was significantly higher than that of check BARI Masur-7 (1,688 kg ha^{-1}) and other tested genotypes. Over the years, BARI Masur-8 exhibited consistently higher yield performance among the genotypes

TABLE 2 Performance of mean yield and micronutrient status of BARI Masur-8 and check cultivars

Genotype	Seed yield 2011	2012	2013	2014	Mean yield	Fe 2012	Zn 2012	Seed Se 2012
	kg ha^{-1}					mg kg^{-1}		μg kg^{-1}
BARI Masur-8	2,036	1,976	1,897	1,983	1,973	74	61	325
LR-9-48	1,281	1,489	1,322	1,492	1,396	58	53	196
BLX-02009-4-1	1,356	1,405	1,338	1,358	1,364	63	49	233
BLX-04008-14	1,315	1,554	1,353	1,371	1,398	65	48	220
BARI Masur-7	1,707	1,718	1,686	1,640	1,688	72	58	337
$LSD_{.05}$	106	101	97	89		3.7	2.7	15

Note. Mean yield was estimated from 2011 to 2014 in different locations (Ishwardi, Gazipur, Jessore, and Jamalpur) of Bangladesh (4 yr; four locations). Nutrition status was measured only in 2012; Fe, Zn, and Se concentration were assessed only in 2012.

TABLE 3 Stemphylium blight and root rot evaluation of BARI Masur-8 and check cultivar/genotypes from 2011 to 2014 in different locations (Ishwardi, Gazipur, Jessore, and Jamalpur) of Bangladesh (4 yr; four locations)

Genotype	Stemphylium blight severity 2011	2012	2013	2014	Root rot severity 2011	2012	2013	2014
	0–5[a]				1–7[b]			
BARI Masur-8	1.00	1.00	1.00	1.00	1.33	1.67	2.00	2.00
LR-9-48	2.00	2.33	1.33	2.00	3.33	3.33	2.67	3.33
BLX-02009-4-1	1.67	1.33	1.67	1.33	2.33	2.33	2.33	2.33
BLX-04008-14	2.67	2.67	2.00	1.67	3.00	3.00	2.33	2.67
BARI Masur-7	1.67	1.33	1.33	1.33	1.83	2.33	2.00	2.33
$LSD_{.05}$	0.48	0.55	0.70	0.49	0.71	0.75	0.65	0.56

[a]0 = highly resistant; 5 = highly susceptible.
[b]1 = resistant; 7 = susceptible.

TABLE 4 Yield performance of BARI released lentil varieties in optimum (20 Nov.) and late (10 Dec.) sowing at PRC, Ishwardi, Pabna, in 2015

Variety	Optimum sowing yield	Late sowing yield	Yield reduction in late sowing
	kg ha^{-1}		%
BARI Masur-1	2,508	1,925	23
BARI Masur-3	2,689	2,041	21
BARI Masur-5	2,325	1,918	17
BARI Masur-7	2,336	1,921	18
BARI Masur-8	2,701	2,153	20
$LSD_{.05}$	220	162	–

(Table 2). Importantly, BARI Masur-8 outyielded BARI Masur-7 by 15–20%.

3.3 | Micronutrient concentrations

The concentration of micronutrients were varied among the cultivars/genotypes (Table 2). BARI Masur-8 was highly enriched with Fe (74 mg kg^{-1}), which was statistically similar to BARI Masur-7 but significantly higher than other genotypes. The Zn concentration was also higher (61 mg kg^{-1}) in BARI Masur-8. Regarding Se concentration, BARI Masur-8 was similar (325 μg kg^{-1}) to BARI Masur-7 (337 μg kg^{-1}) but significantly higher than other genotypes. Despite huge micronutrients in seed, the bioavailability of nutrition of pulses depends on the nutrient and antinutrient concentrations in a given portion size. Unlike other grains, lentils are very low in phytic acid (2.5–4.4 mg g^{-1}), which binds Fe and Zn and thus renders these nutrients poorly available. A 50-g serving of lentils can provide 3.7–4.5 mg Fe, 2.2–2.7 mg Zn, and 22–34 μg Se (Thavarajah et al., 2013).

3.4 | Disease reaction

BARI Masur-8 is tolerant to SB, one of the major constraints to lentil production in Bangladesh (Table 3). Over years and across locations, the severity of SB was consistently lower in BARI Masur-8 than in the other genotypes. BARI Masur-8 had a severity score of 1, which is similar to BARI Masur-7 but lower than other genotypes during the 2011–2014 cropping seasons. Another major disease of lentil in Bangladesh is root rot, which was evaluated under natural infestation. The severity of root rot in BARI Masur-8 was significantly lower than other genotypes, except BARI Masur-7, which showed a similar response to BARI Masur-8 (Table 3).

3.5 | Performance in rice-based cropping

Lentil is mostly grown in rice-based cropping systems after harvesting of Monsoonal aman rice. For the development of high-yielding, long-duration aman varieties, lentil sowing is delayed and reduces lentil yield due to terminal heat stress and disease severity. With the evaluation of late-sowing yield performance, all the BARI-developed varieties showed decreased yield in delayed sowing on 10 December compared with optimum sowing on 20 November. Among the cultivars, there was a significant variation of yield, where BARI Masur-8 exhibited the highest yield in both optimum and late sowing. However, with respect to yield reduction in late sowing, there was no significant variation in cultivars, although BARI Masur-8 matured 7 d later than other varieties. This is due to higher genetic yield potentiality of BARI Masur-8, with a higher number of branches and pods per plant and greater disease resistance than other cultivars (Table 4). Hence, BARI Masur-8 is considered as suitable for both optimum and late sowing compared with other cultivars.

4 | CONCLUSION

Micronutrient deficiency is widely prevalent throughout the world, particularly in developing countries like Bangladesh, where multiple micronutrient deficiencies often present concomitantly. Our research product, the micronutrient-dense, high-yielding lentil cultivar BARI Masur-8, potentially represents a significant enhancement in lentil production in Bangladesh and in the South Asia region. It is tolerant to SB and root rot diseases and fits well in the existing rice-based cropping systems in the region. Large-scale seed increases are underway to disseminate BARI Masur-8 at a national level to enhance nutritional security and improve the livelihoods of small and marginal farmers in Bangladesh.

5 | AVAILABILITY

The PRC, BARI, Ishwardi Pabna is responsible for maintaining the breeder seed of BARI Masur-8. Foundation seed will be produced and maintained by the Bangladesh Agricultural Development Corporation, Bangladesh. A sample seed of BARI Masur-8 has been deposited in the PRC germplasm conservation system, Ishwardi, Pabna, national Plant Genetic Resource Centre, BARI, Cazipur, and USDA Germplasm Resources Information Network. The seed will be available for distribution immediately upon publication. Small quantities of seed for research purposes may be obtained from the corresponding author for at least 5 years from the date of this publication.

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AUTHOR CONTRIBUTIONS

Md Shahin Uz Zaman: Conceptualization; Data curation; Formal analysis; Methodology; Writing – original draft. Md Altaf Hossain: Supervision. Md Jahangir Alam: Methodology. AKM Mahbubul Alam: Conceptualization. Md Omar Ali: Conceptualization; Investigation. Debasish Sarker: Project administration; Resources. Ashutosh Sarker: Conceptualization, Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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