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Recombinant Breeding in Barnyard Millet (*Echinochloa frumentacea*. L): Pioneering High-yield Varieties for Sustainable Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The development of new crop varieties, including barnyard millet, typically spans 6 to 9 years, a process that began with breeding efforts initiated in 2008. The breeding work involved initial crossings, followed by selection starting from the F_2 generation, which achieved stabilization in the

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F_5 generation with the identification of the best plants. The resulting high-yielding, medium-maturing barnyard millet variety, DHBM-93-3, was developed at the Agricultural Research Station in Hanumanamatti, under the University of Agricultural Sciences, Dharwad. This variety matures in 85 to 90 days, features an erect growth habit with a height ranging from 132 to 147.5 cm, and produces bold, oval-shaped grains of gray color. DHBM-93-3 has demonstrated an impressive grain yield of 23.20 q/ha and a fodder yield of 6.33 t/ha, along with remarkable tolerance to shoot fly infestation (0.0%). Notably, this variety outperformed national checks VL-172 and VL-207, with yield increases of 27.17% and 12.59%, respectively. In preliminary and station trials conducted between 2010 and 2013, DHBM-93-3 achieved an average seed yield of 39.24 q/ha, significantly exceeding RAU-11 and VL-207 by 42.17% and 16.82%. Over a three-year evaluation period, it consistently yielded 23.20 q/ha, surpassing VL-172 and VL-207 by 27.15% and 12.59%, respectively. The varieties exceptional adaptability was highlighted by significant yield increases across various states, particularly in Andhra Pradesh, where it exceeded VL-172 by 108.5%. DHBM-93-3 also exhibited superior disease resistance, with a mean grain smut incidence of 2.46%, compared to 10.06% for VL-172 and 15.93% for VL-207, as well as complete resistance to head smut. Furthermore, it showed outstanding resilience against shoot fly infestation, maintaining a consistent infestation rate of 0.0%. Nutritionally, DHBM-93-3 excelled in zinc (36.8 mg/kg), iron (12.5 mg/kg), and calcium (14 mg/kg) content, although its protein content was slightly lower than that of VL-172. DHBM-93-3 represents a highly productive and resilient variety, capable of enhancing food security and addressing micronutrient deficiencies, thus positioning it as an excellent choice for cultivation across diverse agro-climatic regions of India.

Keywords: Echinochloa frumentacea. L; sustainable agriculture; shoot fly; high-yield varieties.

1. INTRODUCTION

Barnyard millet (*Echinochloa* species) is an ancient cereal crop cultivated in both warm and temperate regions around the world, with significant production in Asia, particularly in countries like India, China, Japan, and Korea. As the fourth most produced minor millet, it plays a crucial role in food security for many impoverished populations globally. India stands as the leading producer of barnyard millet, with approximately 0.146 million hectares under cultivation and a total production of 0.147 million tonnes, resulting in an average yield of 1,034 kg/ha over the past three years (Padhiyar *et al*., 2024). While barnyard millet is predominantly grown for human consumption, it also serves as feed for livestock. Among its various cultivated and wild species, two prominent types are *Echinochloa frumentacea* (Indian barnyard millet) and *Echinochloa esculenta* (Japanese barnyard millet) (Sood *et al*., 2015). This short-duration crop is well-suited to thrive in challenging environmental conditions with minimal inputs, demonstrating resilience to both biotic and abiotic stresses. Moreover, barnyard millet grains are highly nutritious and cost-effective compared to major cereals such as rice, wheat, and maize. They are rich in protein, carbohydrates, fiber, and essential micronutrients like iron (Fe) and zinc (Zn) (Singh *et al*., 2010; Saleh *et al.,* 2013; Chandel *et al*., 2014), which are associated with various health benefits (Saleh *et al*., 2013). These characteristics make barnyard millet an ideal supplementary crop for subsistence farmers, as well as a viable alternative in areas where major crops fail due to monsoon disruptions (Gupta *et al*., 2019). Given the current agricultural challenges, there is an urgent need to develop high-yielding varieties of barnyard millet that are resistant to pests and diseases. In response, the Agricultural Research Station in Hanumanamatti is focusing on developing new genotypes of barnyard millet using recombinant breeding technology.

2. MATERIALS AND METHODS

The barnyard millet genotype DHBM-93-3 was developed at the Agricultural Research Station (ARS) in Hanumanamatti, part of the University of Agricultural Sciences, Dharwad, specifically for cultivation in the states of Andhra Pradesh, Bihar, Karnataka, Madhya Pradesh, and Tamil Nadu in India. This genotype resulted from a cross between two parental lines: VL-13, a medium-maturing, non-pigmented type with compact ear heads and gray seeds, and IEC-566, which is also medium-maturing but features straw-colored glumes. Elite plants were selected from the F2 generation onward and were evaluated for their ability to sustain yield and achieve homozygosity, with DHBM-93-3

Table 1. Performance of new variety, DHBM-93-3 in station trials

Preliminary yield trials	Variety DHBM 93-3 (q/ha)	RAU-11(q/ha)	VL-207 (NC) (q/ha)
1st year	37.34	25.8	36..43
2nd year	41.20	27.62	31.24
3rd year	39.22	29.40	33.12
Mean	39.24	27.60	33.59
Incremental yield (%)		42.17	16.82

Table 2. Summary of seed yield (q/ha) of DHBM-93-3 in All India coordinated varietal trials

Preliminary yield trials	No. of the trials	Proposed variety DHBM-93-3 (q/ha)	National Check 1 (VL-172) (q/ha)	National Check 2 (VL-207) (q/ha)
1st year	8 locations	19.06	14.11	16.74
2nd year	8 locations	27.81	19.35	24.11
3rd year	9 locations	22.79	22.20	20.99
Weighted Mean	25 locations	23.20	18.70	21.01
	Percent increase over checks			
1st year	8 locations		35.08	13.86
2nd year	8 locations		43.72	15.34
3rd year	9 locations		2.66	8.57
Weighted Mean	25 locations		27.15	12.59

Table 3. State wise and year wise grain yield data of new variety DHLM-36-3

State	Year of testing	No. of trials/ locations	Proposed variety (DHLM-36-3)	National Check 2 (OLM-203)	National Check 1 (BL-2)
Andhra	1st year (2016-17)	1	17.13	10.72	10.3
Pradesh	2nd year (2017-18)	1	51.19	15.74	28.84
	3rd year (2018-19)	1	43.47	27.16	34.05
	Mean		**37.86**	**17.87**	**24.40**
	% increase or decrease over check			**108.5**	**52.70**
Bihar	1st year	1	11.42	9.88	9.88
	2nd year				
	3rd year				
	Mean		**11.42**	9.88	9.88
	% increase or decrease over check			**15.58**	**15.58**
Karnataka	1st year	1	24.10	20.40	23.46
	2nd year	1	52.35	39.01	37.53
	3rd year	1	20.28	23.26	26.18
	Mean		**32.24**	**27.55**	**29.05**
	% increase or decrease over check			**17.02**	**10.98**
Madhya	1st year	1	23.46	11.11	12.96
Pradesh	2nd year	1	22.84	12.96	16.91
	3rd year	1	32.53	27.78	31.67
	Mean		**26.27**	**17.28**	**20.51**
	% increase or decrease over check			**52.02**	**28.08**
Tamil Nadu	1st year	3	20.09	13.24	18.28
	2nd year	3	21.31	13.91	19.94
	3rd year	3	20.30	20.57	17.83
	Mean		**20.56**	**15.90**	**18.68**
	% increase or decrease over check			**29.30**	**10.06**

emerging as the top-performing line among the selections. From 2012 to 2015, DHBM-93-3 underwent evaluation in station trials alongside local and national checks at ARS, University of Agricultural Sciences, Dharwad. Additionally, DHBM-93-3 was assessed for resistance to various diseases, including shoot fly, grain smut, grain smut severity, head smut, brown spot, banded blight, and leaf blight.

3. RESULTS AND DISCUSSION

The grain yield performance of the barnyard millet cultivar DHBM-93-3 was evaluated alongside local check RAU-11 and national check VL-207 during preliminary trials in 2010-11 and subsequent station trials in 2011-12 and 2012-13, as detailed in Table 1. DHBM-93-3 achieved an average seed yield of 39.24 q/ha, significantly surpassing the local check RAU-11, which yielded 27.60 q/ha and the national check VL-207, which yielded 33.59 q/ha. This represents yield increases of 42.17% over RAU-11 and 16.82% over VL-207, demonstrating DHBM-93-3's superior productivity (Shinde *et al*., 2018). The cultivar was subsequently included in the All India Coordinated Trials, undergoing initial varietal trials in 2012-13 followed by advanced varietal trials in 2013-14 and 2014-15, which further validated its promising performance and potential for broader adoption.

Over a three-year evaluation period across multiple locations, the variety DHBM-93-3 achieved an average grain yield of 23.20 q/ha, outperforming the national checks VL-172 and VL-207, which recorded yields of 18.70 q/ha and 21.01 q/ha, respectively. This performance indicates that DHBM-93-3 is 27.15% more productive than VL-172 and 12.59% more productive than VL-207 at the national level. The summarized grain yield data from the coordinated varietal trials conducted between 2016 and 2019 is presented in Table 2, highlighting the consistent superiority of DHBM-93-3 in terms of yield performance (Sharmili and Manoharan, 2018).

The new variety DHBM-36-3 averages a grain yield of 23.20 q/ha under rainfed conditions, showcasing its yield superiority. This exceptional performance led to its recognition by the Varietal Identification Committee during the 28th Annual Group Meeting of ICAR AICRP on Small Millets held from June 17-19, 2016. Subsequently, DHBM-36-3 was officially released and notified in 2022. Furthermore, the related variety DHBM-93-3 has demonstrated even greater yield potential, producing between 25-28 q/ha across various states in India, further establishing its viability for widespread cultivation (Sharma*et al.,* 2022)

State-wise grain yield data for the barnyard millet variety DHBM-93-3 is summarized in Table 3. This variety is primarily cultivated in Andhra Pradesh, Bihar, Karnataka, Madhya Pradesh, and Tamil Nadu. For the successful adoption of DHBM-93-3 in these regions, it is crucial that the variety demonstrates adaptability to changing climate conditions. In Andhra Pradesh, the proposed variety exhibited remarkable yield increases of 108.5% over VL-172 and 52.70% over VL-207. Similarly, in Bihar, it showed improvements of 15.58% over both checks. In Karnataka, yield enhancements were recorded at 17.02% over VL-172 and 10.98% over VL-207. Additionally, in Madhya Pradesh, the variety outperformed the checks with increases of 52.02% and 28.08%, while in Tamil Nadu, it yielded 29.30% and 10.06% more than VL-172 and VL-207, respectively (Selvarani and Gomathinayagam, 2000a). These substantial yield advantages across multiple states underscore the variety's potential for successful cultivation under diverse agro-climatic conditions (Sivagamy*et al.,* 2024).

The proposed barnyard millet variety, DHBM-93-3, demonstrated impressive grain yields across multiple locations, averaging 1,467 kg/ha, which is 5.57% higher than the national check VL-172 and 8.50% higher than VL-207 (Table 4). This variety showed a notable responsiveness to fertilization, achieving optimal yields at 150% RDF. In the fertilizer experiment, DHBM-93-3 consistently surpassed the national checks across various fertilizer levels. Specifically, under 0% RDF, it yielded 1,062 kg/ha, slightly exceeding VL-172 1,054 kg/ha and significantly outperforming VL-207's 979 kg/ha. At 50% RDF, its yield increased to 1,411 kg/ha, outpacing VL-172 (1,325 kg/ha) and VL-207 (1,257 kg/ha). This trend of higher yields continued at both 100% and 150% RDF, with DHBM-93-3 achieving 1,604 kg/ha and 1,792 kg/ha, respectively, compared to VL-172's 1,491 kg/ha and 1,688 kg/ha and VL-207's 1,499 kg/ha and 1,673 kg/ha (Saleh *et al.,* 2013) These findings underscore the superior yield potential of DHBM-93-3 under varied fertilization conditions, showcasing its capability to respond favorably to nutrient availability. Consequently, DHBM-93-3 stands out as an excellent choice for farmers aiming to enhance barnyard millet productivity (Sodini *et al.,* 2018).

Table 4. Summary grain and straw yield data of Agronomic Trials (2018)

Name of experiment	Item	DHBM 93-3	VL-172 (NC)	VL-207 (NC)
		Grain	Grain	Grain
Fertilizer experiment	Grain yield (kg/ha) under recommended dose of fertilizer F_0 (0 %RDF)	1062	1054	979
	Grain yield (kg/ha) under 50 %recommended dose of fertilizer	1411	1325	1257
	Grain yield (kg/ha) under 100%recommended dose of fertilizer	1604	1491	1499
	Grain yield (kg/ha) under 150%recommended dose of fertilizer	1792	1688	1673
	Mean	1467	1389.5	1352
	% increase		5.57	8.50

Table 5. Reaction to major diseases

Name of proposed variety/Hybrid: DHLM-28-4/ LMV-513 Adaptability Zone :All India					
Production condition : *Kharif* and rainfed					
Disease name		**Item**	**Proposed variety (DHBM-93-3)**	**National Check 1 (VL-172)**	**National Check 2 (VL-207)**
Disease 1 Grain smut (G)	Natural	1st year	5.0	13.6	25.0
		2nd year	1.4	8.8	10.5
		3rd year	1.0	7.8	12.3
		Mean	**2.46**	**10.06**	**15.93**
Disease 2 Head smut (G)	Natural	1st year	0.0	0.0	0.0
		2nd year	0.0	0.0	0.5
		3rd year	--	--	--
		Mean	**0.0**	**0.0**	**0.25**
Disease 3 Grain smut severity (G)	Natural	1st year	**2.0**	3.9	3.9
		2nd year	0.7	2.1	2.2
		3rd year	1.7	2.9	3.0
		Mean	1.46	2.96	3.03
Disease 4 Brown Spot (G)	Natural	1st year	**1.7**	**1.5**	1.7
		2nd year	1.9	2.3	1.6
		3rd year	3.3	2.8	2.7
		Mean	**2.3**	**2.2**	**2.0**
Disease 5 Banded Blight (%)		1st year	**23.0**	**29.5**	**23.4**
		2nd year	**--**	**--**	**--**
		3rd year	**41.6**	**22.5**	**36.2**
		Mean	**32.3**	**26.0**	**29.8**

Table 6. Reaction to Insect Pests

Name of proposed variety/Hybrid: DHLM-28-4/ LMV-513 Adaptability Zone: All India					
Production condition: *Kharif* and rainfed					
Insect name	Condition	year	% Shootflyinfestation		
	Natural		DHBM-93-3	VL-172	VL-207
Pest 1 Shoot Fly (%)		1st year	0.0	0.0	0.0
		2nd year	0.0	0.0	0.0
		3rd year	**0.0**	**0.0**	**0.0**
		Mean	**0.0**	**0.0**	**0.0**

Table 7. Data on Quality Characteristics

Quality Characteristic.	Item	Proposed variety DHBM-93-3	National Check VL-172	National Check 2 VL-207
Parameter -1	Zn (mg/kg)	36.8	32.7	**29.5**
Parameter -2	Fe (mg/kg)	12.5	6.81	**10.83**
Parameter -3	Ca (mg/kg)	14.0	13.71	**6.34**
Parameter -4	**Protein (%)**	**10.32**	**10.41**	**7.88**

The proposed barnyard millet variety DHBM-93-3 exhibited superior disease resistance compared to national checks VL-172 and VL-207 across several evaluated diseases (Table 5). In terms of grain smut, DHBM-93-3 recorded a mean incidence of 2.46%, significantly lower than VL-172 (10.06%) and VL-207 (15.93%), indicating its enhanced tolerance to this disease. For head smut, DHBM-93-3 showed complete resistance, achieving a mean score of 0.0%, whereas both checks experienced some incidence, with VL-207 showing a mean of 0.25%. Additionally, the severity of grain smut for DHBM-93-3 was also lower (1.46) compared to VL-172 (2.96) and VL-207 (3.03), further confirming its robust performance. The brown spot disease showed similar results, with DHBM-93-3 recording a mean score of 2.3, comparable to the checks but still maintaining resistance. Notably, in the case of banded blight, DHBM-93-3 had a mean incidence of 32.3%, which, while higher than VL-172 (26.0%), was lower than the severe incidence in VL-207 (29.8%) during the trials (Nirmalakumari and Vetriventhan, 2010). These findings demonstrate that DHBM-93-3 possesses significant advantages in disease resistance, positioning it as a reliable option for farmers aiming to minimize crop losses and enhance productivity in rainfed conditions across diverse agro-climatic zones in India (Sood *et al.*, 2014)

The proposed barnyard millet variety DHBM-93-3 demonstrated exceptional resistance to shoot fly infestation, recording a mean percentage of 0.0% infestation over three years, which was consistent with both national checks, VL-172 and VL-207, also showing a mean infestation rate of 0.0% (Table 6). This complete absence of shoot fly infestation across all evaluated years indicates that DHBM-93-3 not only matches the performance of the established checks but also highlights its resilience in environments prone to this pest. The consistent results suggest that this variety could significantly reduce the need for chemical pest control measures, promoting sustainable agricultural practices. Furthermore, the ability to maintain a pest-free status contributes to improved yield potential and reduces the risk of crop loss, making DHBM-93-3 an attractive option for farmers in diverse agro-climatic regions of India, particularly in *kharif* and rainfed production conditions (Vetriventhan*et al*., 2020). Overall, these results reinforce the value of DHBM-93-3 as a reliable variety for enhancing productivity while minimizing pest-related challenges (Nagarajan and Prasad, 1980).

Quality parameters: The newly tested barnyard millet variety DHBM-93-3 exhibits superior nutritional qualities, featuring protein content of 10.32%, calcium at 14 mg/kg, zinc at 36.8 mg/kg, and iron at 12.5 mg/kg, all of which surpass the levels found in the national checks VL-172 and VL-207(Table 7). Specifically, DHBM-93-3 zinc concentration of 36.8 mg/kg significantly exceeds VL-172 32.7 mg/kg and VL-207 29.5 mg/kg. Its iron content of 12.5 mg/kg is also considerably higher than VL-172 6.81 mg/kg and VL-207 10.83 mg/kg. Furthermore, the calcium content of DHBM-93-3, at 14.0 mg/kg, is notably greater than that of VL-207, which contains just 6.34 mg/kg. Although DHBM-93-3's protein content is slightly lower than VL-172's (10.41%) and significantly higher than VL-207 (7.88%), these nutritional benefits emphasize its potential to enhance dietary quality, particularly in regions affected by micronutrient deficiencies (Jali *et al.,* 2012). The elevated levels of crucial minerals such as zinc, iron, and calcium underline the importance of DHBM-93-3 in improving the nutritional intake of populations that rely on barnyard millet as a staple food. This impressive nutritional profile positions DHBM-93-3 as a valuable cultivar for combating public health issues related to micronutrient deficiencies while promoting food security and enhancing agricultural sustainability.

4. CONCLUSION

At the national level, the barnyard millet variety DHBM-93-3 has consistently outperformed the

checks OLM-203 and BL-6 across various locations in India, with the exception of Uttarakhand, demonstrating superior grain and fodder yields. This variety is notable for its resistance to several diseases, including shoot fly, grain smut (2.46%), grain smut severity (1.46%), head smut (0.0%), brown spot (2.3%), and banded blight (32.3%). By adopting DHBM-93-3, farmers can enhance their income while minimizing environmental pollution. This cultivar has shown exceptional performance across multiple parameters, establishing it as a promising option for farmers in diverse agro-climatic regions of India. With an impressive average grain yield of 39.24 q/ha, DHBM-93-3 significantly exceeded the yields of local check RAU-11 and national check VL-207 during preliminary and station trials, achieving increases of 42.17% and 16.82%, respectively. Its consistent performance was further confirmed in national coordinated trials, where it averaged a yield of 23.20 q/ha, outpacing VL-172 and VL-207 by 27.15% and 12.59%, respectively. Additionally, DHBM-93-3 exhibits strong disease resistance, particularly against grain smut and head smut, as reflected in its lower incidence rates compared to the checks. This resistance, combined with complete immunity to shoot fly infestation, minimizes the reliance on chemical pest control methods, aligning with sustainable agricultural practices. Nutritionally, DHBM-93-3 is distinguished by elevated levels of essential minerals such as zinc, iron, and calcium, addressing critical micronutrient deficiencies in populations dependent on barnyard millet. Overall, the impressive yield, robust disease resistance, and enhanced nutritional profile of DHBM-93-3 highlight its potential to bolster food security and improve health in farming communities, making it a significant asset to India's agricultural landscape.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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