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Influence of biofortified and non-biofortified genotypes on seed yield and quality in pearl millet [*Pennisetum glaucum* (L.) R. Br.] during storage

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Abstract

A field experiment was conducted at the Regional Agricultural Research Station, Vijayapur, University of Agricultural Sciences, Dharwad, Karnataka to assess the effects of biofortified and non-biofortified genotypes of pearl millet on field performance. The randomized complete block design experiment included eight treatments with different genotypes. The results of the present investigation revealed that the genotype VPMV 9 was found to be significantly superior with respect to growth and yield parameters viz., field emergence (87.57%), plant height (166.39 cm), number of productive tillers (2.67), plant dry matter accumulation (8.86 g plant⁻¹), ear head length (26.88 cm), ear head girth (3.22 cm), ear weight (26.90 g), thousand seed weight (12.40 g) and seed yield (2388 kg ha⁻¹). Seed quality characteristics, specifically seed germination (91.13%) and seedling vigour indices I and II (3161 and 10653) were superior in seeds from the genotype ICTP 8203, as determined by a laboratory experiment conducted in the Department of Seed Science and Technology, College of Agriculture, Vijayapur. The biofortified genotype Dhanashakti exhibited elevated biochemical indicators, specifically Fe and Zn content at 84.33 and 45 ppm, respectively but the genotype VPMV 9 had a superior protein content of 13.14%. Nonetheless, the quality of the seeds and biochemical indicators exhibited a declining tendency with the extension of the storage duration.

Keywords: Pearl millet, biofortification, seed quality, storage, iron and zinc

Introduction

The monocot pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a member of the poaceae family along with its allied species *P. spicatum*, *P. americana*, and *P. typhoides*. In India, it is also referred to as "Sajje" "Bajra" or "Cattail millet". This C₄ plant produces a lot of dry matter and has a high photosynthetic efficiency. After sorghum, it is the second most significant millet crop in India in terms of both production and area. With an area of 7.36 mha, 11.20 mt of production, and a mean productivity of 1523 kg ha⁻¹, India is a capable producer of pearl millet. Grown over an area of 0.12 mha, it is one of the main *kharif* crops in Karnataka, producing 0.15 mt annually with a mean productivity of 1290 kg ha⁻¹ (Anon., 2025)^[3].

Pearl millet is a rich source of energy (361 Kcal 100 g⁻¹), starch (62.8-70.5%), soluble sugar (1.2-2.6%) and amylase (21.9-28.8%) and free sugars (2.6-2.8%) mainly sucrose. It is high in fibre (1.2 g 100 g⁻¹) and α -amylase activity, protein (11.2%) and rich in methionine but poor in sulphur containing amino acids. It is rich in fat content (5 mg 100 g⁻¹) with better fat digestibility and unsaturated fatty acids (75%) with higher content of nutritionally important fatty acids. It is a rich source of vitamins and minerals with overall mineral content (2.3 mg 100 g⁻¹) constituting potassium, phosphorous, magnesium, iron, zinc, copper, manganese and vitamin-B complex (Thiamine, Riboflavin and Niacin).

Biofortification is a process of increasing the density of vitamins and minerals in a crop through plant breeding, transgenic techniques or agronomic practices. Regular consumption of biofortified staple crops will result in quantifiable benefits in human nutrition and health (Bouis *et al.*, 2011)^[5]. It is a feasible and cost effective means of delivering micronutrients to populations. A dry land crop found in arid and semi-arid tropical regions, pearl millet is a good candidate for iron (Fe) and zinc (Zn) biofortification. Biofortification of the staple food crops has emerged as a potent solution to tackle the problem of deficiency of nutrients in

human beings (hidden hunger) in developing countries. In addition to pearl millet, other crops such as rice, wheat, maize, and sorghum are also biofortified with Fe, Zn, provitamin A, and protein, respectively (Garg *et al.*, 2018) [8].

The Fe, Zn, and protein concentrations in pearl millet were shown to be declining as storage period increased. After storage, protein becomes less soluble and breaks down into free amino acids (Anderson, 1973) [2], and iron in fortified diets may not stay in its original form (Lee and Clydesdale, 1980) [16]. The activity of the lipase enzyme affects pearl millet seed storage as well (Yadav *et al.*, 2012) [30].

In light of these, the current study examined the effects of biofortified and non-biofortified genotypes on seedling establishment, growth performance, seed production, and quality during storage in pearl millet.

Materials and Methods

The current study was carried out at the Regional Agricultural Research Station, Vijayapur located in the Northern Dry Zone (Zone-3 and Region-II) in Karnataka, positioned at 16°49' N latitude, 75°43' E longitude, and at an elevation of 593 m above mean sea level. The experimental site had deep, porous, well-drained black clayey (Vertisol) soil. The study used a randomized complete block design with eight treatments and three replications. Rows were spaced 45 cm apart, plants 15 cm within rows, and each plot measured 4.5 m by 3.0 m.

The biofortified genotypes evaluated were Dhanashakti and ICTP 8203, while the non-biofortified genotypes included ICMV 221, VPMV 9, 10, 11, 12, and MBP 2. All eight genotypes were designated as treatments. Cultural practices, including fertilizer application, sowing, plant protection, harvesting, threshing, and cleaning, were implemented in accordance with the package of practice of University of Agricultural Sciences, Dharwad. For the purpose of documenting plant growth and yield parameters, five randomly chosen plants were tagged in each treatment.

After harvest, seeds of pearl millet genotypes were collected from individual plots, divided into three batches, and stored in 700-gauge polythene bags under ambient conditions. Samples were evaluated at three, six, and nine months to assess storage effects on seed quality. Seed germination percentage and seedling vigour indices were recorded per ISTA (2021) [13] protocols. The Fe, Zn content (ppm), and protein (%) were measured at three month intervals. Data were statistically analyzed following Panse and Sukhatme (1989) [20] for interpretation of storage effects.

Results and Discussion

Significant differences were observed among the genotypes with respect to plant growth, flowering, and yield parameters. Genotype VPMV 9 demonstrated the highest field emergence at 87.57%, closely followed by ICTP 8203 (87.47%), while VPMV 12 exhibited the lowest emergence at 75.94% (Table 1). The superior field emergence observed in VPMV 9 is attributable to its elevated zinc content (39 ppm, $r = 0.77$), which is comparable to that of the biofortified genotypes (Fig. 2). Zinc is essential for the biosynthesis of amino acids, thereby promoting proper seed germination and enhancing seed vigour. These findings are consistent with those of Vijaya and Ponnuswamy (1998) [29], who reported improved seed germination in black gram following treatment with a micronutrient combination of

ZnSO₄ (0.2%), MnSO₄ (0.2%), and Na₂MoO₄ (0.1%).

A reduction in the number of days to reach 50% flowering was observed in the genotype ICTP 8203, which flowered at 44 days (Table 1). This early flowering may be attributed to the indirect effect of auxin on ethylene activity, coupled with elevated zinc content that likely enhances flower retention by preventing the formation of the abscission layer. These findings align with those reported by Tekale *et al.* (2009) [27] in pigeonpea.

Among the genotypes, VPMV 9 demonstrated the greatest plant height (166.39 cm), the highest number of productive tillers (2.67), and the maximum dry matter production (8.86 g). In contrast, VPMV 12 exhibited the lowest values for these parameters, with 134.63 cm, 2.07, and 7.10 g, respectively (Table 1). The observed increases in plant height and the number of productive tillers may be attributed to elevated auxin production, specifically indole-3-acetic acid (IAA), which promotes cell elongation and differentiation. These findings are consistent with those reported by Verma *et al.* (2006) [28] in maize, Negm and Zahran (2001) [19] in wheat, and Haider *et al.* (2018) [10] in mung bean. Additionally, the increase in dry matter accumulation is likely a result of the enhanced plant height and productive tiller count. This observation aligns with the results documented by Yang *et al.* (2011) [31] in wheat and Sharanappa and Ravi (2020) [24] in pearl millet.

Genotype VPMV 9 demonstrated significantly superior yield attributes, including ear head length (26.88 cm, $r = 0.94$), ear head girth (3.22 cm, $r = 0.82$), ear weight (26.90 g, $r = 0.96$), test weight (12.40 g, $r = 0.92$), and seed yield (2388 kg ha⁻¹). These parameters were closely followed by ICTP 8203, with 25.88 cm, 3.18 cm, 23.67 g, 12.16 g, and 2058 kg ha⁻¹, respectively (Table 2). The observed enhancement in ear head characteristics is attributable to increased biochemical constituents in the seeds, such as starch, nitrogen, soluble proteins, and enzymatic activities including carbonic anhydrase, acid phosphatase, and ribonuclease. Correlation analysis between Fe, Zn, and protein content with seed yield yielded coefficients of $r = 0.27$, $r = 0.53$, and $r = 0.82$, respectively, demonstrating a notably strong positive correlation between protein content and seed yield. This underscores the critical influence of protein concentration on yield. Similar findings were also reported by Verma *et al.* (2006) [28] in maize. Zinc, as a fundamental component of numerous proteins, significantly contributes to seed weight enhancement (Gupta *et al.*, 2009 [9]; Kanatti *et al.*, 2016 [15]; Rai *et al.*, 2016) [22], indicating the feasibility of genetic improvement for Fe and Zn densities without compromising grain size. The observed increase in seed yield in the non-biofortified genotype is attributable to the negative correlation between Fe and Zn content and seed yield, as documented by Kanatti *et al.* (2016) [15]. This finding is consistent with similar reports by Rai *et al.* (2016) [22] in pearl millet, which identified a negative or non-significant association between seed yield and micronutrient concentrations. Furthermore, Pujar *et al.* (2020) [21] reported a non-significant relationship between seed yield and Fe and Zn levels, underscoring the complex interactions between micronutrient accumulation and yield traits.

Among the genotypes evaluated, ICTP 8203 consistently demonstrated superior seed quality parameters throughout the storage period. Nevertheless, all seed quality attributes exhibited a gradual decline with increasing storage duration,

attributable to natural ageing, diminished metabolic activity, and depletion of seed food reserves due to respiration. The highest seed germination of 91.13% and 87.33%, along with seedling vigour indices I and II of 3161 and 10653 at initial storage, and 2741 and 9345 at nine months, respectively were recorded (Table 3). The superior seed germination and seedling vigour indices observed in genotype ICTP 8203 are attributable to its elevated micronutrient content, specifically iron (Fe, $r = 0.60$) and zinc (Zn, $r = 0.85$). These micronutrients activate essential plant enzymes involved in carbohydrate metabolism, maintenance of cellular membrane integrity, protein synthesis, and regulation of auxin synthesis. The enhanced auxin synthesis subsequently promotes root and shoot growth and development, thereby improving overall seed quality. These findings are consistent with previous reports highlighting the beneficial effects of Fe and Zn on seed germination and vigour via enzymatic and hormonal mechanisms [Boonchuay *et al.* (2013); Kakar *et al.* (2000); Lukaszewski and Blevins (1996); Raja *et al.* (2011); Sujata *et al.* (2013)]^[4, 14, 18 23 26]. Significantly higher Fe content was observed in the genotype Dhanashakti (84.33 ppm), followed by ICTP 8203 (69 ppm), with the lowest Fe concentration recorded in VPMV 11 (55.33 ppm) during the initial month of storage ($r = 0.27$) (Fig. 1). Similarly, Zn content was highest in Dhanashakti (45 ppm), followed by ICTP 8203 (41.67 ppm), and lowest in VPMV 11 (30 ppm) during the same period ($r = 0.53$) (Fig. 2). The observed decline in Fe and Zn contents in seeds throughout the storage period corresponds with the natural degradation processes. The superior mineral retention exhibited by the genotype Dhanashakti at the end of storage underscores its enhanced mineral stability. This

mineral loss is primarily attributed to interactions between Fe and Zn and food matrix components such as proteins and carbohydrates. As transition metals, Fe and Zn tend to form stable complexes with electron-rich compounds (Clydesdale, 1991)^[7], which can modify their bioavailability during storage. Such complexation may alter the original mineral forms, particularly in fortified diets, thereby diminishing the measurable mineral content over time [Akhtar *et al.* (2009); Lee and Clydesdale (1980)]^[1, 16]. These biochemical interactions contribute to the progressive reduction in mineral concentrations observed during seed storage.

Significantly higher protein content was observed in genotype VPMV 9 (13.14%), followed by ICTP 8203 (12.81%), while the lowest protein content was recorded in VPMV 11 (11.71%) during the initial month of storage ($r = 0.82$) (Fig. 3). The reduction in protein content during storage is primarily attributable to the oxidation of amino acids, which is exacerbated by an increased respiration rate as seed deterioration advances. Additional factors contributing to this decline include natural ageing, fluctuations in temperature and relative humidity, elevated moisture content, insect infestations, and the nature of storage containers. These conditions collectively accelerate protein degradation over a time. These results are in agreement with the reports of Braccini *et al.* (2020)^[6], Hosamani *et al.* (2013a)^[11], Hosamani *et al.* (2013b)^[12] in soybean, Lokeshwari *et al.* (2024)^[17] in horse gram and (Sridevi *et al.*, 2025)^[25] in mung bean. Moreover, a negative correlation between protein content and micronutrients such as Fe and Zn (Pujar *et al.*, 2020)^[21], indicating complex interactions that influence seed composition during storage.

Table 1: Response of biofortified and non biofortified genotypes of pearl millet to growth parameters

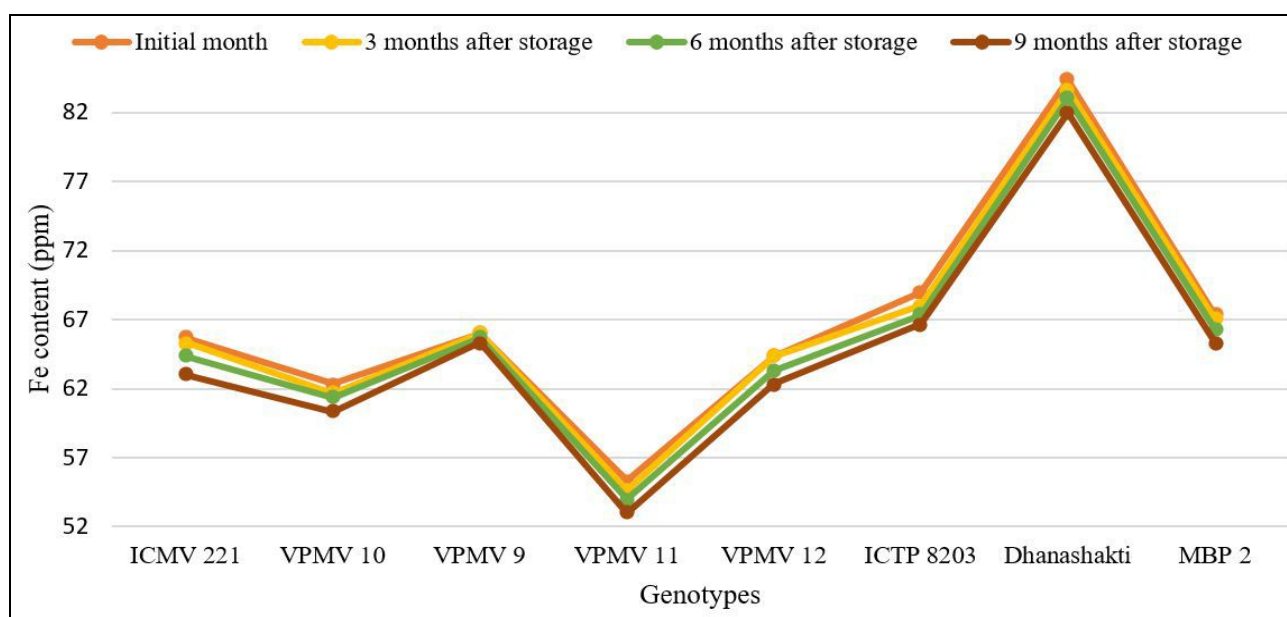
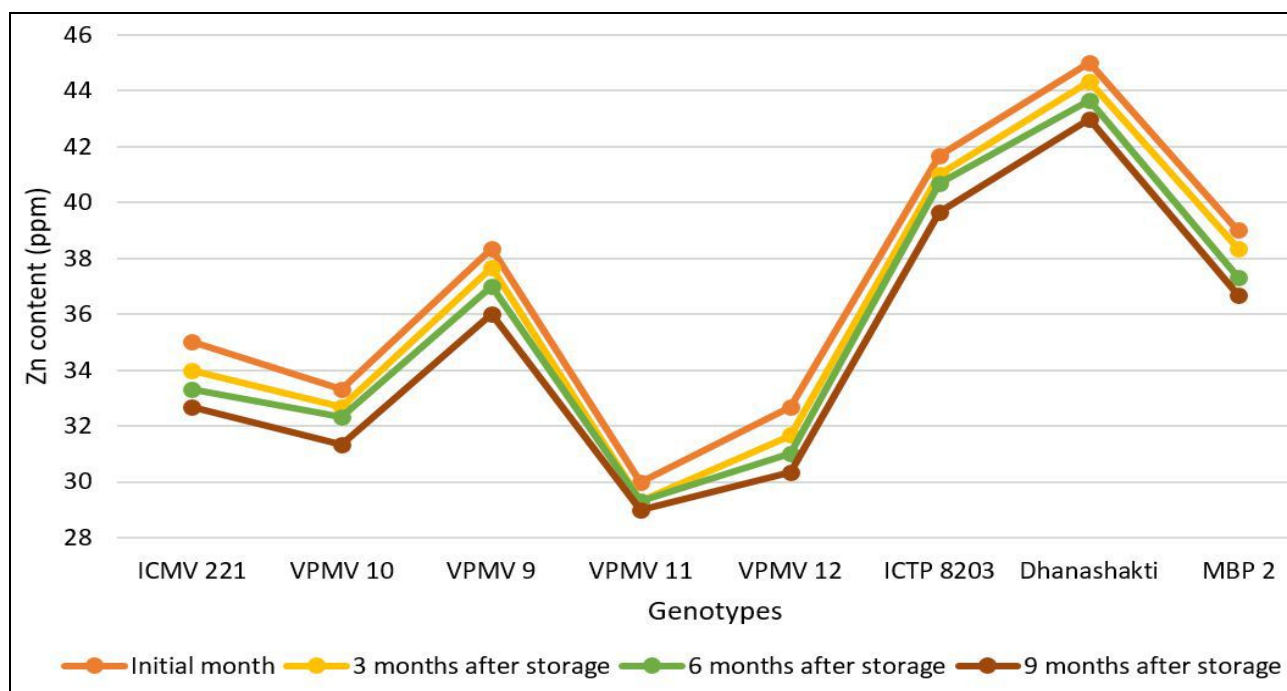
Treatments	Field emergence (%)	Days to 50% flowering	Plant height at harvest (cm)	No. of productive tillers plant ⁻¹	Plant dry matter accumulation (g)
Biofortified					
Dhanashakti	85.66	46	164.27	2.43	8.64
ICTP 8203	87.47	44	165.28	2.53	8.79
Non Biofortified					
ICMV 221	82.30	45	160.77	2.43	8.52
VPMV 10	79.25	50	146.44	2.20	7.19
VPMV 9	87.57	45	166.39	2.67	8.86
VPMV 11	78.97	48	163.96	2.08	8.34
VPMV 12	75.94	50	134.63	2.07	7.10
MBP 2	80.78	49	159.27	2.30	8.02
Mean	82.24	47	157.62	2.33	8.18
S. Em. $\pm$	2.53	1.27	4.84	0.12	0.35
C. D. @ 5%	7.67	3.85	14.70	0.36	1.07

Table 2: Response of biofortified and non biofortified genotypes of pearl millet to yield and yield attributing characters

Treatments	Ear head length (cm)	Ear head girth (cm)	Ear weight (g)	Thousand seed weight (g)	Seed yield (kg ha ⁻¹)
Biofortified					
Dhanashakti	24.72	3.13	22.13	11.56	1739
ICTP 8203	25.88	3.18	23.67	12.16	2058
Non Biofortified					
ICMV 221	25.73	3.15	21.67	11.18	1843
VPMV 10	22.92	2.70	18.33	9.96	1534
VPMV 9	26.88	3.22	26.90	12.40	2388
VPMV 11	22.97	2.73	19.78	9.62	1439
VPMV 12	21.89	2.59	18.17	9.02	1433
MBP 2	23.50	3.08	20.67	10.43	1659
Mean	24.31	2.97	21.41	10.79	1762
S. Em. $\pm$	1.03	0.15	1.11	0.62	58
C. D. @ 5 %	3.15	0.46	3.38	1.90	176

Table 3: Response of biofortified and non biofortified genotypes of pearl millet to seed quality during storage.

Treatments	Seed germination (%)				Seedling vigour index I				Seedling vigour index II			
	Initial	3 MAS	6 MAS	9 MAS	Initial	3 MAS	6 MAS	9 MAS	Initial	3 MAS	6 MAS	9 MAS
Biofortified												
Dhanashakti	89.09	89.00	88.67	87.00	2986	2779	2706	2568	10287	10156	9506	9223
ICTP 8203	91.13	90.00	88.67	87.33	3161	2980	2868	2741	10653	10295	9774	9345
Non Biofortified												
ICMV 221	84.78	83.67	83.00	82.33	2628	2557	2445	2334	9763	9544	8944	8699
VPMV 10	82.92	81.67	81.00	80.33	2403	2299	2205	2170	8730	8831	8259	8109
VPMV 9	87.58	86.67	85.67	85.00	2746	2512	2502	2417	10224	9847	9107	8962
VPMV 11	81.91	81.67	80.67	80.00	2403	2334	2264	2185	9073	9183	8302	8134
VPMV 12	78.03	77.67	76.67	76.00	2230	2134	2070	2016	8193	8054	7396	7202
MBP 2	85.46	84.00	83.67	83.00	2531	2416	2329	2278	9336	9506	8726	8587
Mean	85.11	84.29	83.50	82.62	2637	2502	2424	2339	9532	9427	8752	8533
S. Em. $\pm$	2.22	2.20	2.18	1.91	74.72	62.83	64.80	60.17	305.08	282.90	295.19	257.79
C. D. @ 1 %	6.73	6.70	6.61	5.80	226.64	190.58	196.56	182.52	925.36	858.09	895.38	781.93

**Fig 1:** Fe content (ppm) as influenced by biofortified and non biofortified pearl millet genotypes.**Fig 2:** Zn content (ppm) as influenced by biofortified and non biofortified pearl millet genotypes.

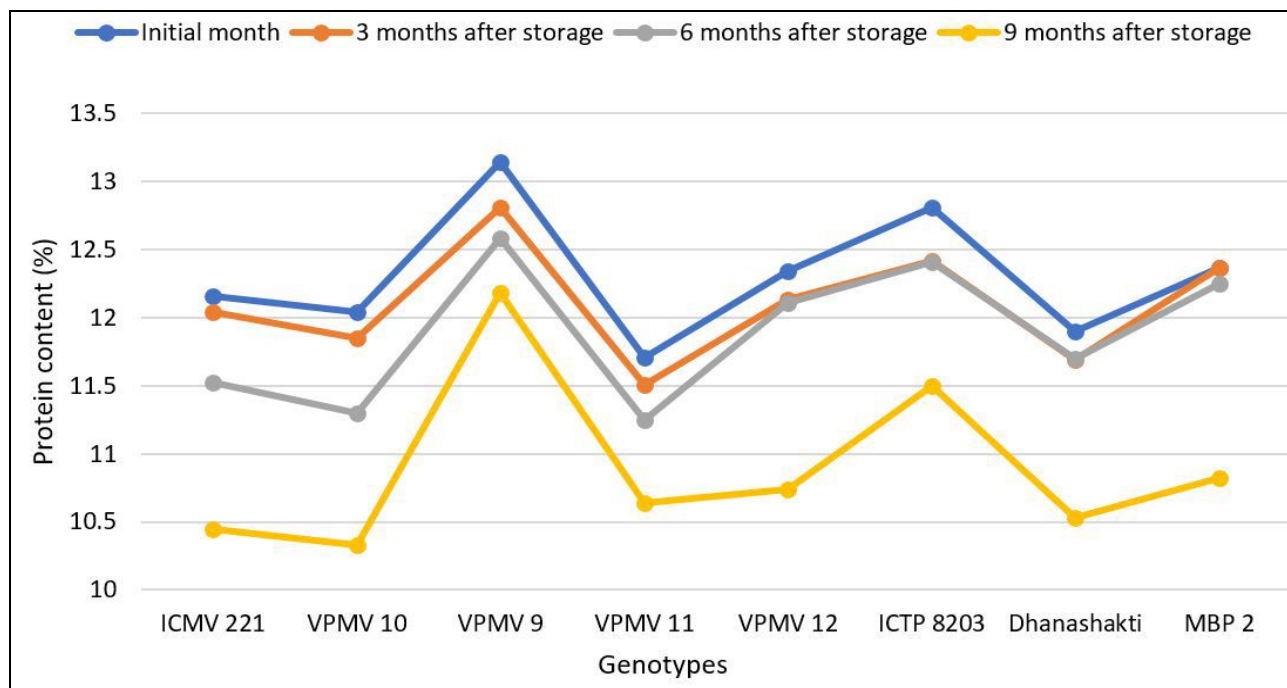


Fig 3: Protein content (%) as influenced by biofortified and non biofortified pearl millet genotypes.

Conclusion

The findings of this study demonstrate that the pearl millet genotype VPMV 9 exhibited significantly superior growth and yield attributes, including increased plant height, number of productive tillers, dry matter accumulation, and enhanced yield components such as ear head length, girth, weight, and grain yield per hectare. In contrast, the genotype ICTP 8203 showed greater seed storage potential, maintaining higher seed quality parameters such as seed germination and seedling vigour indices over prolonged storage durations. These results indicate that VPMV 9 is optimal for maximizing growth and yield, whereas ICTP 8203 is preferable for extended seed storage without compromising seed viability and vigour.

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