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Reassessing the Validity Period of Certified Seeds in Proso Millet (*Panicum miliaceum* L.)

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ABSTRACT: Proso millet (*Panicum miliaceum* L.) is gaining renewed importance as a climate-resilient and nutritionally rich cereal capable of supporting food and nutritional security under marginal and rainfed conditions. With increasing emphasis on millet-based cropping systems, ensuring the availability of high-quality seed throughout the planting season has become critical, necessitating a re-examination of existing seed certification validity norms. The present study evaluated the storability and revalidation requirements of certified Proso millet seed varieties GPUP-25 and GPUP-28 stored under ambient conditions in cloth and high-density polyethylene (HDPE) bags for nine months. The investigation was conducted during 2024–2025 at the Notified State Seed Testing Laboratory, Department of Genetics and Plant Breeding, SHUATS, Prayagraj. Progressive declines in germination percentage, seedling dry weight and vigour indices were observed with increasing storage duration, irrespective of packaging material. However, seeds stored in HDPE bags consistently maintained superior physiological quality compared to those stored in cloth bags. By the ninth month of storage, germination in cloth bags declined below the Indian Minimum Seed Certification Standards (IMSCS) minimum of 75% (72.63%), whereas HDPE-stored seeds retained acceptable germination (83.05%). Higher moisture content and electrical conductivity values in cloth bags indicated accelerated seed deterioration. The findings demonstrate that packaging material significantly influences seed longevity and suggest that uniform certification validity periods may not adequately reflect crop- and storage-specific seed behaviour. HDPE bags are recommended for medium- to long-term storage of Proso millet seeds under ambient conditions, while seeds stored in cloth bags require revalidation beyond eight months. The study provides empirical evidence to support the need for revisiting and refining seed certification and revalidation standards for Proso millet based on storability performance.

Keywords: Proso millet, seed certification standards, cloth and HDPE bags, storage

INTRODUCTION

Millets have gained renewed global prominence following the United Nations' declaration of 2023 as the International Year of Millets, underscoring their critical role in achieving food and nutritional security in the face of climate change [1]. Among these, Proso millet (*Panicum miliaceum* L.) is one of the oldest cultivated cereal crops and is increasingly recognized for its adaptability to adverse agro-ecological conditions. The crop is characterized by a short growth duration and the ability to perform well under low water availability, high temperature and saline soils, making it particularly suitable for cultivation in marginal and rainfed regions [2]. In India, Proso millet is predominantly grown in states such as Tamil Nadu, Karnataka, Andhra Pradesh, Bihar, Madhya Pradesh and Uttarakhand, where climatic uncertainties frequently constrain the productivity of major cereals.

Proso millet exhibits notable tolerance to both biotic and abiotic stresses, contributing to its resilience under low-input farming systems. From a nutritional standpoint, it is superior or comparable to major cereals, containing 11–12% protein along with essential amino acids such as isoleucine, methionine and leucine [3]. Its gluten-free nature makes it a valuable dietary option for individuals with gluten intolerance and has increased its relevance in the expanding gluten-free food market [4]. Additionally, Proso millet has been reported to confer health benefits including cholesterol-lowering effects and liver protection, and serves as a source of important micronutrients such as zinc, iron and vitamin B6 [5]. Despite these advantages, India ranks only ninth in global production of Proso millet, primarily due to low productivity. Among the major constraints are underdeveloped seed systems and limited information on storage behaviour, seed certification validity and storability of seeds [6,7].

The Indian seed sector operates within a regulatory framework in which seed labelling is mandatory, while certification remains voluntary under the Seeds Act of 1966 [8]. According to the Indian Minimum Seed Certification Standards (IMSCS, 2013), certified seed lots are initially valid for a period of nine months, with provision for revalidation for an additional six months, subject to compliance with prescribed germination and quality standards [9]. While these standards are intended to ensure the distribution of high-quality seeds to farmers, the uniform validity period may not adequately reflect the variability in seed longevity arising from differences in crop species, varieties, storage conditions and packaging materials.

Seed viability and vigour decline progressively during storage, and the rate of deterioration is strongly influenced by environmental conditions and the nature of the packaging material. In the context of evolving climate variability and the introduction of improved varieties, fixed seed validity norms warrant re-examination to ensure their relevance and effectiveness. Therefore, there is a growing need for crop-specific and evidence-based assessments of seed storability to guide certification and revalidation policies.

In view of this, the present study was undertaken to evaluate changes in germination, seed vigour and quality parameters of certified Proso millet seeds stored under ambient conditions using different packaging materials. The study further aimed to determine an appropriate certification validity and revalidation period for Proso millet seeds based on their storability and performance over time, thereby contributing to more informed seed management and regulatory decisions.

MATERIALS AND METHODS

Experimental site and seed material

The experiment was conducted during September 2024 to June 2025 at the Notified State Seed Testing Laboratory, Department of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj. Freshly harvested certified seeds of Proso millet (*Panicum miliaceum* L.) varieties GPUP-25 and GPUP-28 were procured from the Seed Research Officer, All India Co-ordinated Research Project (AICRP) on Seed (Crops), Seed Technological Research (STR), University of Agricultural Sciences (UAS), GKVK, Bengaluru.

Storage treatments

The seed lots of each variety were thoroughly mixed and divided into two equal portions. One portion was packed in cloth bags, while the other was packed in high-density polyethylene (HDPE) bags. All seed samples were stored under ambient laboratory conditions for a period of nine months. Seed quality assessments were carried out at monthly intervals throughout the storage period.

Experimental design and sampling

At each sampling interval, seeds from both storage treatments were evaluated in four replications, with each replication consisting of 100 seeds. The experiment followed a completely randomized design for laboratory evaluation of seed quality parameters.

Seed quality parameters

Germination percentage and first count were determined following the procedures prescribed by the International Seed Testing Association (ISTA) [10]. The first count was recorded on the 3rd day, and the final count on the 7th day after sowing.

Seedling length and seedling dry weight (mg) were recorded from ten randomly selected normal seedlings at the time of final count. Seed vigour indices were calculated as described by Abdul-Baki and Anderson [11].

Moisture content (%) of seeds was estimated using the hot air oven method at 103 °C for 17 hours, in accordance with ISTA guidelines [10].

Electrical conductivity of seed leachates was measured to assess membrane integrity. For this purpose, 50 seeds in three replications were soaked in 20 mL of Milli-Q water (Millipore, Gradient SAS-67, France) and incubated for 24 hours at 25 °C. The electrical conductivity of the leachate was recorded using a digital conductivity meter (CM 183, Elico, India).

Germination (%)= (Total number of seeds placed for germination/Number of normal seedlings) × 100

Seed Vigour Index (SVI)-I: Germination% × Seedling length (cm)

Seed Vigour Index (SVI)-II: Germination% × Seedling dry weight (mg)

Statistical analysis

The data were subjected to statistical analysis using the software package GRAPES version 1.1.0. Analysis of variance (ANOVA) was performed following a Completely Randomized Design (CRD). Treatment means were compared using critical difference (CD) values at the 1% level of significance ($p \leq 0.01$). Duncan's Multiple Range Test (DMRT) was employed for mean separation, and statistically significant differences among treatments are indicated by different superscript letters.

RESULTS

Irrespective of genotype, highly significant differences ($p \leq 0.01$) were observed among storage materials and storage durations for all evaluated seed quality parameters, except seedling length, which showed non-significant variation. Germination percentage, first count, seedling dry weight and seed vigour indices of Proso millet seeds stored in different packaging materials (cloth bag and HDPE bag) exhibited a progressive decline with increasing storage duration. However, seeds stored in HDPE bags consistently maintained superior quality attributes compared to those stored in cloth bags.

At the initial stage of storage, germination percentage was statistically at par between the two packaging materials, recording 94.28% in cloth bags and 94.37% in HDPE bags. With advancement of storage, a marked decline in germination was observed, particularly in cloth bags. By the ninth month, germination decreased to 72.63% in cloth bags, falling below the Indian Minimum Seed Certification Standards (IMSCS) threshold of 75%, thereby indicating the need for revalidation. In contrast, seeds stored in HDPE bags retained significantly higher germination (83.05%) even after nine months of storage (Table 1). First count followed a similar declining trend, decreasing from 61.57% to 48.64% in cloth bags and from 62.43% to 52.08% in HDPE bags over the storage period (Table 1).

Seedling length showed a non-significant response to storage duration, although a marginal declining trend was evident in both packaging materials. In cloth bags, seedling length decreased from 15.49 cm to 13.65 cm, while seedling dry weight declined markedly from 183.70 mg to 138.93 mg. Seeds stored in HDPE bags maintained comparatively higher seedling length (15.76 cm to 13.79 cm) and seedling dry weight (183.95 mg to 149.02 mg) throughout the storage period (Table 1).

Seed Vigour Index I (VI-I), which integrates germination percentage and seedling length, exhibited a pronounced decline with prolonged storage, particularly in cloth bags where values decreased from 1460.40 to 991.04. In contrast, HDPE bags showed a relatively slower decline, with VI-I values decreasing from 1487.27 to 1145.26. A similar pattern was observed for Seed Vigour Index II (VI-II), which combines germination percentage and

Table 1. Influence of seed packaging material on seed quality parameters during seed storage

Packing material	Storage period (Month)	Germination	First count	Seedling Length	Dry Weight	VI-I	VI-II
Cloth Bag	1	94.28^{a}	61.57^{a}	15.49^{ns}	183.70^{a}	1460.40^{ab}	17319.86^{a}
	2	92.66^{ab}	60.13^{ab}	15.29^{ns}	176.47^{b}	1416.77^{bcd}	16413.80^{b}
	3	91.04^{abcd}	58.69^{c}	15.11^{ns}	169.24^{b}	1375.16^{de}	15407.74^{c}
	4	88.66^{cde}	56.73^{cd}	14.80^{ns}	164.92^{cd}	1312.64^{fg}	14632.57^{de}
	5	86.29^{efg}	54.77^{d}	14.51^{ns}	160.60^{c}	1251.56^{hl}	13857.40^{f}
	6	82.58^{gh}	52.99^{ef}	14.22^{ns}	155.14^{ef}	1174.05^{jk}	12830.77^{g}
	7	78.86^{h}	51.22^{e}	13.93^{ns}	149.68^{d}	1098.59^{l}	11804.13^{h}
	8	75.25^{l}	49.93^{gh}	13.79^{ns}	144.30^{g}	1023.72^{m}	10947.13^{l}
	9	72.63^{l}	48.64^{f}	13.65^{ns}	138.93^{e}	991.04^{m}	10090.12^{j}
HDPE Bag	1	94.37^{a}	62.43^{a}	15.76^{ns}	183.95^{a}	1487.27^{a}	17359.08^{a}
	2	92.95^{ab}	61.19^{ab}	15.53^{ns}	176.79^{b}	1443.51^{abc}	16442.74^{b}
	3	91.53^{abc}	59.94^{b}	15.30^{ns}	169.63^{b}	1400.41^{cd}	15526.40^{c}
	4	90.92^{abcd}	59.07^{cd}	15.10^{ns}	165.52^{cd}	1372.89^{de}	15051.48^{cd}
	5	90.31^{bcd}	58.20^{c}	14.90^{ns}	161.40^{c}	1346.07^{ef}	14576.56^{de}
	6	87.53^{def}	56.71^{ef}	14.66^{ns}	160.49^{ef}	1283.63^{gh}	14050.26^{ef}
	7	84.75l^{efg}	55.22^{d}	14.43^{ns}	159.56^{c}	1222.59^{lj}	13523.95^{f}
	8	83.90^{fg}	53.65^{gh}	14.11^{ns}	154.29^{g}	1183.83^{jk}	12900.07^{g}
	9	83.05^{g}	52.08^{e}	13.79^{ns}	149.02^{d}	1145.26^{kl}	12376.20^{gh}

Different letters of Dunken indicate significant at 1%, ns indicate Non-significant

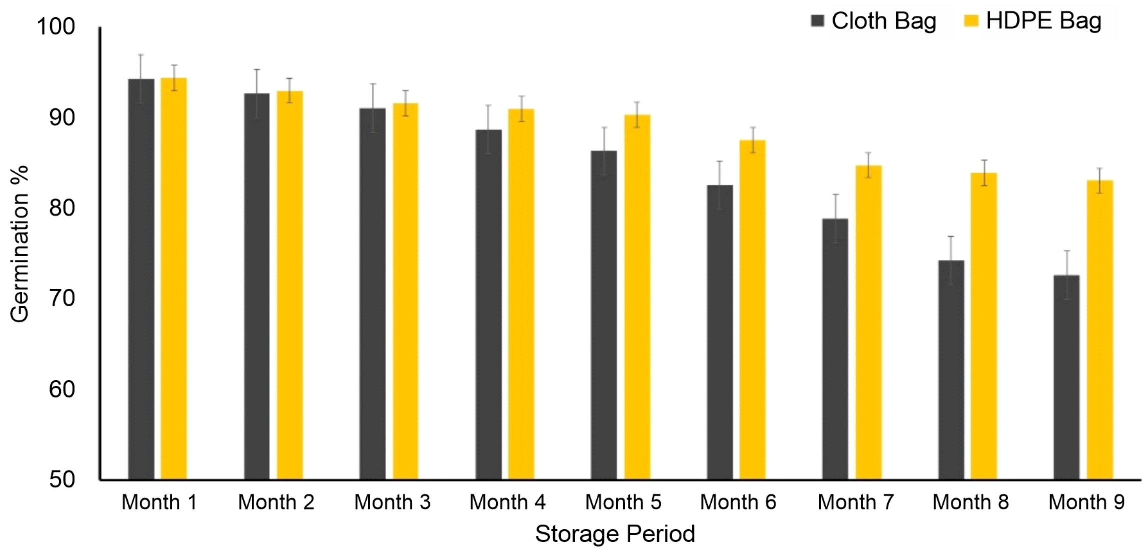

Figure 1. Influence of seed packaging material on seed germination during seed storage

seedling dry weight. VI-II values declined from 17319.86 to 10090.12 in cloth bags, whereas HDPE-stored seeds maintained higher values, declining from 17359.08 to 12376.20 over the storage period. Overall, seeds stored in HDPE bags exhibited superior retention of germination capacity, seedling quality and vigour compared to those stored in cloth bags (Table 1).

Irrespective of the packaging material, electrical conductivity (EC) and moisture content (MC%) increased progressively with storage duration, reflecting gradual seed deterioration. During the first month of storage, both cloth and HDPE bags recorded identical moisture content (12.3%). However, with prolonged storage, moisture accumulation was more pronounced in cloth bags, reaching 13.60% by the ninth month, compared to only 12.80% in HDPE bags (Fig. 2).

Similarly, EC values increased throughout the storage period in both packaging materials, with consistently higher values observed in cloth bags. Initial EC values were identical (13.34 μS cm^{-1} mg^{-1}) in both treatments. By the ninth month, EC increased substantially to 19.36 μS cm^{-1} mg^{-1} in cloth bags, whereas HDPE bags recorded a comparatively lower EC of 16.28 μS cm^{-1} mg^{-1} (Fig. 2), indicating better maintenance of membrane integrity under HDPE storage.

DISCUSSION

The present study clearly demonstrates the critical role of storage conditions and packaging materials in maintaining seed viability and vigour of Proso millet, particularly within the framework of India's seed regulatory system, where seed labelling is mandatory and certification remains voluntary under the Seeds Act, 1966. Although certified seed lots are accorded an initial validity of nine months with provision for revalidation for an additional six months, such uniform validity periods often fail to adequately capture the dynamic nature of seed storability. Seed longevity is strongly influenced by crop species, varietal characteristics, packaging material and the prevailing storage environment. The findings of the present study highlight the significant and interactive effects of packing material and storage duration on multiple seed quality parameters.

Seeds stored in HDPE bags consistently exhibited significantly higher germination percentages across all storage intervals compared to those stored in cloth bags. Similar observations have been reported earlier in pigeon pea [12] and paddy [13], reinforcing the superior protective role of moisture-impermeable packaging materials. The comparatively slower decline in germination under HDPE storage can be attributed to its effective barrier against ambient moisture and gaseous exchange, thereby reducing the rate of seed ageing and physiological deterioration. In contrast, seeds stored in cloth bags showed a more rapid decline in germination, with values falling below the Indian Minimum Seed Certification Standards (IMSCS) threshold of 75% by the ninth month, necessitating mandatory revalidation when stored under such conditions.

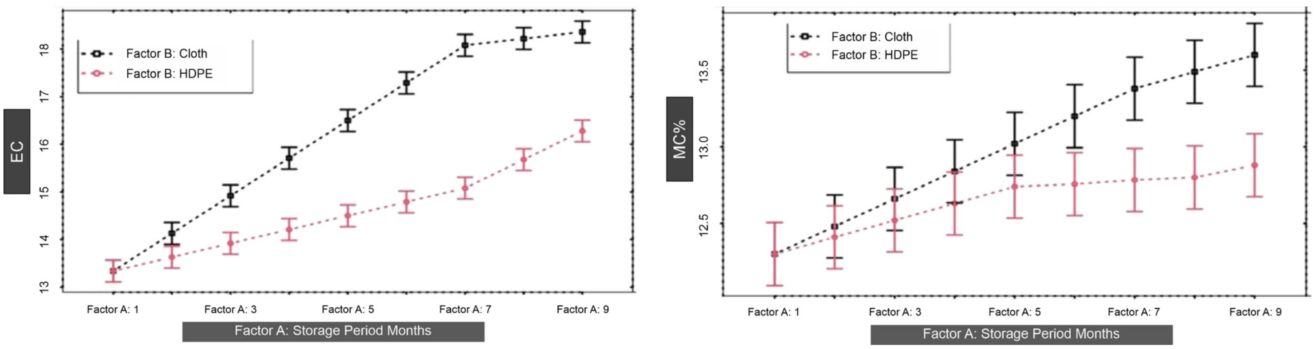

Figure 2. Influence of seed packaging material on Moisture content (%) and Electric conductivity µS/cm/mg during seed storage

The overall decline in germination observed in both packaging materials with increasing storage duration is a natural consequence of seed ageing, involving oxidative stress, membrane disintegration and progressive loss of enzymatic activity required for germination [14]. However, the significantly better performance of HDPE-stored seeds underscores the importance of appropriate packaging in moderating the rate of deterioration [15]. These findings assume greater relevance for climate-resilient crops such as Proso millet, where seed availability and quality are critical for successful crop establishment under marginal environments.

Seed vigour, a more sensitive indicator of seed physiological status than germination alone, declined progressively during storage, with a more pronounced reduction in cloth bags [16]. The lower vigour observed in cloth-stored seeds may be attributed to greater moisture fluctuations, which can trigger premature metabolic activity and accelerate reserve depletion without successful seedling establishment. In contrast, HDPE bags likely provided a more stable micro-environment by limiting moisture ingress, thereby preserving cellular integrity, promoting better seedling growth and sustaining higher dry matter accumulation over time.

Moisture content plays a pivotal role in seed storability, as excessive moisture accelerates hydrolytic enzyme activity, enhances fungal proliferation and increases susceptibility to imbibitional injury [17]. The moisture-impermeable nature of HDPE bags effectively maintained seed moisture within a safer range, thereby reducing the rate of biochemical and physiological degradation during storage [18]. This moisture regulation directly contributed to the improved seed quality observed in HDPE-stored seeds.

Electrical conductivity (EC), an established indicator of membrane integrity and solute leakage, increased progressively with storage duration in both packaging materials, with significantly higher values recorded in cloth bags. Elevated EC values reflect membrane disorganization and increased leaching of cellular solutes, which are hallmarks of seed deterioration [19]. The comparatively lower EC values in HDPE-stored seeds indicate delayed membrane damage and superior maintenance of seed vigour, corroborating the observed trends in germination and vigour indices [20]. Although some degree of seed deterioration is inevitable due to ageing [21], the rate and severity of deterioration are largely governed by the storage microenvironment, particularly moisture regulation and gaseous exchange, both of which are more effectively controlled in HDPE packaging [22]. These findings strongly support the pivotal role of appropriate packaging materials in prolonging seed longevity and quality.

CONCLUSION

The present study demonstrates that while both HDPE and cloth bags are suitable for short-term storage of Proso millet seeds under ambient conditions, HDPE bags are markedly superior for extended storage beyond eight months. Seeds stored in HDPE bags maintained significantly higher germination percentage, seedling dry weight and vigour indices throughout the storage period, particularly evident at the nine-month interval. In contrast, seeds stored in cloth bags exhibited accelerated deterioration due to greater exposure to environmental fluctuations, especially humidity.

From a practical and regulatory perspective, the findings indicate that the existing uniform seed certification validity period may not adequately account for crop- and packaging-specific differences in storability. To ensure compliance with minimum seed certification standards and to preserve seed vigour during prolonged storage, HDPE bags are strongly recommended for storing certified Proso millet seeds. Cloth bags should be restricted to short-term storage, and revalidation becomes essential when storage exceeds eight months. The study provides scientific evidence supporting the need for revisiting seed storage recommendations and revalidation timelines for Proso millet, thereby contributing to improved seed quality management and more informed certification policies.

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