

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(2): 548-554
www.biochemjournal.com
Received: 18-12-2025
Accepted: 21-01-2026

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Effect of grain aging and hydrothermal pretreatments on the quality of pearl millet flakes

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i2Sg.7669>

Abstract

World's growing demand for healthy and gluten-free products has highlighted the need for nutritious alternatives, among which millets have emerged as a promising option. Pearl Millet being nutritive, gluten-free has high potential for value-added processing, though it is limited owing to quality deterioration during storage. This study focused on the effects of grain aging and hydrothermal pretreatments (short soaking tempering method and thermosonication) on the engineering, functional, and sensory qualities of pearl millet flakes. The grains of five different conditions were as follows: fresh pearl millet, pearl millet stored at ambient conditions at 30 °C, and refrigerated conditions at 4 °C for 8 months, hydrothermal treatment using the short soaking tempering method and thermosonication were subjected to product development flakes. Pearl millet flakes were evaluated for flake yield, broken%, dimensional and density properties, functional characteristics (water absorption capacity, oil absorption capacity, and water solubility index), and sensory attributes using a nine-point hedonic scale. The short soaking tempering method and thermosonication pretreatment significantly improved flake yield, reduced breakage, enhanced expansion, and improved functional and sensory attributes. Among the five conditions, the short soaking tempering method treated flakes exhibited superior acceptance across all the properties, producing lighter and well-expanded flakes with a consumer acceptance score of 7 (like). This study indicates that, unlike rice, fresh pearl millet grains are more suitable than aged grains for manufacturing quality products. Additionally, appropriate pretreatment of pearl millet enhances its suitability for producing ready-to-cook flakes.

Keywords: Flakes, hydrothermal, pearl millet, pretreatment, storage, thermosonication

Introduction

The growing consumer perception of healthy and gluten free alternatives has gained attention for millets. Gluten intolerance is a major issue in the European population, affecting 1 in 100 individuals. It affects immune mediated mechanisms and prevents gluten absorption in the villi present in the small intestine. Millets are a group of small-seeded cereal crops of Gramineae family, which grows at arid soils at high temperatures [1]. India shares India being major millet producer contributing to 20% of world millet production (12.49 MMT-in 20%-80% from Asia). Pearl millet (*Pennisetum glaucum*) is a healthy alternative for gluten-intolerant individuals. It is a Nutri-cereal or super grain with a low glycemic index. It contains good sources of energy, protein, fiber, and micronutrients (vitamin B, iron, phosphorus, magnesium, and zinc), along with numerous functional and health benefits. The nutritive quality of pearl millet is better than that of wheat, rice, and sorghum.

Despite the importance and nutritive value of pearl millet, its full potential is masked by its short shelf life due to rancidity and off-odors during storage. The prevailing rancidity because of fatty acids, the peroxidase and lipase act on spoilage and off flavor development during storage [2]. Alongside pearl millets have antinutritional factors that prevents nutrient absorption must be addressed [3]. These attributes emphasize the study on storage of pearl millet is primary to know the quality loss of pearl millet grain at various storage conditions. The effect of pretreatment to pearl millet is also a blooming area of research extends the dimension of keeping quality of pearl millet after treatments. The influence of pretreatment on pearl millet product development is another important aspect that has yet to be studied. This study attempts to address this gap.

Ready to eat food products are important in the food market owing to their convenience and ease of carrying. Flaking is an age-old technique (RTE) in corn and rice, but it is an innovative technology in millet that enhances the nutritive value and shelf life of grain by value in addition to reaching better consumer preference as it is ready-to ready-to-eat product. Flaking involves starch gelatinization, enzyme inactivation, sugar dextrinization, reduced moisture content, and enhanced shelf life of the product. Flaked pearl millet is a millet-based convenient product with huge commercial potential and could be adopted for large scale production with minimum investment, and could be a healthy alternative for age old breakfast flakes. This product could also be helpful for both farmers and health-conscious consumers [4]. India being the largest producer of millet, growing consumer demand for healthy and gluten-free food product.

Therefore, the storage condition of millet must be systematically studied to prevent quality deterioration during storage and to enhance its keeping quality for long term processing. Accordingly, the current study was undertaken to evaluate the quality of stored grains and the product quality obtained under various storage and pretreatment conditions. Pretreatments, namely short soaking tempering, and thermosonication, were employed to assess their effects on the engineering and functional properties of pearl millet. Furthermore, to evaluate the impact of aging and pretreatment on end-product quality, a Ready-To-Cook food product was developed from the stored grains and its engineering, functional and sensory properties were assessed.

Materials and Methods

Fresh pearl millet samples were obtained from a farmer in the Vijayapura district of Karnataka. The grains were meticulously cleaned using a destoner and graded with a perfura grader cum aspirator (Model GCA 35). Subsequently, they were packed in polythene bags and stored under ambient conditions for further analysis.

Aging of millets

Pearl millet was subjected to controlled aging to study the effects of storage-induced physicochemical changes and their modulation by pretreatments. Fresh Pearl Millets (PF1) served as control. The aging process was induced by storing the millets for 8 months under two separate conditions: storage at 30 °C, indicating ambient aging (PF2), and storage under refrigerated conditions (4±1 °C) to represent slow aging (PF3). These conditions were selected to investigate the impact of temperature on the progression of aging related quality changes.

Pre Processing of Millet

To identify the possibility of processing technique effects, fresh millet grains were subjected to hydrothermal treatments, such as short soaking tempering (PF4) and thermosonication (PF5). Various treatment conditions on both PF4 and PF5 were tried and optimal condition for PF4 was found to be 75 °C soaking of pearl millet for 30 minutes, followed by tempering at 30 °C for 2 hours. The samples were then tray-dried at 40 °C to reach 10% moisture content. For PF5, the optimized condition included sonication for 30 min at 100% amplitude with pulse mode (5 s ON, 5 s OFF) at 60 °C. The grains were then separated and

tray dried (40 °C) to reach a moisture content of 10 %. All samples (PF1, PF2, PF3, PF4, and PF5) were subjected to pearl millet flake preparation, as shown in Figure 1. The quality characteristics were assessed, and their effects on the sensory attributes of the products were noted.

Pearl Millet Flakes

Pearl millet of known quality was washed, soaked (5 h), and drained. The millets were then roasted in an uruli roaster at 120 °C for 10 min. The roasted grains were surface-dried for 10 min and then passed through a roller flaking machine. The flakes were collected in a mesh tray for uniform flake collection and then dried for 2 h at 55 °C in a hot air oven to reduce the moisture content to the required level. The flakes were then cooled, packed, and stored in an airtight container for further analysis.

Engineering properties of pearl millet

The flakes and broken yield were calculated by the following equation and are expressed as percentage are calculated as performed by [5]

$$\text{Yield of flakes (\%)} = \frac{\text{Whole flakes weight (g)}}{\text{weight of sample (g)}} \quad (1)$$

$$\text{Broken yield (\%)} = \frac{\text{Weight of broken (g)}}{\text{Weight of Whole Flakes (g)}} \quad (2)$$

1. Expansion ratio (ER): The notable increase in volume owing to flaking was calculated and expressed as given by [4]. In this method, radial dimensions of 25 flakes (randomly selected) were measured by caliper at the maximum points and expansion ratio was calculated in comparison with volume of grains

$$\text{Expansion ratio} = \frac{\text{Volume of flakes (mL)}}{\text{Volume of grains (mL)}} \quad (3)$$

2. Dimensions: The dimensions of the pearl millet flakes, including length, breadth, thickness, and length/breadth ratio, were measured using vernier calipers. The values were expressed as means of 10 randomly selected flakes in mm [6].

3. Density of flakes: The bulk and true density was estimated by method adopted from [7] for flakes. Bulk density was measured against weight per volume in g/ml, whereas the true density was measured by toluene displacement method and both are expressed as

$$\text{Bulk Density } \left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{Weight of flakes (g)}}{\text{Volume of sample (ml)}} \quad (5)$$

$$\text{True Density } \left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{Weight of flakes (g)}}{\text{Volume of sample (ml)}} \quad (6)$$

4. Thousand Flakes Weight: The 1000 pearl flakes were randomly drawn, and weight was calculated in triplicated by weighing 1000 grains on an electronic balance.

Functional Properties

1. Water absorption capacity, Oil Absorption Capacity and Water solubility index of flakes

Water absorption capacity (WAC) and Water solubility index (WSI) of the flakes was determined by [8] method. WAI was measured by weighing 1 g of the sample in a

centrifuge tube added with ten milliliters of deionized water. The mixture was then stirred and mixed using a vortex mixer and allowed to stand for 30 min at room temperature. The sample was then centrifuged at 3000 rpm for 40 min, and the supernatant was decanted and transferred into a pre-weighed Petri dish to determine the dissolved solid content. The tubes were inverted for 5 min to drain excess liquid, and the samples were weighed to determine their final weight. The oil absorption capacity was determined using the same procedure but by adding ten milliliters of oil. The percentage of water absorption capacity and water solubility index was expressed in % by the below expression

$$\text{WAC \& OAC (\%)} = \frac{W(\text{wet}) - W(\text{dry})}{W(\text{dry})} \times 100 \quad (9)$$

$$\text{WSI} = \frac{\text{Weight of dissolved solids in supernatant (g)}}{\text{Weight of Initial Dry Sample (g)}} \times 100 \quad (10)$$

Where W(wet) is the weight of the flakes after soaking and draining, and W(dry) is the initial weight of the flake sample.

Sensory evaluation of Pearl Millet Flakes

The pearl millet flakes were subjected to sensory evaluation by 25 semi-trained members at the School of Sensory Science Laboratory, NIFTEM-Thanjavur. The evaluation was carried out by nine-point hedonic rating scale adopted from^[9] rating indicate “like extremely” to “dislike extremely” with attributes such as appearance, texture, taste, flavor and overall acceptability. Each panelist was provided with sufficient privacy to avoid biased assessments and errors.

Statistical analysis

Statistical analysis was performed using Minitab 16 statistical software package with one way Analysis of Variance (ANOVA) to estimate the significant difference among samples ($P \leq 0.05$), and data were presented as mean $\pm$ standard deviation. The sensory evaluation data compilation and analysis were performed using Fizz Software.

Results and Discussion

Engineering properties of Pearl Millet Flakes

The pearl millet flakes were prepared from PF1, PF2, PF3, PF4 and PF5 samples to know whether there are any treatment effects among the samples with respect to engineering properties were expressed in Table 1. The yield of pearl millet flakes varied significantly among the treatments (i.e. $p < 0.05$). The yield of flakes was noted to be 77.43 ± 1.06 , 72.57 ± 1.75 , 75.87 ± 2.51 , 82.60 ± 2.15 , 80.33 ± 1.72 (%) for PF1, PF2, PF3, PF4 and PF5 respectively. The results express that the yield % was found to be increased for short soaking tempering method and thermosonication in comparison with fresh pearl millet, while noted vice versa for aged millet with respect to ambient and refrigerated storage. The notable increase in flakes yield % in short soaking tempering method may be owing to binding effect of starch when subjected to temperature involved treatment i.e. gelatinization and diffusing of denatured protein into the granular space of starch^[10]. This in turn reduces the broken yield % for the same treatment in comparison with fresh and other treated millet sample by enhancing pearl millet plasticity and

reducing fissures during flaking. The PF2 treatment could have reduced yield of flakes % and increased yield of broken % owing to moisture loss, kernel hardening during storage at ambient condition, ultimately results in increased brittleness. Thermosonication (PF5) pretreated pearl millet flakes gained higher yield % in comparison with fresh pearl millet flakes owing to enhanced hydration (water uptake by endosperm) and microstructural disruption induced by acoustic cavitation, while PF5 showed lower yield % than PF4 where in short soaking tempering method more complete starch gelatinization could have achieved leading to superior flake expansion and structural integrity^[11]. PF3 refrigerated condition also experienced lower flakes yield in comparison with PF1, PF4 and PF5 this may be owing to uneven moisture content during storage and potential stiffening effect that raises the brittleness^[12]. Thus, flakes yield is found to be directly proportional to expansion ratio, the higher the yield the more the expansion ratio and have inverse effect on broken yield percentage respectively.

The dimensional analysis revealed that there was significant change among the samples ($p < 0.05$) with respect to thickness (0.40 ± 0.03 to 0.51 ± 0.03) and not much change in length (5.93 ± 0.21 to 6.56 ± 0.37), width (5.60 ± 0.27 to 5.84 ± 0.28), L/B ratio (1.06 ± 0.02 to 1.12 ± 0.03) as represented in Table 2. PF4 expressed higher length, width and L/B ratio among the other pre-treated and stored samples. This could be owing to lateral expansion during flaking, tempering-conditioning effect of pretreatment and roller setting that majorly influence flake dimension and morphology. The yield % was also found to be higher for PF4 sample and that could also be reason for these dimensional results. Among the five samples PF4 and PF5 had greater L/B ratio owing to plasticization and flow under compressive stress in line with documented effect of pre-treated cereal structures and deformability^[13]. The L/B ratio represents the degree of pretreatment at the time of flaking. Aside from thickness, the dimensional properties of PF1, PF2, and PF3 showed only minor variations, indicating that aging has little impact on pearl millet and product development, while other aspects remain unchanged. Flake thickness was found to be high for PF2 and PF4 had the lowest thickness. The thickness of flakes was found to be reduced owing to hydration effect of short soaking tempering method that pretreated flaking by gelatinization improves the thinner flakes for better quality end product^[14].

The weight of 1000 flakes showed significant changes ($p < 0.05$) among the samples, ranging from 9.98 ± 0.08 to 10.35 ± 0.07 , as shown in Table 3. This indirectly represents the size of pearl millet flakes. The higher the value, the larger the flakes size, and is found to be similar for sample PF1, PF2 and PF3 may be owing to storage of samples without pretreatment, since the sample doesn't go for processing condition, that doesn't alter the starch properties of the samples. PF4 showed changes owing to treatment effect, lower thousand flake weight, this reduction is greatly associated with increased flake spread and porosity, the moisture associated conditions facilitates starch softening and deformation under compressive force during flaking similarly found for cereal flakes.

The bulk density was found to be in the range of 0.36 ± 0.01 to 0.40 ± 0.00 and true density of 1.01 ± 0.02 to 1.07 ± 0.03 respectively represented in table 3. The results deliberate that true density was higher than the bulk density of the

samples, maybe owing to the insignificant volume of void space as the result of external force [15]. The lower bulk density was found in PF4 sample, and it represents the good quality flakes, the flake flatness and it also indicate the storage space required for storage [16]. This could be owing to starch gelation by short-soaking tempering method i.e. When starch granules are exposed to heat and moisture, they absorb moisture and thus swelling occurred. This disrupt their crystalline structure and increase the starch volume, that lowers the bulk density remains its mass unchanged [13]. Thus, notable increase in bulk volume supports this fact as well attributed to lighter, more expanded flake structure. The PF2 and PF3 showed similar bulk density correlates with greater thickness of flakes and reduced expansion, leading to compact packaging. The true density had noted no significant difference among the samples similar to the study by Galal *et al.*, (2023) [16]. These may be owing to the macrostructural porosity changes during storage rather than intrinsic material density. PF5 found to have reduced bulk density than PF1 owing to cavitation during ultrasound processing that improves flake aeration.

Functional Properties of Pearl Millet Flakes

Functional characteristics of pearl millet flakes were determined and found to have significant change among the storage conditions employed. The water absorption capacity ranges between 143.58 ± 1.75 to 157.80 ± 3.98 , while the Water Solubility Index ranges from 5.00 ± 0.10 to 6.13 ± 0.15 and the Oil Absorption Capacity found to be in the range of 97.33 ± 2.52 to 110.00 ± 4.00 respectively were presented in Table 4. PF4 noted to have higher WAC owing to soaking and tempering effect where the starch gelatinization was controlled by the water uptake of the endosperm. The PF4 pretreatment also had notable hike in WSI, maybe due to partial solubilization of starch molecules. This treatment also had notable increase in OAC all these could be attributed to soaking and tempering methods leading to starch gelatinization, protein unfolding and increased exposure of hydrophilic and hydrophobic binding sites. It indicates these flakes have high insoluble dietary fiber and protein content similar to the result observed by Srivastava *et al.*, (2025) [13]. The PF5 also showed higher WAC, OAC compared to other storage conditions except PF4 might be due to starch-protein matrix modification during thermosonication that ultimately end up in higher water and oil uptake ratio [17]. The PF2 and PF3 had notable reductions in WAC and OAC owing to storage induced structural rearrangements that reduce swelling capacity and molecular mobility of the samples. The WSI represents the rehydration and digestibility properties of pearl millet flakes and higher WSI was found to be in PF4 and PF5 (i.e. Pretreated samples) indicate controlled molecular breakdown without excessive degradation by treatment effect produces desirable flake quality.

Sensory Evaluation of Pearl Millet Flakes

Sensory evaluation of all the pearl millet flakes developed (figure 2) was performed for consumer perception of the flakes with the sensory attributes mentioned in Table 5 by semi-trained panelists of NIFTEM-T following the 9-point hedonic scale rating test. The results showed significant differences for all the attributes except aroma as follows: appearance from 5.08 ± 1.00 to 6.17 ± 0.72 , Texture (6.17 ± 0.72 to 7.17 ± 0.72), Taste (6.17 ± 0.72 to 7.00 ± 0.85)

and Overall acceptability of flakes (5.83 ± 0.72 to 6.83 ± 0.72) respectively. All the attributes were found to be high for PF4 and PF5 (that is, Pretreated pearl millet that developed into flakes) than the other stored pearl millet-based flakes. The texture, taste and overall acceptability were the major attributes for consumer acceptance and found that PF4 and PF5 had these in the range of panelist. This could be due to structural changes during both treatments, where controlled gelatinization and starch retrogradation improve flaking properties and attain a reliable texture (that is, Crispness and hardness of the flakes). The enhanced textural properties ultimately lead to improved overall mouthfeel making the flakes overall acceptability enhancement by the panelist [13]. There was no significant difference in aroma content, shows that primary processing doesn't or have negligible volatile profile loss.

The collective results of all the properties along with the sensory analysis showed that pretreatment and storage had a notable significant effect on the engineering, functional, and sensory properties of pearl millet flakes. Prolonged ambient and refrigerated storage of pearl millet without pretreatment resulted in quality loss. This could be rectified by the soaking cum tempering method and thermosonication treatment. Among these pretreatments soaking and tempering method found to be more effective and are economic, scalable, easily introduced into processing line, minimize storage loss, yield better quality end products and liable method than thermosonication method which are not economical and have scalability issue.

Table 1: Yield and Expansion Characteristics of Pearl Millet Flakes

Sample	Yield of flakes (%)	Yield of broken (%)	Expansion ratio
PF1	77.43 ± 1.06^{bc}	19.41 ± 0.74^{bc}	1.71 ± 0.05^{bc}
PF2	72.57 ± 1.75^c	24.24 ± 2.24^a	1.67 ± 0.02^{bc}
PF3	75.87 ± 2.51^{bc}	20.99 ± 2.14^{ab}	1.63 ± 0.03^c
PF4	82.60 ± 2.15^a	13.76 ± 1.98^d	1.83 ± 0.03^a
PF5	80.33 ± 1.72^{ab}	16.18 ± 1.36^{cd}	1.72 ± 0.04^b

Values are mean $\pm$ standard deviation (n = 3). Different superscript letters within the same column indicate significant differences at $p < 0.05$.

Table 2: Dimensional Properties of Pearl Millet Flakes

Sample	Length (mm)	Width (mm)	L/B ratio	Thickness (mm)
PF1	6.01 ± 0.14	5.67 ± 0.14	1.06 ± 0.02	0.48 ± 0.01^{ab}
PF2	5.93 ± 0.21	5.60 ± 0.27	1.06 ± 0.02	0.51 ± 0.03^a
PF3	6.07 ± 0.26	5.62 ± 0.27	1.08 ± 0.04	0.49 ± 0.02^{ab}
PF4	6.56 ± 0.37	5.84 ± 0.28	1.12 ± 0.03	0.40 ± 0.03^c
PF5	6.27 ± 0.20	5.67 ± 0.06	1.11 ± 0.02	0.44 ± 0.02^{bc}

Values are mean $\pm$ standard deviation (n = 10). Different superscript letters within the same column indicate significant differences at $p < 0.05$.

Table 3: Physical Properties of Pearl Millet Flakes

Sample	1000 flakes Wt (g)	Bulk Volume (ml)	True Volume (ml)	Bulk Density (g/ml)	True Density (g/ml)
PF1	10.35 ± 0.07^a	27.33 ± 0.76^{ab}	10.17 ± 0.29^a	0.38 ± 0.01^{bc}	1.02 ± 0.03
PF2	10.27 ± 0.13^a	25.83 ± 0.29^c	10.00 ± 0.00^c	0.40 ± 0.00^a	1.03 ± 0.01
PF3	10.30 ± 0.12^a	26.00 ± 0.50^{bc}	10.17 ± 0.29^{ab}	0.40 ± 0.00^{ab}	1.01 ± 0.02
PF4	9.98 ± 0.08^b	27.50 ± 0.50^a	9.33 ± 0.29^c	0.36 ± 0.01^c	1.07 ± 0.03
PF5	10.10 ± 0.10^{ab}	26.67 ± 0.58^{abc}	9.50 ± 0.00^{bc}	0.38 ± 0.01^{abc}	1.06 ± 0.01

Values are mean $\pm$ standard deviation (n = 3). Different superscript letters within the same column indicate significant differences at $p < 0.05$.

Table 4: Functional Properties of Pearl Millet Flakes

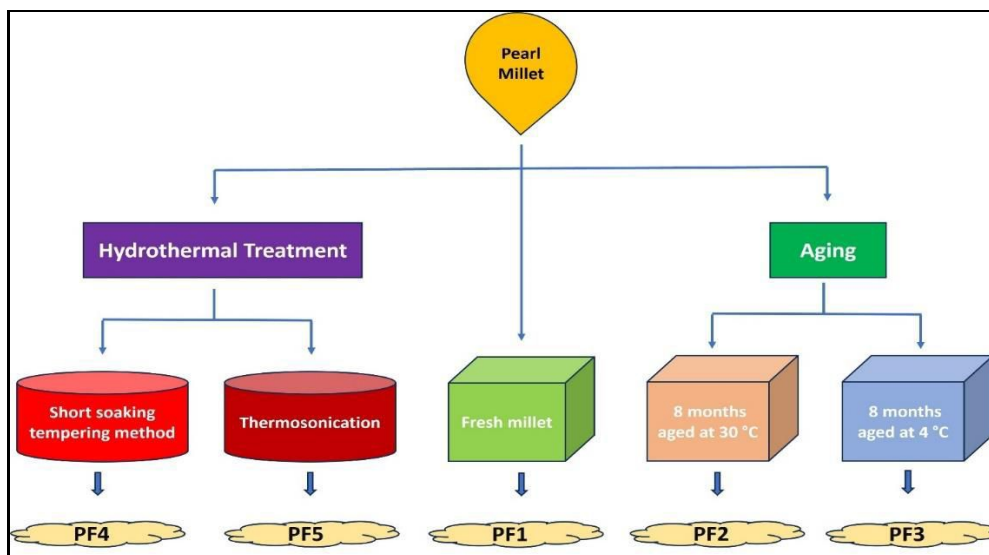
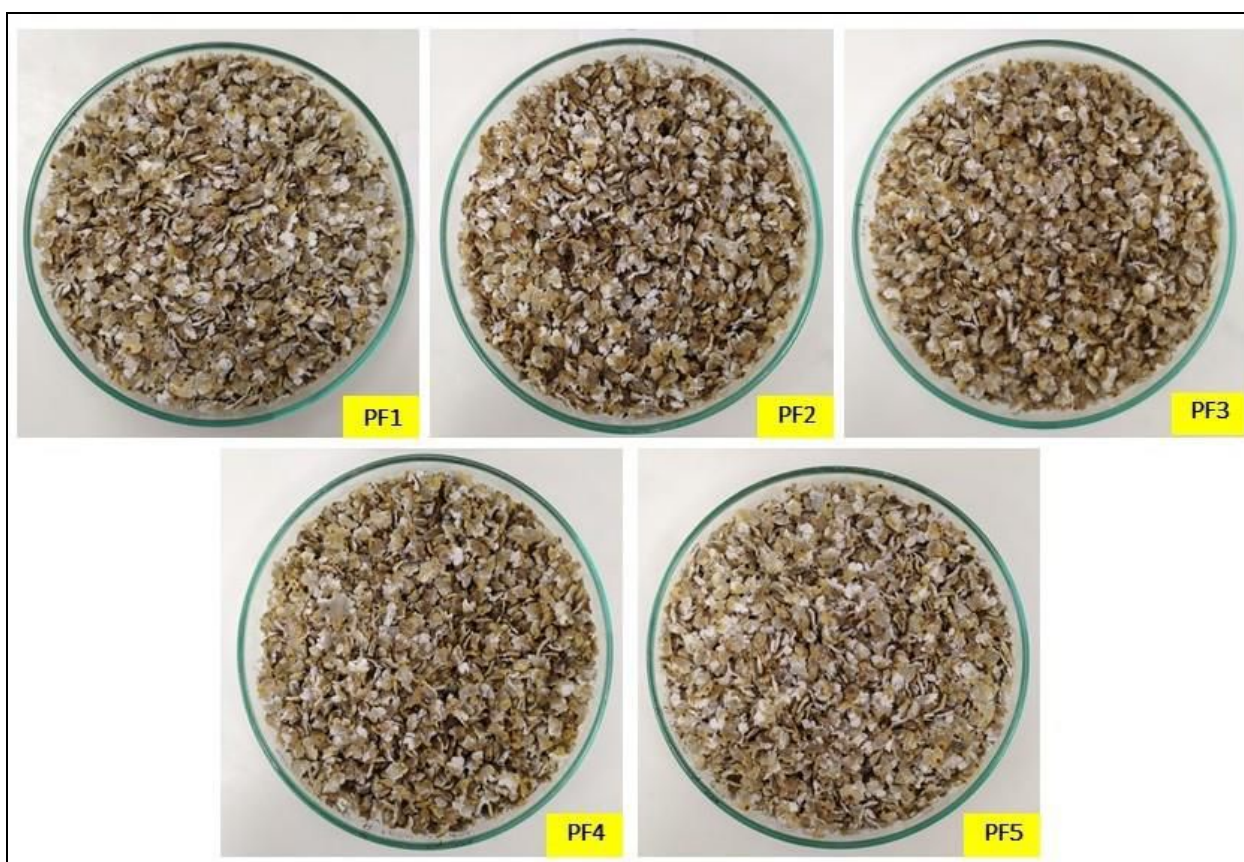
Sample	WAC (%)	OAC (%)	WSI
PF1	150.87±1.47 ^{abc}	102.67±1.53 ^{abc}	5.47±0.15 ^{bc}
PF2	143.58±1.75 ^c	97.33±2.52 ^c	5.27±0.21 ^{cd}
PF3	148.82±3.69 ^{bc}	100.33±2.08 ^{bc}	5.00±0.10 ^d
PF4	157.80±3.98 ^a	110.00±4.00 ^a	6.13±0.15 ^a
PF5	151.56±2.79 ^{ab}	106.00±3.00 ^{ab}	5.73±0.15 ^{ab}

Values are mean ± standard deviation (n = 3). Different superscript letters within the same column indicate significant differences at $p < 0.05$.

Table 5: Sensory Properties of Pearl Millet Flakes

Sample	Appearance	Aroma	Texture	Taste	Overall
PF1	6.08±0.52 ^a	6.17±0.39 ^a	6.92±0.29 ^{ab}	6.67±0.49 ^{ab}	6.67±0.49 ^a
PF2	5.33±0.78 ^{ab}	5.75±1.06 ^b	6.75±0.97 ^{ab}	6.17±0.72 ^b	5.67±0.89 ^c
PF3	5.08±1.00 ^b	5.92±0.90 ^b	6.17±0.72 ^b	6.50±0.80 ^{ab}	5.83±0.72 ^{bc}
PF4	6.17±0.72 ^a	6.33±0.99 ^a	7.17±0.72 ^a	7.00±0.85 ^a	6.83±0.72 ^a
PF5	6.00±0.85 ^a	6.08±0.67 ^a	6.92±0.79 ^{ab}	6.75±0.62 ^{ab}	6.50±0.52 ^{ab}

Values are mean ± standard deviation (n = 12). Different superscript letters within the same column indicate significant differences at $p < 0.05$.

**Fig 1:** Process flow chart from pearl millet to flakes

PF1-Flakes prepared from fresh pearl millet, PF2-Flakes prepared from pearl millet stored at 30 °C (For 8 months), PF3-Flakes prepared pearl millet stored under refrigerated condition 4±1 °C (For 8 months), PF4-Flakes prepared from Pearl Millet subjected to Short Soaking Tempering method, PF5-Flakes prepared from thermosonication pretreated pearl millet.

Fig 2: Pearl millet flakes prepared from grains subjected to different treatments.

Conclusion

The present study clearly demonstrates that aging significantly impacts the engineering, functional, and sensory qualities of pearl millet products. Notably, the quality of pearl millet deteriorates during storage. The non-hydrothermal treated samples showed a significant reduction in flake yield, broken %, lower expansion ratio, reduced functional properties, and reduced sensory acceptability. Hydrothermal pretreated samples mitigate these adverse effects by improving pearl millet plasticity, hydration characteristics, starch gelatinization, and starch-protein interactions, which help improve engineering, functional, and sensory properties. Sensory attributes such as texture, taste, and overall acceptability of the flakes were also better in pretreated pearl millet. Among the evaluated treatment conditions, short soaking tempering treatment had the most effective results, offering superior products, being economical, suitable for large scale production, and easily applicable to existing processing lines. These findings suggest that pearl millet with pretreatment is very effective, and quality loss is minimally noted. Further, research could be carried out for various millets to know its effect and also various pretreatment methods could also be tried to know the quality characteristics of millet products. Overall, the findings highlight the importance of pretreatment approaches to enhance the quality of pearl millet and produce high-quality consumer acceptable ready to cook flakes, thereby helping farmers commercialize pearl millet-based products with high market value.

Acknowledgements

The authors greatly acknowledge the support of the National Institute of Food Technology, Entrepreneurship and Management, Thanjavur, India, for providing the research facilities necessary to carry out this study.

Funding Sources

The author(s) received no financial support for the research, authorship and/or publication of this article.

Conflict of Interest

The author(s) do not have any conflict of interest

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to Reproduce Material from Other Sources

Not Applicable

Author Contributions

- **Sanjay Vinayak Hegde:** Conceptualization, Development or design of methodology, Conducting

the experiments, Acquisition of data, Analysis and interpretation of data, Writing the original draft

- **Dakshayani. R:** Analysis and interpretation of data, Writing the original draft, Review and edit the draft
- **R. Jagan Mohan:** Conceptualization, Development or design of methodology, Review and edit the draft, Supervision, Project administration

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