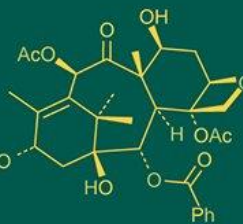
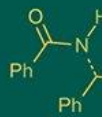


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Sanjay Vinayak Hegde
Ph.D. Research Scholar,
Department of Food Process
Technology, National Institute
of Food Technology,
Entrepreneurship and
Management, Thanjavur,
Tamil Nadu, India

Dakshayani R
Senior Research Fellow,
National Institute of Food
Technology, Entrepreneurship
and Management, Thanjavur,
Tamil Nadu, India

Dr. R Jagan Mohan
Professor and Dean Students
Welfare, Department of Food
Process Technology, National
Institute of Food Technology,
Entrepreneurship and
Management, Thanjavur,
Tamil Nadu, India

Corresponding Author:
Dr. R Jagan Mohan
Professor and Dean Students
Welfare, Department of Food
Process Technology, National
Institute of Food Technology,
Entrepreneurship and
Management, Thanjavur,
Tamil Nadu, India

Influence of storage temperature and low-temperature hydrothermal treatments on the functional, physical and sensory properties of pearl millet pops

Sanjay Vinayak Hegde, Dakshayani R and R Jagan Mohan

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Abstract

Millet is a nutrient-dense, climate-resilient crop attaining greater importance in sustainable food production and value chain of ready-to-eat products. There are very few studies focusing on storage and pre-treatment effect on millets. Thus, this study focused on assessing the effect of storage conditions and pre-treatments given to enhance pearl millet shelf life on ready-to-eat food products (pops). Then the quality characteristics, physical quality and sensory attributes of pearl millet pops were further evaluated to know the effect of storage and pre-treatment of pearl millet on product development. The pearl millet samples were stored for 8 months under ambient conditions at 30 °C and refrigerated conditions at 4 ± 1 °C. Two hydrothermal pre-treatment conditions (short soaking tempering method and thermosonication) were employed, and the grains were conditioned to a uniform moisture content prior to popping. Significant differences were observed among the treatments ($p < 0.050$). Fresh pearl millet exhibited excellent popping yield, expansion, and lowest bulk density, indicating optimal starch integrity and moisture distribution. The ambient temperature of 30 °C observed storage induced hardening and moisture loss, while refrigerated storage had a comparatively lower yield %. Hydrothermal treatments exhibited partial starch gelatinization and resulted in poor pops with respect to quality and sensory attributes. Overall, the popping quality was found to be good in fresh compared to stored and hydrothermal treated. Thus, the study concluded that popping quality was more sensitive to pre-treatments than storage, emphasizing the need to preserve native starch structures.

Keywords: Pearl millet, popping yield, expansion ratio, storage, pre-treatments

Introduction

Millet are tiny seeds belonging to the Poaceae/Gramineae family and is unique among cereal grains with remarkable nutritional value. Since ancient period, millets have been a staple food crops in the Indian diet owing to their nutritional characteristics, and they are remarkably known for their growth in areas of availability of limited water resource in shorter time [1]. They are drought resistant crops, which could be stored for long periods of time without insect damage and mark its importance at the time of famine. The Year 2023 has been observed as International Year of Millet by the United Nations Food and Agriculture Organization (UNFAO) and year 2018 was declared as Year of Millets in India. Lifestyle changes, pandemic situations, eating patterns, malnutrition and healthy food consumption awareness shifted people to move towards healthy alternatives and sustainable food sources ended up in millets as one among sustainable healthy alternative [2]. Pearl millet being one among millet crops, has regained interest owing to its nutrient profile and health benefits. Pearl millet encompasses high carbohydrate, protein, dietary fiber, zinc, Iron, magnesium, phosphorous, vitamin B content, gluten free with relatively low glycemic index [3]. Pearl millet has quality loss during storage owing to rancidity caused by fatty acids, peroxidase and lipase on spoilage and off-flavor generation during storage [4]. In addition pearl millets have antinutritional factors that prohibit absorption of nutrients from millet to be majorly addressed [5]. Thus, a study was made to know the changes (quality and sensory attributes) occurred during storage, pre-treatment of millet-based food product development. Ready to eat (RTE) food products are potential food products that have attained importance for their convenience and easy to carry options. Popping, being an age-old practice of easy-to-make snacks, that inactivates certain antinutritional factors, enhances protein carbohydrate

digestion with improved sensory attributes [6]. Thus, pearl millet popping was performed for stored and pre-treated (hydrothermal treatment-short soaking tempering method & thermosonication) pearl millet grains to know its effect in quality and sensory attributes during the storage and pre-treated samples.

Materials and Methods

The Fresh pearl millets were procured from a farmer at Vijayapura, Karnataka. The grains were cleaned, destoned and graded to remove physical hazards. The samples were then packed in polyethylene bags and stored at room temperature until further processing.

Storage of millets

Pearl millet was kept under two different storage conditions to study the influence of storage conditions on quality deterioration during storage. Fresh pearl millet (PP1) served as the control, while in the second condition, pearl millet was subjected to natural aging by maintaining a storage temperature of 30 °C for 8 months (PP2). In the third condition, pearl millet was kept under refrigerated conditions (4 ± 1 °C) to demonstrate slow aging (PP3) for 8 months. These conditions were selected to investigate the influence of temperature on the storage of pearl millet.

Pre-processing of pearl millet

Various pre-treatments are employed on millets to enhance their quality, after that is crucial to examine their impact on product development, as this determines how a product reaches the end user. Therefore, the effects of optimized pre-treatments on product development were investigated, with pearl millet undergoing hydrothermal treatment, short

soaking-tempering (PP4), and thermosonication (PP5) methods. The optimized short soaking-tempering treatment was performed by soaking pearl millet at 75 °C for 30 min, followed by tempering of pearl millet at 30 °C for 2 h. In addition, the pre-treated sample was tray-dried at 40 °C to obtain the desired moisture content (10%). In the thermosonication method, the optimized sonication conditions were an amplitude (100%), time (30 minutes), sonication (pulse mode (5 s ON, 5 s OFF)), and temperature of 60 °C. The grains were then separated and tray dried at 40 °C to obtain the desired moisture content (10%). Quality traits were analyzed for all the stored and pre-treated samples after food product development (Pearl Millet Pops) as illustrated in Figure 1, to determine whether storage and pre-treatment had any significant effect on product quality.

Pearl millet pops

A known quantity of conditioned pearl millet grains was brought to a moisture content of 16% for all stored and pre-treated grains by adding water and tempering for 6 h in a closed environment. The tempered grains were subjected to popping by high temperature short time method (HTST) in popping machine at 230 ± 5 °C and then evaluated for quality characteristics as similar to the method by [7] with slight modification.

Estimating quality evaluation of popped pearl millet

Popping yield (%): The popping yield was calculated for all five samples by method adopted from [6]. Popping yield was determined with 20 grams of sample by measuring the ratio of total weight of popped pearl millet grain to the sum of total weight of popped and un-popped pearl millet grain as given below

$$\text{Popping Yield (\%)} = \frac{(\text{Total weight of millet popped})}{(\text{Total Popped Millet weight} + \text{Weight of Un-popped millet weight})} \times 100 \quad (1)$$

Puffing index: The puffing index was estimated by adopting method described in [8] with slight modification evaluated with 10 grams of sample. It is the ratio of bulk density of un-popped pearl millet to the popped pearl millet grain and expressed as shown below

$$\text{Puffing Index} = \frac{(\text{Bulk density of raw pearl millet})}{(\text{Bulk Density of popped Pearl millet})} \quad (2)$$

Expansion ratio: It was determined using the method described in [9]. Around 25 grams of raw pearl millet and popped pearl millet was measured for its size in breadth at maximum expansion and are expressed as given below.

$$\text{Expansion ratio} = \frac{\text{Breadth of Popped pearl millet}}{\text{Breadth of raw pearl millet}} \quad (3)$$

Thousand pops weight: Thousand pearl millet pops were randomly selected and weighed using electronic balance having the accuracy 0.01 mg accuracy, following the method described in [10].

Bulk density: Pearl millet pops were measured by method adopted from [9] with minor modification. Around 10 g volume of pops were measured by graduated measuring cylinder, calculated and expressed as kg/m³

$$\text{Bulk Density (kg/m}^3\text{)} = \frac{\text{Weight of popped pearl millet (kg)}}{\text{Volume of popped pearl millet (m}^3\text{)}} \quad (4)$$

Size: The size comprises of length, breadth and length/breadth ratio of the pearl millet pops were measured using vernier clippers. The values were expressed as means of 10 randomly selected pops in mm. [11]

Sensory evaluation

The pearl millet pops were to sensory evaluated by 25 semi-trained panellists at School of Sensory Science Laboratory, NIFTEM-Thanjavur. The assessment was carried out by nine-point hedonic rating scale adopted from [12] rating indicate “like extremely” to “dislike extremely” with attributes such as appearance, texture, taste, flavour, and overall acceptability. Each panel members was given the necessary privacy to prevent biased assessment and errors.

Statistical analysis

Statistical analysis was performed using Mini Tab version 16.0 along with one way Analysis of Variance (ANOVA) to estimate the significant difference between the storage and treatment conditions ($p \leq 0.05$). All datasets are presented in tables as mean ± standard deviation. The sensory data were compiled using Fizz Software.

Results and Discussion

Quality characteristics of pearl millet pops

The pearl millet pops prepared from PP1, PP2, PP3, PP4 and PP5 samples to understand the effect of storage and pre-treatment influence on the quality characteristics of product are given in table 1 and figure 2. The popping yield of the pearl millet was found to vary among the treatments (*i.e.* $p < 0.05$). The pearl millet pops were found to have popping yield, puffing index and expansion ratio in the range of 3.56 ± 0.50 to 61.62 ± 0.91 , 3.49 ± 0.01 to 5.60 ± 0.02 , 1.75 ± 0.09 to 3.00 ± 0.25 respectively. The PP1 showed higher popping yield, puffing index and expansion, as it was fresh millet. The spontaneous transition of internal kernel moisture content into steam at high temperature initiates pressure in the kernel results in rupture of the pericarp known as popping. Thus, the popping efficiency greatly depends on moisture and temperature. The ambient temperature stored grain thus had optimal moisture distribution and intact endosperm structure, which aided pressure building and starch expansion^[2].

The grain stored at 30 °C (PP2) was noted to have a slight but significant decrease in popping yield showed that storage duration had impacted starch retrogradation, protein cross linking and endosperm hardening by reduced moisture content result in low popping yield. This loss of moisture content could be owing to temperature increase as similarly reported by^[13] during pearl millet grain storage in okongo silo.

PP3 (refrigerated storage) had significant reduction in popping yield, than PP1 and PP2 but higher in comparison with PP4 and PP5 (*i.e.* Hydrothermal treatments). The PP3 showed reduction in popping yield may be owing to moderated free fatty acid formation under low temperature thereby preserve kernel integrity, that helps in withstanding internal pressure of the pearl millet grain during popping. This suggests that refrigeration delays storage-induced deformation in pearl millet kernel, resulting in expansion. Though the popping yield shows a decline, the other two parameters puffing index and expansion ratio remained closer to ambient temperature storage, confirming that expansion of those kernels that got popped not affected owing to storage conditions^[14]. This could be due to the intact nature of kernel that supports starch gelatinization and expansion ratio, where storage only influences the success rate of popping not the puffing and expansion ratio.

PP4 (Short soaking and tempering method) showed tremendous reduction in popping yield, expansion ratio and puffing index in comparison with all the treatments. During soaking and tempering method, the water penetrates into starch granules that could disrupt crystalline region promotes swelling and early gelatinization at moderate temperature^[15]. Although the pearl millet grains were tray-dried prior to popping to maintain uniformity in moisture content, the starch undergoes to starch retrogradation and forms denser and less elastic matrices. This makes the popping difficult, by superheating of internal moisture to build rigid pressure network among pre-gelatinized and retrograded starch network facilitating gradual vapor diffusion. This causes the internal steam pressure to dissipate prematurely rather than building explosive expansion. Further, high pearl millet exposure to moisture prior to popping suppressed the popping efficiency thereby weakened pressure buildup and altered starch properties as well.

PP5 (Thermosonicated) pearl millet grains showed improved popping yield, expansion ratio and puffing index in comparison with PP4, but declined results in all other treatments. This could be owing to cavitation effect of ultrasound that creates a micro-fissure effect in starch-protein matrices^[16]. This modified the structural integrity by starch modification owing to cavitation^[17] results in disruption of expansion ratio and puffing of pearl millet pops. The structural damage owing to cavitation reduced the pearl millet popping characteristics by retaining steam pressures. Thus, it could be said that the quality of pops various significantly with respect to pretreatments and are minimally affected by storage conditions.

Physical parameters of pearl millet pops

The physical properties such as 1000 pop weight, bulk volume and bulk density were presented in the table 2 and are in ranges between 10.82 ± 0.07 to 11.37 ± 0.08 , 51.83 ± 0.29 to 88.33 ± 1.53 and 128.73 ± 1.37 respectively. PP1 and PP3 showed low bulk density pre-treatments with enhanced bulk volumes representing superior expansion, representing good quality product^[9]. Reduction in density of the product is majorly associated with creation of a highly porous internal structure. As already discussed, popping occurs by rapid heating makes moisture to vaporise in pearl millet and upon cooling the stability of product changes and results in lower bulk density. Thus 1000 pearl millet pops weight represents indirectly these treatments had better popping effect.

PP4 showed higher density represents poor expansion of pearl millet kernels with limited pore formation. This could be owing to partial starch gelatinization and structural deformation prior to popping, results in reduced pore formation^[18]. The reduction in 1000 pop weight also supports the occurrence of incomplete popping, structural collapse and fragmentation rather than uniform expansion. whereas PP5 exhibited intermediate bulk density, 1000 pearl millet pop weight owing to partial effectiveness and starch-protein network integration during thermosonication cavitation effect^[19]. In general these variations in bulk density among the pre-treatments contribute to change in gelatinization dynamics, viscoelastic behaviour and the pearl millet popping stability. The storage conditions slight poses to exhibit changes that is minimal and could be studied further at various storage and packaging conditions.

Dimensional properties of pearl millet pops

The dimensional properties such as length, width and Length/breadth ratio of pearl millet pops reflect the expansion and uniformity of popped grains. Those were in the range of 4.49 ± 0.28 to 7.29 ± 1.07 mm, 4.47 ± 0.24 to 8.09 ± 0.66 mm and 0.81 ± 0.05 to 1.01 ± 0.09 as mentioned in table 3. The stored and pre-treated popped pearl millet showed significant difference among the dimensional properties. PP1 showed greater width representing efficient radial expansion owing to uniform internal steam pressure and optimal starch plasticization. The hydrothermal treatments PP4 and PP5 had adverse effect and found to have smaller popped pearl millet dimensions, representing restricted puffing. This is owing to hydration that reduced starch integrity, making the endosperm rigid and the pearl millet pops brittle, reducing dimensional growth. The L/B ratio found to be similar for PP1, PP2 and PP3 indicates the spherical expansion, a desired characteristics of well-puffed

cereal grains [20]. The variation in PP4 suggests irregular deformation by inadequate internal pressure in the pearl millet pops during popping.

Sensory evaluation

The popped grains were subjected to sensory evaluation by semi-trained panellist using nine-point hedonic scale rating test at NIFTEM-T and the sensory attributes scores were mentioned in table 4. PP1 showed highest overall acceptability score of 8.17 ± 0.39 and the other stored samples PP2 & PP3 were in like extremely zone of the hedonic scale rating. This demonstrates that storage of pearl millet at different conditions doesn't have an impact on sensory quality of the popped kernel. PP4 was found to have the least score of overall acceptability in the scale of dislike owing to its texture. The high bulk density also represents indirectly the hard mouthfeel and low crispness that reduces PP4 acceptability by consumer. PP5 was showed moderate acceptability score of like scale, representing Thermosonication enhanced texture relative to hydrothermal soaking but doesn't restore optimal puffing characteristics. The other attributes were also found to record a similar pattern for appearance, aroma, texture, taste respectively.

Table 1: Quality characteristics of pearl millet pops prepared from differently treated grains

Sample	Popping yield (%)	Puffing index	Expansion ratio
PP1	61.62 ± 0.91^a	5.58 ± 0.06^a	3.00 ± 0.25^a
PP2	58.29 ± 1.34^b	5.39 ± 0.00^b	2.69 ± 0.18^{ab}
PP3	50.32 ± 1.11^c	5.60 ± 0.02^a	2.97 ± 0.37^a
PP4	3.56 ± 0.50^c	3.49 ± 0.01^d	1.75 ± 0.09^c
PP5	17.60 ± 0.71^d	4.37 ± 0.00^c	2.19 ± 0.09^{bc}

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

Table 2: Physical characteristics of pearl millet pops

Sample	1000 pop wt (g)	Bulk Volume (ml)	Bulk Density (kg/m ³)
PP1	11.37 ± 0.08^a	88.33 ± 1.53^a	128.73 ± 1.37^e
PP2	11.08 ± 0.08^b	79.50 ± 0.50^b	139.37 ± 0.13^c
PP3	11.35 ± 0.09^a	86.33 ± 0.58^a	131.51 ± 0.42^d
PP4	10.82 ± 0.07^c	51.83 ± 0.29^d	208.81 ± 0.58^a
PP5	11.09 ± 0.08^b	66.50 ± 0.50^c	166.77 ± 0.18^b

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

Table 3: Dimensional attributes of pearl millet pops

Sample	Length (mm)	Width (mm)	L/B ratio
PP1	7.29 ± 1.07	8.09 ± 0.66^a	0.90 ± 0.06
PP2	6.42 ± 2.30	6.98 ± 0.48^{ab}	0.93 ± 0.38
PP3	6.37 ± 1.16	7.80 ± 0.98^a	0.81 ± 0.05
PP4	4.49 ± 0.28	4.47 ± 0.24^c	1.01 ± 0.09
PP5	4.59 ± 0.66	5.62 ± 0.23^{bc}	0.82 ± 0.12

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

Table 4: Sensory properties of pearl millet pops

Sample	Appearance	Aroma	Texture	Taste	Overall
PP1	8.17 ± 0.39^a	7.50 ± 0.52^a	8.17 ± 0.39^a	8.00 ± 0.43^a	8.17 ± 0.39^a
PP2	7.42 ± 0.67^a	6.83 ± 0.84^a	7.25 ± 0.62^b	7.17 ± 0.84^a	7.08 ± 0.79^b
PP3	8.00 ± 0.74^a	7.25 ± 0.75^a	7.92 ± 0.90^{ab}	7.83 ± 0.72^a	7.58 ± 0.79^{ab}
PP4	4.58 ± 0.90^c	5.75 ± 0.97^b	4.75 ± 0.75^d	5.00 ± 0.95^c	4.83 ± 0.72^d
PP5	6.08 ± 0.79^b	6.92 ± 0.79^a	6.25 ± 0.75^c	6.00 ± 0.74^b	6.17 ± 0.72^c

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

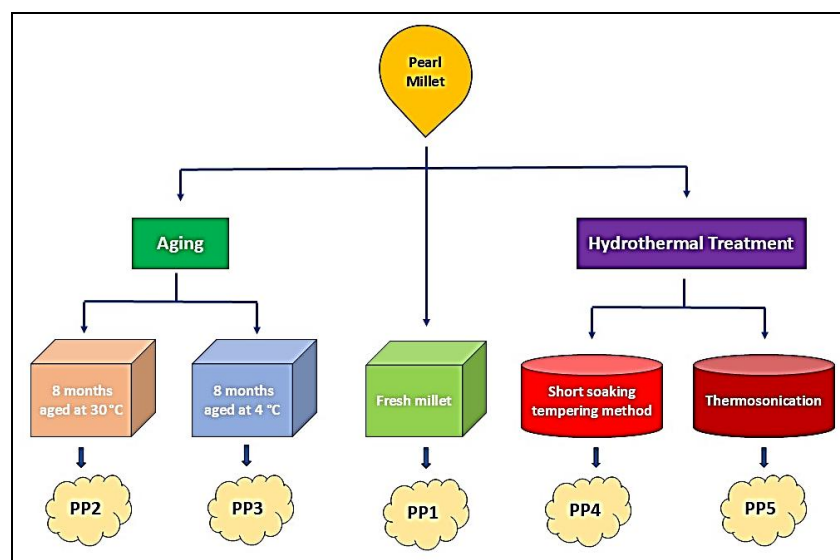
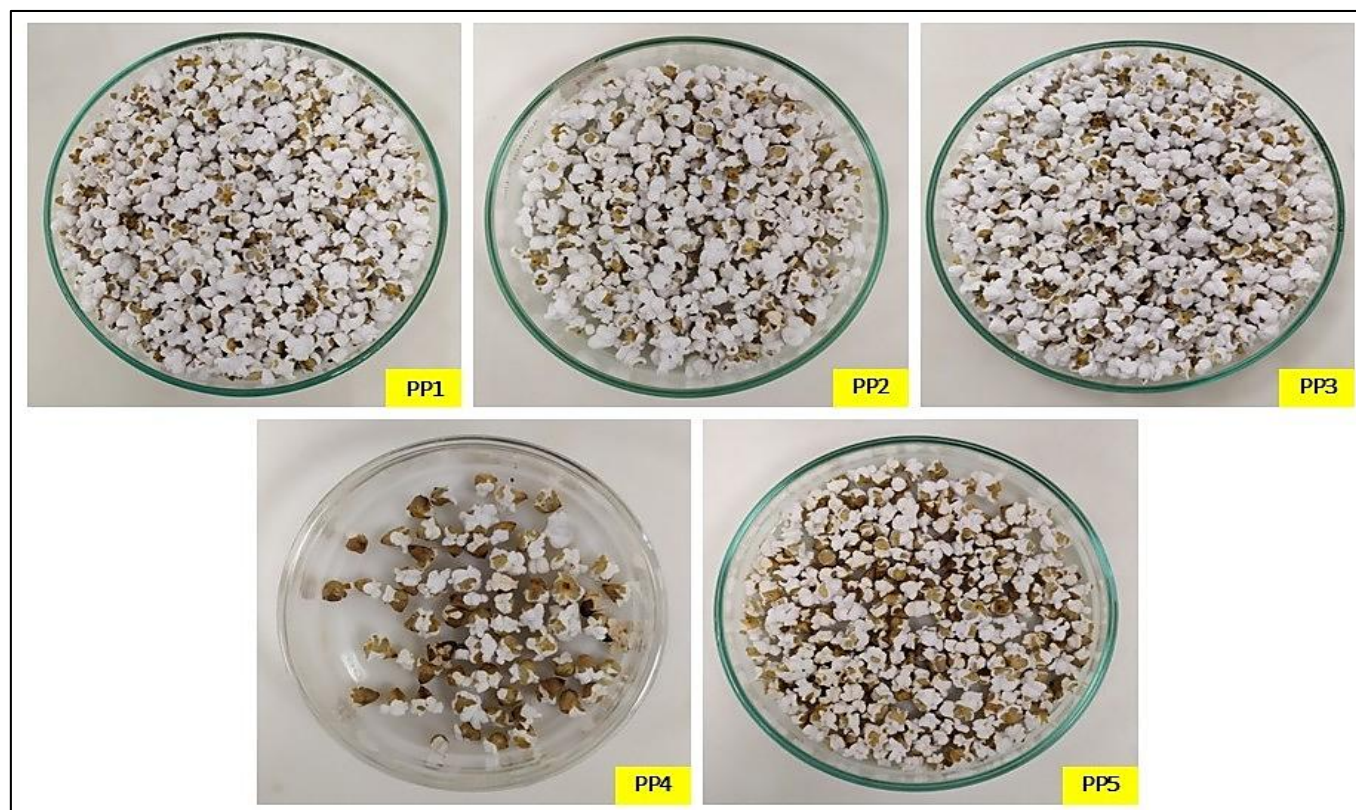


Fig 1: Process flow chart from pearl millet to pops



PP1 – Pops prepared from freshly harvested pearl millet, PP2 – Pops prepared from pearl millet stored at 30 °C for 8 months, PP3 – Pops prepared from pearl millet stored under refrigerated condition (4 ± 1 °C) for 8 months, PP4 – Pops prepared from pearl millet subjected to short soaking tempering method prior to popping, PP5 – Pops prepared from thermosonication pretreated pearl millet prior to popping

Fig 2: Pearl millet pops prepared from different treatments.

Conclusion

The present investigation clearly demonstrates the effect of pearl millet storage and pre-treatment on the quality of developed pearl millet pops. Among all the conditions, fresh pearl millet PP1 was found suitable for pearl millet pops-based products compared to all other conditions. PP1 exhibited superior popping yield, puffing index, expansion ratio, bulk density, dimensional uniformity, and sensory acceptability by consumers. Refrigerated storage PP3 resulted in moderate loss in yield %, bulk density, and puffing index, suggesting that storage primarily affects the proportion of kernels that pop rather than the expansion behavior of successfully popped grains. PP2 exhibited a slight decline in the quality characteristics of popped grains owing to storage conditions. The pre-treatments PP4 and PP5 led to pregelatinization of starch, which had an impact on product quality characteristics. Overall, the study concludes that although pearl millet pops had minimal impact by storage conditions, the fresher the grain, the better the quality, and they have high sensitivity to hydrothermal pre-treatments. In popping of grains, maintaining the native starch structure and balancing the moisture content of the grain are important parameters to be considered to obtain a product with superior quality and consumer acceptance. These findings provide valuable insights into processing and storage strategies aimed at developing high-quality pearl millet pops.

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