ORIGINAL RESEARCH ARTICLE

Effect of pressure and moisture content on physicochemical properties of popped finger millet (*Eleusine coracana*)

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ABSTRACT

Finger millet (*Eleusine coracana*) is a nutritious grain whose traditional processing methods have received inadequate application in modern processing to enhance its commercialization. This study investigated how pressure and moisture content affected the puffing yield, density, expansion ratio, colour, proximate composition, selected minerals and antinutritive factors of popped finger millet *grain*. Grains were equilibrated at 15,18, or 21% moisture content and popped at 120, 140, or 160 psi. The results show that progressively raising the moisture content and pressure significantly ($p \leq 0.05$) increased the popping yield and expansion ratio while reducing density. Pressure and moisture content interactions significantly ($p \leq 0.05$) influenced the popping yield, expansion ratio and density. Popped grain lightness and total colour difference significantly ($p \leq 0.05$) increased when the moisture content was increased from 15% to 21 %. The redness and browning index were significantly ($p \leq 0.05$) reduced when the moisture content and pressure were progressively raised from 15% to 21% and 120 psi to 160 psi respectively. Progressive increase of pressure and moisture content, and their synergistic interactions significantly ($p \leq 0.05$) reduced the crude fat and moisture contents of popped grain. Moreover, crude protein significantly ($p \leq 0.05$) improved when pressure was increased. Zinc and iron and total phenol contents significantly ($p \leq 0.05$) increased when the popping pressures and moisture content were progressively raised from 120 psi to 160 psi, and 15% to 21% respectively. Phytates content declined significantly ($p \leq 0.05$) when pressure was increased from 120psi to 140 psi or 160psi.Tannins significantly reduced ($p \leq 0.05$) when the moisture content was raised from 15% to 21 %. These findings demonstrate that popping finger millet can improve its nutritional value making it a viable avenue for value addition.

Key words: Popped finger millet, Pressure, Moisture content, Physico-chemical properties.

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1.0 Introduction

Finger millet (*Eleusine Coracana*) is an annual small-seeded cereal crop belonging to the *Poaceae* family of the monocotyledon group, mostly grown for its grain that is used for food and brewing (Shonisani Eugenia Ramashia *et al.*, 2019). Its origin can be traced to Ethiopia and is now produced in most parts of the world including Kenya. It can grow in varied agro-climatic conditions and performs better than wheat and rice for its ability to grow in drylands (Chandra *et al.*, 2016). Traditionally, it has been a staple food in most African and Asian diets, consumed as a non-alcoholic beverage (porridge), stiff porridge (*ugali*), local brew (*busaa*), and flatbread. It is the fourth most important millet after sorghum, pearl, and foxtail millet (Shonisani Eugenia Ramashia *et al.*, 2019).

Finger millet contains nutrients such as carbohydrates (59%), protein (7.3%), Ash (3.0%), Fat (1.3%), total dietary fiber (19.1%), Calcium (344mg/100g), and potassium (443 mg/100g), among others. It can contribute to the United Nation's resolution to end all forms of malnutrition by the year 2030 (Kumar *et al.*, 2018). Furthermore, its remarkably high polyphenol and dietary fiber content have been associated with health benefits such as antimutagenic, antioxidative, and anti-glycemic activities (Devi *et al.*, 2014).

Finger millet has received relatively less attention from the research community as compared to other major cereal staple crops such as maize, wheat and rice. Its worldwide production and commercialization remain low, accounting for 0.13% of all the cereals produced. In developed nations, finger millet is primarily used as animal while in developing countries, it serves as a staple food for humans and is often considered as a "poor man's food"(Maharajan *et al.*, 2021). Nevertheless, it is an important source of sustenance in most marginalized areas such as the arid and semi-arid areas.

The incorporation of finger millet in food products can increase the nutrient content, improve palatability and reduce the glycemic index of the products. The bulky fibers and slow digestion rates provide prolonged satiety and reduced calorie intake(Shobana *et al.,* 2013). These features make it suitable for feeding the elderly, convalescents and invalids. Cereal snack bars are prepared from multiple ingredients including cereals, fruit, nuts and sugars, and have a long shelf-life of 6-12 months. They offer a fast, convenient food source that requires no preparation, have a long shelf life and requires no refrigeration (*Sohan et al.,* 2021).

Over the years, various researchers have studied the possibilities of developing finger millet-based foods to promote their consumption in urban areas, focusing on composite flours and extruded products (Ramashia *et al.*, 2019). Furthermore, its realization as a neglected crop is currently drawing attention as it can alleviate hunger and food shortages in developing countries. Accordingly, the various processing methods aim to reduce antinutritional factors such as phytic acid and increase zinc and iron bioavailability(Saleh *et al.*, 2013). Popping, fermentation, cooking, milling, malting germination, roasting, and extrusion have been performed to improve nutritional quality, improve starch digestibility, preserve, soften,

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improve functionality, improve sensory quality, and reduce antinutritive factors of finger millet products (Ramashia *et al*., 2019).

Popping or puffing is a traditional processing method that is used to prepare expanded cereals and grain legumes resulting in shelf-stable and crunchy products used as ready-to-eat convenience foods. It is performed by conditioning the grains through defined moisture addition followed by tempering to defined conditions and exposure to high-temperature short time (HTST) conditions to result in grain explosion and subsequent expansion. The popped products have improved aroma, taste, starch digestibility and solubility, reduced antinutritive factors, and can be consumed directly or used to make enriched snack bars and composite flours (Ramashia *et al*., 2019; Saleh *et al*., 2013) There is a need for further scientific application of traditional processing methods in modern processing methods to enhance the commercialization of the finger millet grain (Ramashia *et al*., 2019).

A current review of literature indicates that significant strides have been achieved in the nutritional analysis, characterization and value addition of the finger millet grains. Hence, Chandra *et al*. (2016) recommends further exploration of adding value to finger millet for consumers to realize more benefits. Therefore, this study aimed to assess the influence of pressure and moisture conditions on selected physico-chemical properties of popped-finger millet grains.

2.0 Materials and methods

2.1 Preparation of popped finger millet grain

Finger millet grains were purchased from Jamhuri market in Thika Town and transported to the JKUAT food processing unit. It was then cleaned, dried sorted for best quality. The initial moisture content of the finger millet grains was determined using AOAC 2000 method as described by Momanyi et al. (2020) The samples were raised to 15%,18%, or 21% moisture by adding predetermined amounts of water followed by confirmatory moisture content tests. Triplicate 200g samples were weighed for each level and popped in an enclosed puffing chamber (Delostlewis *et al*., 1992). The puffing chamber was pre-heated and charged with the sample. Its temperature and pressure were allowed to equilibrate for 2 minutes or until a pressure of 60 psi was attained. Heating continued to raise the internal pressure to 120, 140, and 160 psi and discontinued once the desired pressure was attained. The chamber was pointed to a bin and the popped grains were discharged, collected, cooled, and packed in airtight zip-lock bags then kept at room temperature until subsequent analyses. Popped finger millet flour was prepared by pulsing in a grinder (Omniblend I TM.767, Japan) for 60 seconds followed by passing through a 1 mm sieve, packing in airtight HDPE pouches, and storing in a cool and dry place awaiting analysis.

2.2 Determination of popped yield, expansion ratio and density

The popped yield was established using the method described by Sharma *et al.*, (2014) with slight modifications. Popped finger millet grains were separated from unpopped grains and weighed. The popped yield was then obtained using the formula:

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$$Popped\ yield = \frac{Popped\ grain\ weight\ (g)}{Total\ discharged\ grain(g)} \times 100$$

The expansion ratio was determined according to the method described by Sharma *et al.,*(2014)with slight modifications. Popped grains were filled up to the 100 ml mark in a 100 ml cylinder and weighed. The volume of unpopped grain (in ml) of equal weight (in grams) for the sample was then determined. An average of three measurements were taken and the expansion volume was calculated as:

$$Expansionratio = \frac{100\ mlofpoppedgrain}{Volumeofequalweightofunpuffedgrain}$$

The density of popped grain was established using the method described by Delostlewis*et al.* (1992).A 100 ml beaker was filled to the 100 ml mark with popped grain and weighed and density was computed using the formula:

$$Density = \frac{Mass\ of\ known\ volume\ of\ grain}{Known\ volume\ ofpopped\ grain}$$

2.3 Determination of colour

Colour was quantified with a method described by Patharee*t al*. (2012). A hunter color difference meter was calibrated using a standard white plate (L=98.5, a= 0.1, b=4.9) and used to read the L*, a*, and b* values of the popped and unpopped finger millet samples directly. Values were displayed on the color meter screen as L* for lightness/darkness (100 for perfect lightness, 0 for black), a* for chromaticity from red (+) to green (-) axis, and b* for chromaticity from yellow (+) to blue axis (-). The measurements were done in triplicate at different positions of the sample. The procedure was repeated to get three values that were averaged. The values were then tabulated and used to calculate hue angle, Chroma values (purity), and total color difference.

The colour purity, expressed as chroma (c) was obtained using the formula $(a^{*2} + b^{*2})^{0.5,}$ and the hue angle was determined using $\tan^{-1}(b^*/a^*)$. If a* > 0 and b* > 0, then $h^o = \tan^{-1}(b^* / a^*)$; if a* < 0 and b* > 0, then $h^o = \tan^{-1}(b^* / a^*)] + 180$; if a* > 0 and b* < 0, then $h^o = \tan^{-1}(b^* / a^*)] + 360$. The total colour difference ΔE was determined using the formula $[(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2]^{0.5}$(Bolade et al., 2009)

L* =value (0 = black=high value, 100 = white)

The browning index (*BI*) was determined using the formula below which was adapted from Dharshini & Meera (2023)

$$BI = 100 \times (x - 0.31)/0.17$$

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$$x = \frac{(a * + 1.75L *)}{5.645 + a * - 0.3012b *)}$$

Where L*,a*, and b* represent lightness, redness, and yellowness respectively.

2.4 Determination of proximate composition

Proximate composition was performed according to the protocol outlined in the Association of Official Analytical Chemists (AOAC 2000) as outlined by Momanyi et al., (2020). The moisture content was determined using the oven-drying method. Crude ash was quantified gravimetrically using the incineration method in a muffle furnace. The crude fiber was determined by acid and base hydrolysis. Crude protein was quantified using the semi-micro-Kjeldahl method. Crude fat was quantified by Soxhlet extraction. The carbohydrate content was quantified by subtracting the sum of moisture, ash, protein, crude fiber, and crude fat content from 100%(Momanyi et al., 2020). All analyses were performed in triplicate.

2.5 Determination of Calcium, Iron, and Zinc

Mineral analysis was carried out by dry-ashing and atomic absorption spectrophotometer (AAS) (Shimadzu AA-7000), as per AOAC 2000 method (Momanyi et al., 2020). A clean and dry crucible was weighed. 2 grams of samples were then added into the crucible and charred on a hot plate in a fume hood, while slowly increasing the temperature until smoking ceased. The charred samples were incinerated in a muffle furnace set at 550°C for 5-18 hours. The ash was cooled in a desiccator and then transferred into a 100 ml volumetric flask, dissolved with 20 ml of 0.5 N HNO_3, and topped up to the mark with 0.5 N HNO_3. 1mlof lanthanum chloride solution was added to achieve 0.5% in the sample solution for Calcium determination. Insoluble matter was filtered and the filtrate kept in a labeled polyethylene bottle. The absorbance of the solutions was read by Atomic Absorption Spectrophotometer (AAS). Calcium, iron, and zinc absorbances were read at 422.7nm,248nm and 213nm, respectively. The various mineral standards were also prepared to make the calibration curve.

2.6 Determination of phytates, tannins, and total phenols

Phytates were determined by the HPLC technique described by Camire(1982). Approximately 0.5 g of sample was extracted using 10 mL of 3% sulphuric acid in triplicates. The contents were filtered and placed in a boiling water bath for 5 minutes and 3 mL of $FeCl_3$ solution was added. This was followed by heating for 45 minutes to completely precipitate the ferric-phytate complex. Centrifugation of the contents was carried out at 4500 rpm for ten minutes and then the supernatant was discarded. The resultant precipitate was washed using 30 ml distilled water then centrifuged, and the supernatant was disposed of. Into the residues, 3 mL of 1.5 N sodium hydroxide was added and topped up to 30 mL using distilled water. Heating was then performed for 30 minutes using a bath of boiling water for precipitation of the ferric hydroxide. The samples were cooled, centrifuged and the supernatant poured in a 50 mL volumetric flask. It was then micro-filtered and injected into the HPLC (Shimadzu

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Refractive Index Detector (RID- 6A) using 0.005 N sodium acetate mobile phase at a 0.5 µL/min flow rate.

The vanillin-hydrochloric acid technique was used to analyze condensed tannins (Price *et al*., 1978). Approximately 0.25 grams of the sample was extracted in triplicates with10ml of 4% hydrochloric acid in methanol by shaking for 20 minutes with a shaker and separation was performed using a centrifuge for 10 mins at 4,500 revolutions per minute at 25°C. The residue was subjected to a second extraction using 5 mL of 1% hydrochloric acid in methanol. The 2 supernatants were transferred into a 25ml volumetric flask and topped up to the mark with 1% hydrochloric acid in methanol. Catechin standards were prepared using catechin hydrate at concentrations of 0,10,20,40,60, 80, and 100 ppm. 1 mL of each sample was placed intoduplicate test tubes, one serving as the sample blank. 5 mL of vanillin-HCL reagent was reacted with both the samples and standard solutions and then permitted to rest for 20 minutes. 5 mL of 4% HCL in methanol was added into the sample blanks. All solutions' absorbance was read at 500 nm using a double-beam UV spectrophotometer. The tannin content was quantified from the standard calibration curve as mg/100g catechin equivalent (CE).

The Folin-Ciocalteu method as documented by Nino *et al*. (2021), with slight modifications was used to establish the total phenols. Polyphenol-containing samples produce a blue-colored complex due to the reduction by the Folin-Ciocalteu reagent. 1 g of sample was weighed into clean centrifuge tubes in triplicates. 25 ml of pure methanol was added and incubated at 25^{o}C in a dark place for 72 hours. The content was filtered using Whatman filter paper no. 1, then the filtrate was centrifuged at 13000g for 10 minutes. The supernatant was collected and microfiltered into clean test tubes. 2ml of 10% Folin-Ciocalteu reagent was added, vortexed, and 4 ml of saturated sodium carbonate added. It was then left to rest for 60 minutes in the dark. The standards for creating the calibration curve were prepared using methanolic gallic acid at 0,5,10,20,30,40,50,100, and 125 ppm and mixed with 2 ml of 10 % Folin–Ciocalteu reagent and 4 mL of saturated sodium carbonate and left to rest for 30 minutes at 25^{o}C. The absorbance for standards and samples was obtained using a UV Spectrophotometer at 765nm. The quantification of total phenol content was performed from the calibration curve, and the results were expressed as mg/100 g of gallic acid equivalent (Baba & Malik, 2015).

2.7 Statistical analysis

The results were expressed as mean values ±SD of 3 replicates using Microsoft Excel 2019.Analysis of variance (ANOVA)to detect statistical significance was performed in the Stata software version 13.0. Means separation to detect significant differences in each treatment was carried out using Bonferroni's method with statistically significant differences established at p≤0.05.

3.0 Results and discussions

3.1*Popped*yield, expansion ratio and density of popped finger millet

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The results for popped yield, expansion ratio and density are shown in Table 1. Pressure, moisture, and pressure-moisture interactions had a significant ($p \leq 0.05$) effect on the puffing yield. The puffing yield increased when the moisture content of the grain was increased from 15% to 21% at popping pressures of 140 psi and 160 psi. At 15% moisture content, water was not sufficient for the grains to achieve superheated steam which is the driving force for optimal grain puffing. At 18% and 21% moisture, the grains achieved relatively superheated steam which was sufficient for optimal puffing (Delostlewis et al., 1992). Similarly, the yield generally increased when the pressure was increased from 120 psi to 140 psi, or 160 psi. A drop in popping yield was observed when grain moisture was raised from 18% to 21% at 120 psi. This is because heating time was insufficient for the moisture in the grain to achieve superheated state that enable popping, as compared to lower moisture contents of 15% and 18%.

A similar inference was drawn in a study to establish the effect of hydration and pan-roasting pre-treatments on the puffing characteristics of the *ragi* (finger millet) variety 'MR1' (Bawa *et al.*, 2021). Water and buttermilk hydration improved puffing yield but water conditioning wasmore economical. Popping of conditioned pearl millet using heated sand at 250°C resulted ina yield of popped grains ranging from 8.3-77.1% (Saraswathi & Rs, 2022).

Table 1: Popping yield, density and expansion ratio of popped finger millet

Pressure (psi)	Moisture (%)	Puffing yield (%)	Density (g/cm^3)	Expansion ratio
120	15	25.03±2.05^{c}	0.21±0.01^{f}	3.34±0.15^{c}
	18	37.96±1.30^{d}	0.13±0.00^{ac}	5.51±0.09^{be}
	21	15.81±0.59^{e}	0.17±0.00^{cd}	4.21±0.04^{a}
140	15	43.85±1.67^{f}	0.18±0.01^{e}	3.82±0.21^{ac}
	18	61.15±0.58^{ab}	0.12±0.01^{ab}	5.79±0.37^{b}
	21	64.63±1.25^{a}	0.12±0.00^{ab}	5.04±0.09^{de}
160	15	57.03±2.58^{b}	0.16±0.01^{d}	4.43±0.35^{ad}
	18	62.82±0.63^{a}	0.11±0.01^{b}	6.19±0.06^{bf}
	21	78.16±013^{g}	0.13±0.00^{ac}	6.63±0.37^{f}
P values	Pressure	0.0000	0.0000	0.0000
	Moisture	0.0000	0.0000	0.0000
	Pressure-Moisture	0.0000	0.0019	0.0000

Values based on means ± SD of triplicate measurements. Mean values within the same column with different letters are significantly different ($P \leq 0.05$).

The expansion ratio in a grain is determined by the conversion of water to superheated steam and the difference in pressure between the vessel and the atmosphere (Singh *et al.*, 2007). A general increase in the expansion ratio was observed when the puffing vessel pressure increased from 120 psi to 160 psi with the lowest and highest being 3.34±0.15 and 6.63±0.37 at 120 psi and 160 psi, respectively (Table 1). Pressure, moisture, and pressure-moisture interactions had significant ($p \leq 0.05$) effects on the expansion ratio ($p \leq 0.05$).

The expansion ratio of popped finger millet increased when the moisture content of the grains was raised from 15% to18% at 120 psi and 140 psi and dropped when it was raised to

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21 %. At 160 psi, the expansion ratio increased when moisture content was progressively raised from 15% to 21%. A moisture content of 15% was inadequate for optimal expansion of the grain, whereas 21% moisture content was adequate, having produced the highest expansion ratio of 6.63±0.37 at 160 psi. Insufficient moisture generates insufficient steam pressure during heating (Taylor *et al*., 2012).

The results agree with previous studies that obtained expansion ratios within the range achieved. An increase in pressure and moisture yielded an increase in the expansion ratio because gelatinization increases and starch expands increasing the expansion ratio (Athmaselvi, 2019). An expanded decorticated finger millet product prepared at a high-temperature short-time treatment had an expansion ratio of 5.64 (Dharmaraj *et al*., 2012).Popping of conditioned pearl millet using heated sand at 250^{o}C resulted in an expansion ratio of 2.3 to 11.3% (Saraswathi &Hameed, 2022). The expansion ratio of grain is important in the food industry because it can help to predict the shelf life of grain-based products. For instance, highly expanded flour can absorb free water released during the staling of bread and maintain its softness for longer (Dharmaraj *et al*., 2012).The puffing index of wheat increased significantly when puffing pressure was increased from 690kPa to 1240kPa(Subramani *et al*., 2023).

The density of popped products may be influenced by process conditions such as grain moisture content before puffing. The popped grain densities ranged from 0.11±0.01 g/cm^3 to 0.18±0.01g/cm^3 (Table 1). There was a significant effect of pressure, moisture content, and their interaction on the density of popped finger millet ($p \leq 0.05$). The densities exhibited a generally decreasing trend when moisture content was increased from 15% to 18% or 21%, and pressure was increased from 120 psi to 140 psi or 160 psi. This can be attributed to popping producing highly expanded and less dense products (Delostlewis*et al*., 1992). The 18% and 21% moisture tempering produced mostly highly expanded and therefore lowest in density. Dharmaraj *et al*. (2012)obtained a density of 0.14 g/cm^3 after subjecting decorticated finger millet to a high-temperature short-time process. Farahnaky *et a*l. (2013) observed that a moisture content lower than 18% yielded higher popcorn density in their investigation on the effect of moisture content on density.

3.2 Color properties of the popped finger millet grain

Colour is an important characteristic of popped finger millet. Colour affects the appearance, acceptance and likely purchase of a product by consumers. Color changes during processing give data about the level of browning reactions such as Maillard reaction, caramelization, the degree of cooking and pigment deterioration during the cooking process (Athmaselvi, 2019). Upon heating, a Maillard reaction occurs and in this case, the sugars in the aleurone layer react with the amino acids in the millet grain(Saraswathi &Hameed , 2022) which changes the pigment of the popped product.

The colour properties of popped finger millet grain are indicated in Table 2. The finger millet grain was brown. Popped finger millet was relatively lighter because popping exposed the

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white endosperm that is white. The L* values obtained ranged from 65.2±2.59- 74.87±1.85, a* values 2.03±0.06 - 3.73±0.12, and b* values 6.97±2.14 -9.60±0.35.

Table 2: Colour properties of the popped finger millet grain

Pressure (psi)	Moisture (%)	L*	a*	b*	Chroma	Hue angle	Color difference	Browning index
120	15	65.23±2.71^{a}	3.73±0.12^{a}	8.17±1.15^{a}	8.97±0.98^{a}	65.13±3.52^{ac}	35.81±2.66^{a}	5.33±0.27^{c}
	18	70.17±1.50^{ab}	3.60±1.04^{a}	7.00±0.69^{a}	7.87±1.09^{a}	63.20±4.85^{c}	40.41±1.90^{ab}	5.36±0.02^{c}
	21	73.07±3.93^{ab}	3.00±1.21^{a}	6.97±2.14^{a}	7.53±2.37^{a}	67.27±2.71^{abc}	43.05±4.62^{ab}	4.87±0.01^{ce}
140	15	67.13±1.25^{ab}	2.60±0.75^{a}	8.00±0.52^{a}	8.40±0.70^{a}	74.23±1.23^{ab}	36.95±1.28^{ab}	3.58±0.39^{ab}
	18	70.67±4.65^{ab}	2.50±0.72^{a}	8.07±0.60^{a}	8.47±0.55^{a}	72.77±5.25^{abc}	39.98±3.92^{ab}	4.05±0.42^{ae}
	21	74.87±1.85^{b}	2.03±0.06^{a}	7.13±0.64^{a}	7.43±0.64^{a}	74.00±1.91^{ab}	44.82±1.81^{b}	2.90±0.07^{bd}
160	15	65.2±2.59^{a}	2.33±0.58^{a}	9.60±0.35^{a}	9.90±0.17^{a}	76.30±3.81^{b}	35.68±2.14^{a}	3.61±0.02ab
	18	67.83±3.58^{ab}	2.37±0.12^{a}	8.60±0.17^{a}	8.93±0.23^{a}	74.90±0.01^{ab}	38.24±3.01^{ab}	3.76±0.36^{a}
	21	70.83±2.15^{ab}	2.20±0.66^{a}	7.07±0.40^{a}	7.43±0.49^{a}	72.83±4.46^{abc}	40.56±2.10^{ab}	2.72±0.39^{d}
*P*value	Pressure	0.1290	0.0043	0.0776	0.3220	0.0000	0.2031	0.0315
	Moisture	0.0003	0.3176	0.0091	0.0114	0.6215	0.0004	0.0535
	Pressure. Moisture	0.9338	0.9581	0.4113	0.6344	0.5960	0.8406	0.9813

Values based on means ± SD of triplicate measurements. Mean values within the same column with different letters are significantly different (P≤0.05).

The effect of pressure was not significant (p>0.05) on the lightness of finger millet pops while that of moisture content was significant P≤0.05). Pressure and moisture content interaction was not significant (p>0.05) on the lightness of popped finger millet grain. The lightness generally increased when puffing moisture was raised from 15% to 18% or 21%. This is because, at 15%, the moisture did not generate enough steam for puffing to expose the endosperm as it escaped when the grains were discharged from the puffing chamber. On the other hand, at18% or 21% moisture content, sufficient superheated steam was generated, and it provided optimum explosion and exposure of the endosperm.

There were significant (p≤0.05) differences in the redness of finger millet puffs due to pressure, whereas moisture content and pressure-moisture content interactions had no significant (p>0.05) effects. When the pressure was increased from 120psi to 140 psi or 160 psi, the redness increased. Moisture content had a significant (p≤0.05) effect on the yellowness of puffs, whereas pressure and pressure-moisture content interactions had no significant effects. The yellowness generally decreased when moisture was increased from 15% to 18%or 21%.

The Hue angle represents the qualitative property of colour seen by the naked eye. It aids in differentiating particular colours and grey colour with the same luminance. Large hue angles indicate weak yellow components (Dharshini & Meera, 2023). 0^{o},90^{o},180^{o},and 270^{o} represent redness, yellowness, green-ness, and blueness respectively (Ramashia *et al.*, 2017). The hue angles ranged from 63.20±0.4.85^{o} to 76.30±3.81^{o}(Table 2). Pressure significantly affected the hue angle (p≤0.05) while moisture content and pressure-moisture content interactions had no significant effect. The total colour difference for popped finger millet grains ranged from 35.68±2.14 to 44.82±1.81 (Table 2). These are distinctive colour changes because they are greater than 3 (Dharshini & Meera, 2023).

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Chroma is the quantitative measure of colorfulness and measures how different a hue is from a grey colour of the same luminance (Pathare *et al*., 2012). The chroma values ranged from 7.43±0.49 to 9.90±0.17 (Table 2). Moisture content significantly affected the chroma values, while pressure and pressure moisture-content interactions had no significant effect ($p>0.05$). Similar results for lightness were observed in previous studies. In a study to investigate the effect of moisture content on colour of popcorn, Farahnaky*et al*. (2013) reported an increase in lightness when moisture content was increased from 10% to 12,14,16,18, or 20%. Colour of popped samples is largely affected by material volume and density. Higher volumes cause the inclusion of more air bubbles and a reduction of the percentage of sample surface covered by dry substance.

Browning index indicates non-enzymatic reactions in food due to protein and starch interactions and is obtained using colour changes during processing (Dharshini & Meera, 2023). The browning index of popped finger millet grain ranged from 2.72±0.39 to 5.36±0.02 (Table 2). When the lightness increased, the browning index dropped. There was a significant effect($p\leq0.05$) of pressure on the browning index of popped millet grain. Moisture and pressure-moisture interactions had no significant effect ($p>0.05$) on the browning index of popped finger millet grain. This could be attributed to the increased extent of Maillard and caramelization reactions when the puffing pressures and moisture content were raised. In a study to evaluate the influence of popping and milling on the chemical properties of finger millet, Dharshini & Meera (2023) obtained a browning index of 5.59±1.71 after popping finger millet grains on dry heat on an open pan and also observed a drop in browning index when lightness increased.

3.3 Proximate composition

The proximate composition of the popped finger millet is shown in Table 3. The moisture content of popped finger millet flour ranged from 6.06±0.04%to 7.98±0.02%. This is within the range for the effective flour storage(Oladunmoye *et al*., 2010). Low moisture content in popped grain and flour could be due to extreme dehydration during the puffing process as water is converted to steam and made to escape during expansion (Sreenatha *et al*., 2023). Puffing results in reduced moisture in the end product. The moisture content of 12-15.5% has been recommended for cereal flour storage, failure to which moisture absorption from the atmosphere can take place and lead to caking. The pressure and moisture content effect were significant ($p\leq0.05$). The moisture content of popped grain increased when the puffing moisture was raised from 15% to 18 % or 21% at constant pressure. A general decline in moisture content of popped grain was observed when the puffing pressure was increased from 120 psi to 140psi or 160 psi. This could be due to the extended time that is taken to raise the pressure to 140 psi or 160 psi and this gives more time for enhanced conversion of water to steam for subsequent expulsion when the grain is discharged from the puffing vessel.

Table 3: Proximate composition of thepopped finger millet (wb)

Pressure	Moisture	Proximate Composition

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(psi)	(%)	Moisture (%)	Crude fibre (%)	Crude ash (%)	Crude fat (%)	Crude protein (%)	Carbohydrates (%)
120	15	7.12±0.01^{a}	2.93±0.34^{a}	2.44±0.50^{a}	0.95±0.02^{e}	7.15±0.16^{b}	79.40±0.30^{ab}
	18	7.68±0.03^{b}	2.46±0.38^{a}	2.02±0.30^{a}	0.73±0.04^{ab}	8.27±0.96^{abc}	78.83±0.72^{ab}
	21	7.98±0.02^{c}	2.56±0.61^{a}	1.83±0.60^{a}	0.84±0.05^{c}	6.96±0.35^{b}	79.83±1.21^{b}
140	15	6.47±0.02^{d}	3.20±0.67^{a}	1.81±0.42^{a}	0.80±0.06^{ac}	9.15±0.19^{a}	78.55±0.69^{ab}
	18	7.02±0.01^{e}	3.40±0.45^{a}	2.35±0.14^{a}	0.77±0.01^{ac}	7.61±0.34^{bc}	78.85±0.84^{ab}
	21	7.77±0.05^{f}	3.37±0.23^{a}	2.46±0.36^{a}	0.71±0.01^{ab}	8.23±0.67^{abc}	78.45±0.63^{a}
160	15	6.06±0.04^{g}	3.52±0.18^{a}	2.84±0.93^{a}	0.65±0.04^{bd}	9.16±0.10^{a}	77.77±0.75^{ab}
	18	6.28±0.03^{h}	3.12±0.27^{a}	2.44±0.12^{a}	0.71±0.02^{ab}	8.96±0.07^{ac}	78.49±0.36^{ab}
	21	7.14±0.03^{a}	3.02±0.28^{a}	2.17±0.31^{a}	0.57±0.01^{d}	8.86±0.33^{ac}	78.22±0.81^{ab}
P value	Pressure	0.0000	0.0059	0.2341	0.000	0.0000	0.0059
	Moisture	0.0000	0.4073	0.6402	0.000	0.1075	0.8162
	Pressure. Moisture	0.0000	0.5446	0.1368	0.000	0.0012	0.0909

Values based on means ± SD of triplicate measurements. Mean values within the same column with different letters are significantly different ($p \leq 0.05$).

Crude protein content ranged between 6.96±0.35 and 9.16±0.10. Proteins in the diet provide cellular structures, promote movement and regulate body fluid balance. The effect of pressure and pressure-moisture interaction was significant ($p \leq 0.05$). A general increase in protein was observed when pressure was increased from 120 psi to 140 or 160 psi. This could be due to the progressive loss of moisture during popping that could have resulted in the rise of dry matter content in the grain and hence higher levels of detectable crude protein. No significant ($p > 0.05$) differences due to moisture content were observed.

Crude ash refers to the inorganic residue remaining after either ignition or complete oxidation of organic matter in a foodstuff. It is a measure of the total amount of minerals present within a food (Verma *et al*., 2022). In this study, crude ash content ranged between 1.81±0.42% and 2.84±0.93%. Pressure and moisture content had no significant effect ($p > 0.05$) on the crude ash content of popped finger millet.

Crude fat content ranged from 0.57±0.01% to 0.95±0.02%. The effect of pressure and moisture on crude fat was significant ($p \leq 0.05$). A general decline in crude fat was noted as the pressure was increased from 120 psi to 140 psi or 160 psi. This could be attributed to the interactions of lipids with other grain constituents such as protein and carbohydrates that render lipids less available for extraction (Delostlewis *et al*., 1992).Fats or lipids are esters of fatty acids and alcohols that provide energy and form components of eye and nerve tissues(Gaikwad *et al*., 2024).

Crude fiber content ranged from 2.46±0.38% and 3.40±0.45%. Pressure had a significant ($p \leq 0.05$) effect, but no significant differences ($p > 0.05$) were observed due to moisture and moisture-pressure interactions on the crude fibre content of popped finger millet. These components provide the bulk necessary for proper peristaltic action in the intestinal tract and lower post-meal glucose in the bloodstream because they are slowly absorbed and assimilated in the body(Onipe *et al*., 2024).

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Carbohydrate content of popped finger millet flour ranged from 77.77±0.75%and 79.40±0.30%. Pressure had a significant effect($p \leq 0.05$) on the carbohydrate content of popped finger millet. Carbohydrates are mainly used as a source of energy in nutrition(Gaikwad *et al*., 2024).

3.4 Calcium, Iron and Zinc composition

The calcium, zinc, and iron contents of popped finger millet are illustrated in Table 4. The calcium content of popped finger millet ranged from 1030.42±93.09mg/100g to 1164.40±72.08mg/100g. There were no significant differences ($p>0.05$) in calcium content due to pressure and moisture content. Zinc and iron contents ranged between 2.45±0.17mg/100g and 4.47±0.08mg/100g and1.05±0.06mg/100g and 1.58±0.07mg/100g, respectively. Significant ($p \leq 0.05$) differences in zinc content due to pressure and moisture content were observed, and the effect of pressure-moisture interactions was not significant. Pressure, moisture, and their interaction had significant ($p \leq 0.05$) effects on the iron content. The iron content generally increased when the pressure and moisture were increased from 120 psi to 140 psi or 160 psi and 15% to 18% or 21 %, respectively. This could be due to the simultaneous reduction of antinutritive factors such as phytates and tannins during the popping process that could have otherwise bound the iron and zinc and made them unavailable. In a study by Krishnan *et al.* (2012) on the effect of popping on finger millet, the calcium, zinc, and iron contents were 369±3.5mg/100g, 12.7±0.21mg/100g, and 2.2±0.1mg/100g, respectively.

Table 4: Calcium, iron and Zinc compositions of popped finger millet

Pressure	Moisture	Calcium (mg/100g)	Zinc (mg/100g)	Iron (mg/100g)
120	15	1030.42±93.09^{a}	1.05±0.06^{b}	2.48±0.01^{a}
	18	1047.85±94.59^{a}	1.25±0.06^{ab}	2.45±0.17^{a}
	21	1048.86±30.02^{a}	1.29±0.01^{a}	3.38±0.09^{b}
140	15	1122.33±75.4^{a}	1.23±0.11^{ab}	2.41±0.16^{a}
	18	1087.94±54.25^{a}	1.28±0.05^{a}	2.73±0.45^{a}
	21	1055.38±49.48^{a}	1.45±0.05^{ac}	3.78±0.13^{b}
160	15	1092.97±81.15^{a}	1.32±0.12^{a}	3.28±0.39^{b}
	18	1164.40±72.08^{a}	1.38±0.06^{ac}	4.20±0.17^{c}
	21	1128.89±82.96^{a}	1.58±0.07^{c}	4.47±0.08^{c}
P value	Pressure	0.07	0.02	0.00
	Moisture	0.79	0.03	0.00
	Pressure- Moisture	0.68	0.06	0.00

Values based on means ± SD of triplicate measurements. Mean values within the same column with different letters are significantly different ($P \leq 0.05$).

The role of Calcium in the diet is to renew the skeleton, facilitate calcium and muscular contractions, transmit nerve impulses, and facilitate hormone release. A deficiency of calcium leads to joint and cardiovascular problems, and osteoporosis. Zinc maintains the structural integrity of proteins, regulates gene expression, and contributes to the development of the

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male sexual organs. A zinc deficiency can cause male sterility (Momanyi *et al*., 2020). Iron plays the role of manufacturing haemoglobin and binds with myoglobin, a protein involved in muscle oxygenation. An iron deficiency will cause anaemia, and this affects about 33% of women in the reproductive age bracket, and 25 % of children under the age of five globally *(*Momanyi *et al.,* 2020).

3.5 Tannins, total phenols and phytates composition

The tannin content of popped finger millet flour ranged from 0.0158±0.02 to 0.0738mg/100g catechin equivalent (Table 5). Moisture content had a significant effect on the tannin content, whereas pressure and pressure-moisture content effects had no significant effect ($p>0.05$).

The polyphenol content of popped finger millet ranged from 0.0802±0 and 0.1226±0.002mg/100g gallic acid equivalent (GAE) (Table 5). Pressure, moisture content and their interactions had significant effects ($p\leq0.05$) on the polyphenol content of popped finger millet. The phytate content of popped finger millet ranged from 219.00±10.00mg/100g to 247.00±9.64mg/100g (Table 5). Significant ($p\leq0.05$) differences due to pressure were observed. The phytate content generally declined when popping pressure was increased from 120 psi to 140 psi or 160 psi. Moisture content and pressure-moisture content interactions had no significant ($p>0.05$) effect on the phytate content.

Popping improves the nutritional value of food by inactivating some of the antinutritive factors. The breakdown of phytic acid in finger millet can lead to the bioavailability of iron and other minerals (Subramani *et al*., 2023). Anti-nutritive factors can cause poor protein and carbohydrate digestion by inhibiting digestive enzymes and reducing the bioavailability of minerals such as calcium and iron. Majorly, phytates and tannins have been associated with the reduced bioavailability of vital nutrients (Gaikwad *et al*., 2024), therefore reducing them in the popped finger millet increases the nutritional value of the product.

Table5: Tannins, total phenols and phytates content ofpopped finger millet

Pressure	Moisture	Tannins (% CE)	Total Phenols (mg/100g) GAE	Phytates(mg/100)
120	15	0.0762±0.002^{a}	0.1070±0.002^{bc}	247.00±9.64^{b}
120	18	0.0329±0.008^{bcd}	0.1033±0.004^{abc}	247.00±5.29^{b}
120	21	0.0234±0.003^{bc}	0.0974±0.007^{ab}	239.33±6.51^{ab}
140	15	0.0565±0.016^{ad}	0.0802±0.000^{e}	231.67±7.57^{ab}
140	18	0.0738±0.005^{a}	0.0942±0.001^{a}	242.00±5.57^{ab}
140	21	0.0523±0.003^{acd}	0.0937±0.001^{a}	229.33±8.08^{ab}
160	15	0.0678±0.003^{a}	0.1083±0.003^{c}	238.67±4.51^{ab}
160	18	0.0346±0.003^{bcd}	0.1188±0.002^{d}	222.33±9.61^{a}
160	21	0.0158±0.002^{b}	0.1226±0.002^{d}	219.00±10.00^{a}
*P*value	Pressure	0.0561	0.0000	0.0005
	Moisture	0.0024	0.0005	0.0323
	Pressure-Moisture	0.0606	0.0000	0.0891

Values based on means ± SD of triplicate measurements. Mean values within the same column with different letters are significantly different ($P\leq0.05$).

4.0 Conclusion

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Moisture content and puffing pressures distinctly affected the popping yield, density, and expansion ratio of finger millet. These factors are crucial considerations for commercial production as popped grain producers obtain raw grain by weight and sell popped products by volume. The nutritional quality of finger millet was enhanced by the reduction of phytates and tannins along with increase in iron, zinc and protein content when pressure and moisture content were raised. Moreover, the shelf-life stability improved by a reduction in moisture content when popping pressure and moisture content were increased.

This study provides insights into the physico-chemical changes that occur during the popping of finger millet, offering a base for optimizing the formulation of popped finger millet-based products. Further research is necessary to explore the possibilities of enhancing specific nutrient contents and drive the advocacy for consumption of finger-millet-based foods.

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6.0 Conflict of interest

The authors declare no competing interest.

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