



Optimization of Popping Parameters and Nutritional Profiling of Kodo Millet Pops

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study investigates the optimization of popping parameters to enhance the nutritional profile of Kodo millet pops

Study Design: Experimental design.

Place and Duration of Study: The present study was conducted During 2023-2024 at Department of Foods and Nutrition, Post Graduate and Research Centre (PGRC), Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad (India).

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Methodology: Kodo millet analyzed for physical parameters viz. Popping capacity, Bulk density, True density, Expansion ratio and popped ratio. Functional properties of Kodo millet grains such as Water absorption capacity, water solubility index, oil absorption capacity; and nutritional properties like moisture, fat, ash, crude fiber, carbohydrates, protein, energy, Starch; Minerals like Sodium, potassium, Iron, Zinc, Calcium.

Results: The analysis revealed that in Kodo millet pops, physical parameters such as popping capacity, true density, and bulk density decreased. The popped ratio decreased notably for KM29 (14%, 18%, 22%), while the expansion ratio showed a decrease with increased moisture content. Functional properties like water solubility index and water absorption capacity significantly increased ($p \leq 0.05$), whereas oil absorption capacity decreased significantly in KMC2514 (6.48%) and KMM2914 (78.70%). There was a significant decrease ($p \leq 0.05$) in moisture content for KMM2914 (42.8%) and KMC2514 (50.5%), ash content for KMM2914 (7.6%) and KMC2514 (3.84%), crude fiber for KMM2914 (16.7%) and KMC2514 (15.6%), protein for KMM2914 (4.16%) and KMC2514 (0.41%), fat for KMC2514 (31.4%) and KMM2914 (30.81%), starch for KMM2914 (0.17%) and KMC2514 (0%), and energy for KMC2514 (5.73%) and KMM2914 (6.3%), whereas carbohydrate content increased significantly ($p \leq 0.05$). Mineral analysis showed significant increases ($p \leq 0.05$) in calcium, iron, zinc, and sodium content, while potassium content decreased significantly ($p \leq 0.05$) in KMM2914 (50.57%) and KMC2514 (51.7%).

Keywords: Kodo millet; machine popping; conventional popping; physical; functional; nutritional parameters of kodo millet pops.

1. INTRODUCTION

The word name "millet" is derived from the French word "mille," which means "thousand," a handful of millet must contain thousands of grains [1]. Minor millets are small coarse of grains belonging to the group of forage grass called millet, belongs to the family Poaceae; most of the genera belongs to the sub-family Panicoideae, that can grow in extreme ecological conditions. Minor millets are an important traditional food with tremendous nutritional and medicinal application but, less concern about the importance of minor millets among the people [2].

Kodo millet (*Paspalum scrobiculatum* L.) was domesticated in India almost 3000 years ago. It is found across the old world in humid habitats of the tropics and subtropics. It is a minor grain crop in India, and an important crop in the Deccan plateau. Its cultivation in India is generally confined to Gujarat, Karnataka, Chhattisgarh, Eastern Madhya Pradesh and parts of Tamilnadu. Kodo grains contain 8.35% protein, 1.45% fat, 65.65% carbohydrate and 2.95% ash. It may be considered as nutri-cereal. Nutritionally it is comparable with other common cereals and in some respect it is superior to rice and wheat. The grain is recommended as a substitute for rice the patients suffering from diabetes disease. Kodo grains provide cheap proteins, minerals and vitamins to poor people [3].

Popping is a simultaneous starch gelatinization and expansion process, during which grains are exposed to high temperatures for a short time. During this process, the superheated vapor produced inside the grains by instantaneous heating, cooks the grain and expands the endosperm suddenly, breaking out the outer skin [4].

Popping is a thermal processing technique widely used to transform whole grains into expanded, edible snacks. This process involves the application of heat to dry grains, causing rapid moisture expansion within the kernel. The sudden increase in internal pressure leads to the rupture of the grain's outer hull, resulting in the characteristic "pop" and expansion of the kernel into a light, crispy texture. Comparing minor millets in popped form highlights their nutritional richness and potential as healthy snacks. Popping enhances their digestibility, texture, and flavor, making them competitive with traditional grains like wheat and maize in terms of nutritional value and consumer appeal.

In the past, popping and puffing were used to extend shelf life, improve organoleptic qualities, and make it easier to incorporate ingredients into ready-to-eat meals [5]. Popping millet is becoming increasingly popular as a snack and as an ingredient for different formulations in baby foods due to its ready-to-eat, lighter and crispness characteristics, nutritional quality and increased palatability [6]. The study was

designed to optimize popping characteristics and physicochemical and nutritional profiling of kodo millet. The popping constitutes an interest for food industries and the results of this study will provide information in order to produce good-quality popped kodo millet.

2. MATERIALS AND METHODS

The present study was conducted during 2023-2024 at the Department of Foods and Nutrition, Post Graduate and Research Centre (PGRC), Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad (India).

2.1 Pre-conditioning of Grain

Grain Procuring: The kodo millet was procured from the market, after which it was cleaned and graded.

Soaking: The cleaned and graded grain samples were soaked in water for 2 hours, then they were tray dried at 60°C for 15 minutes until desired moisture is obtained.

Moisture: The moisture of the grain was monitored by using a Mini Gae plus moisture tester.

Popping: Then the preconditioned grain was then popped by using conventional and hot air popping method at different temperature and moisture levels as given in Table 1.

The popping technologies used: Conventional method (Sand roasting): In sand roasting method, pre-conditioned kodo millet grains were exposed to hot sand, while the temperature of sand is about 230°C to 250°C [4].

Machine popping method: (Technocrats popping machine): The popping machine was designed by the Indian Institute of Food Processing Technology, Thanjavur, Tamil Nadu, and purchased from Technocrats was used. The

popping experiments were conducted using the experimental high temperature short time (HTST) machine popping.

Process parameters: The process variables for machine popping temperature and initial grain moisture content were optimized keeping hot-air velocity constant to obtain the best yield and quality of kodo millet pops.

Physical parameters: Popping capacity, bulk density [7], true density [8]. Expansion ratio, popped ratio [9] was estimated for the control (kodo whole grain), conventional popped and machine popped samples.

Sensory evaluation of Kodo millet pops: The sensory analysis was conducted in a sensory evaluation laboratory. Semi trained panel members (15) from the Foods and Nutrition Department at Post Graduate and Research Centre, PJTSAU, Rajendranagar, Hyderabad, were selected as panel members for the study. They were given written instructions and asked to evaluate the products for acceptability in terms of appearance, color, texture, taste, flavour, crispness and overall acceptability using a 9-point hedonic scale, where 1= dislike extremely, 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like, nor dislike; 6 = like slightly; 7 = like moderately and 8 = like very much 9= Like extremely. The samples were presented in plates coded with three -digit numbers in individual booths in sensory evaluation lab. Panelists rinsed their mouth with water after testing each sample.

Functional parameters: Water absorption capacity (WAC), water solubility index (WSI), and oil absorption capacity (OAC) [10;11] were analysed for selected samples.

Nutritional composition: moisture [12], ash [12], protein [13], fat [12], carbohydrate [14], energy [15] and crude fiber [16], minerals like sodium, potassium, zinc, iron and calcium [17] were analyzed by following standard methods.

Table 1. Processing parameter of kodo millet pops

| Sl. No | Sample | Temp of conventional pops | Temp of machine pops | Moisture (%) |
|--------|--|---------------------------|----------------------|--------------|
| 1. | Kodo millet (<i>Paspalum scrobiculatum</i>) | 230 °C | 290 °C-300 °C | 14,18 & 22 |
| | | 240 °C | 300 °C-310 °C | 14,18 & 22 |
| | | 250 °C | 310 °C-320 °C | 14,18 & 22 |

Statistical analysis: All experiments were performed three times. All the data were presented as mean \pm standard deviation of the mean. The data was analyzed using MS Excel and Indostat software. The results are presented in the form of mean and standard deviation. The data of different sensory characteristics, physical properties and functional properties was subjected to analysis of variance (ANOVA) and the means were compared by Turkey test at a 5% level of significance [18].

3. RESULTS AND DISCUSSION

Physical parameters: The data on popping capacity of kodo millet grain are presented in Table 2. The popping percentage in the conventional method ranged from $6 \pm 1.00\%$ (KC2522) to $16 \pm 1.00\%$ (KC2414) where as in the machine it was $10.67 \pm 1.15\%$ to $18.67 \pm 1.15\%$ (KM2922 and KM3122). The results indicated that in both the methods, as the moisture content is increased the percentage of popping decreased. The highest popping percentage was at 290°C temperature with 14% moisture and the lowest popping percentage was at 250°C temperature at 22% moisture content. When compare to the conventional method, unpopped grains were less in the machine method. At 290°C with 18% of moisture the unpopped grains ($36.67 \pm 1.15\%$) and 300°C with 14% of moisture it was $40.00 \pm 0.00\%$. Hence it can be concluded that popping capacity is more in machine method when compare to the conventional method (Table 2).

Bulk density: Bulk density was highest in KW ($0.76 \pm 0.00\text{g/ml}$) then all the experimental samples. The bulk density in conventional and machine popping ranged from $0.10 \pm 0.00\text{g/ml}$ (KM2914) to $0.17 \pm 0.00\text{g/ml}$ (KC2422) (Table 3). It was observed that in all temperatures, as the moisture content was increasing the bulk density of pops was increased. The highest bulk density is observed at 240°C temperature with 22% moisture ($0.17 \pm 0.00\text{g/ml}$) (Table 3). The volume of puffing depends on the bulk density of the rice. As the grain weight increases, bulk density will be decreased but volume will be increased. In puffing operation, the volume of puffing is depends on the bulk density of grain [19].

True density: True density of kodo whole grain was highest ($1.67 \pm 0.58\%$) when compare to both popping methods ranged from KC2414 ($0.10 \pm 0.00\%$) to KM2914, KM2918, KM2922 ($1.00 \pm 0.00\%$) (Table 3). In conventional at 230°C

with an increase of moisture true density was decreased (0.67% to 0.54%) when compared to 240°C and 250°C as the moisture increased, true density was decreased. In the machine at 290°C temperature as the moisture increases true density remains constant when compared to 300°C and 310°C temperature the moisture increases true density has been decreased (Table 3).

Expansion ratio: The expansion ratio in the conventional method ranged from 0.423 ± 0.03 (KC2522) to 1.15 ± 0.04 (KC2414) the machine it was 0.663 ± 0.03 (KM3122) to 1.833 ± 0.06 (KM2914) (Table 3). The results indicated that in both methods as moisture content is increases the expansion ratio was decreased. The highest expansion ratio was 290°C with 14% of moisture and the lowest expansion ratio at 250°C with 22% of moisture. The volume of puffing depends on the bulk density of grain. Higher density results in a higher expansion ratio [19].

Popped ratio: The results indicated that the popped ratio in all the temperatures, (except 290°C with moisture of 14%, 18%, 22%) as the moisture content was increased, popped ratio increased at 14% but decreased at 18% and again increased at 22% moisture. The popped ratio in conventional method ranged from 0.203 ± 0.02 (KC2518) to 0.476 ± 0.01 (KC2522) the machine it was 0.34 ± 0.02 (KM3115) to 0.62 ± 0.01 (KM2918) (Table 3). The highest popped ratio (0.62 ± 0.01) was at 290°C with 18% moisture and the lowest (0.203 ± 0.02) at 250°C with 18% moisture.

Based on highest popping capacity and popping ratio the samples KMC1423, KMC1424, KMC1425, KMM1429, KMM1430, KMM1431 were selected for analysis of functional properties and sensory evaluation (Table 2 and Table 3).

Sensory scores of kodo millet pops: The sensory evaluation of appearance ranged from 6.93 ± 0.889 (KMM1431) to 7.53 ± 0.74 (KMM1429), color ranged from 7.07 ± 0.70 (KMM1431) to 7.40 ± 0.91 (KMM1429), flavor ranged from 6.93 ± 0.80 (KMM1431) to 7.67 ± 0.63 (KMM1429), taste ranged from 7.33 ± 0.82 (KMM1431) to 7.73 ± 0.59 (KMM1429) (Table 4), and texture ranged from 6.87 ± 0.64 (KMM1431) to 7.53 ± 0.83 (KMM1429). Among these attributes, appearance, color, flavor, taste, and texture exhibited their narrowest range at 310°C temperature with 14% moisture, while their

Table 2. Popping capacity of kodo millet (%)

| Sample | Popped | Semi popped Conventional | Unpopped |
|----------------|----------------------------|-----------------------------|----------------------------|
| KC2314 | 14.00 ^c ±1.00 | 24.33 ^{gh} ±0.58 | 61.67 ^c ±0.58 |
| KC2318 | 12.00 ^{de} ±1.00 | 19.33 ^j ±1.15 | 68 ^b ±1.00 |
| KC2322 | 10.00 ^{fg} ±1.00 | 30.00 ^{cde} ±1.00 | 60.00 ^{cde} ±2.00 |
| KC2414 | 16.00 ^b ±1.00 | 24.33 ^{gh} ±0.58 | 59.67 ^{cde} ±1.53 |
| KC2418 | 11.67 ^{def} ±1.53 | 28.33 ^{ef} ±0.58 | 60.00 ^{cde} ±2.00 |
| KC2422 | 11.00 ^{ef} ±1.00 | 31.00 ^{cd} ±1.00 | 58.00 ^e ±1.00 |
| KC2514 | 10.00 ^{fg} ±1.00 | 32.00 ^c ±1.00 | 58.67 ^{de} ±1.15 |
| KC2518 | 9.00 ^g ±1.00 | 11.33 ^b ±0.58 | 79.67 ^a ±1.53 |
| KC2522 | 6.00 ^h ±1.00 | 41.67 ^b ±0.58 | 52.33 ^f ±0.58 |
| | | Machine | |
| KM2914 | 18.67 ^a ±1.15 | 21.33 ^{ij} ±1.15 | 60.00 ^{cde} ±0.00 |
| KM2918 | 13.33 ^{cd} ±1.15 | 50.00 ^a ±2.00 | 36.67 ^h ±1.15 |
| KM2922 | 10.67 ^{efg} ±1.15 | 30.67 ^{cde} ±1.15 | 58.67 ^{de} ±1.15 |
| KM3014 | 16.67 ^b ±1.15 | 43.33 ^b ±1.15 | 40.00 ^g ±0.00 |
| KM3018 | 11.33 ^{ef} ±1.15 | 30.00 ^{cde} ±2.00 | 58.67 ^{de} ±1.15 |
| KM3022 | 10.67 ^{efg} ±1.15 | 22.00 ^{hi} ±2.00 | 67.33 ^b ±1.15 |
| KM3114 | 13.33 ^{cd} ±1.15 | 26.00 ^{fg} ±2.00 | 60.67 ^{cd} ±1.15 |
| KM3118 | 12.00 ^{de} ±0.00 | 23.00 ^{hi} ±3.61 | 66.00 ^b ±2.00 |
| KM3122 | 10.67 ^{efg} ±1.15 | 28.67 ^{de} ±1.15 | 60.67 ^{cd} ±1.15 |
| Mean | 12.05 | 28.74 | 59.25 |
| S.E | 0.41 | 1.23 | 1.28 |
| C.D | 1.83 | 2.54 | 2.10 |
| C.V (%) | 9.17 | 5.33 | 2.13 |

Note: Values are expressed as mean ± standard deviation of three determinations.
Means within the same column followed by a common letter do not differ significantly at (p ≤ 0.05)

KC2314: Conventional popping of kodo millet 230°C with 14% moisture.
 KC2318: Conventional popping of kodo millet 230°C with 18% moisture.
 KC2322: Conventional popping of kodo millet 230°C with 22% moisture.
 KC2414: Conventional popping of kodo millet 240°C with 14% moisture.
 KC2418: Conventional popping of kodo millet 240°C with 18% moisture.
 KC2422: Conventional popping of kodo millet 240°C with 22% moisture.
 KC2514: Conventional popping of kodo millet 250°C with 14% moisture.
 KC2518: Conventional popping of kodo millet 250°C with 18% moisture.
 KC2522: Conventional popping of kodo millet 250°C with 22% moisture.

KM2914: Machine popping of kodo millet 290°C with 14% moisture.
 KM2918: Machine popping of kodo millet 290°C with 18% moisture.
 KM2922: Machine popping of kodo millet 290°C with 22% moisture.
 KM3014: Machine popping of kodo millet 300°C with 14% moisture.
 KM3018: Machine popping of kodo millet 300°C with 18% moisture.
 KM3022: Machine popping of kodo millet 300°C with 22% moisture.
 KM3114: Machine popping of kodo millet 310°C with 14% moisture.
 KM3118: Machine popping of kodo millet 310°C with 18% moisture.
 KM3122: Machine popping of kodo millet 310°C with 22% moisture.

Table 3. Physical parameters of kodo millet

| Sample | Bulk density(g/ml) | True density (%) | Expansion ratio | Popped ratio |
|---------------------|--------------------------|--------------------------|---------------------------|-----------------------------|
| kw | 0.76 ^a ±0.00 | 1.67 ^a ±0.58 | - | - |
| Conventional | | | | |
| KC2314 | 0.14 ^{fg} ±0.00 | 0.67 ^d ±0.00 | 0.97 ^e ±0.02 | 0.383 ^h ±0.01 |
| KC2318 | 0.16 ^{cd} ±0.00 | 0.56 ^d ±0.09 | 0.81 ^f ±0.02 | 0.32 ⁱ ±0.01 |
| KC2322 | 0.16 ^c ±0.00 | 0.54 ^d ±0.00 | 0.65 ^{hi} ±0.02 | 0.433 ^d ±0.04 |
| KC2414 | 0.14 ^{fg} ±0.00 | 0.10 ^d ±0.00 | 1.15 ^{cd} ±0.04 | 0.403 ^{efgh} ±0.02 |
| KC2418 | 0.15 ^{fg} ±0.01 | 0.70 ^{cd} ±0.52 | 0.8 ^{fg} ±0.04 | 0.4f ^{gh} ±0.02 |
| KC2422 | 0.17 ^b ±0.00 | 1.00 ^{bc} ±0.00 | 0.66 ^{hi} ±0.02 | 0.42 ^{def} ±0.01 |
| KC2514 | 0.15 ^{de} ±0.01 | 0.53 ^d ±0.00 | 0.646 ^{hi} ±0.07 | 0.413 ^{defg} ±0.01 |
| KC2518 | 0.15 ^{ef} ±0.01 | 0.54 ^d ±0.01 | 0.6 ⁱ ±0.03 | 0.203 ^j ±0.02 |
| KC2522 | 0.16 ^{cd} ±0.00 | 0.99 ^{bc} ±0.00 | 0.423 ^j ±0.03 | 0.476 ^c ±0.01 |
| Machine | | | | |
| KM2914 | 0.10 ⁱ ±0.00 | 1.00 ^b ±0.00 | 1.833 ^a ±0.06 | 0.4 ^{gh} ±0.00 |
| KM2918 | 0.12 ⁱ ±0.00 | 1.00 ^b ±0.00 | 1.13 ^d ±0.09 | 0.62 ^a ±0.01 |
| KM2922 | 0.14 ^{gh} ±0.00 | 1.00 ^b ±0.00 | 0.76 ^{fg} ±0.09 | 0.413 ^{defg} ±0.01 |
| KM3014 | 0.10 ⁱ ±0.00 | 1.01 ^b ±0.00 | 1.63 ^b ±0.06 | 0.6 ^b ±0.00 |
| KM3018 | 0.12 ⁱ ±0.00 | 0.99 ^{bc} ±0.00 | 0.903 ^e ±0.06 | 0.413 ^{defg} ±0.01 |
| KM3022 | 0.14 ^{fg} ±0.00 | 0.99 ^{bc} ±0.00 | 0.72 ^{gh} ±0.03 | 0.426 ^{de} ±0.01 |
| KM3114 | 0.11 ⁱ ±0.00 | 0.99 ^{bc} ±0.00 | 1.21 ^c ±0.10 | 0.393 ^{gh} ±0.01 |
| KM3118 | 0.13 ^h ±0.00 | 0.68 ^d ±0.00 | 0.9 ^e ±0.00 | 0.34 ⁱ ±0.02 |
| KM3122 | 0.16 ^{cd} ±0.01 | 0.43 ^d ±0.00 | 0.663 ^{hi} ±0.03 | 0.406 ^{efgh} ±0.01 |
| Mean | 0.1732 | 0.8094 | 0.9119 | 0.4156 |
| S.E | 0.188 | 0.0479 | 0.0487 | 0.0126 |
| C.D | 0.0815 | 0.30180 | 0.08955 | 0.02586 |
| C.V (%) | 2.841 | 22.518 | 5.919 | 3.750 |

Note: Values are expressed as mean ± standard deviation of three determinations
Means within the same column followed by a common letter do not differ significantly at (p ≤ 0.05)

KC2314: Conventional popping of kodo millet 230°C with 14% moisture.
 KC2318: Conventional popping of kodo millet 230 °C with 18% moisture.
 KC2322: Conventional popping of kodo millet 230°C with 22% moisture.
 KC2414: Conventional popping of kodo millet 240°C with 14% moisture.
 KC2418: Conventional popping of kodo millet 240°C with 18% moisture.
 KC2422: Conventional popping of kodo millet 240°C with 22% moisture.
 KC2514: Conventional popping of kodo millet 250°C with 14% moisture.
 KC2518: Conventional popping of kodo millet 250°C with 18% moisture.
 KC2522: Conventional popping of kodo millet 250°C with 22% moisture.

KW- kodo whole grain.

KM2914: Machine popping of kodo millet 290°C with 14%
 KM2918: Machine popping of kodo millet 290°C with 18%
 KM2922: Machine popping of kodo millet 290°C with 22%
 KM3014: Machine popping of kodo millet 300°C with 14%
 KM3018: Machine popping of kodo millet 300°C with 18%
 KM3022: Machine popping of kodo millet 300°C with 22%
 KM3114: Machine popping of kodo millet 310°C with 14%
 KM3118: Machine popping of kodo millet 310°C with 18%
 KM3122: Machine popping of kodo millet 310°C with 22%

Table 4. Sensory scores of kodo millet pops

| Sample | Appearance | Colour | Flavour | Taste | Texture | Crispiness | Overall Acceptability |
|-------------|---------------------------|--------------------------|---------------------------|--------------------------|--------------------------|---------------------------|---------------------------|
| KMC1423 | 7.40 ^{ab} ± 0.74 | 7.33 ^a ± 0.62 | 7.53 ^{ab} ± 0.64 | 7.40 ^a ± 0.63 | 7.47 ^a ± 0.64 | 7.60 ^a ± 0.51 | 7.53 ^{ab} ± 0.52 |
| KMC1424 | 7.40 ^{ab} ± 0.73 | 7.33 ^a ± 0.62 | 7.53 ^{ab} ± 0.64 | 7.40 ^a ± 0.63 | 7.47 ^a ± 0.64 | 7.60 ^a ± 0.51 | 7.53 ^{ab} ± 0.52 |
| KMC1425 | 7.33 ^{ab} ± 0.72 | 7.27 ^a ± 0.88 | 7.20 ^{bc} ± 0.86 | 7.40 ^a ± 0.83 | 7.47 ^a ± 0.83 | 7.60 ^a ± 0.99 | 7.60 ^{ab} ± 1.06 |
| KMM1429 | 7.53 ^a ± 0.74 | 7.40 ^a ± 0.91 | 7.67 ^a ± 0.62 | 7.73 ^a ± 0.59 | 7.53 ^a ± 0.83 | 7.60 ^a ± 0.74 | 7.87 ^a ± 0.52 |
| KMM1430 | 7.27 ^{ab} ± 0.74 | 7.33 ^a ± 0.62 | 7.40 ^{ab} ± 0.64 | 7.40 ^a ± 0.63 | 7.40 ^a ± 0.64 | 7.27 ^{ab} ± 0.51 | 7.53 ^{ab} ± 0.52 |
| KMM1431 | 6.93 ^b ± 0.88 | 7.07 ^a ± 0.70 | 6.93 ^c ± 0.80 | 7.33 ^a ± 0.82 | 6.87 ^a ± 0.64 | 7.13 ^b ± 0.52 | 7.20 ^b ± 0.56 |
| Mean | 7.31 | 7.28 | 7.38 | 7.44 | 7.36 | 7.46 | 7.54 |
| S.E | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.77 | 0.07 |
| C.D | 0.56 | 0.50 | 0.43 | 0.46 | 0.45 | 0.46 | 0.46 |
| C.V% | 10.53 | 9.55 | 8.16 | 8.51 | 8.41 | 8.57 | 8.40 |

Note: values are expressed as mean ± standard deviation of three determinants
Means within the same column followed by a common letter do not differ significantly at (p ≤ 0.05)

KMC1423 - Kodo millet conventional (230 °C with 14% of moisture)
KMC1424 - Kodo millet conventional (240 °C with 14% of moisture)
KMC1425 - Kodo millet conventional (250 °C with 14% of moisture)

KM1429: Kodo millet Machine (290°C with 14% moisture)
KM1430: kodo millet machine (300°C with 14% moisture)
KMC1431: Kodo millet machine (310 °C with 14% of moisture)

Table 5. Functional parameters of kodo millet pops

| Sample | Functional parameters | | |
|----------------|--------------------------|--------------------------|--------------------------|
| | WAC (g/100g) | WSI (%) | OAC (g/100g) |
| KMW | 1.16 ^c ± 0.01 | 1.15 ^c ± 0.01 | 1.08 ^b ± 0.01 |
| KMC | 3.85 ^b ± 0.01 | 2.65 ^b ± 0.01 | 1.01 ^c ± 0.01 |
| KMM | 4.16 ^a ± 0.02 | 2.76 ^a ± 0.01 | 1.93 ^a ± 0.01 |
| Mean | 3.06 | 2.19 | 1.34 |
| S.E | 0.47 | 25.82 | 0.14 |
| C.D | 0.13 | 0.002 | 0.01 |
| C.V (%) | 0.01 | 0.0005 | 0. |

Note: values are expressed as mean ± standard deviation of three determinants

KMM–Machine popping of Kodo millet pops
KMC- Conventional popping of Kodo millet pops

KMW - Whole grain of Kodo millet

Table 6. Nutritional composition of kodo millet pops (g/100g)

| Sample | Moisture | Ash | Crude fiber | Carbohydrate | Protien | Fat | Starch | Energy Kcal/100g |
|----------------|-------------------------|-------------------------|--------------------------|--------------|--------------------------|--------------------------|--------------------------|------------------------|
| KMW | 9.25 ^a ±0.01 | 2.60 ^b ±0.01 | 8.80 ^a ± 0.01 | 71.13±0.001 | 8.41 ^a ± 0.01 | 3.25 ^a ± 0.06 | 5.60 ^a ± 0.16 | 349 ^b ±0.41 |
| KMC1425 | 4.57 ^c ±0.01 | 2.50 ^c ±0.01 | 7.43 ^a ± 0.01 | 73.71±0.01 | 8.06 ^a ± 0.01 | 2.10 ^c ± 0.12 | 5.60 ^a ± 0.16 | 329 ^a ±0.58 |
| KMM1429 | 5.29 ^b ±0.01 | 2.80 ^a ±0.00 | 7.33 ^a ± 0.01 | 72.99±0.01 | 8.16 ^a ± 0.01 | 2.11 ^b ±0.06 | 5.59 ^a ± 0.15 | 327 ^a ±0.30 |
| Mean | 6.37 | 2.633 | 7.853 | 78.94 | 8.21 | 2.48 | 5.59 | 335s |
| S.E | 0.728 | 0.043 | 1.324 | 4.69 | 0.156 | 0.912 | 0.4965 | 0.0212 |
| C.D | 0.031 | 0.017 | 1.115 | 0.45 | 0.854 | 2.118 | 2.002 | 0.0831 |
| C.V (%) | 0.219 | 0.297 | 9.389 | 0.04 | 4.657 | 19.458 | 18.271 | 0.479 |

Note: values are expressed as mean ± standard deviation of three determinants
Means with same column followed by a common letter do not differ significantly at ($p \leq 0.05$)

KMW - Whole grain of Kodo millet
KMM1429- Machine popping of Kodo millet pops

KMC1425 - Conventional popping of Kodo millet pops

Table 7. Minerals composition kodo millet (mg/100g).

| Sample | Calcium | Iron | Zinc | Potassium | Sodium |
|----------------|--------------------------|--------------------------|--------------------------|-------------------------|-------------------------|
| KMW | 0.25 ^c ± 0.01 | 0.02 ^b ± 0.01 | 2.23 ^c ± 0.01 | 4.35 ^a ±0.01 | 0.11 ^c ±0.01 |
| KMC1425 | 0.26 ^b ±0.01 | 0.03 ^a ±0.01 | 2.65 ^b ±0.01 | 2.10 ^c ±0.01 | 0.12 ^b ±0.01 |
| KMM1429 | 0.27 ^a ±0.01 | 0.03 ^a ±0.01 | 2.72 ^a ±0.01 | 2.15 ^b ±0.01 | 0.13 ^a ±0.11 |
| Mean | 0.26 | 0.026 | 2.5 | 2.8 | 0.12 |
| S.E | 0.001 | 0.013 | 0.011 | 0.014 | 0.011 |
| C.D | 0.002 | 0.001 | 0.003 | 0.001 | 0.004 |
| C.V (%) | 0.05 | 0.04 | 0.484 | 0.001 | 0.367 |

Note: values are expressed as mean ± standard deviation of three determinants
Means with same column followed by a common letter do not differ significantly at ($p \leq 0.05$)

KMW - Whole grain of Kodo millet
KMM1429-Machine popping of kodo millet pops at 290°C with 14 % moisture

KMC -Conventional popping of Kodo millet pops 250°C14% moisture

widest range was observed at 290°C temperature under the same moisture conditions. Sensory attributes for appearance, color, flavor, texture, and taste remained consistent at 230°C and 240°C but decreased at 250°C, 300°C, and 310°C temperatures. Crispiness increased notably at 290°C, remained stable at 230°C, 240°C, 250°C, and 290°C, and showed further increases at 300°C and 310°C temperatures. Overall acceptability was highest at 290°C temperature with a score of 7.87 ± 0.52 and lowest at 310°C temperature with a score of 7.20 ± 0.56 (Table 4).

Based on the popping ratio and sensory evaluation, best accepted samples KW, KMC1425, KMM1429 were used for further analysed for functional and nutritional properties. The KM1425 (Kodo millet conventional 14% moisture with 250°C temperature and kodo millet machine 14% moisture 290°C temperature can be denoted as KMC and KMM).

Functional parameters: The data of functional parameters of kodo millet samples (whole grain, conventional pops, and machine pops) were statistically analysed and presented in Table 5 and the percentage change in experimental sample when compared with control were presented in Fig. 1.

Water absorption capacity (WAC): The results showed that KMM2914 (4.16 ± 0.02 g/100g) had more WAC than KMC2514 (3.85 ± 0.01 g/100g), followed by KMW (1.16 ± 0.01 g/100g). There was a significant ($p \leq 0.05$) increased in KMM2914 (231.8%), KMC2514 (258.6%) when compared to the control (KMW) (Fig. 1). According to [20] reported that water absorption capacity of Maize - pop corn flour was $1.73 \pm 0.3\%$.

Water solubility Index (WSI): The water solubility index of KMM2914 ($2.76 \pm 0.01\%$), and KMC2514 ($2.65 \pm 0.01\%$) was increased when compared to control ($1.15 \pm 0.01\%$). The increase of WSI was 140% (KMM2914) and 130.43% (KMC2514), when compared to the control KMW (Fig. 1). Stated that water solubility index of puffed rice was $4.69 \pm 0.16\%$ white rice was $1.39 \pm 0.07\%$ [21].

Oil absorption capacity (OAC): It was found that KMM2914 (1.93 ± 0.01 g/100g) had a higher OAC but KMC2514 (1.01 ± 0.01 g/100g) had lower when compared to KMW. There was an 78.70% increase of OAC in KMM2914 and 6.48% decrease in KMC2514 of oil absorption capacity with respect to control (Fig. 1). According to [20] reported that the oil absorption capacity of maize flour was (0.63 ± 0.02 g/100g).

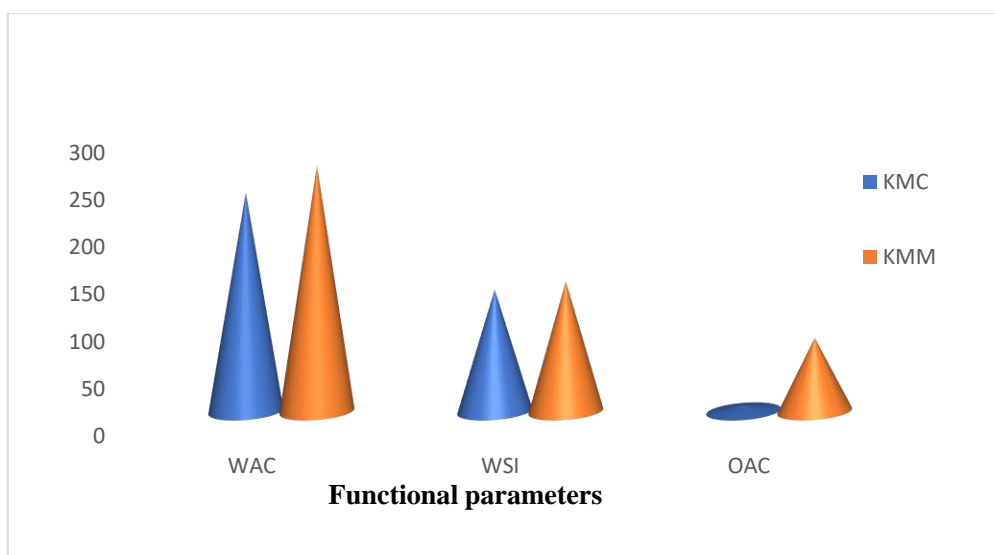


Fig. 1. The percentage changes in the functional parameters of kodo millet experimental samples to control

WAC: Water absorption capacity
 OAC: Oil absorption capacity
 KMM: Kodo millet machine pops

WSI : Water solubility Index
 KMC: Kodo millet conventional pops

3.1 Proximate Composition of Kodo Millet Pops

Moisture: Moisture content of KMW (9.25 ±0.02%), which was significantly ($p \leq 0.05$) more than the KMM (5.29 ± 0.01%) and KMC samples (4.5 ±0.01%) (Table 6). In KMW 42.8% reduction in moisture content was observed, While KMC showed a 50.5% reduction (Fig. 2). According to [22] the moisture content of popped maize flour (was 4.78% ± 0.20) and the moisture content of popped sorghum flour was (5.53 ± 0.32%).

Ash: KMM, KMC and KMW showed significant differences ($p < 0.05$). The ash content of KMM was 2.80 ±0.00g/100g is greater than KMC (2.50 ±0.0100g/100g) and KMW. In KMM 7.6% increase inf ash content observed,where as in KMC 3.84% decreases when compared with control (Fig. 2). The findings of ash content of puffed rice were 1.36 ± 0.220g/100g [23].

Crude fiber: The crude fiber content of KMC (7.43 ± 0.060g/100g) and KMM (7.33 ± 0.030g/100g) had less than KMW (8.80 ± 0.200g/100g) Table 6. In KMC 15.56% decrease of crude fiber was observed where as in KMM 16.7% decrease compared to the control (Fig.

2). According to (20) reported that crude fiber content of Maize- pop corn flour was 6.74±0.020g/100g.

Carbohydrate: The carbohydrate content of KMC (73.71±0.120g/100g) (Table 6) was significantly higher ($p < 0.05$) than the KMM (72.99±0.080g/100g) and KMW (71.13±0.00g/100g) with an increase of KMC 3.62% and KMM 2.61% in (Fig. 2). According to [23] reported carbohydrate contents on puffed rice was 83.28 ± 0.38 g/100g.

Protein: KMM (8.16 ± 0.03 g/100g) and KMC (8.06 ± 0.03 g/100g) showed no significant difference compared to the KMW (8.41 ± 0.04 g/100g). In KMM 4.16% decrease of protein content was observed where as in KMC 0.41% was observed (Fig. 2). According to [22] stated on popped sorghum flour of protein content was 8.49 ± 0.16 g/100g.

Fat: KMC (2.10± 0.12 g/100g) and KMM (2.11± 0.06 g/100g) showed no significant difference compared to the KMW (3.05±0.02 g/100g), in KMC 31.14% decreases of fat content and in KMM 30.81% was observed (Fig. 2).

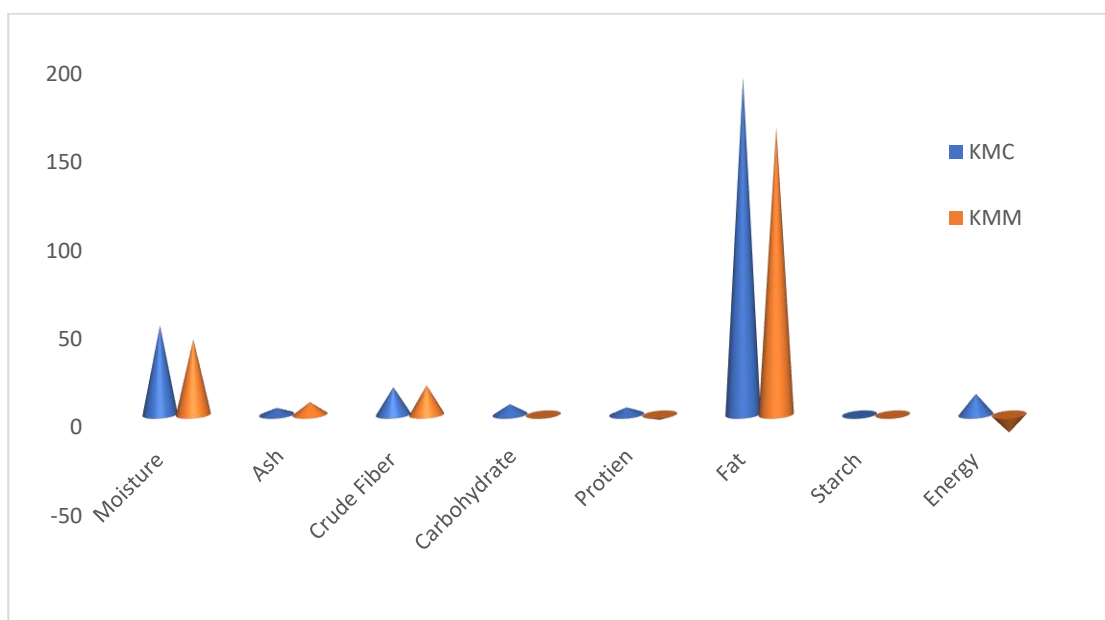


Fig. 2. The percentage change in the Nutritional parameters of kodo millet compared with control

Note:

KMC1425: Kodo Millet Conventional pops 250°C with 14% moisture.

KMM1429: Kodo millet machine pops 290°C with 14% moisture.

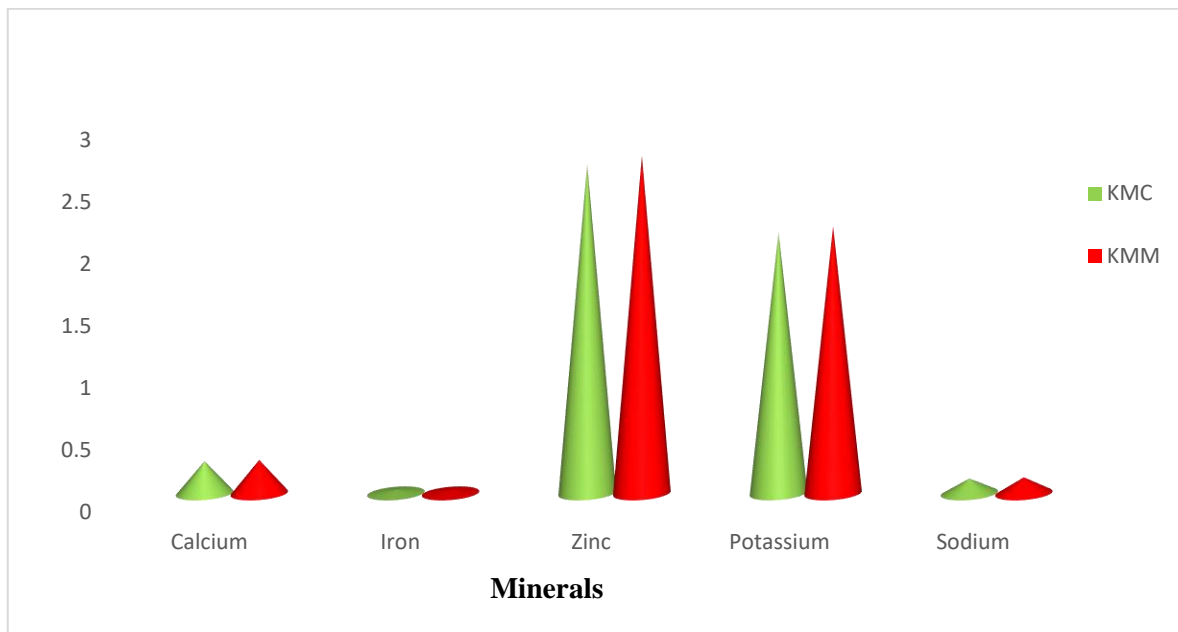


Fig. 3. The percentage changes in the Mineral content of kodo millet experimental samples to control

Note:
KMC1425- Kodo millet pops conventional at 250 °C with 14% moisture

KMM1429- Kodo millet pops machine 290°C with 14% moisture

Starch: The starch content of KMW (5.60 ± 0.16 g/100g), KMC (5.60 ± 0.16 g/100g) and KMM (5.59 ± 0.15 g/100g) found that there is no significant difference, with a decrease of KMM 0.17% and KMC 0.00% when compared to control. (Fig. 2).

Sodium: The sodium content of KMM (0.13 ± 0.11 mg/100g), followed by KMC (0.12 ± 0.01 mg/100g) and KMW (0.11 ± 0.01 mg/100g). In Fig. 3, it was graphically illustrated that, there was an increase of KMM 8% and KMC 4% when compared to control.

Energy: The energy content of KMC (329Kcal/100g) and KMM (327Kcal/100g), showed no significant difference with the control (349Kcal/100g). In KMM 6.3% decrease of energy was observed, where as in KMC 0% was observed (Fig. 2).

Iron: The iron content of KMM (0.03 ± 0.01 mg/100g) and KMC (0.03 ± 0.01 mg/100g) was greater than KMW (0.02 ± 0.01 mg/100g) was significantly ($p \leq 0.05$). The iron content of KMM 50% and KMC 50% significant difference is greater than control (Table 7).

Calcium: The results indicated in Table 7 that the calcium content of KMM (0.27 ± 0.01 mg/100g) and KMC (0.26 ± 0.01 mg/100g) was significantly ($p \leq 0.05$) more when compared to KMW (0.25 ± 0.01 mg/100g), with an increase of 8% KMM and 4% of KMC (Fig. 3).

Zinc: The results in Table 7 indicated that KMM (2.72 ± 0.01 mg/100g) and KMC (2.65 ± 0.01 mg/100g) had significantly greater ($p \leq 0.05$) when compared to KMW (2.23 ± 0.01 mg/100g). In KMC 18% decrease in zinc content, and KMM 21% increase was observed (Fig. 3).

Potassium: The results indicated in Table 7 that potassium content of KMM (2.15 ± 0.01 mg/100g) and KMC (2.10 ± 0.01 mg/100g) was significantly ($p \leq 0.05$) greater when compared to KMW (4.35 ± 0.01 mg/100g), with an increase of 5.07% KMM and 51.7% of KMC (Fig. 3).

4. CONCLUSION

The analysis of kodo millet pops revealed significant changes across various parameters, reflecting the effects of processing on their physical, functional, and nutritional attributes. Physically, decreases were observed in true

density, and bulk density, indicating alterations in the structural integrity of the millet grains upon popping. While the expansion ratio showed a decrease with higher moisture content, affecting the overall texture and volume of the pops.

The ideal temperature for conventional popping and machine popping is 250°C and 290°C with 14% moisture.

Functionally, there were notable increases in the water solubility index and water absorption capacity, suggesting improved water interaction properties post-processing. Conversely, oil absorption capacity decreased significantly in KMC2514 (6.48%) and KMM2914 (78.70%), which could influence the sensory attributes and shelf-life stability of the pops.

Nutritionally, significant decreases were observed in moisture content for KMM2914 (42.8%) and KMC2514 (50.5%), as well as in ash, crude fiber, protein, fat, starch, and energy contents. In contrast, carbohydrate content increased significantly.

Mineral analysis revealed significant increases in calcium, iron, zinc, and sodium content, which are beneficial for overall nutritional value. However, potassium content decreased notably in KMM2914 (50.57%) and KMC2514 (51.7%).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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