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Effect of microwave treatment on physical and functional properties of foxtail millet flour

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Abstract

Foxtail millet is one of the common millets used for multiple purposes in India. It contains a good amount of fiber along with other nutrients and thus serves as a digesting aid. Because of its diversified benefits, foxtail millet has a wide range of applications in the bakery, brewery, and beverage industries. The application of novel thermal technologies to maintain and improve the nutritional and quality characteristics is of great importance in recent days. The present study investigates the application of microwave pre-treatment to the foxtail millet and understanding of its effects on physical and functional properties. Physical properties like tapped density, bulk density, Carr's index, and Hausner ratio didn't show any difference in the obtained values. Even though, there was a noticeable change in color of microwave treated flour, that didn't show any impact on its visual appearance. Oil absorption capacity decreased with microwave treatment while water absorption capacity resulted increased. Swelling power decreased with an increase in power level and time. However, the solubility of flour increased with microwave treatment and the highest solubility was noticed at 840 W and 2 min treatment conditions.

Keywords: Microwave, physical and functional properties, foxtail millet flour

1. Introduction

Millets refers to small-seeded annual cereal grains and consumed as a staple food for millions of people mainly those who live in the part of arid and semiarid regions of the world. Among various millet varieties, foxtail millet (*Setaria italica*) is one of the most important and oldest cultivated millet species and is also recognized as the sixth-highest yielding grain. Foxtail millet is also named as Italian millet which belongs to the Poaceae family of *Setaria* genus (Sunil *et al.*, 2016)^[19]. Foxtail millet gains prominence because of its many health benefits like hypoglycaemic effects, prevention of cancer, and hypolipidemic effects, and these benefits are primarily attributed to the presence of antioxidants in the form of phenolics and carotenoids (i.e., phytochemicals), which induces a deactivation of free radicals inside the human body (Sharma *et al.*, 2018)^[13].

The nutritional profile of foxtail millet is also superior to the staple cereals (rice and wheat), and possess comparable contents of protein (12-19%), fat (5-9%), soluble fiber (3-4%), minerals (3.3%), iron (2.8%) and calcium (31%). It also a greater source of vitamins and phytochemicals like riboflavin, thiamine, niacin, folacin, and β -carotene (Sunil & Venkatachalapathy, 2017)^[18].

Morphologically, the endosperm of foxtail millet is encased in a tough outer aleurone layer along with a husk portion of 13.5% (w/w) as a distinct entity. The foxtail millet needs to be milled to separate the inedible husk prior to its consumption as similar to rice. Moreover, the majority of fiber, phenolics, and phytates are also concentrated in the layers of a pericarp, seed coat, and aleurone of the grain which hinders the nutrient absorption of millets to the body. These anti-nutrients can be reduced by using simple processing methods such as milling, germination, roasting, and other further heat treatments (dry, and wet) to enhance its texture and cooking quality (Umesha *et al.*, 2015)^[20].

Over the decades, the foxtail millet was processed by conventional methods to improve its edible, nutritional, and sensory properties. Recently, microwave processing has come into a light to enhance the physicochemical accessibility of micro and macronutrients by improving the dehulling efficiency (Sunil & Chacko, 2019)^[17] and reducing the anti-nutritional factors.

Moreover, microwave processing is also the most suitable technique because of its faster drying rate, uniform and rapid heating, lesser time, precise control, and low operational cost and time (Devraj *et al.*, 2020; Naik *et al.*, 2021) [2, 8]. Even though foxtail millet consumption and utilization are limited because of their insufficient availability of ready-to-cook, and ready-to-eat millet products as are available for rice and wheat. The majority of the processed foxtail millets are marketed in the form of rice, flour, or semolina (like rava). But, there is a greater scope of its exploitation in the development of various food products including baked products like biscuits, cookies, cakes, bread, muffins, pies, pancakes, snacks, extruded foodstuffs, and breakfast cereals (idli, dosa, papad, and chakli) which is primarily dependent on its flour functionality (Karupphasamy *et al.*, 2013) [4].

Considering the scope and demand of novel food ingredients and processing technologies efforts have been made to investigate the effects of microwave treatment on the physical and functional properties of foxtail millet flour. We believed that the microwave treated foxtail millet flour serves as a “novel food ingredient” for the development of various processed food products. In this study, we have explored the effect of microwave pre-treatment prior to milling on physical (Color, Bulk density, Tapped density, Carr’s index, and Hausner ratio) and functional properties such as water and oil absorption capacities, solubility, and swelling capacity of foxtail millet flours and their quality.

2. Material and methods

2.1. Materials

Foxtail millet grains (*Setaria italic* L) were procured from Thanjavur local market, Tamilnadu. The grains were cleaned with an 850-micron sieve (ASTM No. 20) in a mechanical sieve shaker to separate foreign impurities and damaged kernels. The cleaned sample was packed tightly in a zip-lock polyethylene bag and stored in a dry place at room temperature (30 ± 2°C) for further processing.

2.2. Microwave treatment of foxtail millet grains and milling

Foxtail millet grains of 500 g were conditioned to 24% (w.b.) from initial moisture of 10 ± 0.5% (w.b.) by adding the desired quantity of double distilled water (92.1 ml) according to the methodology given by Yadav *et al.*, (2012) [21, 22]. The conditioned foxtail millets (250 g) were spread uniformly (grain thickness: 1.6 ± 0.1 cm) in the petri plates and allowed for microwave treatment.

The domestic microwave (MW) oven (Model: 30 SC2, IFB, India) having an operating frequency of 2450 MHz with a maximum input power of 1400 W and rated output power of 900 W was used for treatment. The conditioned foxtail millet grains of 24% (w.b.) moisture was used for microwave (MW) treatment at the ambient condition with varying power levels (720, 810, and 900 W) for different exposure times (2, 4, and 6 min). The treated millet grains were cooled and dried to constant moisture of 11.5 ± 0.5% (wb) at room temperature. Furthermore, the dried grains were dehusked in a laboratory abrasive (emery roll) polisher (Model: TM 05, Satake Corporation, Japan). The dehusked millets were cleaned by air winnowing for removal of dust and husk material before the grinding. The dehusked millet grains were pulverized into a fine flour using a laboratory mill and sieved using a 500-micron sieve for uniform size particles. The foxtail millet flour (< 500 microns) was used for further analysis and the whole experiments were carried out in triplicates.

The samples were named as C (Control), T₁ (720W-2 min), T₂ (720W-4 min), T₃ (720W-6 min), T₄ (840W-2 min), T₅ (840W-4 min), T₆ (840W-6 min), T₇ (900W-2 min), T₈ (900W-4 min) and T₉ (900W-6 min).

2.3. Physical properties

2.3.1. Color

The color values of samples were estimated using a hunter lab colorimeter (Colourflex EZ model: 4510, Hunter Associates Laboratory, Reston, VA). The color values were calibrated with a white tile (X= 80.06, Y= 85.06, Z= 89.63) and a black tile as a standard supplied by the manufacturer before experimenting. The L*, a*, b* values (where L* - lightness to darkness; a* - redness to greenness; b* - yellowness to blueness) of a millet flours were recorded. The total color differences (ΔE) between the different FMF samples were calculated according to (Khushbu *et al.*, 2020) [5].

2.3.2. Bulk density and Tapped density

Control and MW treated flours were analyzed for bulk density and tapped density according to (Smita *et al.*, 2019) [15]. Briefly, a graduated cylinder of 100 ml was taken and filled with flours up to the mark of 100 ml. Afterward, the weight of the cylinder was noted to calculate the bulk density (g/ml), and then the cylinder was tapped 10 times on the flat surface to allow the flow particles get settle. Tapped density (g/ml) was calculated from the final weight of tapped cylindrical tube after filling the material up to a 100 ml volume.

2.3.3. Carr’s index (CI) and Hausner ratio (HR)

Carr’s index (CI) and Hausner ratio (HR) indicates the compressibility and cohesiveness of the millet flour particles. These were measured with the values of bulk and tapped densities as per the equations (1 & 2) given by (Smita *et al.*, 2019) [15].

$$CI = \frac{\text{Tapped density} - \text{Bulk density}}{\text{Tapped density}} \times 100 \quad (1)$$

$$HR = \frac{\text{Tapped density}}{\text{Bulk density}} \quad (2)$$

2.4. Functional properties

2.4.1. Water and oil absorption capacities:

The water absorption capacity (WAC) and oil absorption capacity (OAC) of the FMF were measured according to (Nikitha & Natarajan, 2020) [9]. Briefly, 1 gram of FM flour sample was precisely weighed and added to a centrifuge tube containing 10 ml of either water or refined sunflower oil and mixed thoroughly for 30 sec. The sample was kept aside at room conditions for 30 min without stirring followed by centrifugation of the sample at 2000 rpm for 30 min. The supernatant was removed and the tubes with pellets were weighed. The water/oil absorption capacity (OAC/WAC) values were calculated from the increase in weight of the sample and are indicated as a gram of water/oil absorbed by the gram (d.b.) of the sample.

2.4.2. Swelling power (SP) and water Solubility index (S)

The swelling power (SP) and solubility (S) of FMF were measured by heating a flour-water slurry (0.5 g flour in a 15 mL of distilled water) in a water bath at 90°C for 30 min, with continuous stirring (Obadi *et al.*, 2018) [11]. The resulting flour-water slurry was cooled to ambient temperature and

centrifuged at 4000 rpm for 15 min. The supernatant was decanted into a weighed evaporating petri dish and dried at 100°C for 20 min. The weight of dried supernatant and sediment was noted. The percentage solubility (S%) and swelling power (SP g/g) on a dry basis were determined as per equations (3 & 4) given below:

$$S (\%) = \frac{\text{dry supernatant weight}}{\text{weight of a dry sample}} \times 100 \quad (3)$$

$$SP \left(\frac{\text{g}}{\text{g}}\right) = \frac{\text{sediment weight} \times 100}{\text{dry sample weight} \times (100 - S\%)} \quad (4)$$

2.5. Statistical analysis

All the statistical analyses required for the experimental results were performed using Minitab statistical software (Version 17.0). One-way analysis of variance (ANOVA) with multiple comparisons was used to compare the data obtained from various treatments. Tukey's pairwise comparisons was performed to establish a probability level of $p \leq 0.05$ for considering significance. All the experiments were performed in triplicates and values were reported as mean \pm standard deviation.

3. Results and discussions

3.1. Effect of microwave treatment on physical properties

3.1.1. Tapped density and bulk density

From the experimental study, it was noticed that the tapped density of flour samples was higher than the bulk density as it at all the treatment levels and in the control sample, as the volume of voids become negligible due to external force

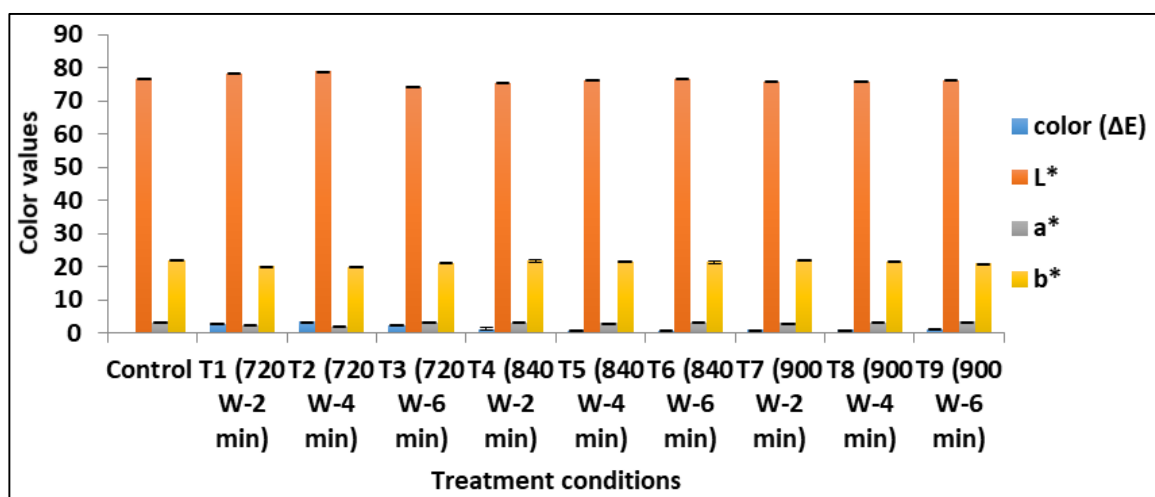
applied (Smita *et al.*, 2019) [15]. In the case of tapped density, some of the treated samples resulted in higher values compared to untreated flour. Flour treated at 720 W for 2 min showed higher tapped density (0.734 ± 0.055 g/mL) compared to control (0.702 ± 0.005 g/mL). However, no statistical difference was found between the highest value reported and samples treated at 840 W. Tapped density decreased with increasing treatment time at 720 and 900 W, while the trend in 840 W treatments was unclear. On the other hand, there was no significant difference found between the bulk density of treated and untreated flour as explained in table 1. Increasing the power level and treatment time did not report any notable difference in the BD and TD of sample flours ($P > 0.05$). Table 1 represents the values obtained for bulk and tapped densities in treated and untreated samples.

Table 1: Bulk density and tapped density of microwave treated foxtail millet flour

Treatment conditions	BD(g/ml)	TD (g/ml)
Control	0.61 ± 0.006^a	0.70 ± 0.005^b
T1 (720 W-2 min)	0.64 ± 0.012^a	0.73 ± 0.051^a
T2 (720 W-4 min)	0.63 ± 0.007^a	0.71 ± 0.011^b
T3 (720 W-6 min)	0.61 ± 0.003^a	0.71 ± 0.002^b
T4 (840 W-2 min)	0.62 ± 0.008^a	0.72 ± 0.006^{ab}
T5 (840 W-4 min)	0.62 ± 0.003^a	0.71 ± 0.006^{ab}
T6 (840 W-6 min)	0.63 ± 0.007^a	0.72 ± 0.007^{ab}
T7 (900 W-2 min)	0.61 ± 0.034^a	0.72 ± 0.004^{ab}
T8 (900 W-4 min)	0.61 ± 0.005^a	0.71 ± 0.021^{ab}
T9 (900 W-6 min)	0.61 ± 0.004^a	0.70 ± 0.003^b

All the data are expressed in the form of mean \pm standard deviation; Means that do not share a common alphabet are significantly different $p \geq 0.05$.

3.1.2. Effect of microwave treatment on color values



All the data are expressed in the form of mean \pm standard deviation; Means that do not share a common alphabet are significantly different $p \geq 0.05$.

Fig 1: L*, a*, b* and ΔE values of microwave treated foxtail millet flour

Figure 1 explains the effect of microwave treatment on the color of untreated and microwave treated foxtail millet flour. The lowest ΔE values along with closer L* values to the control sample were observed in the treatment condition, 840 W for 6 min.

On the other hand, a* value similar to control was reported at 720 W and 6 min while b* value was reported at 900 W and 2 min. The lowest values of L*, a*, and b* with high ΔE were observed during the treatment condition of 720 W power. The slight differences in color values might be caused by the

transformation of flavanols in color pigments into intermediate compounds induced by a microwave treatment during heat treatment (Yadav, Kaur, *et al.*, 2012) [21, 22].

Microwave parameters like treatment time and power used for treatment can have a significant impact on the degree of change in color parameters and these slight changed ΔE may attribute to the formations of brown pigments with high and low molecular weights by a Millard reaction (Srinivas *et al.*, 2020) [16].

3.1.3. Effect on Carr's index (CI) and Hausner ratio (HR):

Carr's index and Hausner ratio exhibited no significant difference between the microwaves treated and control samples. Carr's index for the control sample was found to be 0.13 ± 0.005 while the lowest value, 0.10 ± 0.019 was at 720 W and 4 min treatment condition with the highest flowability. Carr's index also called compressibility index is a measurement of flowability of flour, i.e., flour with CI less

than 15 has good flowability while above 35 shows bad flowability (Smita *et al.*, 2019) [15]. In the present study, the lowest value for HR was reported at the treatment condition 720 W and 4 min, similar to that of CI. Flour with HR greater than 1.35 has poor flow properties, while it is the reverse case in the present study, confirming the retaining of flow properties of flour upon microwave treatment as in the case of the control sample ($P = 0.684$) (Hamdani *et al.*, 2014) [3].

Table 2: Carr's index and Hausner ratio of microwave treated foxtail millet flour

Treatment conditions	Carr's index (CI)	Hausner ratio (HR)
Control	0.13 ± 0.005^a	1.15 ± 0.007^a
T1 (720 W-2 min)	0.13 ± 0.023^a	1.16 ± 0.030^a
T2 (720 W-4 min)	0.10 ± 0.019^a	1.12 ± 0.023^a
T3 (720 W-6 min)	0.14 ± 0.006^a	1.16 ± 0.009^a
T4 (840 W-2 min)	0.13 ± 0.015^a	1.15 ± 0.020^a
T5 (840 W-4 min)	0.14 ± 0.003^a	1.16 ± 0.005^a
T6 (840 W-6 min)	0.13 ± 0.011^a	1.14 ± 0.014^a
T7 (900 W-2 min)	0.14 ± 0.02^a	1.17 ± 0.073^a
T8 (900 W-4 min)	0.14 ± 0.019^a	1.16 ± 0.026^a
T9 (900 W-6 min)	0.14 ± 0.003^a	1.16 ± 0.004^a

All the data are expressed in the form of mean \pm standard deviation; Means that do not share a common alphabet are significantly different $p \geq 0.05$.

3.2. Effect of microwave treatment on functional properties**3.2.1. Effect on water absorption and oil absorption capacity**

The oil absorption capacity of FMF was found to be decreased with microwave treatment while it is vice versa in the case of water absorption capacity. The lowest oil absorption capacity was noticed at 840 and 900 W when flour is treated for 6 min. In the case of water absorption capacity, the highest water absorption capacity was noticed at treatment level 840 W and 6 min, i.e., 1.58 ± 0.047 g/g. Similar trends of oil and water absorption capacities were observed by Sahni and Sharma performed microwave treatment studies on alfa-

alfa flour and reported similar trends of oil and water absorption capacities (Sahni & Sharma, 2020) [12].

Heat-induced protein denaturation results in the unfolding of protein molecules, followed by exposure to polar side chains. This leads to an increase in water absorption and a decrease in the oil absorption capacity of treated flour (Singh, 2001) [14]. An increase in water absorption capacity leads to increased water availability, which plays a major role in starch gelatinization and turns the final texture of cooked products. Decreased OAC can be attributed to the presence of a lesser amount of hydrophobic amino acids in the sample (Ashraf *et al.*, 2012) [1].

Table 3: Oil absorption and water absorption capacity of microwave treated foxtail millet flour

Treatment	OAC(g/g)	WAC(g/g)
Control	1.63 ± 0.030^a	1.15 ± 0.061^f
T1 (720 W-2 min)	1.45 ± 0.033^{bc}	1.24 ± 0.0184^{ef}
T2 (720 W-4 min)	1.60 ± 0.028^a	1.33 ± 0.025^{de}
T3 (720 W-6 min)	1.48 ± 0.014^b	1.30 ± 0.003^{de}
T4 (840 W-2 min)	1.58 ± 0.035^a	1.33 ± 0.041^{de}
T5 (840 W-4 min)	1.17 ± 0.032^e	1.47 ± 0.015^{bc}
T6 (840 W-6 min)	1.15 ± 0.032^e	1.58 ± 0.047^a
T7 (900 W-2 min)	1.38 ± 0.016^c	1.26 ± 0.020^e
T8 (900 W-4 min)	1.28 ± 0.031^d	1.38 ± 0.042^{cd}
T9 (900 W-6 min)	1.15 ± 0.029^e	1.48 ± 0.012^b

All the data are expressed in the form of mean \pm standard deviation; Means that do not share a common alphabet are significantly different $p \geq 0.05$.

3.2.2. Effect of microwave treatment on solubility and swelling power

Swelling power of the microwave treated flour found to be decreased with an increase in power level and treatment time, except at 840 W-2 min.

Various studies confirmed the negative correlation between the swelling power and moisture content, i.e. increase in water absorption by flour results in less swelling power (Li *et al.*, 2019) [6].

The above inference can be attributed to the enhancement of intra and intermolecular forces upon microwave treatment, i.e., the formation of hydrogen bonding of water with various

hydroxyl groups. These phenomena result in lesser availability of water to the amylose and amylopectin, thus decreasing the swelling power of the sample (Luo *et al.*, 2006) [7].

The solubility of flour increased with microwave treatment when compared to untreated samples. The solubility of flour increased enormously from $17.94 \pm 1.81\%$ to $41.96 \pm 1.67\%$ at 840 W and 2 min treatment conditions, while it was in the range of 20% with other treatment conditions.

The degree of depolymerization and structural weakening of starch granules that occur due to microwave treatment is responsible for the solubility of flour (Obadi *et al.*, 2016) [10].

Table 4: Solubility and swelling power of microwave treated foxtail millet flour

Treatment	S (%)	SP (g/g)
Control	17.94±1.81 ^{de}	38.39±1.59 ^{de}
T1 (720 W-2 min)	27.20±1.50 ^b	38.82±0.82 ^b
T2 (720 W-4 min)	21.70±0.19 ^{cd}	34.07±0.51 ^{de}
T3 (720 W-6 min)	26.38±1.20 ^b	36.90±1.46 ^{bc}
T4 (840 W-2 min)	41.96±1.67 ^a	48.71±0.30 ^a
T5 (840 W-4 min)	19.67±0.63 ^{cde}	35.15±0.66 ^{cd}
T6 (840 W-6 min)	20.55±1.73 ^{cde}	32.23±0.59 ^{de}
T7 (900 W-2 min)	18.47±1.13 ^{cde}	34.84±1.36 ^{cde}
T8 (900 W-4 min)	22.85±1.63 ^{bc}	34.80±0.40 ^{cde}
T9 (900 W-6 min)	16.47±2.48 ^c	32.57±0.93 ^{de}

All the data are expressed in the form of mean±standard deviation; Means that do not share a common alphabet are significantly different $p \geq 0.05$.

4. Conclusion

The microwave pre-treatment prior to the milling of foxtail millets results in significant changes of functional properties (OAC, WAC, SP, and S) of flour ($p < 0.05$). The color values of MW treated sample flours were slightly changed with an acceptable limit as compared with the untreated sample. But, there was no significant effect on the bulk density, tapped density, HR, and CI values ($p > 0.05$). These results indicate that microwave heating as a pre-treatment can effectively enhance the functional properties of millet flours without affecting its physical parameters. The flour from microwave treated foxtail millet can exploit its applications in different food process purposes which can certainly help in the value addition of under-utilized foxtail millet.

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