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Effect of hot air assisted radio frequency technology on physical and functional properties of pearl millet

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Abstract
Pearl millet, an abundant source of essential macro-and micronutrients, carbohydrates, protein, dietaryfiber, lipids, and phytochemicals. However, the conventional techniques significantly influence the nutrient content and functional properties that are of importance in food application. Improved techniques are necessarily applied for value addition to give out more products of wide acceptance, thereby promoting food security. Therefore, the main objective of this work was to investigate the effect of hot air assisted radio frequency (HARF) treatment at different exposure periods (5, 8, 11 &14 min) on physical (moisture, colour, water activity, bulk density, tapped density, CI and HR) and functional (WAC, OAC, WSI) properties of pearl millet. As the exposure time increased, the moisture content and water activity were reduced significantly while the colour values and bulk density changed insignificantly. The functional properties such as WAC and WSI decreased insignificantly while the OAC was insignificantly increased as the exposure time increased.

Keywords: Hot air assisted radio frequency, pearl millet, physical and functional properties

Introduction
Millets are important crops in the semi-arid tropics of Asia and Africa (especially in India and Nigeria), with 97 percent of millet production in developing countries. Pearl millet (*Pennisetum glaucum* L.) is an important gluten-free drought resilient versatile cereal crop cultivated for food, feed, and forages. It is a staple food in most parts of Asia and Africa (Nithiyanantham *et al*., 2019) [22]. Because of its antioxidant, hypocholesterolemic, antimicrobial, antihypertensive, anti-inflammatory, and anticarcinogenic characteristics, pearl millet benefits in preventing heart diseases and diabetes (Chandrasekara *et al*., 2012; Gull *et al*., 2015) [6, 9]. Providing millets in the diet will help combat malnutrition, micronutrient deficiency diseases such as obesity, and celiac disease (Goswami *et al*., 2020) [8]. In addition, consumption of grains is inversely associated with risk of major chronic diseases such as cancer, diabetes and cardiovascular diseases (Reynolds *et al*., 2019) [24]. Pearl millet is a rich source of energy, quality protein (9–13%), vitamins, minerals (calcium, magnesium, phosphorous, iron, and zinc), crude fibers, phytochemicals, and fat (3–8%) with better fat digestibility than other cereals (Goswami *et al*., 2020) [8]. Although millets are nutritionally superior, lack of refined and processed millets limit their extensive use and acceptability. As the physical and functional characteristics of flour affect the final processed product quality, it is required to evaluate the functional attributes, and predict how the variation in occurs proteins, fat, fibre, and carbohydrates due to the treatment as well as demonstrate whether or not such protein can be used to stimulate or replace conventional protein. Functional properties are the properties that reveal the intricate relations between the structure, molecular components, and their behavior during processing (Chandra *et al*., 2015) [5]. The physical and functional properties are of importance in food application. Improved techniques applied for value addition are giving out more products of wide acceptance. The processed millet with improved qualities makes it fit for developing new food, thereby promoting food security.

An emerging technique, radio frequency (RF) (non-ionizing electromagnetic waves) generates heat from molecular friction between water molecules in the interior portion of the material owed to ionic conduction and/or dipole rotation. RF waves have higher wavelength and depth penetration compared with microwave which facilitates treating bulk food materials (Hassan *et al*., 2019) [12]. RF energy has been tentatively applied to different food processing, including thawing of frozen food like chicken breast meat (Bedane *et al*., 2018), disinfestation (Hou *et al*., 2016), pasteurization/sterilization (Jiao *et al*., 2018) [19], drying of agriculture products such as macadamia nuts, walnuts and kiwifruits (Wang *et al*., 2014) [33], roasting cashew nut kernels (Liao *et al*., 2018) [20] and protein modification (Ling *et al*., 2019) [21] etc. The main challenge for RF is the non-uniform heating caused by the inevitable uneven distribution of the electromagnetic field between the product and surrounding space (mostly air), particularly for food products (Fadiji *et al*., 2021) [7]. Therefore, RF is assisted with hot air for uniformity heating and to improve treatment efficiency (Wang *et al*., 2014) [34]. However, effect of HARF on the pearl millet is yet to be known to the readers. Therefore, this study evaluates the effect of HARF on the physical and functional characteristics of pearl millet.

Material and methods

Raw material

Pearl millet grains were procured from Thanjavur's local market, Tamil Nadu, India, cleaned to remove the dirt that may pass through a sieve of <1.00-mm opening, and then graded to treat the uniform-sized grains. The estimated moisture of the market sample was found as 12.5±0.4% w.b. The procured grains were sealed in plastic laminated packaging bags for further studies and avoiding the external environmental influence. All chemicals were of analytical grade.

HARF processing

Based on preliminary trials, procured pearl millet grains at an initial moisture of 12.5±0.4% w.b. were exposed to HARF (10 kW power, 40.68 MHz ± 0.5% operating frequency) for 5, 8, 11 and 14 min. After the treatment, pearl millet grains were decorticated by a laboratory steel polisher (Model: TM 05, Stake corporation, Japan), and then milled into flour (sieved to obtain the particle size <1 mm) by a hammer mill (Almech enterprise technologies, Coimbatore, India). The resultant flours were packed in labeled, airtight zip-lock polyethylene bags, and stored in refrigerated condition (3-4 ºC) for further studies.

Physical properties

Moisture content

The moisture content of procured grains was determined using hot air oven method (AOAC, 2005). In a dried silver dish (98–100°C), 5 g of pearl millet grains were heated in hot air oven at 130 ± 3°C and for every one-hour time interval, the weight loss (%wb) was measured until equilibrium moisture was reached.

Colour of pearl millet flour

The color values of flour from HARF-treated and HARF-untreated (control) pearl millets were assessed using Hunter lab colorimeter (Colourflex EZ model: 4510 Hunter Associates Laboratory, Reston, VA) in terms of L* (whiteness-darkness), a* (redness-greenness), and b* (yellowness-blueness). The instrument was calibrated using white and black tiles as standard, supplied by the manufacturer. Pearl millet flour samples were filled into a custom-designed quartz sample cup (2.9 D × 4.5 H cm^2) and gently tapped to remove air spaces to obtain uniformity. Triplicate determinations were averaged.

Water activity

The water activity of flours from HARF-treated and untreated pearl millet was determined using Water Activity Meter (4TE, Aqua Lab). Triplicate measurements were performed.

Bulk density

Bulk density was determined by finding the ratio of the sample's mass to its total volume (Omowaye-Taiwo *et al*., 2015) [23].

Tapped density

While filling the sample into a 10 mL graduated cylinder, it was gently tapped at the bottom several times to avoid air spaces in the flour (Omowaye-Taiwo *et al*., 2015) [23].

Carr's index and Hausner ratio

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 below given by Smita *et al*. (2019) [26].

$$\mathrm{CI} = \frac{\text{Tapped density} - \text{Bulk density}}{\text{Tappaed density}}$$

$$\mathrm{HR} = \frac{\text{Tapped density}}{\text{Bulk density}}$$

Functional properties

Water absorption capacity (WAC) and Water solubility index (WSI)

WAC and WSI were determined using the method Yadav *et al*. (2014) [35]. Pearl millet flour (2.5 g) was suspended, gently stirred for 30 min in water (25 mL) at room temperature (25–35°C), and then centrifuged at 3,000 g for 15 min. The supernatants were decanted into an evaporating dish of known weight. WAC and WSI were calculated as follows:

$$\mathrm{WAC\ (g/g)} = \frac{\text{Weight gain by gel}}{\text{Dry weight of sample}}$$

$$\mathrm{WSI(\%)} = \frac{\text{Weight to dry solids in supernatant}}{\text{Dry weight of sample}}$$

Oil absorption capacity (OAC)

OAC of the flours was determined by the method explained by Siroha *et al*. (2016) [25]. The flour sample (2 g) was mixed with 20 mL of oil in 50-mL centrifuge tubes, allowed to stand at 30 ± 2°C for 30 min and then centrifugation at 3,000 rpm for 10 min. The volume of collected supernatant from centrifuge tubes was determined.

Statistical analysis

Multivariate analysis of variance (MANOVA)

MANOVA is used to analyze the variations between mean values of dependent and independent variables and correlate the variations among the dependent variables between the different levels of the independent variables (Sridhar & Charles, 2018) [28]. All the experiments were conducted in triplicate runs to find the variability in data collection by measuring the standard deviation. Statistical analysis of experimental data was conducted using SPSS for Windows version 25.0 (IBM Corp, USA). The tabulated data are mean values and SD of triplicate observations. Multivariate analog of the analysis of variance (MANOVA) and Pearson correlation coefficient (r) were adopted to determine significant differences ($P< 0.05$) in physical and functional properties of pearl millet.

Results and discussion

Effect of HARF treatment on physical properties of pearl millet

Moisture content and water activity

The moisture levels of raw and HARF treated pearl millet were presented in Table 1. The moisture content of untreated pearl millet was 12.5% w.b while the values for the treated samples range between 11.1-7.7 % w.b, reduced significantly ($P< 0.05$) as the HARF treatment time was increased gradually (5-14 min). There was a statistically significant ($P< 0.05$) difference was noted in the moisture levels between the untreated and HARF treated pearl millets due to the RF waves generated heat from molecular friction between water molecules in the interior portion of the material owed to ionic conduction and/or dipole rotation (Hassan *et al*., 2019) [12]. Similar experimental results were obtained in the study demonstrated for soft wheat flour (Boreddy *et al*., 2019) [3], which was due to the water evaporation with the effect of temperature increase during the RF processing.

No significant difference in water activity of flours from HARF treated pearl millets was observed. With the increase of HARF treatment time (up to 14 min), the reduced *aW* of flours from HARF treated pearl millets was observed, indicating that the lower the moisture content of the kernel, the lower is the water activity value (Haque *et al*., 2004) [11]. Similar finding was reported by Carbajal-Padilla *et al*. (2022) [4] for black beans.

Table 1: Moisture content and water activity of pearl millet

	M.C (%d.b)	aW
Control	12.5±0.4^{a}	0.65±0.02^{a}
5 min	11.1±0.4^{ab}	0.41±0.01^{b}
8 min	9.9±0.7^{bc}	0.43±0.03^{b}
11 min	8.9±0.1^{cd}	0.45±0.02^{b}
14 min	7.7±0.1^{d}	0.46±0.03^{b}

Note: Values are mean ± SD of triplicate observations. Superscripts with same letters in the column are not significant ($p< 0.05$).

Colour of pearl millet flour

The effect of HARF treatment on the color attributes of pearl millet flour is depicted in Fig 1. No significant changes in *L** (darkness-whiteness) and a* (greenness-redness) values were observed with the enhanced HARF exposure time (5–14 min), but *b** (blueness-yellowness) values slightly increased leading to an increase of the yellow index. However, the different HARF exposure periods did not show significant ($P< 0.05$) effect on the *L**, *a**, and *b** values of pearl millet. In various studies using RF processing for low moisture foods, the process was reported to have no significant effect on color values (Jiao *et al*., 2012; Wang *et al*., 2012) [32].

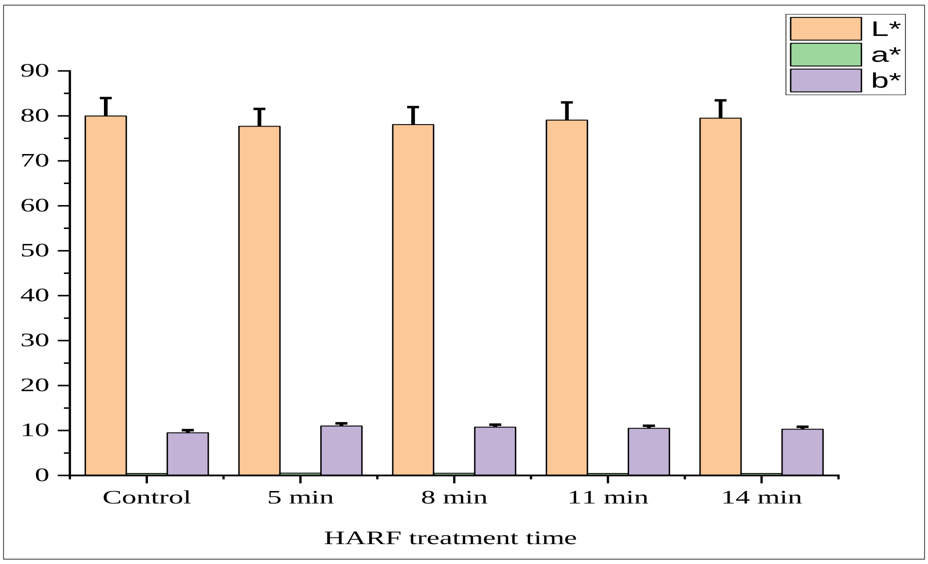

Fig 1: Colour values of pearl millet

Bulk density and tapped density

Table 2 shows the effect of HARF treatment on bulk density and tapped density of pearl millet flour samples. The bulk density and of density treated flours for 14 min exposure was 0.364 g/mL and 0.500 g/mL, respectively, while in case of control flours, they were 0.720 g/mL and 0.822 g/mL, respectively.

Table 2: Bulk density, tapped density, CI and HR of pearl millet

	BD (g/ml)	TD (g/ml)	CI (%)	HR
Control	0.720±0.053^{a}	0.822±0.056^{a}	12.3±0.004	1.141±0.005
5 min	0.292±0.094^{b}	0.552±0.048^{b}	46.1±0.219	2.024±0.821
8 min	0.357±0.049^{b}	0.510±0.081^{b}	29.9±0.014	1.427±0.029
11 min	0.350±0.021^{b}	0.500±0.021^{b}	30.0±0.011	1.430±0.024
14 min	0.364±0.025^{b}	0.500±0.036^{b}	27.1±0.002	1.373±0.004

Note: Values are mean ± SD of triplicate observations. Superscripts with same letters in the column are not significant ($P< .05$).

It was observed that the tapped density of all treated and control flour samples was higher than that of the bulk density, as the volume of voids become negligible due to external force applied (Smita *et al*., 2019) [26]. The bulk density and tapped density of HARF treated flour samples were lower than those of control flours. Moreover, a significant ($P< 0.05$) variation in bulk density and tapped density was noticed between the untreated and HARF treated flours. The low bulk density would be useful in the formulation of complementary foods (Suresh and Samsher, 2013) [29].

Carr's index and Hausner ratio

Carr's index, compressibility index, a measure of flowability of flours, i.e., flour with CI less than 15 has good flowability while above 35 shows bad flowability (Smita *et al*., 2019) [27]. In the present study (Table 2), CI was 12.3% for control with good flowability, while the lowest value in HARF treated flours (14 min) was 27.1% with cohesive flowability. The HR was reduced (2.02-1.37) with the increase of HARF exposure period (up to 14 min). The lowest value of HR was found to be 1.37 for the treatment condition 14 min HARF exposure, indicating that the flour is less free flowing (Venkateswararao *et al*., 2020) which is related to the interparticulate friction (Hamdani *et al*., 2014) [10]. The lowest CI and HR were noticed for pearl millets treated for 14 min.

Effect of HARF treatment on functional properties of pearl millet

Water absorption capacity (WAC) and Water solubility index (WSI)

Table 3 shows the effect of HARF treatment at different exposure periods on functional properties (WAC and WSI) of pearl millet with WAC (8.05 g/g), and WSI (8%) of control. The WAC of HARF treated pearl millets increased slightly as compared to raw pearl millet. The highest WAC (8.66 g/g) was found for the HARF treated pearl millet for 5 min while the lowest (8.49 g/g) was found for 14 min. There was no statistically significant ($P< 0.05$) difference found between raw and HARF processed pearl millets. These findings are in agreement with Hassan *et al*. (2019) [12] for RF treated wheat flour. Larger WAC benefits in products where hydration is necessary to improve handling characteristics like doughs and pastes (Ildikó *et al*., 2006; Yadav *et al*., 2012) [15, 35].

With increase of HARF exposure period (5-14 min), the enhancement in WSI was found. The WSI of HARF treated sample for 14min exposure was 7.5% while it was 8% for raw pearl millet sample, indicating that HARF treatment insignificantly ($P< 0.05$) lowered the WSI of pearl millet as compared to untreated one.

Generally, these findings indicated that HARF processing of pearl millet up to 14 min time period maintained the WAC and WSI properties.

Table 3: Functional properties of pearl millet

	WAC (g/g)	WSI (%)	OAC (g/g)
Control	8.05±0.04^a	8±0.01^a	0.07±0.01^a
5 min	8.66±0.24^a	5.5±0.01^a	1.03±0.69^a
8 min	8.62±0.24^a	4.8±0.29^a	1.56±0.02^a
11 min	8.53±0.04^a	6.5±0.00^a	1.02±0.70^a
14 min	8.49±0.12a	7.5±0.00^a	1.06±0.67^a

Note: Values are mean ± SD of triplicate observations. Superscripts with same letters in the column are not significant ($P< 0$ .05).

Oil absorption capacity (OAC)

OAC is the ability of flour to absorb oil and this is expedient as oil acts a flavor retainer and improves mouth feel (Iwe *et al*., 2016) [16]. The effect of HARF treatment on OAC of pearl millet is shown in Table 2. The highest OAC (1.56g/g) was found for HARF treated pearl millet exposed for 8 min. Ildiko *et al*. (2006) [15] reported that RF heat-treated mustard seed flour revealed good oil absorption capacity (OAC). In the present study, the trend was unclear. On the other hand, no statistically significant ($P< 0.05$) difference was noticed between untreated and HARF treated pearl millets.

Conclusion

HARF treatment prior to milling of pearl millet grains did not show any significant ($P< 0.05$) effect on functional characteristics (WAC, WSI, OAC) of pearl millets compared to untreated sample while the physical properties (moisture, water activity, bulk density and tapped density) were reduced significantly ($P< 0.05$). At the greatest exposure time of HARF (14 min), CI and HR were found to be greater than untreated pearl millet, indicated the cohesive flowability of flours. The colour values of HARF treated pearl millet changed slightly with an acceptable limit compared to untreated one. Therefore, these results indicate that HARF treatment can effectively improve the functional properties of pearl millet.These studies would be helpful in value addition and promote the utilization of nutricereals, pearl millet, which is underutilized.

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