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ORIGINAL PAPER

Optimization of Process Parameters for Decortication of Finger Millet Through Response Surface Methodology

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Abstract Decorticated finger millet is prepared by hardening the endosperm by hydrothermal processing and polishing the processed grains. The yield of the decorticated grains is of paramount importance in the millet industry. Milling yield depends on the grain moisture content and incipient moisture conditioning during milling. It was found that steaming conditions such as steaming time and steam pressure significantly influenced the milling yield. Hence, studies were undertaken to determine the influence of moisture and steaming conditions on the yield of decorticated millet. Steaming conditions were optimized through response surface methodology. The responses studied were hardness, milling yield, porosity and water uptake of hydrothermally processed millet. The studies indicated that hydrothermally processed millet with 16±1% moisture content, tempered with 5% added water at I stage and 4% water in the II stage milling, resulted in a yield of 64.6%. The relationship of milling yield, hardness and porosity of the millet was quadratic with the severity of steaming conditions, while water uptake of the steamed millet exhibited a linear relationship. Based on the regression analysis, optimum conditions estimated for steaming time and pressure were 17.5 min and 313.8 kPa, respectively. At this condition, the milling yield, water uptake, porosity and hardness values were also predicted and the values were 68.33 g/100 g, 63.43 g/100 g, 52.23% and 204.01 N, respectively. The studies indicate that steaming the millet at elevated pressure and temperature increases the milling yield and steaming beyond the threshold level has a detrimental effect on the yield of head grains.

Keywords Finger millet · Decortication · Moisture content · Steaming conditions · Milling yield · Response surface methodology

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Introduction

Finger millet (*Eleusine coracana*) or ragi is one of the important millets with superior nutritional qualities. The millet possesses unique morphological features such as soft and fragile endosperm with a tough seed coat rigidly attached to it. Thus, decortication or removal of seed coat from the endosperm was difficult by normal methods. Hence, the millet is invariably powdered and the whole meal is used in the traditional food preparations such as roti (pancake) or mudde (stiff porridge) (Malleshi 1989). But recently, the possibility of decortication of the millet by hardening its endosperm following hydrothermal processing has been established (Malleshi 2006). The decorticated finger millet could be cooked to discrete grains or could be subjected to secondary processing to prepare ready-to-eat products like expanded millet (Ushakumari et al. 2007). Thus, decortication of finger millet diversifies its food uses and facilitates value addition to the millet. The process of decortication is slowly gaining prominence in food industry, and in recent days, decorticated millet is being marketed to a limited extent.

Decortication or milling the hydrothermally treated finger millet involves removal of seed coat from the endosperm. Thus, yield of the decorticated grains plays an important role in milling industry. The yield of head grains for paddy varies as a function of several factors such as the percentage of cracked grains, harvesting conditions, drying conditions, preprocessing methods and the efficiency of milling machinery used (Bhattacharya 1980). It was also reported that parboiling is one of the efficient methods to reduce the breakage during milling of paddy (Bhattacharya 1969). However, along with parboiling, drying conditions and moisture content of the grains during milling also play a significant role in deciding the yield (Bhattacharya and Indudhara Swamy 1967). Reports are also available on the influence of environmental conditions on milling yield (Mohapatra and Bal 2010). However, in case of finger millet, the grains need to be hardened before decortication. Hence, parboiling or hydrothermal treatment is one of the pre-requirement for decortication. The preliminary studies on decortication of finger millet has been reported by Shobana and Malleshi (2007) which indicates that horizontal twin carborundum disc mill is most suitable for decortication and moistening the kernels before milling is highly feasible. However, this report confines to the decortication studies of finger millet steamed for 20 min only and not on the millet steamed at elevated pressure or temperature. Grain hardness is one of the important factors which determine the decortication characteristics of finger millet (Ushakumari 2011). It is well known that the hardness of kernels varies as a function of the severity of heat treatment (Islam et al. 2004). Moreover, it was observed that the yield of decorticated millet does not cross beyond 55% when the batch size is more than 10 kg (Ushakumari 2011). Hence, the main objective of this study was to determine the effect of steaming time and steam pressure on the hardness of finger millet and thereby to determine its influence on the yield of decorticated head grains.

Materials and Methods

Finger Millet

Finger millet (variety, GPU 28), procured from University of Agriculture Sciences, Bangalore, Karnataka, was used for the studies. The millet was cleaned to remove impurities and deglumed in an Engelberg huller (Sri Ganesha Engineering Works, Chennai, India). The deglumed material was sifted through a screen of 12 Tyler series to separate the small sized and shriveled grains and the well filled bold grains which remained as the overtails of the screen was used for the studies.

Preparation of Hydrothermally Processed Millet

The millet was steeped at ambient conditions for 8–10 h in water, to facilitate the grains to attain their equilibrium moisture content (Shobana and Malleshi 2007; Usha and Malleshi 2011). The steeped grains were washed to remove dirt, and the excess water was drained off. The adhering surface water of the steeped millet was blotted with the aid of a blotting paper, spread in steel trays (80×40×3 cm) in about 1-in bed thickness and steamed in an autoclave (Krauss Maffee Munchen, Germany) at atmospheric pressure (temperature 98°C) for 30 min. The steamed millet was dried in a mechanical dryer (Cross air flow truck dryer; Armstrong and Smith, Mumbai, India), maintained at 40±2°C until the moisture content of the millet dropped to 14±1%, and used for further studies.

Influence of Moisture Content of Hydrothermally Processed Millet on Decortication Characteristics

To determine the influence of grain moisture content on decortication characteristics, hydrothermally processed finger millet (HM) in a batch size of 10 kg each, equilibrated to different moisture levels ranging from 6% to 21%, was decorticated in a carborundum disc mill (Emery Stone Manufacture Company, Rajasthan, India) with horizontal alignment. From the preliminary experiments, it was observed that instead of single pass, two-stage milling is beneficial in terms of the yield of decorticated grains. Accordingly, the equilibrated samples were passed through the gap of the horizontal plates adjusted to about 1.3 mm (just below the average diameter of hydrothermally processed grains). The millet after the first pass was sifted through a sieve of 16 Tyler series followed by a sieve of 28 Tyler series and all the three fractions were collected separately. The "+16" Tyler series fraction was termed as head grains; "−16+28" Tyler series fraction as brokens and "−28" Tyler series fraction as seed coat or husk. The partially decorticated head grains were again decorticated in the same setup, and the decorticated head grains, brokens and seed coat were separated. The brokens and the seed coat matter from both the passes were pooled. The grains that were almost free from seed coat (>90%) were considered as decorticated grains. All three milling fractions were equilibrated to 12% moisture content, weighed and the yield of head grains and other fractions were calculated using the following relation:

$$\begin{aligned}
&(a)\text{Yield of head grains }(\%) = \frac{\text{Weight of head grains}}{(\text{Weight of head grains} + \text{brokens} + \text{husk})} \times 100 \\
&(b)\text{Yield of brokens }(\%) = \frac{\text{Weight of brokens}}{(\text{Weight of head grains} + \text{brokens} + \text{husk})} \times 100 \\
&(c)\text{Yield of seed coat }(\%) = \frac{\text{Weight of seed coat}}{(\text{Weight of head grains} + \text{brokens} + \text{husk})} \times 100
\end{aligned} \quad (1)$$

An average of three replications was taken.

Influence of Incipient Moist-Conditioning

The experiments on influence of moisture content on the yield of head grains indicated that the millet at the 16±1% moisture level was more suitable for decortication and accordingly, HM equilibrated to 16±1% moisture level in 10-kg batches, was sprayed with 1–7% additional water with 1% increment, tempered for 10 min and decorticated as described above. The head grains from the first stage of milling were again mixed with 1–6% additional water, with 1% increment, equilibrated and milled in the same set up. The milling fractions (head grains, brokens and seed coat) were equilibrated and weighed to determine the milling yield. Based on these experiments, a decortication protocol was developed (Fig. 1).

Influence of Steaming Conditions

To study the influence of steaming conditions, namely, steaming time and steam pressure, on the decortication characteristics of finger millet, an experiment was designed using response surface methodology. The experiment was designed to find out the most suitable conditions of steaming, that produces the millet with desirable level of hardness, which on decortication yields maximum percentage of decorticated head grains. The responses studied were mainly hardness and milling yield. In addition to this, porosity and water uptake of HM, which indicate the severity of steaming, were also included as part of the measured responses.

Hardness

Hardness of the processed millet was measured using texture analyzer (Stable Microsystems, Model TA-HDi, Surrey, UK) with 50 kg load cell, by recording maximum force required to cause 80% compression of the products, at a crosshead speed of 100 mm/min.

The peak force required to compress the samples was referred as a measure of hardness and an average for ten replicate values is reported.

Porosity

A known amount of each of the samples was taken in a measuring cylinder and tapped on a wooden plank so that the voids between the kernels were minimal, and the volume was noted to calculate the apparent density. The kernels were then

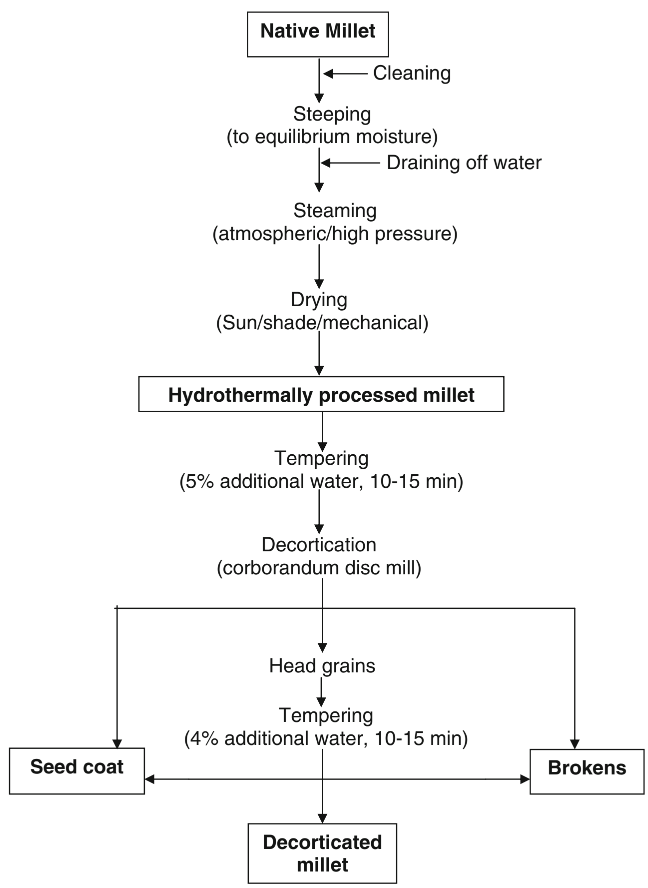


Fig. 1 Flow chart for the preparation of hydrothermally treated and decorticated finger millet

immersed in toluene to note down the true volume, and true density of the kernels was calculated. Porosity of the samples was calculated using the equation (Mohsenin 1996);

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad (2)$$

where ε is the porosity in %, ρ_b is the bulk density in kg/m^3 and ρ_t is the true density in kg/m^3.

Water Uptake

Five grams of each of the samples was added to 15 ml of distilled water taken in a test tube and stirred momentarily with a wire to dislodge any air bubble, and left to hydrate for 12 h. The contents were strained through a wire strainer and the surface water was removed using blotting paper and weight of each of the samples was noted to calculate the percent water uptake (Ali and Bhattacharya 1972).

Scanning Electron Microscopy

To visualize the textural changes of the millet after hydrothermal processing, the grains of native and HM were cut transversely into two halves using a sharp blade. The cut portions were mounted on metallic stubs and were gold coated (about 100 Å) in a KSE 2 AM Evaporation Seevac gold sputter (Polaron SEM Sputter Coating System, Hertfordshire, UK). The samples were scanned in a LEO 435VP scanning electron microscope (Leo Electron Microscopy Limited, Cambridge, UK) and the selected portions depicting morphological features were photographed (Meek 1976).

Experimental Design

A two-variable (steaming time and steaming pressure), five-level central composite rotatable (CCRD) experimental design (Myers 1971) was employed. The complete experimental design is shown in Table 1 with coded as well as actual levels of independent variables. The experimental design included star points (±1.414), and five centre design points. All experiments were carried out in a randomized order to minimize any effects of extraneous factors on the responses observed. The responses analyzed were, milling yield, hardness, porosity and water uptake. The regression coefficients of the response function, their statistical significances and processing conditions were evaluated. Coefficients of the model given in Eq. 3 were evaluated by regression analysis and tested for their significance. The insignificant coefficients were eliminated based on the p values and the final equation for prediction of the responses was provided.

Table 1 Variables and their coded and actual levels used in the experimental design of central composite rotatable design

Parameters	Coded levels of variables				
	−1.414	−1.0	0	+1.0	+1.414
Steaming time, X_1 (min)	0	5.12	17.5	29.88	35.0
Steam pressure, X_2 (kPa)	0	57.86	196.13	334.41	392.23

Statistical Analysis

Canonical analysis described by Myers (1971) was used to determine the nature of responses—whether they are minimum, maximum or mini-max (Ravi and Susheelamma 2005; Mangaraj and Singh 2011). The data were analyzed by multiple regression analysis to fit second-order (quadratic) polynomial model.

$$y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} x_i^2 + \sum_{i=1}^{2} \beta_{ij} x_i x_j \quad (3)$$

where y is the predicted response, β_0, β_i, β_{ii}, and β_{ij} are constant regression coefficients of the model, whereas, X_i and X_j are the independent factors. The effect of individual linear, quadratic and interaction terms has been determined (Khuri and Cornell 1987). The significance of all the terms in the polynomial was judged by F-test and p values. The significance of the multiple correlation coefficient (R) was judged by probability levels. To visualize the relationships between responses and independent factors, statistical software Statistica (version 5, StatSoft, Tulsa, OK) was used and the results were expressed graphically by generating response surfaces.

Results and Discussion

Influence of Grain Moisture Content

The decortication characteristics of hydrothermally processed millet were influenced by the grain moisture content. It was observed that the millet with moisture content less than 12% resulted in considerable breakage of the kernels without peeling the seed coat. As the moisture content of HM increased up to 16±1%, the yield of decorticated millet improved and beyond that, breakage as well as deshaping of the kernels occurred (Fig. 2). Under the experimental conditions, the millet with about a 16±1% moisture content exhibited maximum yield of decorticated grains (45%). For efficient decortication of hydrothermally processed millet, the grains should be hard but not brittle. The moisture content below 12% rendered the grains brittle and hence, increased the breakage. However, the grains with moisture content beyond 16%, turned soft and thus increasing the breakage.

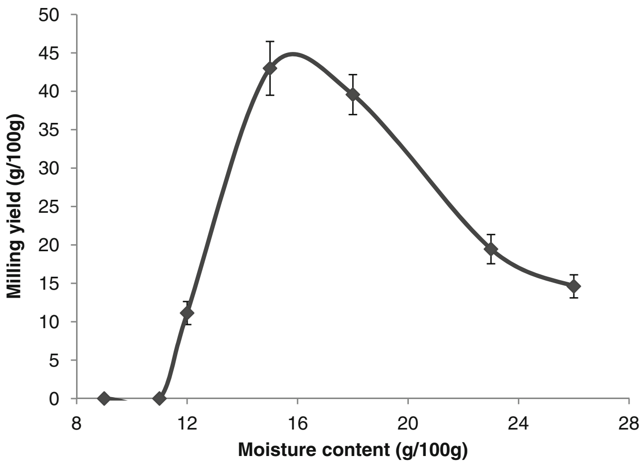


Fig. 2 Yield of head grains as a function of the grain moisture content

Influence of Incipient Moist Conditioning

Moist-conditioning improved the decortication characteristics of the millet. It could be inferred from the Table 2 that the yield of the head grains varied as a function of added moisture. The yield increased from 56.3% to 85.3% as the percentage of added water increased from 1% to 5% and after that, it decreased with a significant increase in the brokens. The highest yield of 85.3% was obtained for the sample with 5% added water during the first stage milling. During the second-stage milling, it was observed that the yield of the decorticated grains increased (50% to 64.6%) as the percentage of added water increased from 1 to 4 and thereafter the yield started declining. Thus, HM with 16±1% moisture content tempering with 5% added water at I stage milling, followed by tempering with 4% water in the II stage, resulted in a milling yield of 64.6% (Table 2). Thus, under the experimental conditions of milling, the yield of head grains, brokens and seed coat fractions were 64.6%, 19.6% and 15.8%, respectively.

The effect of grain moisture content on milling yield has been well documented in case of rice. Generally, at low moisture content, the grains are brittle and will not withstand the milling impact resulting in breakage whereas, at high moisture content, the grains are soft and get fragmented decreasing the total head grain yield (Bhattacharya and Indudhara Swamy 1967). Also, in case of finger millet, Shobana and Malleshi (2007) reported that tempering with 6% additional water improved the decortication characteristics. Incipient moist conditioning softens the seed coat rendering it slightly leathery and hence gets easily scrapped between the carborundum discs of the mill. Moist-conditioning the millet beyond 5% at I stage and 4% at II stage milling, again rendered to millet soft and hence caused deshaping leading to decrease in the milling yield.

Response Surface Plotting

The effect of steaming time and steam pressure on the responses namely, hardness, milling yield, porosity and water uptake of hydrothermally treated millet are presented in Fig. 3a-d. The response surfaces were selected based on the significant interaction terms between the two variables within the experimental range. The treatment schedule and the measured responses were indicated in Table 3.

Effect of Steaming Time and Steam Pressure on Hardness

Hardness of the kernels generally indicates the grain strength, which can be defined as the ability of a material to withstand applied forces without fracture (Chandrashekar

Table 2 Yield of milling fractions as influenced by the moist conditioning

Trial No.	Added moisture (%)	Head grains (%)	Brokens (%)	Seed coat (%)
I Stage				
a	1	56.3±1.2^{a}	39.4±1.0^{f}	4.3±0.4^{a}
b	2	60.0±1.5^{b}	35.2±1.2^{e}	4.8±0.5^{ab}
c	3	69.0±1.3^{c}	25.4±0.9^{d}	5.6±0.5^{b}
d	4	75.7±2.0^{d}	15.5±0.6^{c}	8.8±0.8^{cd}
e	5[1]	85.3±2.1^{e1}	$^{(i)}$5.7±0.5^{a}	$^{(ii)}$9.0±0.8^{d}
f	6	85.2±2.1^{e}	6.9±0.5^{b}	7.9±0.6^{c}
II Stage milling with sample "e"				
i	1	50.0±1.1^{a}	30.7±0.8^{c}	4.6±0.5^{a}
ii	2	55.2±1.2^{b}	24.8±0.7^{d}	5.3±0.5^{ab}
iii	3	60.4±1.1^{c}	18.9±0.6^{c}	6.0±0.6^{bcd}
iv	4	64.6±1.2^{c}	$^{(iii)}$13.9±0.4^{a}	$^{(iv)}$6.8±0.6^{d}
v	5	62.3±1.1^{d}	16.6±0.6^{b}	6.4±0.5^{cd}
Milling yield		64.6±1.2	$^{(v)}$19.6±0.5	$^{(vi)}$15.8±0.8

Values in the same column with different superscripts differ significantly ($P \leq 0.5$) according to Duncan's multiple range test (DMRT)

[1]Sample "e" is taken for II stage milling

v=(i)+(iii)

vi=(ii)+(iv)

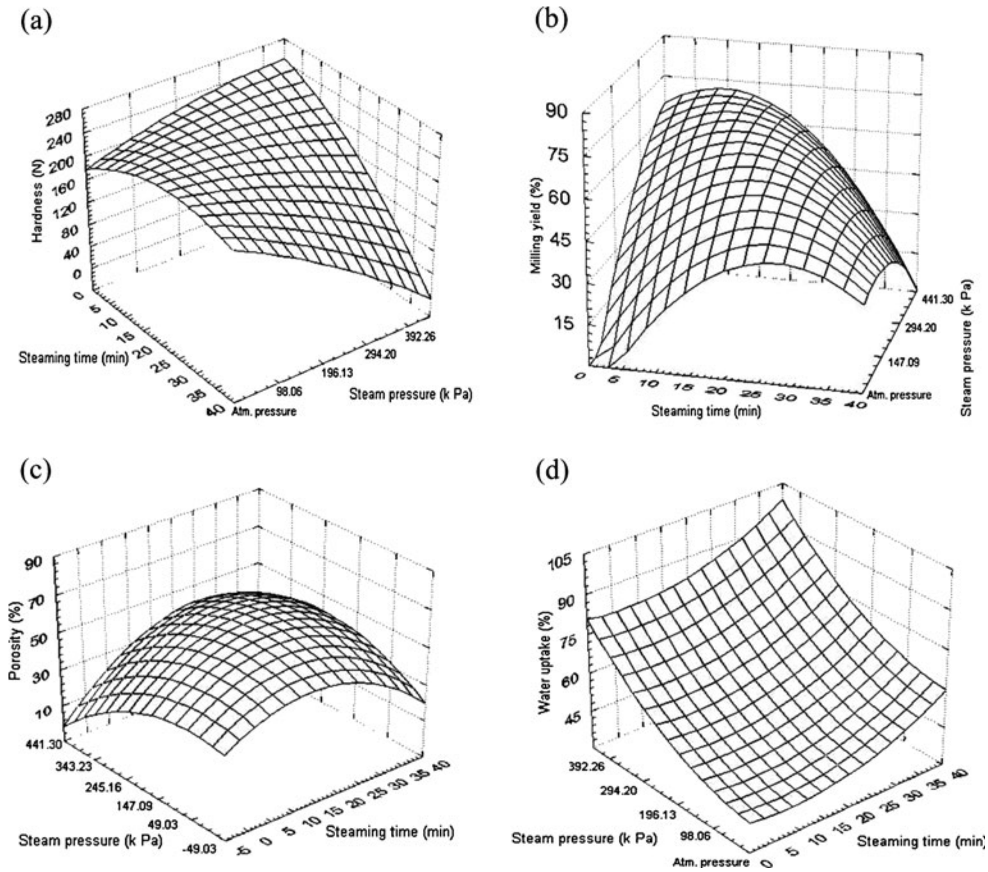


Fig. 3 Response surface generated for **a** hardness, **b** milling yield, **c** porosity and **d** water absorption capacity, as a function of steaming time and steaming pressure

and Mazhar 1999). In case of finger millet, the grain hardness increases to several folds due to hydrothermal treatment. Steaming time and steam pressure profoundly influence the hardness of the millet kernels as indicated in Fig. 3a. The interaction between hardness and steaming time found to be linear as the hardness of the millet increased with the increase in steaming time. Whereas, the effect of steam pressure on hardness was quadratic. Steaming at high pressure (334.4 kPa) for a few minutes increased the hardness to 235 N and prolonged steaming, beyond 15 min, caused exuding part of the endosperm fracturing the seed coat. Naturally, this resulted in decreased hardness (76.3 N) of the kernels. Thus, the effect of severity of steaming on hardness was positive up to a certain extent and was negative thereafter. The interaction between steaming time and pressure was also found to be significant. The experimental and observed values were not significantly different ($p<0.05$) as seen in Fig. 4a. The decrease in hardness values at higher pressure may be

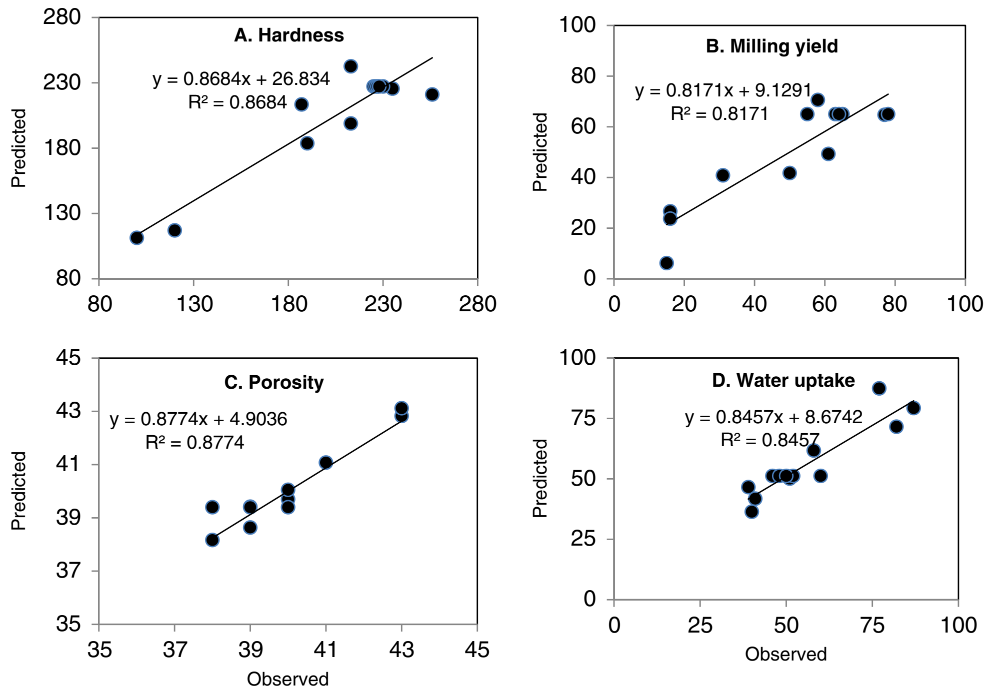
Table 3 Treatment schedule for central composite rotatable design and response

Sl. no.	Independent variables		Response variables			
	Steaming time, X_1 (min)	Steaming pressure, X_2 (kPa)	Hardness (N)	Milling yield (g%)[a]	Porosity (%)	Water uptake (%)
1	−1	−1	256±5.2	15±1.5	39±0.2	40±0.5
2	−1	1	235±5.6	77±2.6	41±0.3	82±0.6
3	1	−1	213±4.1	50±1.2	38±0.4	51±0.5
4	1	1	100±2.2	61±2.0	43±0.5	87±0.4
5	−1.414	0	187±3.3	16±1.5	40±0.5	39±0.6
6	1.414	0	120±2.5	31±1.0	40±0.5	58±0.5
7	0	−1.414	213±4.6	16±1.5	39±0.4	41±0.6
8	0	1.414	190±3.7	58±1.2	43±0.5	77±0.7
9	0	0	225±4.5	78±0.5	40±0.6	60±0.5
10[b]	0	0	226±5.1	63±0.6	40±0.4	46±0.4

[a] Milling yield is the weight (g) of decorticated head grains obtained when 100 g of the hydrothermally treated finger millet is polished

[b] Centre point replicated five times

Fig. 4 Predicted and experimental values of responses measured



attributed to the endosperm properties, as at higher pressure a part of the seed coat fractures and endosperm exudes out leading to hollowness and cracks. Due to these factors, the hardness values decrease on steaming at high pressure for longer time. Similar observation was made for rice by Islam et al. (2004), wherein, rice was parboiled at two different temperatures (90 and 100°C) at varying steaming time (5 to 60 min) and reported that steaming rice at 100°C over 20 min decreased its hardness. Similar observations were also made by Biswas and Juliano (1988) on parboiling of rice, and they reported that steaming at 147.1 kPa pressure for 10 min resulted in exuding part of the endosperm.

Effect of Steaming Time and Steam Pressure on Milling Yield

Similar to hardness, milling yield also varied significantly with steaming time and steam pressure. With the increase in steaming time, milling yield increased up to 78 g/100 g and thereafter the increase was not significant. However, the steam pressure after certain threshold limit caused detrimental effect on milling yield. With the increase in steam pressure, the milling yield increased proportionally to 78 g/100 g, and thereafter it decreased exponentially (Fig. 3b). This is mainly due to the fractured seed coat and loss of a portion of endosperm due to exuding. This causes considerable increase in breakage or decrease in yield of decorticated head grains. However, at steaming time of 17.5 min and steam pressure of 313.8 kPa, the milling yield was maximum (68%), which could be considered as optimum under the experimental conditions. The experimental and observed values were not significantly different ($p<0.05$) (Fig. 4b).

Table 4 Analysis of variance (coded values) sum of squares and error terms

	Grain hardness	Milling yield	Porosity	Water uptake
Steaming time (L)	9,299.228	202.138	0.125	229.730
Steaming time (Q)	6,674.439	1,698.370	0.392	14.879
Steaming pressure (L)	3,466.402	2,191.120	20.024	2,077.278
Steaming pressure (Q)	338.439	547.935	3.784	313.445
1L by 2L	2,116.000	650.250	2.250	9.000
Error	3,272.671	1,138.243	3.676	476.417
Total SS	24,889.692	6,210.923	30.000	3,108.308

Table 5 Regression coefficients (uncoded) for the fitted second order polynomial

	Grain hardness	Milling yield	Porosity	Water uptake
Steaming time (L)	182.780*	−40.193*	40.441*	34.164*
Steaming time (Q)	6.961*	5.440*	−0.130*	0.268
teaming pressure (L)	−0.202*	−0.102*	0.002	0.010
Steaming pressure (Q)	22.366	42.338*	−1.110	−0.495
Steaming time × pressure	−3.509	−4.460	0.369*	3.352
(1 L by 3 L)	−1.318	−0.730	0.043	−0.086
R^2	0.868	0.817	0.877	0.846

*Significant at $p<0.05$

Table 6 Predicted and experimental values of responses measured at optimum condition

Optimum conditions	Hardness (N)		Milling yield (g/100 g)		Water uptake (g/100 g)		Porosity (%)	
Steaming time 17.5 min	Pred. value	Exp. Value[a]	Pred. value	Exp. Value[a]	Pred. value	Exp. Value[a]	Pred. value	Exp. Value[a]
Steam pressure 313.8 kPa	202	204.01	69	68.33	62.5	63.43	51.6	52.23

Pred predicted, *Exp* experimental

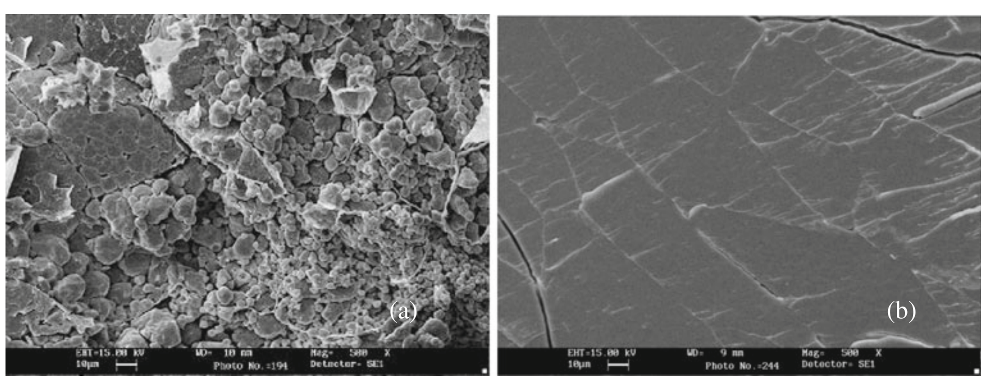
[a] Mean value of five determinations

Effect of Steaming Time and Steam Pressure on Porosity

The influence of steam pressure on porosity of the millet was higher compared to that of steaming time (Fig. 3c). Porosity of the millet varied from 37% to 41% depending on the severity of the steaming conditions. The response modeling of porosity as a function of steam pressure and steaming time showed the optimum values within the experimental limits. Maximum porosity value of 59.35% was predicted for the steaming time and pressure of 18.63 min and 149.1 kPa, respectively. The experimental and observed values were not significantly different ($p<0.05$) (Fig. 4c). The decrease in the porosity of the millet on hydrothermal treatment may be due to the filling up of the air vents and voids present in the endosperm and also between the endosperm and the seed coat. However, steaming at higher pressure (334.4 kPa) for a longer time (29.88 min) resulted in increased porosity values (43%), probably as a result of the opening of the kernel and loss of endosperm constituents. As expected, grain porosity and the hardness were inversely proportional and the kernels with higher porosity were highly susceptible to breakage during milling. It was reported that the shape of the millet kernels change due to hydrothermal processing and visible undulations develop on the grains (Ushakumari 2011). The intensity of these visible undulations varies as a function of the severity of the steaming conditions. Since, porosity is directly related to the shape of the grains, the variations in its values as a function of steaming conditions may be expected.

Effect of Steaming Time and Steam Pressure on Water Uptake

Unlike hardness, milling yield and porosity of the millet, which exhibited a quadratic behavior, there was near linear relationship between water uptake and severity of the steaming conditions. The response surface of water uptake was a mini-max or a saddle point (Fig. 3d). Slight and steady increase of water uptake was noticed as the steaming time increased from 0 to 35 min. However, water uptake increased significantly when the steaming pressure increased from atmospheric pressure to 392.3 kPa. The experimental and observed values were not significantly different ($p\leq0.05$) as indicated in the Fig. 4d.The water uptake of the steamed cereal generally indicates the severity of the heat treatment. It depends mainly on the status of the starch. As the degree of gelatinization increases, water uptake by the grains also increases (Ali and Bhattacharya 1972). However, under normal as well as under pressure steaming, the starch undergoes partial dextrinization (Chandrasekhar and Chattopadhyay 1990; Ramesh et al. 1999) and the dextrinized starch is also known to absorb higher proportion of water than the normal starch. In view of this, the millet steamed under severe conditions continuous to take more water. However, the extent of increase in water uptake was higher for pressure steamed millet compared to millet steamed at normal conditions.



a. Native b. Hydrothermally processed

Fig. 5 Scanning electron photomicrographs of **a** native and **b** hydrothermally processed finger millet

Optimization

The analysis of variance (ANOVA) for the model is presented in Table 4. Based on the regression analysis (Table 5), optimum steaming time and pressure predicted were 17.5 min and 313.8 kPa, respectively, and at these optimum conditions, the predicted values for milling yield, water uptake, porosity and hardness were 68.33 g/100 g, 63.43 g/100 g, 52.23% and 204.01 N, respectively (Table 6). It was noticed that the predicted response values were verified and confirmed by conducting experiments under the specified conditions. The differences between actual and predicted values were not statistically ($p>0.05$) significant. The suitability of the model developed for predicting the optimum response values was also tested using the recommended optimum conditions of the variables and subsequently used to validate the experimental and predicted values of the responses. The R^2 values for all four dependent parameters were significantly high, ranging from 0.81 to 0.86, indicating the fitness of the model. The experimental and observed values are also presented in Fig. 4a–d.

Hydrothermal treatment caused changes in physical, textural and functional properties of finger millet. However, the extent of these changes varied as a function of the severity of the treatment, namely, steaming time and steam pressure. All four important responses—hardness, milling yield, porosity and water uptake—were influenced by the process variables. Hydrothermal processing hardens the kernel by filling the void spaces and cementing the vacuoles inside the endosperm (Kaddus et al. 2002). Due to this treatment, the starch gets gelatinized and the protein bodies get disintegrated in the endosperm, expanding in all directions and filling the internal spaces. As a result of this expansion, the swollen starch granules become pressed together besides, the partially damaged cell walls and protein bind to starch due to a strong cohesion between them. Thus, the endosperm looks like a homogeneous mass (Fig. 5). This imparts hardness to the grain (Nawab and Pandya 1974; Bakshi and Singh 1980). This phenomenon is true with all the cereals on hydrothermal processing but has special relevance to finger millet, enabling its decortication.

Conclusions

This study showed that the decortication characteristics of hydrothermally processed finger millet was influenced by the grain moisture content and the steaming conditions. It was observed that incipient moisture conditioning improved the decortication characteristics and two-stage milling was beneficial compared to the single stage milling. Steaming time and steam pressure significantly influenced the hardness of finger millet and in turn influenced its milling yield. Steaming the millet for 17.5 min at 313.8 kPa steam pressure yielded a milling yield of 68%. The studies indicate that steaming finger millet at elevated pressure for specific time period results in improved yield of decorticated millet. Decorticated millet is a novel product from finger millet and no exclusive milling machineries are developed for its decortication so far. In this connection, improving the milling yield by suitably varying the steaming conditions may help the millet industry. Decorticated millet, being a versatile product, can find diversified food uses and thus this study may help to improve the widespread use of finger millet.

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