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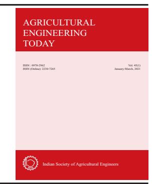


RESEARCH ARTICLE

# Effect of parboiling on cooking characteristics of finger millet and foxtail millet

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**ABSTRACT:** Experiments on parboiling of finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*) were conducted by soaking at 30, 40, 50, 60 and 70°C and steaming for 10, 15, 20, 25 and 30 min. The parboiled millet grains were shade dried and pearled in a laboratory scale pearler-polisher. The cooking characteristics of these parboiled millet grains were assessed in terms of cooking time, water uptake, swelling index and expansion ratio. In the case of finger millet, the cooking time, water uptake, swelling index and expansion ratio ranged 8-13 min, 1.6-3.7 g/g, 0.98-2.27 and 1.26-1.69, respectively. For foxtail millet these quality parameters ranged 9-13 min, 2.5-4 g/g, 1.32-2.75 and 1.45-2.4, respectively. Soaking at 70 and 60°C and steaming for 20 and 10 min, respectively for finger millet and foxtail millet resulted in better cooking characteristics, *viz.*, water uptake, swelling index and expansion ratio, and lower cooking time.



## 1. INTRODUCTION

Millets are a group of small seeded annual grasses belonging to family *Poaceae*, originated from both Asia and Africa. These crops are more resistant to drought and have a shorter growing cycle than other major cereal grains and this make millet an ideal crop for assuring food security in semi-arid areas in Asia and Africa. Millets have been important foods and feed crops producing more reliable harvest than many other crops. Many varieties of millets, around 6,000, with grains varying in colour from pale yellow to grey, white, and red are cultivated worldwide (Chandrasekara and shahidi, 2010). Sorghum (*Sorghum bicolour*) and pearl millet (*Pennissetum glaucum*) are considered as the major millets and other millets *viz.*, finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica), kodo millet (Paspalum scrobiculatum)*, little millet (*Panicum sumatrense*), proso millet (*Panicum miliaceum*) and barnyard millet (*Echinochloa crusgalli*) as the small millets. Millets are used as grain or forage and cooked in the same way as rice, by boiling. Millet has also been reported to be richer in proteins, lipids, and B vitamins than other cereal grains, such as wheat and rice (Parameswaran and Sadasivam, 1994), the presence of all the required nutrients in millets makes them suitable for industrial scale utilisation in the manufacture of food stuffs *viz.* baby foods, snack foods and dietary foods (Shobana and Malleshi, 2007). Considering the importance of the millets in India towards the food and nutritional security, Government of India has declared the millets as *nutri-cereals* (Anonymous, 2018).

India is the major producer of finger millet (*Eleusine coracana*) producing nearly 60% of global production (Shukla and Srivastava, 2014). This millet is rich in protein, fibre, minerals, *viz,* iron, calcium, phosphorus and vitamin content. Being indigenous minor millet, it is used in the preparation of geriatric, infant and health foods both in natural and malted forms. Usually, it is used for preparation of pudding, porridge and *roti* (Chaturvedi and Srivastava, 2008). Ready to eat/cook products from various millets, in the form of novel foods, convenience mixes from pearl millet (Balasubramanian *et al.,* 2014a; Balasubramanian *et al.,* 2014b), pasta from pearl millet, barley and whey protein concentrate (*Balasubramanian et al.,* 2014b), expanded millet, a ready-to-eat new generation product from decorticated finger millet (Ushakumari *et al.*, 2007), finger millet incorporated noodles for nutritive value and glycaemic index (Shukla and Srivastava, 2014), finger millet and pearl millet flour based pasta replacing durum wheat semolina (Gull *et al.,* 2015), semolina from foxtail millet (Dharmaraj *et al.,* 2016), gelatinized foxtail

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millet (α millet) (Wang *et al.,* 2017) were developed by the earlier researchers.

Foxtail millet grains were popped using common salt as heating medium in an open iron pan containing sample and salt in the ratio 1:20 at 240-260°C for 15- 25 s (Srivastava *et al.,* 2003). The polished foxtail grains were cooked into discrete grains similar to rice or further subjected to size reduction and the flour can be used in many traditional as well as contemporary products (Ushakumari *et al.,* 2004). Composite flours prepared by adding 10-30% of foxtail, barnyard and finger millet flour with wheat flour increased the concentration of protein, fat and ash with decrease in the carbohydrates (Singh *et al.*, 2005). Flakes of 0.6 mm thick were prepared from foxtail millet by cooking the flour with excess of water followed by extrusion, flaking and roasting at 90-110°C for 5–15 min (Viswanathan *et al.,* 2009). Finger millet flour was also incorporated upto 40% in bakery items like biscuits, chocolate, cakes, muffins, *etc*. (Begum *et al.,* 2003; Yenagi *et al.,* 2013) which resulted in good appearance, texture, flavour and overall acceptability.

Millet is processed by dehulling to remove husk, the non-edible component of grain. Dehulled grains are pearled / polished / decorticated to remove bran. Hydrothermal treatment to the millet hardens the endosperm texture and enables its decortication for food uses rather than flour based products (Shobana and Malleshi, 2007). Parboiling, a three-step hydrothermal treatment consisting of soaking, heating and drying of rough rice or any food grain, substantially reduces the level of breakage of kernels during milling. It increases head rice yield (Buggenhout e*t al.,* 2013), texture, nutritional value and resistance to spoilage by insects and mould (Buggenhout *et al.,* 2014; Purohit and Rao, 2017). Though the hydrothermal treatment - parboiling was initially developed and adopted for paddy, considering its benefits and various requirements, the process has been adopted for other grains, *viz.,* finger millet (Dharmaraj and Malleshi, 2011) and foxtail millet (Dharmaraj *et al.,* 2016) to increase its use and product diversification. These studies, especially on millets are limited only to the level of giving a pre-treatment with aim of product diversification. The process of parboiling and the associated quality parameters are yet to be studied for further adoption in case of millets. With this aim, the present study has been taken up to evaluate the effect of parboiling of finger millet and foxtail millet on cooking characteristics.

## 2. MATERIALS AND METHODS

### 2.1. Raw Materials

The bulk grains of finger millet (*Eleusine coracana*) and foxtail millet (*Setaria italica*), obtained from Department of Millets, Tamil Nadu Agricultural University, Coimbatore, India, were dried, cleaned and stored in air tight containers for use in experiments. All the moisture content estimation of grains was determined for the triplicate samples by measuring the loss in weight of 5 g sample by drying at 130±2°C for 2 h (AOAC, 1995) in a ventilated hot air oven. All weights were measured using an electronic balance with the least count of 0.001 g.

### 2.2. Parboiling and Pearling of Millet Grain

#### 2.2.1. Parboiling unit

A laboratory scale parboiling unit consisting of a drum with lid (250 mm inner diameter and 300 mm height), steam distributor and electric heating coil (1000 W – kettle type) was used for parboiling the millets. The steam distributor was fitted into the drum on an inclined support (35°) provided at 100 mm depth from the bottom, acts as vapour space. The steam distributor was provided with vertical main pipe (20 mm diameter for 150 mm height) and lateral pipes (15 mm diameter and 120 mm length) for uniform distribution of vapour / steam. Below the steam distributor unit, a kettle type immersion heater of 1000 W capacity was provided with suitable power connection to heat the water filled in the drum. When water started boiling, as heated by the immersion heater, steam is produced and distributed uniformly through the central vertical pipe and laterals to the grain mass already soaked and placed for parboiling. At the end of parboiling, as noted from either grain splitting or the characteristic smell, the parboiled grain was removed through the outlet by opening the lid. Dharmaraj and Malleshi (2011) steamed soaked finger millet in an autoclave spread in steel trays (80x40x3 cm) for 25 mm bed thickness at atmospheric pressure.

#### 2.2.2. Soaking

Hydration process is important for parboiling and the work by the earlier researchers were reviewed for paddy (Shanthilal and Anandharamakrishnan, 2013) and (Behera and Sutar, 2018). For the finger millet, equilibration to 33% moisture content (Shobana and Malleshi, 2007) and soaking for 10 h at 30°C in excess water (Dharmaraj and Malleshi, 2011), and steeping for 8-10 h at room temperature (Dharmaraj *et al*., 2016) and soaking at room temperature for 1 h for foxtail millet (Wang *et al*., 2017) were followed for parboiling. Based on these earlier works, finger millet and foxtail millet samples of about 250 g filled in cloth bag was soaked in a thermostatically controlled water bath at 30, 40, 50, 60 and 70°C for the durations noted to reach equilibrium as given in Table 1. In the remaining of the text when mentioned soaking at a particular temperature will mean soaking for the corresponding duration to reach equilibrium (Visvanathan and Balkrishna, 2020).

**Table 1.**
Effect of soaking temperature on Equilibrium moisture content and duration of soaking of finger millet and foxtail millet grains.

| Millet | Soaking temperature (°C) | Initial moisture content (% d.b) | Equilibrium moisture content (% d.b) | Soaking duration (h) |
|---|---|---|---|---|
| Finger millet | 30 | 12.29 | 53.01 | 16 |
| | 40 | 12.29 | 54.63 | 13 |
| | 50 | 12.29 | 56.80 | 7 |
| | 60 | 12.29 | 59.02 | 3 |
| | 70 | 12.29 | 60.92 | 2 |
| Foxtail millet | 30 | 12.04 | 40.93 | 17.5 |
| | 40 | 12.04 | 41.53 | 15.5 |
| | 50 | 12.04 | 42.78 | 10 |
| | 60 | 12.04 | 44.49 | 6 |
| | 70 | 12.04 | 46.33 | 3.5 |

### 2.2.3. Parboiling

For parboiling the grains, parboiling unit was filled with about 2 litres of water to completely immerse the heating coil and the heater was switched on. As soon as the produced steam started coming out, soaked grain samples filled in the cloth bags were placed in the parboiling unit and closed. Steaming for 1 to 3 min in continuous steaming of paddy (Venkatachalapathy and Udhayakumar, 2013), 10–30 min (Purohit and Rao, 2017), 15 and 20 min at 106, 120 and 130°C (Buggenhout *et al.,* 2014), 10, 15 and 20 min (Nasirahmadi *et al.,* 2014) were followed by the earlier researchers for paddy parboiling. Open steaming for 20 min (Shobana and Malleshi, 2007) and 30 min (Wang *et al.,* 2017), 5-40 min (Dharmaraj *et al.,* 2016) were practised for parboiling of finger millet and foxtail millet, respectively as pre-treatments for product development.

Based on this information, steaming of millet grains was done for various durations of 10, 15, 20, 25 and 30 min. The steaming duration was reckoned from placing the sample after generation of steam. During steaming studies, 5 samples of soaked grains in cloth bags were placed simultaneously in the vapour space of the parboiling tank. The samples were taken out after steaming to the desired steaming durations as per the experimental design.

### 2.2.4. Drying

Drying is the third major unit operation in the parboiling process. Shade drying was adopted (30±2°C; 65 to 70% relative humidity) for drying the parboiled samples by spreading in galvanised iron trays in a single layer to the moisture content of 12-14 per cent (w.b.). The dried parboiled samples were packaged separately as per the treatments in 200 micron thick polypropylene bags and kept safely in air tight containers for further experiments / analysis.

### 2.2.5. Pearling

Dried parboiled finger millet and foxtail millet samples were pearled in an abrasion type table top rice polisher. This unit, operated by a one hp motor, is made of abrasion disc, normally used for polishing of rice and other grains at laboratory level. Similar polishing unit was used by Shobana and Malleshi (2007) and Dharmaraj *et al*. (2016) for millets. Polishing was done by taking about 150 g of sample and the degree of polishing was limited to 6%, a moderate polish (Dharmaraj *et al.,* 2016). It required 2 or 3 passes and took about 10-12 minutes to complete polishing to this desired level. Care was taken during polishing to avoid breakage of grains by adjusting the clearance between the abrasion disc and the concave.

## 2.3. Cooking Characteristics of Parboiled Millet

Very little information is available on the cooking characteristics of millets and such information would be important for consumer acceptance and widespread food uses of the product (Lianga, *et al.,* 2018). The cooking characteristics in terms of cooking time, water uptake ratio, swelling index and elongation / expansion ratio of the parboiled millet samples were assessed.

### 2.3.1. Cooking time

Cooking time is the highly significant aspect of cooking quality. Cooking is considered to be complete, when the grains no longer had opaque and uncooked centres, besides loosing hardness. The corresponding duration is the (optimal) cooking time. The optimal cooking time for the grains and other products like pasta are generally determined following the Ranghino test (Juliano and Bechtel, 1985). By this method, the cooked white core in the grain / pasta is still present but disappeared after squeezing between two clean glass slides / plates and observed under polarized light. Cooking time is recorded when at least 90% of the grains no longer had an opaque core or an uncooked centre. Since no exclusive methodology was developed till date for the assessment of cooking time for millets, Ranghino test was followed in this study. A stainless steel vessel of diameter 285 mm and 250 mm depth provided with a 300 mm x 300 mm hylum board as cover was used in the cooking studies. The hylum board was provided with 20 holes each of 25 mm diameter to hold test tubes of 23 mm diameter and 150 mm length. The vessel was filled with water to three-fourth of its volume and heated. A digital thermometer (100$^oC$) was used to measure the temperature of water in the vessel. Twenty test tubes with 5 g each of pearled millet grains and 25 ml of distilled water were fitted in the holes on the hylum board and placed in the vessel when the water reached 98$^oC$ and noted as the start of the cooking time. The initial water level in the test tube was noted to measure the water uptake during cooking.

After every one minute, one test tube was taken out and immediately immersed in cold water to stop further cooking. Simultaneously, two grains were taken out randomly from every removed test tube and pressed between two glass slides. Disappearance of white core in the grain after squeezing and softness at pressing is judged as cooked and the corresponding exposure time is the optimum cooking time. Cooking time was determined for both parboiled as well as raw millet grain samples. Mohapatra and Bal (2006) and Gull *et al.* (2015) also adopted similar method for rice samples.

#### 2.3.2. Water uptake ratio

Water uptake is the ratio of water absorbed by the grains during cooking to the initial weight of uncooked rice. Higher the amount of water absorbed during cooking will result in higher expansion. Water uptake was determined from the data recorded in the cooking experiments to determine the cooking time. The test tube with grains judged for the optimum cooking time was taken for the determination of water uptake ratio. With the initial and final water levels marked in the test tube, corresponding volume of water was determined using the water replacement method, neglecting the volume of grains taken for the Ranghino test. Using water absorbed during cooking, water uptake ratio was calculated as follows:

$$W_{up} = \frac{(v_{bc} - v_{ac})\rho_w}{w_g} \quad ...(1)$$

Where $W_{up}$ is the water uptake ratio, $v_{bc}$ is the volume of water in the test tube before cooking (ml), $v_{ac}$ is the volume of water in the test tube, after cooking (ml), $\rho_w$ is the density of water (g/ml) and $w_g$ is the mass of grains before cooking (g).

Mohapatra and Bal (2006) and Gayin *et al.* (2017) used this method for rice. Since no established and exclusive methodology is standardised for millets, this method popularly followed for rice kernels was used.

#### 2.3.3. Swelling index

Swelling index also the volume expansion ratio is the ratio of the final volume of the cooked grains to the initial volume of the grains. It was determined for grains in bulk rather than for a single grain. Swelling index also was determined simultaneously with the cooking time. With the initial and final grain levels marked in the test tube, corresponding volume of grain was determined using water replacement method. Mohapatra and Bal (2006) also suggested the same method for rice. Using the readings recorded, swelling index was calculated as follows using the following formula,

$$I_s = \frac{V_f - V_i}{V_i} \quad ...(2)$$

Where $I_s$ is swelling index, $V_f$ is the volume of grains after cooking (cc), $V_i$ is the volume of grains before cooking (cc).

#### 2.3.4. Expansion ratio of grains

Expansion ratio is the ratio between the dimensions of cooked and uncooked grain. Mohapatra and Bal (2006) and Gayin *et al.* (2017) determined the length expansion ratio for rice as the ratio of the length of cooked grain to length of uncooked grain. Here, millet grains being spherical, these dimensions are taken as diameter along major axis and minor axis. About 10 grains were randomly selected from the unsoaked grains used for parboiling and the parboiled sample, and their major and minor axes were measured using a digital vernier calliper with 0.01 mm least count. Expansion ratio was calculated for both raw and parboiled millet grains using the following formula (Giri and Bandyopadhyay, 2000):

$$E_r = \frac{M_{jf}}{M_{ji}} \times \frac{M_{nf}}{M_{ni}} \quad ...(3)$$

Where $E_r$ is the expansion ratio, $M_{ji}$ is the mean major axis diameter of grain before cooking (mm), $M_{jf}$ is the mean major axis diameter of grain after cooking (mm), $M_{ni}$ is the mean minor axis diameter of grain before cooking (mm) and $M_{nf}$ is the mean minor axis diameter after cooking (mm).

### 2.4. Statistical Analysis

All experiments were replicated three times and data were statistically analysed using MS Excel and AgRes ANOVA software. The mean values w reported.

## 3. RESULTS AND DISCUSSION

### 3.1. Cooking Time

The analysis of variance (Table 2) on the effect of soaking temperature (t) and steaming duration (T) on cooking time of finger millet shows significance at 1% level. As seen from Table 3, the optimum cooking time for the parboiled finger millet varied from 8 to 13 min in the experimental range, with 6 min for the raw grain (control). Among the different combinations of soaking temperature and steaming duration, soaking temperatures of 30°C and 70°C and 10 min of steaming time, shown the minimum cooking time of 8 min. Cooking time of 9 min found at 30°C soaking temperature and 15 and 20 min steaming duration, and 70°C soaking temperature and 15 min steaming duration were at par. Also 10 min cooking time exhibited at 20 and 25 min of steaming duration at 30°C soaking temperature, and at 15 min of steaming duration at 70°C soaking temperature, were at par.

The statistical analysis and data of cooking time of foxtail millet given in Tables 4 and 5 shows that the effect of soaking temperature (t) and steaming duration (T) on cooking time are significant on cooking time of foxtail millet at 1% level. Among the different combinations of soaking temperature and steaming time, the cooking time of 9 min is the lowest at soaking temperatures of 30°C and 10 and 15 min of steaming time, which are at par. The higher cooking time of 12 and 13 min were at par as found at 60°C soaking temperature; 10 min steaming duration and 10 – 25 min of steaming duration at 70°C soaking temperature. Foxtail millet grains soaked at lower temperatures and parboiled at lower steaming duration resulted in less cooking time while the control, raw grain was cooked in 6 min. To achieve complete cooking of parboiled foxtail millet in shorter time (9 min), soaking

**Table 2.**
Analysis of variance (ANOVA) for cooking characteristics of parboiled finger millet grains

| Source of variation | Degrees of freedom | Sum of squares | Mean squares | F-value |
|---|---|---|---|---|
| Cooking time | | | | |
| Treatment | 24 | 3.674 | 0.153 | 2523.56** |
| Soaking temperature (t) | 4 | 1.852 | 0.463 | 7634.26** |
| Steaming duration (T) | 4 | 1.225 | 0.306 | 5049.59** |
| t x T | 16 | 0.596 | 0.037 | 6143.79** |
| Error | 50 | 0.00 | 0.00 | 1 |
| Total | 74 | 3.674 | 0.05 | 8184.53** |
| Water uptake | | | | |
| Treatment | 24 | 18.240 | 0.760 | 196.55* |
| Soaking temperature (t) | 4 | 6.623 | 1.656 | 428.22** |
| Steaming duration (T) | 4 | 1.824 | 0.456 | 117.96** |
| t x T | 16 | 9.793 | 0.612 | 158.28** |
| Error | 50 | 0.193 | 0.004 | 1 |
| Total | 74 | 18.434 | 0.249 | 64.42 |
| Swelling index | | | | |
| Treatment | 24 | 7.229 | 0.301 | 148.54** |
| Soaking temperature (t) | 4 | 3.246 | 0.811 | 400.20** |
| Steaming duration (T) | 4 | 0.603 | 0.151 | 74.36** |
| t x T | 16 | 3.380 | 0.211 | 104.17** |
| Error | 50 | 0.101 | 0.002 | 1 |
| Total | 74 | 7.331 | 0.099 | 48.85 |
| Expansion ratio[@] | | | | |
| Treatment | 24 | 4.729 | 0.197 | 23.77** |
| Soaking temperature (t) | 4 | 3.497 | 0.874 | 105.47** |
| Steaming duration (T) | 4 | 0.239 | 0.060 | 7.22 ** |
| t x T | 16 | 0.993 | 0.062 | 7.48** |
| Error | 225 | 1.865 | 0.008 | 1 |
| Total | 249 | 6.593 | 0.026 | 3.19 |

*[@] with 10 replications; * significant at 5% level; ** significant at 1% level.*

**Table 3.**
Cooking characteristics of parboiled finger millet grains

| Soaking temperature for parboiling (°C) | Steaming duration (min) | Cooking time (min) | Water uptake (g/g) | Swelling index | Expansion ratio |
|---|---|---|---|---|---|
| | 10 ($T_1$) | 8[a] | 2.6 | 1.63 | 1.31 |
| | 15 ($T_2$) | 9[b] | 2.5 | 1.53 | 1.27 |
| 30 ($t_1$) | 20 ($T_3$) | 9[bc] | 2.4 | 1.31 | 1.31 |
| | 25 ($T_4$) | 10[c] | 2.2 | 1.33 | 1.27 |
| | 30 ($T_5$) | 10 | 1.9 | 1.17 | 1.26 |
| | 10 ($T_1$) | 10 | 2.0 | 1.21 | 1.37 |
| | 15 ($T_2$) | 10 | 2.2 | 1.12 | 1.35 |
| 40 ($t_2$) | 20 ($T_3$) | 11 | 1.9 | 1.01 | 1.40 |
| | 25 ($T_4$) | 11 | 1.7 | 0.94 | 1.36 |
| | 30 ($T_5$) | 11 | 1.6 | 1.03 | 1.32 |
| | 10 ($T_1$) | 10 | 1.9 | 0.98 | 1.33 |
| | 15 ($T_2$) | 10 | 2.0 | 1.05 | 1.39 |
| 50 ($t_3$) | 20 ($T_3$) | 11 | 2.2 | 1.14 | 1.41 |
| | 25 ($T_4$) | 11 | 2.7 | 0.91 | 1.46 |
| | 30 ($T_5$) | 12 | 2.2 | 1.73[c] | 1.56[c] |
| | 10 ($T_1$) | 11 | 2.5 | 1.33 | 1.69[a] |
| | 15 ($T_2$) | 12 | 1.9 | 1.24 | 1.43 |
| 60 ($t_4$) | 20 ($T_3$) | 12 | 1.8 | 1.33 | 1.39 |
| | 25 ($T_4$) | 13 | 2.5 | 1.38 | 1.60[bc] |
| | 30 ($T_5$) | 13 | 3.1[c] | 1.29 | 1.63[abc] |
| | 10 ($T_1$) | 8[a] | 2.4 | 1.38 | 1.58[c] |
| | 15 ($T_2$) | 9[bc] | 2.1 | 1.29 | 1.52 |
| 70 ($t_5$) | 20 ($T_3$) | 10 | 2.4 | 2.27[a] | 1.70[a] |
| | 25 ($T_4$) | 12 | 3.4[b] | 1.44 | 1.57[c] |
| | 30 ($T_5$) | 13 | 3.7[a] | 1.96[b] | 1.66[ab] |
| Control | Raw grain | 6 | 2.8 | 1.21 | 1.32 |

**All treatments bearing same alphabet belong to one group and are on par.*

the grain at 30°C temperature and steaming for 10 or 15 min can be followed. Cooking time of 17-21 min (Gayin *et al.*, 2017), 22-16 min (Mohapatra and Bal, 2006) and 3-5 min (Dissanayaru and Jayawardena, 2016) for finger millet – rice blended noodles were reported by the earlier researchers.

### 3.2. Water Uptake

Statistical analysis of water uptake ratio of finger millet (Table 2) shows that the effect of soaking temperature (t) and steaming duration (T) on water uptake ratio was significant at 1% level. Among the different combinations of soaking temperature and steaming time, soaking temperature of 70°C and 30 min of steaming duration resulted in the highest uptake of 3.7 g/g and the lowest value of 1.6 g/g was at 40°C soaking temperature and 30 min steaming duration. The control sample had 2.8 g/g of water uptake. At the soaking temperatures of 50, 60 and 70°C, the water uptake increased with increase in steaming duration, whereas at 30 and 40°C soaking temperatures, decrease in water intake was noted with increase in steaming duration. The increase in water uptake, the soaking at higher temperatures and longer duration of steaming may be due to the softened grains. The reason for the decrease in water uptake at lower soaking temperatures and increase in steaming duration was not well understood, but may be the grains become harder.

The water uptake is significant with respect to soaking temperature (t) and steaming duration (T) at 1% level for parboiled foxtail millet (Table 4 and 5). Among the various experimental combinations of soaking temperature and

**Table 4.**
Analysis of variance (ANOVA) for cooking characteristics of parboiled foxtail millet grains

| Source of variation | Degrees of freedom | Sum of squares | Mean squares | F-value |
|---|---|---|---|---|
| Cooking time | | | | |
| Treatment | 24 | 1.599 | 0.066 | 9768.76 ** |
| Soaking temperature (t) | 4 | 1.067 | 0.266 | 3909.70** |
| Steaming duration (T) | 4 | 0.073 | 0.018 | 2673.42** |
| t x T | 16 | 0.460 | 0.029 | 4210.52** |
| Error | 50 | 0 | 0 | 1 |
| Total | 74 | 1.599 | 0.021 | 3168.24 |
| Water uptake | | | | |
| Treatment | 24 | 13.634 | 0.568 | 213.02** |
| Soaking temperature (t) | 4 | 7.410 | 1.852 | 694.67** |
| Steaming duration (T) | 4 | 2.926 | 0.731 | 274.30** |
| t x T | 16 | 3.298 | 0.206 | 77.30** |
| Error | 50 | 0.133 | 0.003 | 1 |
| Total | 74 | 13.767 | 0.186 | 69.76 |
| Swelling index | | | | |
| Treatment | 24 | 9.636 | 0.401 | 142.51* |
| Soaking temperature (t) | 4 | 4.792 | 1.198 | 425.21** |
| Steaming duration (T) | 4 | 1.355 | 0.339 | 120.20** |
| t x T | 16 | 3.489 | 0.218 | 77.41** |
| Error | 50 | 0.141 | 0.003 | 1 |
| Total | 74 | 9.777 | 0.132 | 46.89 |
| Expansion ratio[@] | | | | |
| Treatment | 24 | 19.837 | 0.827 | 6.57** |
| Soaking temperature (t) | 4 | 9.997 | 2.500 | 19.87** |
| Steaming duration (T) | 4 | 1.184 | 0.296 | 2.35 (ns) |
| t x T | 16 | 8.655 | 0.541 | 4.30** |
| Error | 225 | 28.292 | 0.126 | 1 |
| Total | 249 | 48.129 | 0.193289 | 1.53 |

[@] *with 10 replications; * significant at 5% level; ** significant at 1% level;* [ns] *not significant*



steaming time, soaking temperature of 50°C and 10 and 20 min of steaming time, resulted in higher water uptake ratio of 4, which are at par. While the control (raw grain) showed a water uptake ratio of 3.4, parboiling the foxtail millets by soaking at lower temperatures (30 and 40°C) and steaming for shorter durations resulted in less water uptake of 2.5 to 2.9. The samples soaked at higher temperatures resulted in higher water uptake due to softening of grain that had taken place before steaming. For the process to achieve the highest water uptake ratio of parboiled grains, where higher swelling is preferred, soaking temperature of 50°C with steaming duration of 10 or 20 min can be followed. When lesser or moderate water uptake is preferred, soaking at 60°C and steaming for 10 min or soaking at 70°C and steaming for 20 min may be desirable. The increase in water uptake for soaking at higher temperatures and longer duration of steaming may be due to the softened grains.

### 3.3. Swelling Index

Higher swelling index of cooked grains will be preferred as good cooking quality. Statistical analysis and the data of swelling index of finger millet are presented in Tables 2 and 3, respectively. It shows that the soaking temperature and steaming duration on swelling index is significant at 1% level. Among the different combinations of soaking temperature and steaming time, soaking temperature of 70°C and 20 min of steaming duration exhibited the

**Table 5.**
Cooking characteristics of parboiled foxtail millet grains

| Soaking temperature for parboiling (°C) | Steaming duration (min) | Cooking time (min) | Water uptake (g/g) | Swelling index | Expansion ratio |
|---|---|---|---|---|---|
| | 10 ($T_1$) | 9[a] | 2.7 | 1.32 | 1.74 |
| | 15 ($T_2$) | 9[a] | 3.1 | 1.34 | 2.39[a] |
| 30 ($t_1$) | 20 ($T_3$) | 10[b] | 2.9 | 1.48 | 2.40[a] |
| | 25 ($T_4$) | 10[b] | 2.5 | 1.41 | 2.38[a] |
| | 30 ($T_5$) | 11[c] | 2.7 | 1.48 | 2.20[abc] |
| | 10 ($T_1$) | 11[c] | 3.4 | 1.61 | 2.27[ab] |
| | 15 ($T_2$) | 10[b] | 3.0 | 1.52 | 2.06[bc] |
| 40 ($t_2$) | 20 ($T_3$) | 10[b] | 3.0 | 0.91 | 2.39[a] |
| | 25 ($T_4$) | 10[b] | 3.1 | 1.28 | 2.29[ab] |
| | 30 ($T_5$) | 10[b] | 2.9 | 1.39 | 2.02[bc] |
| | 10 ($T_1$) | 10[b] | 4.0[a] | 2.75[a] | 1.45 |
| | 15 ($T_2$) | 10[b] | 3.7[c] | 1.92 | 2.32[ab] |
| 50 ($t_3$) | 20 ($T_3$) | 10[b] | 4.0[a] | 1.92 | 1.80 |
| | 25 ($T_4$) | 11[c] | 3.3 | 1.85 | 1.88 |
| | 30 ($T_5$) | 11[c] | 2.9 | 1.43 | 1.83 |
| | 10 ($T_1$) | 12[d] | 3.8[b] | 2.05[c] | 2.18[abc] |
| | 15 ($T_2$) | 11[c] | 3.1 | 1.57 | 2.23[abc] |
| 60 ($t_4$) | 20 ($T_3$) | 11[c] | 2.9 | 1.63 | 1.87 |
| | 25 ($T_4$) | 11[c] | 2.9 | 1.57 | 1.95[c] |
| | 30 ($T_5$) | 11[c] | 2.7 | 1.57 | 2.17[abc] |
| | 10 ($T_1$) | 12[d] | 3.7 | 1.84 | 1.93[c] |
| | 15 ($T_2$) | 12[d] | 3.5 | 1.87 | 1.60 |
| 70 ($t_5$) | 20 ($T_3$) | 12[d] | 3.8[bc] | 2.22[b] | 1.71 |
| | 25 ($T_4$) | 13[d] | 3.4 | 1.60 | 1.65 |
| | 30 ($T_5$) | 11[c] | 3.7 | 1.93 | 1.70 |
| Control | Raw grain | 6 | 3.4 | 1.13 | 1.56 |

**All treatments bearing same alphabet belong to one group and are on par.*

highest swelling index of 2.27 and the least of 0.91 for 50°C soaking temperature and 25 min steaming duration with the control value of 1.21. For achieving the highest swelling index value of parboiled grains, soaking temperature of 70°C with steaming duration of 20 min can be suggested. Other treatments such as soaking at 70°C and steaming for 30 min or other combinations of both as per the tabulated results can be used if comparatively low swelling index is desirable.

The effect of soaking temperature (t) and steaming duration (T) on swelling is significant at 1% level for the parboiled foxtail millet grains (Table 4). In Table 5, it shows that the soaking temperature of 50°C and 10 min steaming duration resulted in the swelling index of 2.75, followed by 2.22 at 70°C soaking temperature and 20 min steaming duration. The control sample has shown a swelling index of 1.13. The lowest value of swelling was found as 0.91 at 40°C and soaking temperature and 20 min of steaming time. Higher swelling at higher temperatures of soaking is seen as in the case of other grains.

### 3.4. Expansion Ratio

Statistical analysis and the data of expansion ratio of finger millet are given in Table 2 and 3, respectively. It shows that the effect of soaking temperature (t) and steaming duration (T) on expansion ratio was significant at 1% level. Among the different combinations of soaking temperature and steaming time, the higher values of expansion ratio of 1.63 to 1.7 was noted at steaming duration of 10 and 30 min at 60°C soaking temperature and steaming duration of 20 and 30 min at 70°C soaking temperature, which are at par. Lower values of expansion were noted at lower temperatures of soaking at all steaming durations. Partial expansion is achieved during soaking at elevated temperatures and thus further expansion during steaming. Elongation ratio of 1.41 to 1.62 (Gayin *et al.,* 2017) and 1.36 to 1.72 (Mohapatra and Bal, 2006) were reported for rice samples.

The analysis of variance of expansion ratio on cooking of parboiled foxtail millet shows significant effect of soaking temperature (t) at 1% level (Table 4 and 5). The steaming duration (T) shows non significance and the interaction of the soaking temperature and steaming duration shown significance for expansion ratio. Among the different combinations of soaking temperature and steaming time, 30°C (15, 20, 25 and 30 min), 40°C (10, 15, 20, 25 and 30 min), 50°C (15 min) and 60°C (10, 15 and 30 min), the expansion ratio were at par with a range of 2.17 to 2.4. The control (raw foxtail millet grain) has shown the expansion ratio of 1.56 and in general, the soaking at higher temperatures and prolonged steaming resulted in lower expansion ratios. Elongation ratio of 1.41 to 1.62 (Gayin *et al.,* 2017) and 1.36 to 1.72 (Mohapatra and Bal, 2006) were reported for rice samples.

## 4. CONCLUSIONS

Feasibility of parboiling of finger millet (*Eleusine coracana)* and foxtail millet (*Setaria italica),* by open steaming was found from this study. Quality of parboiling with respect to soaking temperature and steaming duration was assessed based on cooking time, water uptake, swelling index and expansion ratio. In the case of finger millet, the cooking time, water uptake, swelling index and expansion ratio ranged from 8-13 min, 1.6-3.7 g/g, 0.98-2.27 and 1.26-1.69, respectively. These values for foxtail millet were, cooking time 9-13 min, water uptake 2.5-4 g/g, swelling index 1.32-2.75 and expansion ratio 1.45-2.4. Soaking at 70 and 60°C and steaming for 20 and 10 min, respectively for finger millet and foxtail millet resulted in better cooking characteristics in terms of higher water uptake, swelling index and expansion ratio and less cooking time, which are considered as optimum conditions. These parboiled millets will be useful for incorporation and development of value added products.

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