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Sprouting, Soaking, and Drying Methods Alter the Proximate Composition of Millet Varieties: A Comparative Study

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ABSTRACT

Millets are climate-resilient nutri-cereals valued for their dietary fibre, micronutrient density, and low glycaemic index, yet the choice of pre-treatment and drying method can substantially alter their proximate composition. This study evaluated the combined effect of two pre-treatments (soaking for 24–26 h and sprouting for 60–74 h following a 10–12 h soak) and three drying methods (oven drying at 40 ± 2 °C, open sun drying, and shade drying) on the moisture, carbohydrate, protein, crude fibre, fat, and ash content of eight millet varieties - finger millet (Eleusine coracana), sorghum (Sorghum bicolor), pearl millet (Pennisetum glaucum), proso millet (Panicum miliaceum), foxtail millet (Setaria italica), little millet (Panicum sumatrense), barnyard millet (Echinochloa frumentacea), and browntop millet (Brachiaria ramosa). Proximate analysis was carried out in triplicate using standard AOAC (2016) protocols. Sprouting reduced mean carbohydrate content from 68.66% (unprocessed) to 65.14-66.22% while increasing crude fibre from 7.93% to 10.08-10.54%, whereas soaking increased carbohydrate content to 69.00–69.27% and moderately reduced fibre relative to the unprocessed grain. Protein content was highest after soaking (8.49-8.84% mean) and comparable to or higher than sprouted and unprocessed samples in most varieties, with foxtail millet consistently recording the highest protein (11.35-11.86%) among all treatments. Oven drying produced the lowest residual moisture within each pre-treatment group, while shade-dried, sprouted samples retained the highest moisture and fibre. Fat content declined most sharply in soaked, oven-dried samples, particularly in great millet and browntop millet. These findings indicate that soaking combined with oven drying is best suited for maximising carbohydrate and protein recovery with minimal fat loss, whereas sprouting combined with shade or sun drying favours fibre enrichment, and that the optimal processing combination should be selected according to the intended nutritional or functional application of the millet flour.

Keywords: *Millets; sprouting; soaking; drying methods; proximate composition; nutri-cereals; food processing*

1. Introduction

Millets are a group of small-seeded annual grasses cultivated for over 10,000 years, primarily in the semi-arid tropics of Asia and Africa, and are increasingly recognised as “nutri-cereals” because of their favourable dietary fibre, protein, and micronutrient profile relative to major cereals such as rice and wheat [1]. Their C4 photosynthetic pathway, low water requirement, and tolerance of marginal soils make them well suited to climate-resilient cropping systems, and they have consequently gained renewed policy and research attention as “smart food” crops capable of contributing to food and nutrition security under changing climatic conditions.

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Despite this nutritional promise, raw millet grains contain relatively high levels of antinutritional factors such as phytates, tannins, and trypsin inhibitors, and their dense, low-porosity endosperm limits digestibility and culinary versatility. Traditional household- and industry-level processing techniques soaking, sprouting (germination), fermentation, and drying are widely used to overcome these limitations. Soaking hydrates the grain and facilitates leaching of soluble antinutrients and solutes, while sprouting activates endogenous hydrolytic enzymes (α-amylase, protease, phytase) that mobilise stored starch and protein to support seedling growth, altering the residual macronutrient balance of the grain [2, 3]. Because both treatments raise the moisture content of the grain substantially, an effective drying step is required before milling and storage, and the method chosen for this step oven, open sun, or shade drying differs in temperature, exposure time, and airflow, all of which can further influence the final proximate composition of the flour [4].

While the individual effects of sprouting and soaking on millet nutrient content have been documented for several species [5, 6], comparative data on the combined effect of pre-treatment (sprouting versus soaking) and drying method (oven, sun, and shade) across a wide panel of millet varieties within a single controlled study remain limited.

Such data are important for processors seeking to standardise millet-flour production for specific end uses, since the same grain may need to be optimised for either maximum fibre enrichment (for dietary-fibre-fortified products) or maximum protein and carbohydrate retention (for energy-dense weaning foods). The present study therefore aimed to determine and compare the moisture, carbohydrate, protein, crude fibre, fat, and ash content of eight millet varieties subjected to six sprouting/soaking × drying combinations, benchmarked against unprocessed raw grain, in order to identify the processing combination best suited to different nutritional objectives.

2. Materials and Methods

2.1 Raw Material

Eight millet varieties finger millet (*Eleusine coracana*), sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), proso millet (*Panicum miliaceum*), foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), barnyard millet (*Echinochloa frumentacea*), and browntop millet (*Brachiaria ramosa*) were procured from the Kanakapura Organic Producer Company, Yerandappanahalli, Kodihalli Hobli, Kanakapura Taluk, Ramanagara district, Karnataka, India. Grains were manually cleaned to remove foreign matter, broken kernels, and immature seeds prior to processing.

2.2 Sample Preparation

2.2.1 Soaking treatment

For the soaking-only treatment, cleaned grains of each variety were soaked in potable water for 24–26 h at 25–27 °C without subsequent sprouting, and then drained prior to drying.

2.2.2 Sprouting treatment

All eight millet varieties were washed thoroughly under running water and soaked in potable water for 10–12 h at 25–27 °C. The soaked grains were then drained, spread on moistened germination trays lined with clean muslin cloth, and allowed to sprout for 60–74 h at 27–30 °C, with intermittent sprinkling of water to maintain adequate moisture and aeration.

2.2.3 Drying methods

Both the sprouted and the soaked samples of each variety were divided into three equal lots and subjected to one of three drying methods: (i) oven drying at 40 ± 2 °C for 8 h in a hot-air oven; (ii) sun drying, carried out by spreading the samples in a thin layer under direct sunlight until visually and texturally dry; and (iii) shade drying, carried out under ambient conditions away from direct sunlight until a comparable degree of dryness was achieved. This design generated six sprouted/soaked × dried sample groups per variety (Sprouted–Oven, Sprouted–Sun, Sprouted–Shade, Soaked–Oven, Soaked–Sun, Soaked–Shade), which were compared against unprocessed (raw, undried) grain of each variety as the control. Following drying, all samples were pulverised using a hammer mill fitted with a fine mesh screen and stored in labelled airtight containers at ambient temperature until proximate analysis was performed.

2.3 Proximate Analysis

Proximate composition moisture, carbohydrate, crude protein, crude fat, crude fibre, and, ash was determined for the raw grain and for all six processed variants of each of the eight millet varieties using standard methods of the Association of Official Analytical Chemists (AOAC, 2016) [7].

Moisture content was determined gravimetrically by the hot-air oven method, drying samples at 105 °C to constant weight. Crude protein was estimated by the Kjeldahl method, using a nitrogen-to-protein conversion factor of 6.25. Crude fat was extracted using the Soxhlet method with petroleum ether as solvent. Crude fibre was determined by sequential acid–alkali digestion. Ash content was determined by incineration of the sample in a muffle furnace at 550 °C to a constant, white-to-grey residue. Carbohydrate content was calculated by difference, i.e., 100 minus the sum of the percentages of moisture, protein, fat, fibre, and ash.

2.4 Statistical Analysis

All determinations were performed in triplicate and results are reported as mean ± SD. Data were tabulated and compared descriptively across the seven treatment groups (three sprouted-dried combinations, three soaked-dried combinations, and unprocessed grain) for each of the eight millet varieties to identify consistent trends associated with pre-treatment (sprouting versus soaking) and drying method (oven, sun, and shade).

3. Results and Discussion

The proximate composition (moisture, carbohydrate, protein, crude fibre, fat, and ash) of the eight millet varieties under each of the six processing combinations and under the unprocessed condition is presented.

3.1 Moisture Content

Moisture content ranged from 8.89% (sprouted, oven-dried pearl millet) to 14.74% (sprouted, sun-dried little millet). Within every pre-treatment group, oven drying consistently produced the lowest residual moisture (treatment means: 10.53% for sprouted-oven and 9.94% for soaked-oven), followed by sun drying and then shade drying, reflecting the more controlled and sustained heat transfer of the hot-air oven relative to the variable and comparatively lower effective temperatures of open sun and shade exposure [8, 9]. Sprouted samples retained appreciably more moisture after drying (10.53–11.37% mean) than soaked samples (9.94–10.24% mean) or unprocessed grain (10.57%), which is consistent with the elongated, more porous seedling structure created during germination that increases the surface area and internal water-holding capacity of the kernel [7, 10]. Little millet showed the highest moisture retention among sprouted samples (13.70–14.74%) in all three drying methods, likely reflecting its comparatively fine bran layer and higher water absorption capacity relative to the other varieties [11, 12].

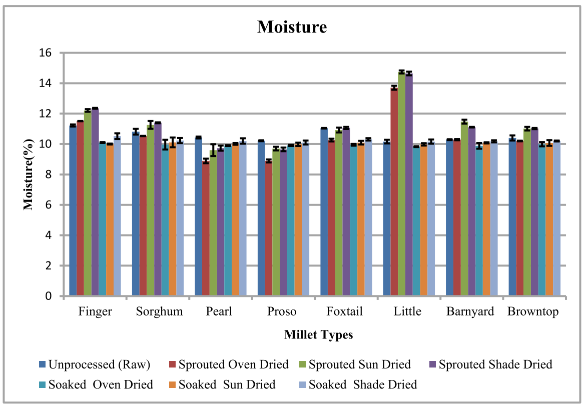

Fig. 1. Effect of processing treatment (raw, sprouted, and soaked) and drying method (oven, sun, and shade) on the moisture content (%) of eight millet varieties (mean ± SD, n = 3)

3.2 Carbohydrate (CHO) Content

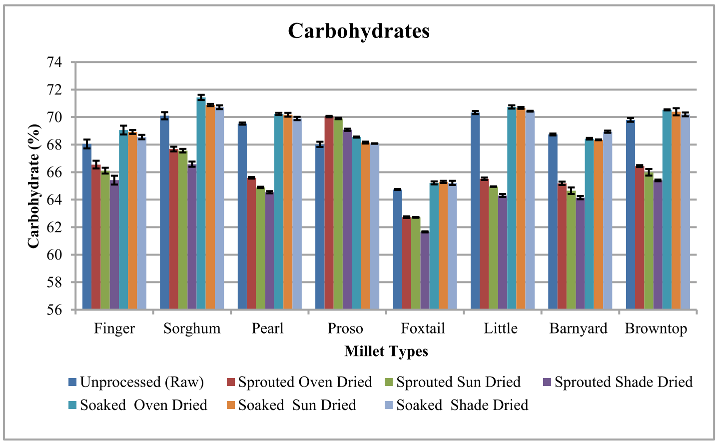

Fig. 2. Comparative carbohydrate content (%) of eight millet varieties under raw, sprouted, and soaked conditions, followed by oven, sun, or shade drying (values expressed as mean ± SD, n = 3)

Carbohydrate content, calculated by difference, was consistently higher in soaked samples (69.00–69.27% mean) than in unprocessed grain (68.66% mean), and was consistently lower in sprouted samples (65.14–66.22% mean). The largest reductions relative to the unprocessed control were observed in little millet (up to −4.81 percentage points) and pearl millet (up to −3.94 percentage points) following sprouting, while soaked samples of great millet and browntop millet showed carbohydrate gains of over 1 percentage point. This pattern is consistent with the well-documented mobilisation of starch reserves by α-amylase during germination, which is hydrolysed to sugars and used as an energy and carbon source for radicle and coleoptile growth, thereby lowering the residual starch/carbohydrate fraction of the dried, deculmed grain [2, 13, 14]. The slight increase in carbohydrate percentage on soaking, despite no active germination, is attributable to the proportionally greater loss of other soluble constituents (minerals, some proteins, and antinutrients) into the soak water, which concentrates the remaining starch fraction on a percentage basis [15].

3.3 Protein Content

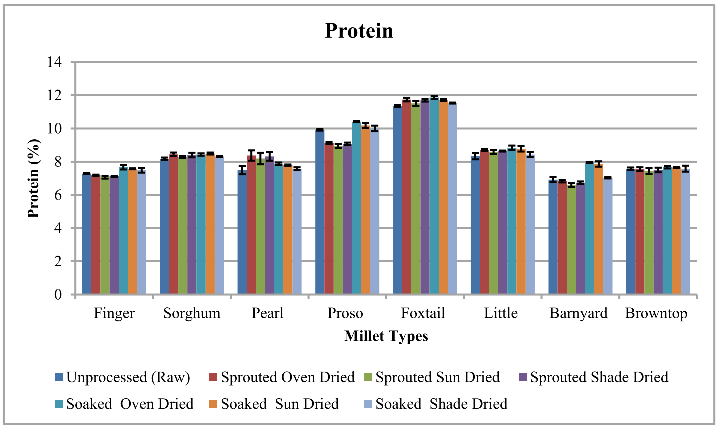

Fig. 3. Protein content (%) of eight millet varieties subjected to different processing treatments raw (unprocessed), sprouted, and soaked, followed by oven, sun, or shade drying expressed as mean ± SD (n = 3)

Protein content across all treatments and varieties ranged from 6.58% (sprouted, sun-dried barnyard millet) to 11.86% (soaked, oven-dried foxtail millet), with foxtail millet recording the highest protein content of any variety in every treatment group. Soaking increased mean protein content relative to unprocessed grain in all eight varieties (treatment means 8.49–8.84% versus 8.38% for unprocessed), which may be explained by the net loss of dry matter (mainly soluble carbohydrates and antinutrients) into the soak water, concentrating the residual protein fraction. The effect of sprouting on protein content was more variable: pearl millet, great millet, foxtail millet, and little millet showed clear protein increases after sprouting (up to +0.88 percentage points), whereas finger millet, proso millet, and barnyard millet showed slight protein reductions (−0.10 to −0.79 percentage points). This variety-dependent response mirrors previous reports that sprouting can either increase or decrease protein content depending on the balance between proteolytic breakdown of nitrogenous compounds and the concentrating effect of dry-matter loss during germination [14], and is consistent with germination-related protein changes reported for finger and pearl millet flours [5, 16].

3.4 Crude Fibre Content

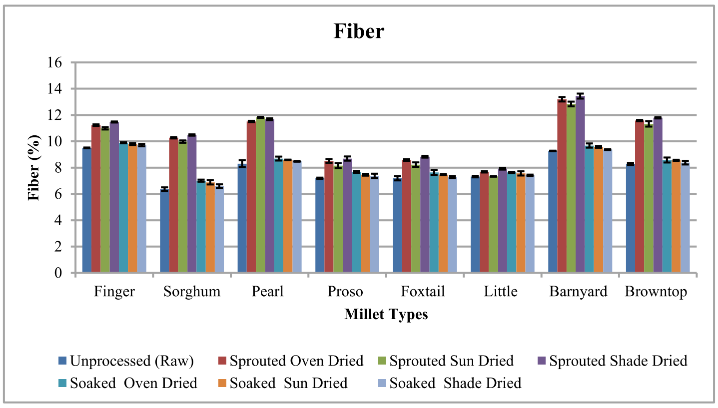

Fig. 4. Effect of processing treatment (raw, sprouted, and soaked) and drying method (oven, sun, and shade) on the fiber content (%) of eight millet varieties (mean ± SD, n = 3)

Crude fibre showed the most consistent and pronounced response to processing among all parameters measured. Sprouting increased mean crude fibre content from 7.93% (unprocessed) to 10.08–10.54% across the three drying methods, with the largest increases observed in great millet (+3.91 percentage points), barnyard millet (+3.93 percentage points), and browntop millet (+3.30 percentage points) after sprouting. Soaking alone produced a much smaller fibre increase (8.07–8.35% mean). The highest crude fibre value recorded in the entire dataset was 13.44% in shade-dried, sprouted barnyard millet, while the lowest was 6.36% in unprocessed great millet. The fibre enrichment associated with sprouting can be attributed to synthesis of structural, non-starch polysaccharide material in the emerging radicle and shoot tissue, together with a concentrating effect as starch reserves are respired away [3, 10]. It should be noted that some earlier reports on sorghum and millet sprouting describe a net reduction in crude fibre with germination, attributed to partial degradation of cell-wall polysaccharides by hydrolytic enzymes [14]; the direction of this effect appears to depend on species, sprouting duration, and whether the emergent rootlets are removed (deculmed) before analysis, and the present results in which sprouts were retained and dried together with the kernel align with the fibre-enrichment pattern reported for germinated finger, pearl, and sorghum flours [5,17].

3.5 Fat Content

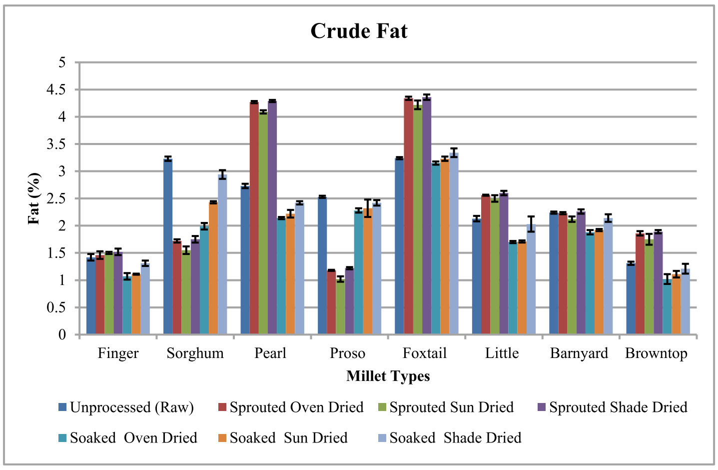

Fig. 5. Comparative fat content (%) of eight millet varieties under raw, sprouted, and soaked conditions, followed by oven, sun, or shade drying (values expressed as mean ± SD, n = 3)

Fat content ranged widely, from 1.02% (soaked, oven-dried browntop millet and finger millet) to 4.36% (sprouted, shade-dried foxtail millet), reflecting substantial inherent varietal differences: foxtail and pearl millet were consistently the highest-fat varieties across all treatments, while finger and proso millet were consistently the lowest. Soaking, particularly when followed by oven drying, reduced fat content relative to unprocessed grain in most varieties (sorghum fell from 3.23% to 1.99%, and browntop millet from 1.31% to 1.02%), consistent with partial leaching of lipid-associated compounds and enzymatic lipid breakdown during the extended soak [18]. The effect of sprouting on fat content was again variety-dependent: great millet and proso millet showed marked fat reductions after sprouting (−1.51 and −1.35 percentage points, respectively), while pearl millet and foxtail millet showed fat increases (+1.54 and +1.10 percentage points), which may reflect differences in the relative size and lipid density of the germ layer across species and its contribution to the whole, undeculmed sprouted kernel analysed in this study [13].

3.6 Ash Content

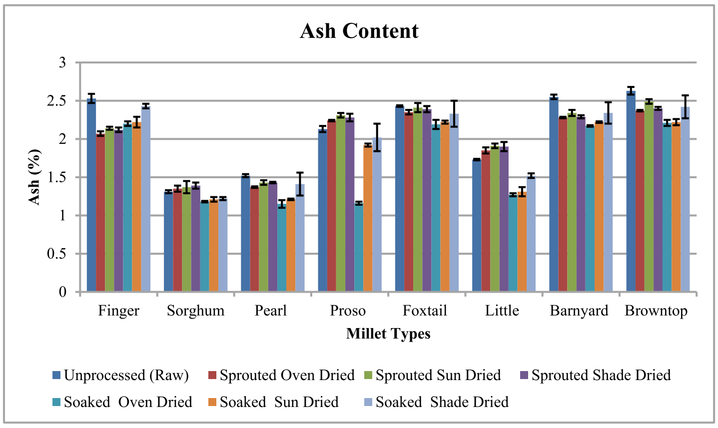

Fig. 6. Ash content (%) of eight millet varieties subjected to different processing treatments raw (unprocessed), sprouted, and soaked, followed by oven, sun, or shade drying expressed as mean ± SD (n = 3)

Ash content, an index of total mineral matter, was generally highest in unprocessed grain (2.10% mean) and lowest in soaked, oven-dried samples (1.69% mean), ranging overall from 1.15% (soaked, oven-dried pearl millet) to 2.63% (unprocessed browntop millet). Both soaking and sprouting reduced ash content relative to the raw grain in most varieties, consistent with the leaching of soluble mineral salts into the steep or germination water, an effect that has been widely reported for other cereals and pulses undergoing wet processing [15, 19]. Shade-dried samples tended to retain marginally higher ash content than oven or sun-dried samples within the same pre-treatment group, possibly reflecting the longer drying duration and correspondingly greater opportunity for further mineral loss to be minimised under the lower-temperature shade environment relative to oven drying, although the differences were generally small (well within 0.3 percentage points) [20].

3.7 Comparative Effect of Pre-Treatment and Drying Method

Taken together, the data indicate two broad, complementary processing strategies. Soaking followed by oven drying produced flours with the highest carbohydrate and protein retention and the lowest residual moisture and fat, making this combination best suited for applications requiring energy-dense, shelf-stable flours, such as composite flours for baked or extruded products. Sprouting followed by shade or sun drying, by contrast, produced flours with the highest crude fibre content, at the expense of some carbohydrate and, in most varieties, higher residual moisture, making this combination more appropriate for dietary-fibre-enriched or functional food formulations where enhanced digestibility and bioactive content resulting from germination are also desirable [2].

Table 1. Mean proximate composition (%) by treatment group, averaged across all eight millet varieties

Millets treatment	Moisture (%)	CHO (%)	Protein (%)	Fiber (%)	Fat (%)	Ash (%)
Sprouted, Oven Dried	10.53	66.22	8.49	10.32	2.45	1.99
Sprouted, Sun Dried	11.36	65.84	8.32	10.08	2.34	2.05
Sprouted, Shade Dried	11.37	65.14	8.44	10.54	2.49	2.02
Soaked, Oven Dried	9.94	69.27	8.84	8.35	1.90	1.69
Soaked, Sun Dried	10.04	69.10	8.75	8.24	2.01	1.82
Soaked, Shade Dried	10.24	69.00	8.49	8.07	2.23	1.96
Unprocessed (Raw)	10.57	68.66	8.38	7.93	2.35	2.10

Among drying methods, oven drying at 40 ± 2 °C was the most effective at reducing moisture content within a fixed processing time and is therefore preferable where rapid, standardised drying and extended shelf life are priorities, whereas sun and shade drying being lower-cost, non-mechanised options – remain relevant for small-scale or resource-limited processing settings despite their slightly lower moisture-reduction efficiency [4]. Foxtail millet emerged as the variety with the highest protein content under every processing combination tested, while great millet (sorghum) and little millet consistently showed the highest carbohydrate content, underscoring those varieties as strong candidates for protein-fortified and energy-dense product development, respectively.

4. Conclusion

This comparative study demonstrated that both pre-treatment (sprouting versus soaking) and drying method (oven, sun, and shade) significantly influence the proximate composition of eight millet varieties.

Sprouting reduced carbohydrate content while enriching crude fibre, whereas soaking increased carbohydrate and, in most varieties, protein content, with comparatively smaller changes in fibre. Oven drying was the most efficient method for reducing residual moisture within each pre-treatment group, while shade drying tended to preserve marginally higher fibre and ash levels. Foxtail millet consistently showed the highest protein content, and great millet and little millet the highest carbohydrate content, across all treatments. These findings provide a practical basis for selecting millet variety and processing combination according to the intended nutritional target for example, soaked and oven-dried millets for protein- and energy-dense formulations, or sprouted and shade/sun-dried millets for fibre-enriched functional foods and support the wider utilisation of diverse millet varieties as climate-resilient, nutritionally versatile nutri-cereals.

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Conflict of interest: The authors declare that they have no competing interests relevant to the content of this manuscript.

Ethical issues: None

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