

NUTRITIONAL PROFILING OF RAW AND GERMINATED FOXTAIL MILLET (*SETARIA ITALICA* L.): CHANGES IN NUTRITIONAL COMPOSITION, DIGESTIBILITY, MINERAL CONTENT AND PHYTOCHEMICAL CHARACTERISTICS

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Research Highlights

- Germination significantly improved the nutritional quality of foxtail millet grains.
- Dietary fibre, protein digestibility and essential amino acid contents increased after germination.
- Germination modified starch fractions and improved *In-vitro* carbohydrate and protein digestibility.
- Mineral bioavailability was enhanced through reduction of anti-nutritional factors during germination.
- Germinated foxtail millet exhibited improved phytochemical profile and functional food potential.

ABSTRACT

Foxtail millet (*Setaria italica* L.) is a nutrient-rich minor cereal receiving increasing attention because of its superior nutritional quality, low glycaemic index and suitability for functional food development. Germination is a simple, cost-effective bioprocess that enhances nutrient bioavailability and improves the functional characteristics of cereal grains. The present study evaluated the influence of germination on the nutritional profile, carbohydrate fractions, digestibility, amino acid composition, fatty acid profile, mineral composition and phytochemical characteristics of foxtail millet by comparing raw foxtail millet (RFM) with germinated foxtail millet (TFM). The crude fibre content increased significantly from $3.77 \pm 0.01\%$ in RFM to $6.86 \pm 0.01\%$ in TFM, while total dietary fibre increased from $11.10 \pm 0.00\%$ to $15.00 \pm 0.00\%$. Total sugars increased marginally from $9.56 \pm 0.06\%$ to $11.00 \pm 0.00\%$, whereas reducing sugars decreased from $0.54 \pm 0.01\%$ to $0.41 \pm 0.00\%$ and non-reducing sugars increased from $9.02 \pm 0.06\%$ to $10.58 \pm 0.00\%$. Total starch content increased from $56.70 \pm 0.32\%$ in RFM to $60.90 \pm 0.89\%$ in TFM. Amylose content increased markedly from $18.67 \pm 0.35\%$ to $52.40 \pm 0.23\%$, whereas amylopectin decreased from $38.03 \pm 0.65\%$ to $8.50 \pm 0.74\%$. Statistically significant differences ($p \leq 0.05$) were observed for reducing sugars, amylose and amylopectin, while differences in total sugars, non-reducing sugars and total starch were not significant. The samples exhibited dose-dependent inhibition of *In vitro* α -amylase activity, with IC₅₀ values of $76.99 \pm 0.01 \mu\text{g/mL}$ and $65.33 \pm 0.01 \mu\text{g/mL}$ for RFM and TFM, respectively. Germination substantially enhanced *in vitro* protein digestibility from $55.30 \pm 0.27\%$ to $148.27 \pm 4.09\%$, accompanied by an improvement in amino acid content. Linolenic and oleic acids remained the predominant fatty acids in both samples with only minor variations following germination. Mineral analysis demonstrated significant enhancement of calcium ($41.05 \pm 1.45 \text{ mg/100 g}$) and iron ($5.50 \pm 0.08 \text{ mg/100 g}$) in germinated millet ($p \leq 0.05$), although magnesium, manganese, zinc and phosphorus decreased slightly after germination. Qualitative phytochemical screening revealed the strong presence of carbohydrates and alkaloids in both samples. Proteins were more intensely detected after germination, while amino acids were observed only in germinated millet. Fixed oils, fats, terpenoids and cardiac glycosides were detected in both samples, whereas flavonoids, steroids, saponins, tannins, phlobatannins, phenols and quinones were absent. The findings demonstrate that germination significantly improves the nutritional quality, dietary fibre, protein digestibility, amino acid availability and selected mineral contents of foxtail millet while modifying carbohydrate characteristics. These improvements support the utilization of germinated foxtail millet as a functional ingredient for the development of health-promoting foods targeting metabolic disorders and improved nutritional security.

KEYWORDS: Foxtail millet; Germination; Nutritional profiling; Dietary fibre; Protein digestibility; α -Amylase inhibition; Minerals; Functional foods

1. INTRODUCTION

Millets constitute one of the oldest cereal groups cultivated by humans and are increasingly recognized as climate-resilient crops capable of contributing to global food and nutritional security. Their adaptability to marginal lands, low water requirements and tolerance to drought make them particularly suitable under changing climatic conditions. In recent years, millets have gained renewed scientific and commercial interest owing to their superior nutritional composition, low glycaemic response and abundance of health-promoting phytochemicals [25, 27, 28, 30]. Among the small millets, foxtail millet (*Setaria italica* L.) has emerged as an important functional cereal because of its balanced nutrient composition and potential application in the prevention and dietary management of several chronic non-communicable diseases [10, 25].

Foxtail millet is widely cultivated in Asia, particularly in India and China, where it has traditionally served as an important staple food. Compared with refined cereals such as rice and wheat, foxtail millet possesses higher dietary fibre, minerals, essential amino acids and bioactive compounds while remaining naturally gluten-free [10, 25, 26]. These nutritional attributes make it an attractive alternative grain for individuals affected by gluten intolerance, celiac disease and metabolic disorders [20, 26]. The grain is also characterized by a relatively low glycaemic index resulting from its complex carbohydrate composition and resistant starch fractions, thereby producing slower glucose release after consumption [24, 25].

The nutritional composition of foxtail millet includes approximately 10–12% protein, 3–4% fat, 65–70% carbohydrates and appreciable quantities of dietary fibre, calcium, phosphorus, iron, zinc and B-complex vitamins [10, 25]. It is also recognized as a valuable source of β -carotene compared with several other cereals [27]. The protein fraction contains both essential and non-essential amino acids, including methionine and cysteine, which are generally limiting in most cereal grains [10, 25]. In addition, foxtail millet contains unsaturated fatty acids such as oleic and linolenic acids that contribute to cardiovascular health and normal physiological functions [20, 28].

Apart from its nutritional richness, foxtail millet contains numerous bioactive constituents including phenolic acids, antioxidants and other phytochemicals associated with anti-inflammatory, antioxidant, antihyperglycaemic and hypolipidaemic activities [7, 13, 20, 29]. Epidemiological and experimental evidence suggests that regular millet consumption may reduce the risk of obesity, cardiovascular diseases, hypertension and type 2 diabetes mellitus [20, 25, 27, 28]. The relatively slow digestibility of millet starch delays glucose absorption, while its dietary fibre increases satiety, slows gastric emptying and improves gastrointestinal health [6, 24, 25]. Consequently, foxtail millet has been increasingly incorporated into functional foods intended for diabetic individuals, elderly populations and consumers seeking healthier cereal alternatives [20, 27].

Despite these nutritional advantages, the bioavailability of several nutrients in cereal grains is frequently limited by naturally occurring antinutritional factors. Phytic acid, tannins and enzyme inhibitors can reduce mineral absorption and impair protein digestibility [3, 8, 12]. Therefore, processing methods that improve nutrient availability without compromising nutritional quality have received considerable research attention. Among these methods, germination represents one of the simplest, economical and environmentally sustainable approaches for improving cereal quality [3, 8, 9].

Germination activates endogenous hydrolytic enzymes that initiate the mobilization of stored nutrients required for seedling growth. During this process, amylases hydrolyse starch into simpler carbohydrates, proteases degrade storage proteins into peptides and free amino acids, while phytases reduce phytic acid content, thereby enhancing mineral bioavailability [3, 9, 12]. Simultaneously, modifications occur in dietary fibre composition, vitamin concentration and antioxidant activity [2, 18, 23]. These biochemical transformations collectively improve digestibility, nutritional quality and functional properties of cereal grains [3, 8, 9].

Several studies have demonstrated that germination positively influences the nutritional profile of foxtail millet. Soluble sugars and protein content increase during germination because of enhanced enzymatic hydrolysis of storage macromolecules [9, 17, 21]. Germination has also been associated with improvements in amino acid composition, in vitro protein digestibility and mineral availability, particularly calcium and iron [12, 17, 21]. Reduction of antinutritional compounds further contributes to enhanced nutrient utilization and digestibility [3, 9, 12].

Foxtail millet proteins consist predominantly of alcohol-soluble prolamins together with glutelins, albumins and globulins. Although the grain exhibits moderate protein digestibility in its raw form, germination substantially improves protein quality through proteolytic degradation of storage proteins into more digestible peptides and amino acids [3, 9, 21]. Previous investigations have reported enhanced concentrations of essential amino acids including leucine, isoleucine, valine, methionine, threonine and phenylalanine following germination [17, 21]. Improved protein digestibility is of particular nutritional importance in populations dependent on cereal-based diets where protein quality often limits nutritional adequacy [3].

Carbohydrate quality is another important nutritional attribute of foxtail millet. Besides total starch, the relative proportions of amylose and amylopectin strongly influence starch digestibility, glycaemic response and technological functionality [11, 22, 24]. Processing-induced modifications in starch fractions may alter enzymatic susceptibility to α -amylase, thereby affecting glucose release during digestion [16, 24]. The inhibition of

carbohydrate-digesting enzymes has gained considerable attention as a dietary strategy for glycaemic control, particularly among diabetic populations [5]. Therefore, evaluating changes in carbohydrate digestibility following germination provides important information regarding the potential application of germinated millet in functional foods.

Minerals such as calcium, iron, magnesium, phosphorus, zinc and manganese perform indispensable physiological functions including bone mineralization, oxygen transport, enzyme activation and energy metabolism [10, 25]. Although foxtail millet contains appreciable concentrations of these micronutrients, their absorption is frequently restricted by mineral-chelating compounds [12]. Germination has been shown to reduce phytate levels and consequently increase mineral bioavailability [12]. Enhanced calcium and iron concentrations following germination further strengthen the nutritional significance of foxtail millet as a functional cereal for combating micronutrient deficiencies [17, 21].

In addition to nutrients, phytochemicals present in foxtail millet contribute substantially to its biological activities. Alkaloids, terpenoids, phenolic compounds and other secondary metabolites exhibit antioxidant, antimicrobial and anti-inflammatory properties [7, 13, 19, 29]. Processing treatments may modify both qualitative and quantitative phytochemical profiles, thereby influencing the functional potential of millet-based foods [7, 18]. Qualitative phytochemical screening therefore provides useful information regarding changes associated with germination [19]. The growing prevalence of diabetes mellitus, obesity and cardiovascular diseases has intensified interest in cereal grains possessing low glycaemic characteristics and high nutritional value. Clinical and nutritional studies have demonstrated that regular consumption of foxtail millet-based foods improves fasting blood glucose, glycated haemoglobin, serum lipid profile and insulin sensitivity in individuals with impaired glucose metabolism [20, 25, 27, 28]. Furthermore, the naturally gluten-free nature of foxtail millet enables its incorporation into specialized formulations suitable for individuals with celiac disease or gluten sensitivity [26].

Although numerous investigations have reported individual aspects of foxtail millet composition, comprehensive evaluation of the nutritional modifications occurring during germination remains limited. Simultaneous assessment of dietary fibre, carbohydrate fractions, digestibility, amino acid composition, fatty acid profile, mineral composition and phytochemical characteristics provides a more complete understanding of the nutritional improvements associated with germination [9, 17, 21]. Such information is essential for developing value-added functional foods with enhanced nutritional quality and health-promoting properties [20, 25, 30].

Therefore, the present study aimed to evaluate the effect of germination on the nutritional profile of foxtail millet by comparing raw and germinated grains. The investigation focused on dietary fibre, carbohydrate fractions, starch composition, *in vitro* carbohydrate and protein digestibility, amino acid profile, fatty acid composition, mineral content and qualitative phytochemical characteristics. The findings are expected to provide scientific evidence supporting the utilization of germinated foxtail millet as a functional food ingredient for improving nutritional security and promoting the dietary management of metabolic disorders.

2. MATERIALS AND METHODS

2.1 Sample preparation

Raw foxtail millet (*Setaria italica* L.) grains were cleaned manually to remove dust, immature seeds and foreign materials before analysis. A portion of the grains was retained as raw foxtail millet (RFM), while the remaining grains were subjected to controlled germination to obtain germinated foxtail millet (TFM). The germinated grains were dried, milled into fine flour, passed through a standard laboratory sieve and stored in airtight polyethylene containers at 4 °C until further analysis. All analyses were performed in triplicate unless otherwise specified.

2.2 Determination of total dietary fibre

Total dietary fibre (TDF) was determined according to the AOAC enzymatic-gravimetric method (AOAC 2000). Briefly, moisture-free and defatted flour samples (1.0 g) were subjected to sequential enzymatic digestion using heat-stable α -amylase, pepsin and pancreatin to hydrolyse starch and protein fractions. Following enzymatic digestion, soluble dietary fibre was precipitated using 95% ethanol and the digest was filtered through pre-weighed crucibles containing Celite.

The residue was washed successively with 78% ethanol, 95% ethanol and acetone, dried overnight at 105 °C and weighed. Protein and ash corrections were performed using the Kjeldahl method and muffle furnace incineration, respectively. Blank corrections were included in each analytical batch. Total dietary fibre was calculated as the residue remaining after correction for protein, ash and blank values and expressed as percentage on dry weight basis.

2.3 Determination of carbohydrate fractions

2.3.1 Total sugars

Total sugars were estimated by the anthrone method of Somogyi (1952). Finely powdered samples (100 mg) were hydrolysed with dilute hydrochloric acid, neutralized with sodium carbonate and centrifuged. Appropriate aliquots of the supernatant were reacted with freshly prepared anthrone reagent in boiling water. After rapid cooling, absorbance was measured at 630 nm using a UV–Visible spectrophotometer. Glucose was used for calibration and results were expressed as percentage of dry sample.

2.3.2 Reducing sugars

Reducing sugars were estimated using the alkaline copper tartrate method described by Somogyi (1952). Ethanol extracts of the samples were reacted with alkaline copper tartrate reagent followed by arsenomolybdate reagent. The resulting blue colour was measured spectrophotometrically at 630 nm against glucose standards. Results were expressed as percentage of dry weight.

2.3.3 Non-reducing sugars

Non-reducing sugars were calculated indirectly as the difference between total sugars and reducing sugars:

$$\text{Non-reducing sugars (\%)} = \text{Total sugars (\%)} - \text{Reducing sugars (\%)}$$

2.4 Determination of starch fractions

2.4.1 Total starch

Total starch content was determined according to the anthrone method of Southgate (1976). Soluble sugars were first removed from the flour using hot 80% ethanol. The starch residue was extracted with perchloric acid and reacted with anthrone reagent. Absorbance was recorded at 630 nm, and starch concentration was calculated from a glucose calibration curve using a conversion factor of 0.90.

2.4.2 Amylose content

Amylose content was determined according to the iodine-binding method of Williams et al. (1958). Flour samples were dispersed in sodium hydroxide, neutralized and reacted with iodine solution to form a blue amylose-iodine complex. The absorbance was measured at 590 nm and amylose concentration was calculated using a standard amylose calibration curve.

2.4.3 Amylopectin content

Amylopectin content was calculated from the relationship:

$$\text{Amylopectin (\%)} = \text{Total starch (\%)} - \text{Amylose (\%)}$$

2.5 *In-vitro* carbohydrate digestibility

The inhibitory effect of millet extracts on α -amylase activity was evaluated following the method of Singh and Jambunathan (1982). Different concentrations of sample extracts (10–100 $\mu\text{g/mL}$) were incubated with α -amylase prepared in phosphate buffer (0.2 M, pH 6.9). Following enzymatic hydrolysis, reducing sugars released were quantified using 3,5-dinitrosalicylic acid (DNSA) reagent after heating in a boiling water bath. Absorbance was measured at 550 nm.

Percentage inhibition of α -amylase activity was calculated as:

$$\text{Inhibition (\%)} = [(\text{Control activity} - \text{Sample activity}) / \text{Control activity}] \times 100$$

The concentration required to inhibit 50% of enzyme activity (IC_{50}) was determined from dose-response curves generated using triplicate observations. Maltose was used as the reference standard.

2.6 *In-vitro* protein digestibility

In vitro protein digestibility was determined according to Schacterle and Pollak (1973). Samples containing 100 mg protein were sequentially digested with pepsin in 0.1 N hydrochloric acid for 3 h at 37 °C, followed by pancreatic digestion in phosphate buffer (pH 8.0) for 24 h after neutralization.

The digested mixture was centrifuged and soluble protein in the supernatant was quantified by the Kjeldahl method (AOAC 2005). Protein digestibility was expressed as percentage of soluble protein released during enzymatic digestion.

2.7 Amino acid and fatty acid profiling

The amino acid and fatty acid profiles of raw and germinated foxtail millet were determined at the Agricultural MFPI-Quality Control Laboratory, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Hyderabad.

Amino acids were analysed using High Performance Liquid Chromatography (HPLC) following the laboratory's validated standard operating procedure. Fatty acid composition was determined by Gas Chromatography equipped with a Flame Ionization Detector (GC-FID). Individual amino acids and fatty acids were identified by comparison with authenticated standards and quantified using calibration curves generated from certified reference materials.

2.8 Mineral analysis

2.8.1 Sample digestion

For mineral determination, 0.5 g of millet flour was digested with a nitric acid-perchloric acid mixture (9:4, v/v) until a clear solution was obtained. The digest was cooled, diluted to 100 mL with distilled water and filtered before instrumental analysis.

2.8.2 Determination by flame atomic absorption spectrophotometry

The concentrations of calcium, magnesium, iron, zinc, manganese, sodium, potassium and phosphorus were determined using Flame Atomic Absorption Spectrophotometry (FAAS) following AOAC (1990) procedures. Calibration curves were prepared using certified standard solutions covering the expected concentration ranges.

Instrumental conditions were optimized according to the manufacturer's recommendations, and all determinations were performed under oxidizing air-acetylene flame conditions using element-specific wavelengths. Blank solutions

and quality-control standards were analysed with every analytical batch to ensure analytical accuracy. Mineral concentrations were expressed as mg/100 g dry weight.

2.9 Preliminary phytochemical screening

Methanolic extracts of raw and germinated foxtail millet were prepared by cold maceration for 24 h followed by centrifugation and filtration. The extracts were stored at 4 °C until analysis.

Qualitative phytochemical screening was carried out according to Harborne (1993). Standard chemical tests were employed for the detection of carbohydrates (Molisch's test), alkaloids (Mayer's, Wagner's and Hager's tests), proteins (Biuret test), amino acids (Ninhydrin test), flavonoids, fixed oils and fats, terpenoids (Salkowski test), cardiac glycosides (Keller–Killiani test), steroids (Liebermann–Burchard test), saponins (foam test), tannins (lead acetate test), phlobatannins, phenolic compounds (Ferric chloride and Liebermann's tests) and quinones. The presence or absence of each phytochemical constituent was recorded based on the characteristic colour development or precipitate formation.

2.10 Statistical analysis

All experiments were conducted in triplicate and the results are presented as mean $\pm$ standard deviation. Statistical analysis was performed using standard statistical procedures described by Snedecor and Cochran (1983). Differences between raw and germinated foxtail millet were evaluated using Student's *t*-test. Statistical significance was considered at $p \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 Fibre composition

The fibre composition of raw foxtail millet (RFM) and germinated foxtail millet (TFM) is presented in Figure 1 and Table 1. Germination significantly ($p < 0.05$) improved both crude fibre and total dietary fibre (TDF) contents, indicating favourable structural modifications in the grain during sprouting. Crude fibre increased from $3.77 \pm 0.01\%$ in RFM to $6.86 \pm 0.01\%$ in TFM, representing an increase of 81.96%. Similarly, TDF increased significantly from $11.10 \pm 0.00\%$ to $15.00 \pm 0.00\%$, corresponding to a 35.13% increase following germination.

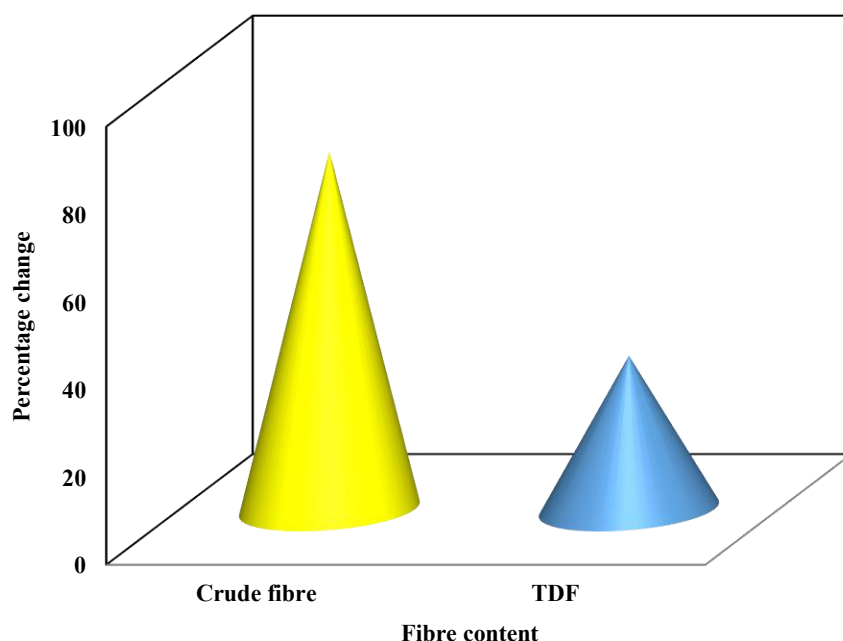


Figure 1: Percentage change in fibre content of foxtail millet

TDF: Total dietary fibre

Table 1: Sugars and starch composition of foxtail millet

Sample	Total sugars	Reducing Sugar	Non-reducing sugar	Total starch	Amylose	Amylopectin
RFM	9.56 $\pm$ 0.06	0.54 ^{ab} $\pm$ 0.01	9.02 ^c $\pm$ 0.06	56.70 ^c $\pm$ 0.32	18.67 $\pm$ 0.35	38.03 $\pm$ 0.65
TFM	11.00 ^c $\pm$ 0.00	0.41 ^{ba} $\pm$ 0.00	10.58 ^c $\pm$ 0.00	60.90 ^c $\pm$ 0.89	52.40 $\pm$ 0.23	8.50 $\pm$ 0.74
Mean	10.28	0.47	9.80	58.80	35.53	23.26
SE	0.32	0.02	0.34	1.03	7.54	6.61
CD	0.28	0.01	0.29	4.69	1.51	5.77

CV%	0.79	0.85	0.85	2.27	1.21	7.07
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Note: Values are expressed as mean $\pm$ standard deviation of three determinations.

Means within the same column followed by a common letter do not significantly differ at $p < 0.05$

Unit of measurement is expressed as %

RFM: Raw foxtail millet

TFM: Test foxtail millet

The substantial increase in crude fibre can be attributed to physiological and biochemical changes occurring during germination. Seed germination activates cellular metabolism and promotes embryo growth, resulting in the synthesis of structural polysaccharides such as cellulose, hemicellulose and lignin that contribute to cell wall development. Simultaneously, hydrolysis of starch reserves reduces the relative proportion of digestible carbohydrates, thereby increasing the apparent fibre content. Similar observations have been reported by Vayupharp and Laksanalamai (2013), who demonstrated that sprouting enhances structural carbohydrate accumulation as part of seedling development.

The increase in TDF further supports the beneficial influence of germination on cereal nutritional quality. During germination, activation of endogenous enzymes modifies the architecture of cell wall polysaccharides and weakens protein-carbohydrate interactions, resulting in the formation and greater availability of dietary fibre components. Cell wall biosynthesis occurring during early seedling growth also contributes to the synthesis of new insoluble and soluble fibre fractions. Comparable findings have been reported in germinated cereals and legumes, where germination promoted increased dietary fibre through enzymatic restructuring of the grain matrix (Cabrejas *et al.* 2003; Duodu 2014).

Dietary fibre is recognized as an important functional food component because of its beneficial physiological effects, including improved gastrointestinal health, regulation of blood glucose response, reduction of serum cholesterol and enhancement of satiety. Therefore, the observed increase in fibre following germination enhances the nutritional and functional value of foxtail millet, making it more suitable for the development of health-promoting foods. The present findings agree with previous reports demonstrating that controlled germination is an effective and economical bioprocess for improving the dietary fibre profile of millet grains.

3.2 Sugar and starch composition

Changes in sugar and starch composition following germination are presented in Figure 2. Germination altered carbohydrate fractions considerably, although not all parameters exhibited statistically significant differences. Total sugars increased from $9.56 \pm 0.06\%$ in RFM to $11.00 \pm 0.00\%$ in TFM, representing a 15.06% increase, whereas the difference was not statistically significant ($p > 0.05$). The increase in total sugars reflects the hydrolytic degradation of reserve polysaccharides during germination. Activation of α -amylase and other hydrolytic enzymes converts starch into soluble sugars that are utilized as respiratory substrates and energy sources for embryonic growth. Similar increases in soluble sugars during germination have been reported for proso millet and other cereal grains (Parameswaran and Sadasivam 1994).

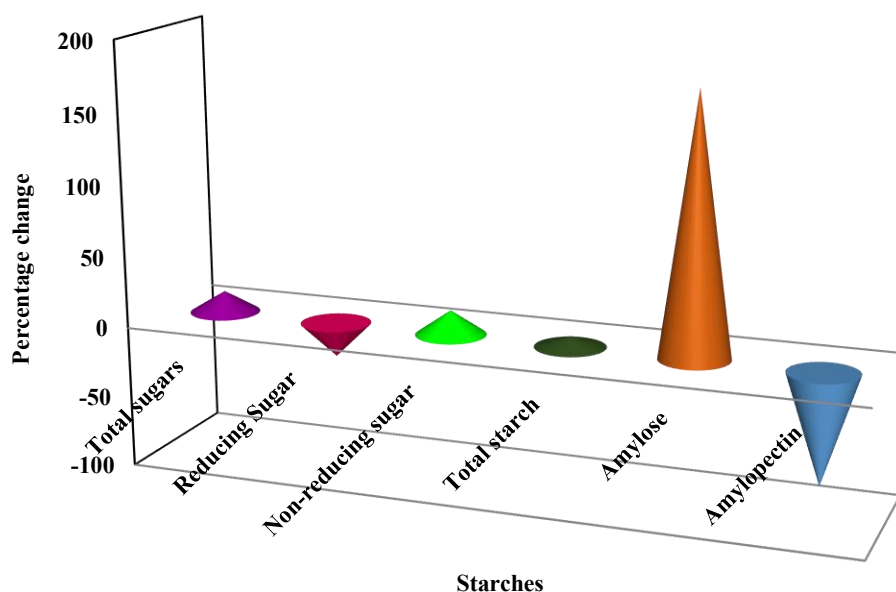


Figure 2: Percentage change in starch composition of germinated foxtail millet

In contrast, reducing sugars decreased significantly ($p < 0.05$) from $0.54 \pm 0.01\%$ in RFM to $0.41 \pm 0.00\%$ in TFM, corresponding to a reduction of 24.07%. Although germination initially promotes starch hydrolysis and production of reducing sugars, these sugars are rapidly metabolized through glycolysis and other respiratory pathways to sustain seedling growth. Consequently, their steady-state concentration declines despite continued enzymatic starch degradation. This metabolic utilization explains the lower reducing sugar content observed in germinated foxtail millet.

Non-reducing sugars increased from $9.02 \pm 0.06\%$ to $10.58 \pm 0.00\%$, representing an increase of 17.29%, although the difference was not statistically significant. The accumulation of non-reducing sugars may result from enzymatic interconversion of simple sugars and the synthesis of transport carbohydrates required for developing tissues. Such carbohydrate transformations are characteristic of germinating cereal grains and contribute to improved sweetness and fermentability of malted products.

Total starch content increased slightly from $56.70 \pm 0.32\%$ in RFM to $60.90 \pm 0.89\%$ in TFM, with no statistically significant difference between treatments. Although starch is generally hydrolysed during germination, changes in starch concentration are influenced by moisture loss, degradation of other storage components and analytical expression on a dry weight basis. Similar observations have been reported in germinated cereal grains, where apparent starch content may remain unchanged or increase marginally despite enzymatic activity. Foxtail millet starch constitutes approximately 60–61% of the grain dry matter and possesses unique physicochemical properties that make it valuable for food and industrial applications (Ushakumari et al. 2004; Kim et al. 2009; Zhu 2014).

The most pronounced changes were observed in starch fractions. Amylose content increased significantly ($p < 0.05$) from $18.67 \pm 0.35\%$ in raw millet to $52.40 \pm 0.23\%$ after germination, representing an increase of 180.66%. Conversely, amylopectin content decreased significantly from $38.03 \pm 0.65\%$ to $8.50 \pm 0.74\%$, corresponding to a reduction of 77.64%. These marked alterations indicate extensive structural modification of starch during germination.

The increase in amylose may be attributed to preferential enzymatic degradation of highly branched amylopectin molecules by endogenous amylolytic enzymes. Hydrolysis of α -(1 $\rightarrow$ 6) branch points produces shorter linear glucan chains that exhibit amylose-like characteristics, thereby increasing the measured amylose fraction. Simultaneously, selective degradation reduces the proportion of intact amylopectin within the starch granule. Consequently, the amylose-to-amylopectin ratio shifted markedly following germination, with amylose becoming the predominant starch fraction in TFM. Such compositional changes are known to influence starch gelatinization behaviour, retrogradation tendency, digestibility and functional properties of cereal flours.

The overall carbohydrate profile demonstrated that germination substantially modified carbohydrate metabolism through coordinated enzymatic activities. Increased total sugars, non-reducing sugars and amylose, together with enhanced dietary fibre, indicate mobilization and restructuring of reserve carbohydrates during seed germination. Meanwhile, the decline in reducing sugars and amylopectin reflects their utilization as metabolic substrates and preferential enzymatic degradation. These biochemical transformations improve the nutritional quality and functional characteristics of foxtail millet flour and support its application in the formulation of value-added functional foods with improved health benefits. Similar improvements in carbohydrate composition following germination have been widely reported in cereal grains and are considered one of the major advantages of germination as a natural bioprocess for enhancing grain quality.

3.3 *In-vitro* carbohydrate and protein digestibility

The effect of germination on the digestibility characteristics of foxtail millet is presented in Figure 3, Figure 4 and Table 2. Germination modified both carbohydrate and protein digestibility, reflecting the biochemical and structural changes that occur during seed sprouting. The inhibitory activity against α -amylase, expressed as IC_{50} , decreased from 76.99 ± 0.01 μ g/ml in raw foxtail millet (RFM) to 65.33 ± 0.01 μ g/ml in germinated foxtail millet (TFM), representing a reduction of approximately 15.10%. Although this decrease was not statistically significant ($p > 0.05$), it indicates that germination altered the carbohydrate matrix and enzyme accessibility within the grain.

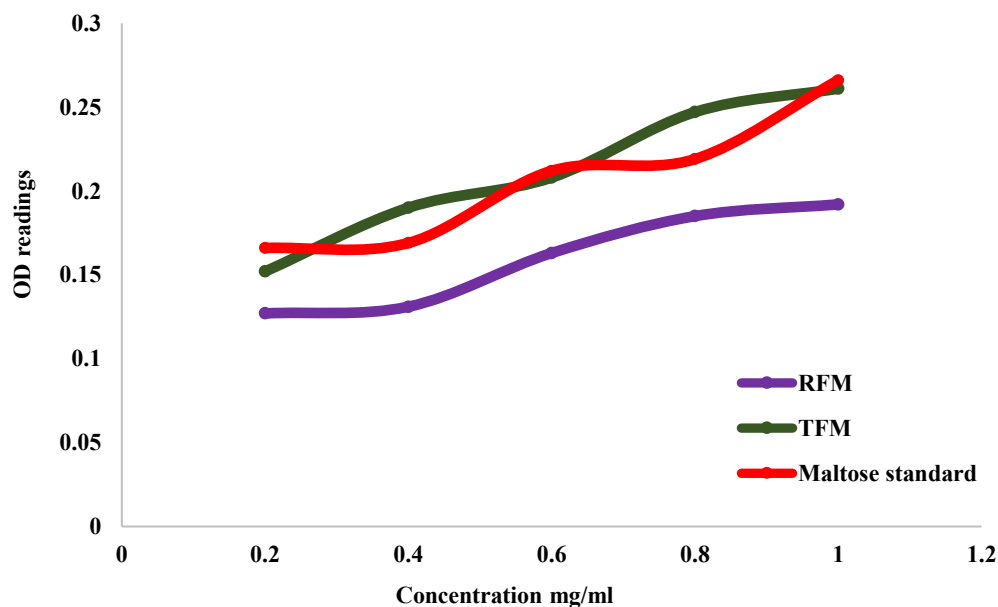


Figure 3: Inhibition of *in-vitro* carbohydrate digestibility with α -amylase

RFM: Raw foxtail millet

TFM: Test foxtail millet

Carbohydrate digestibility is largely governed by starch structure, dietary fibre and interactions among starch, proteins and other cell wall components. The increase in dietary fibre observed after germination, together with the structural modification of starch fractions, may have influenced the susceptibility of carbohydrates to enzymatic hydrolysis. Increased fibre forms a viscous matrix capable of entrapping starch granules, thereby reducing enzyme accessibility and slowing starch digestion. Similar observations have been reported in composite cereal products, where increased fibre reduced carbohydrate digestibility by restricting the diffusion of digestive enzymes through protein–fibre–starch networks (Chinma et al. 2011).

Controlled inhibition of α -amylase activity is considered nutritionally desirable because it slows starch hydrolysis and reduces the rate of postprandial glucose release. Foods exhibiting moderate α -amylase inhibitory activity are therefore regarded as potential functional ingredients for the dietary management of hyperglycaemia and type 2 diabetes. Dastjerdi et al. (2015) similarly suggested that inhibition of carbohydrate-digesting enzymes can contribute to improved glycaemic control and may support the development of functional foods with hypoglycaemic potential. The present findings indicate that germinated foxtail millet retains favourable carbohydrate digestibility characteristics while simultaneously improving other nutritional attributes.

In contrast to carbohydrate digestibility, protein digestibility was markedly enhanced by germination. The *in vitro* protein digestibility increased significantly ($p < 0.05$) from $55.30 \pm 0.27\%$ in RFM to $148.27 \pm 4.09\%$ in TFM, corresponding to an increase of approximately 168.11%. This substantial improvement demonstrates that germination effectively enhanced protein bioavailability through activation of endogenous proteolytic enzymes.

The enhanced protein digestibility may be attributed to several complementary mechanisms. During germination, storage proteins are hydrolysed into low-molecular-weight peptides and free amino acids to support embryo development. Simultaneously, partial degradation of protein–starch complexes and reductions in antinutritional factors improve enzyme accessibility during digestion. These biochemical modifications increase the susceptibility of proteins to gastrointestinal proteases, resulting in greater digestibility. Comparable improvements have been reported in germinated pearl millet, where germination significantly enhanced both protein and starch digestibility following enzymatic activation (Archana and Kawatra 2001). Kamara et al. (2009) also reported moderate protein digestibility values for defatted foxtail millet flour, suggesting that processing methods such as germination further improve protein utilization.

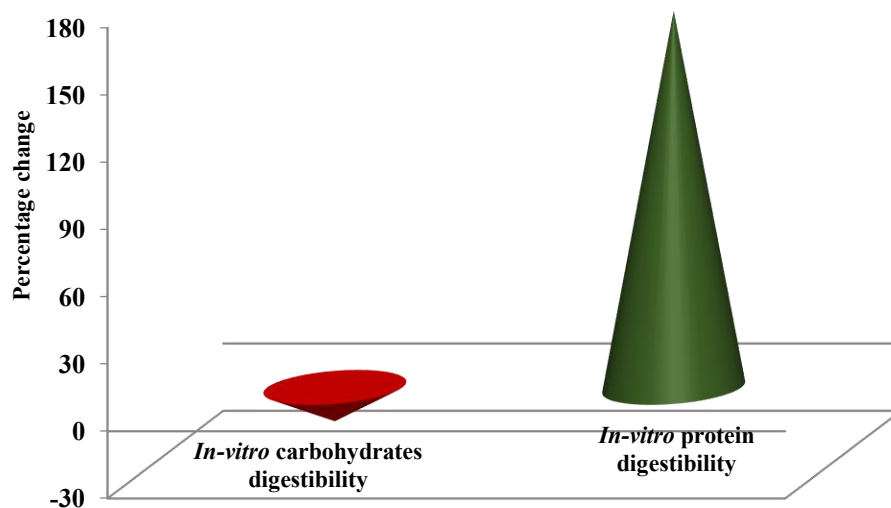


Figure 4: Percentage change in *In-vitro* digestibility of germinated foxtail millets

The contrasting responses of carbohydrate and protein digestibility demonstrate that germination selectively modifies the nutritional functionality of foxtail millet. While slight inhibition of carbohydrate digestion may contribute to a lower glycaemic response, enhanced protein digestibility increases amino acid availability and overall protein quality. These complementary changes improve the nutritional value of germinated foxtail millet and support its application in functional foods designed for improved metabolic health.

Table 2: IC₅₀ of *in-vitro* carbohydrates and protein digestibility

IC ₅₀ of sample	<i>In-vitro</i> carbohydrates digestibility (µg/ml)	<i>In-vitro</i> protein digestibility (%)
RFM	76.99 ^c ±0.01	55.30 ^a ±0.27
TFM	65.33 ^c ±0.01	148.27 ^b ±4.09
Mean	71.16	100.78
SE	2.60	21.31
CD	0.00	16.60
CV%	0.00	4.68

Note: Values are expressed as mean ± standard deviation of three determinations.

Means within the same column followed by a common letter do not significantly differ at $p < 0.05$

RFM: Raw foxtail millet

TFM: Test foxtail millet

3.4 Amino acid profile

The amino acid composition of raw and germinated foxtail millet is presented in Table 3 and Figure 5. Germination resulted in a substantial increase in both essential and non-essential amino acids, indicating extensive protein hydrolysis and active amino acid biosynthesis during seed germination. Glutamate was the predominant amino acid in both samples, increasing from 0.015 to 0.115 mg/g, whereas histidine, arginine and cysteine were present at the lowest concentrations in raw millet. In germinated millet, valine exhibited the lowest concentration among the quantified amino acids.

Table 3: Amino acids profile of raw and germinated foxtail millet

Name of amino acids	Concentration (mg/g)	
	Raw foxtail millet	Germinated foxtail millet
Aspartate	0.007	0.086
Glutamate	0.015	0.115
Serine	0.007	0.025
Histidine	0.001	0.016

Glycine	0.011	0.017
Threonine	0.002	0.021
Arginine	0.001	0.002
Alanine	0.003	0.008
Tyrosine	0.009	0.109
Cysteine	0.001	0.015
Valine	0.004	0.006
Methionine	0.004	0.040
Phenylalanine	0.002	0.018
Isoleucine	0.005	0.026
Leucine	0.003	0.029
Lysine	0.005	0.049
Proline	0.002	0.007

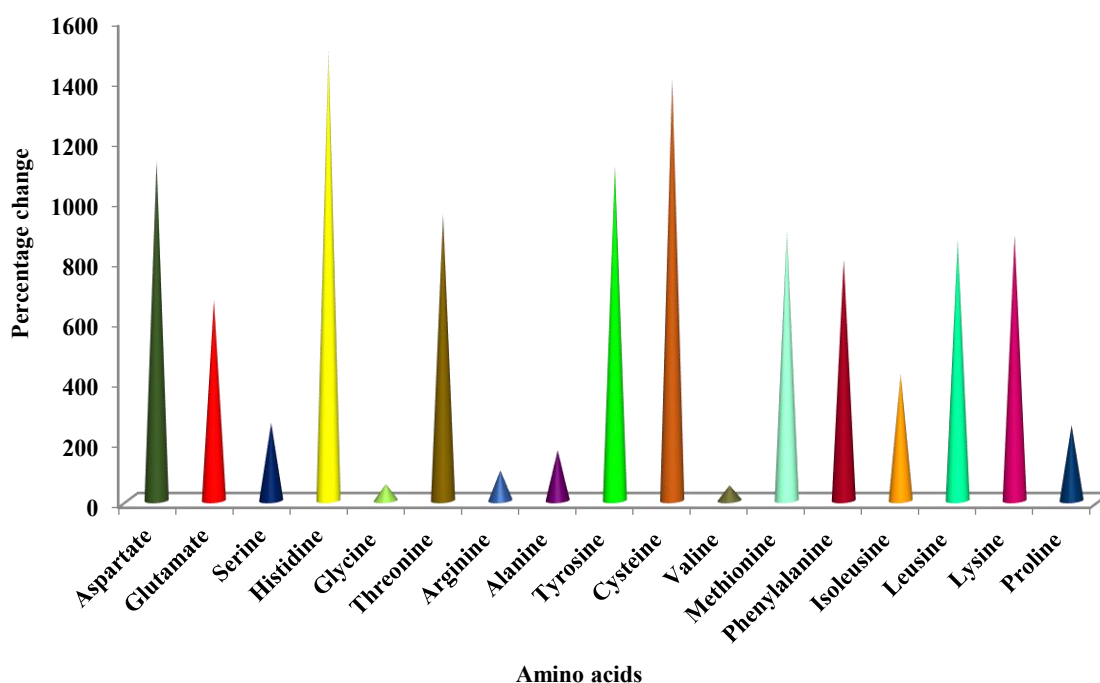


Figure 5: **Percentage change in amino acids**

Among the essential amino acids, remarkable increases were observed following germination. Histidine increased from 0.001 to 0.016 mg/g, threonine from 0.002 to 0.021 mg/g, methionine from 0.004 to 0.040 mg/g, phenylalanine from 0.002 to 0.018 mg/g, isoleucine from 0.005 to 0.026 mg/g, leucine from 0.003 to 0.029 mg/g and lysine from 0.005 to 0.049 mg/g. Relative increases were particularly pronounced for histidine (1500%), methionine (900%), leucine (866.66%), lysine (880%) and phenylalanine (800%). Valine showed a comparatively smaller increase of 50%, while arginine doubled during germination.

The enrichment of lysine is particularly significant because lysine is generally regarded as the first limiting amino acid in cereal proteins. Improvement of lysine concentration therefore enhances the biological value of millet proteins and contributes to a more balanced amino acid profile. Increased methionine, a sulphur-containing amino acid essential for methyl group metabolism and antioxidant synthesis, further improves the nutritional quality of germinated foxtail millet.

Non-essential amino acids also increased considerably following germination. Aspartate increased more than eleven-fold, glutamate increased over seven-fold, tyrosine increased more than twelve-fold, while serine, alanine, cysteine and proline also showed substantial improvements. These changes reflect the activation of proteolytic enzymes during germination, which degrade storage proteins into smaller peptides and free amino acids required for embryo growth and metabolic activity.

The enhanced amino acid profile is consistent with previous reports demonstrating that germination improves the nutritional quality of cereal proteins. Kamara et al. (2009) reported the presence of all major essential and non-essential amino acids in white and yellow varieties of foxtail millet, with leucine, threonine and histidine occurring

as major essential amino acids. Similarly, Parameswaran and Sadasivam (1994) observed increased lysine, tryptophan and non-protein nitrogen in germinated proso millet, suggesting that germination promotes protein synthesis and amino acid accumulation across millet species.

Overall, germination substantially improved the amino acid composition of foxtail millet by increasing both essential and non-essential amino acids. These modifications contribute directly to improved protein quality, greater nutritional value and enhanced digestibility, thereby increasing the suitability of germinated foxtail millet for functional and protein-enriched food formulations.

3.5 Fatty acid profile

The fatty acid composition of raw and germinated foxtail millet is shown in Table 4 and Figure 6. Nine fatty acids were identified, including saturated, monounsaturated and polyunsaturated fatty acids. Linoleic acid (C18:2n6c) was the predominant fatty acid in both samples, accounting for 70.517% of total fatty acids in RFM and 69.267% in TFM. Palmitoleic acid (C16:1) was present in the lowest concentration in both treatments.

Table 4: Fatty acids profile of raw and germinated foxtail millet

Name of fatty acids	Area percentage	
	Raw foxtail millet	Germinated foxtail millet
Palmitic acid methyl ester (C16:0)	7.745	7.876
Palmitoleic acid methyl ester (C16:1)	0.094	0.103
Stearic acid methyl ester (C18:0)	1.379	1.539
Oleic acid methyl ester (C18:1n9C)	17.473	18.108
Linoleic acid methyl ester (C18:2n6c)	70.517	69.267
α -Linolenic acid methyl ester (C18:3n3)	1.795	1.802
Arachidic acid methyl ester (C20:0)	0.479	0.640
Cis-11-Eicosaenoic acid methyl ester (C20:1n9)	0.323	0.316
Behenic acid methyl ester	0.198	0.348

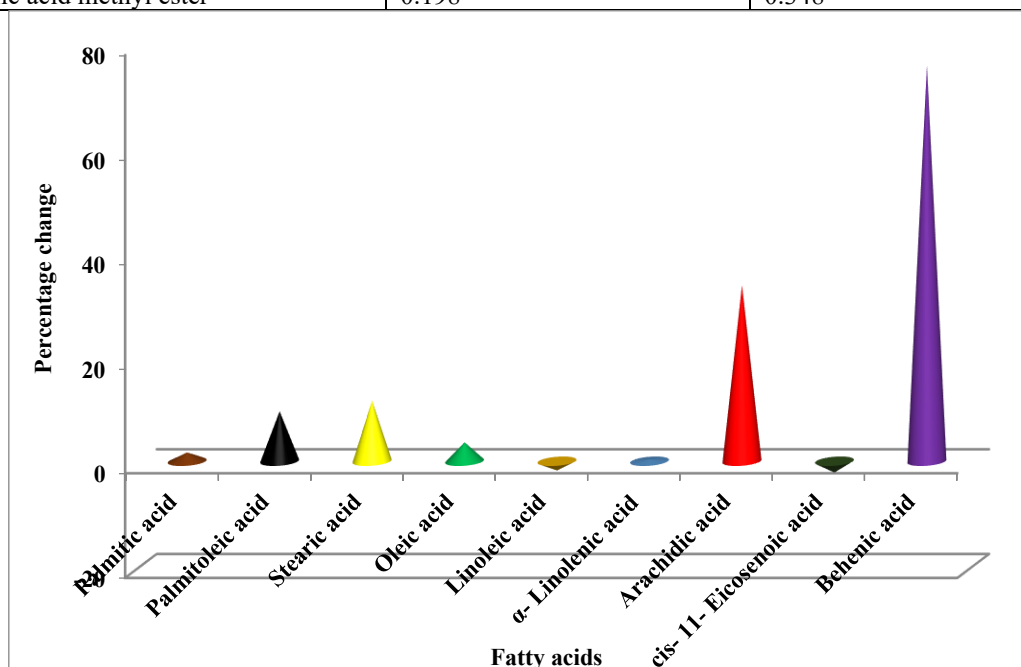


Figure 6: Percentage change in fatty acids

Germination produced only minor alterations in the fatty acid profile, indicating that lipid composition remained relatively stable throughout the sprouting process. Palmitic acid increased slightly from 7.745 to 7.876%, while stearic acid increased from 1.379 to 1.539%. Oleic acid increased from 17.473 to 18.108%, corresponding to an increase of approximately 3.63%. Conversely, linoleic acid decreased marginally by less than 2%, whereas cis-11-eicosaenoic acid showed only a slight reduction. Small increases were also observed in α -linolenic, arachidic and behenic acids.

The slight increase in oleic acid is nutritionally advantageous because oleic acid is a monounsaturated fatty acid associated with improved cardiovascular health, enhanced lipid metabolism and reduced oxidative stress. Similarly, maintenance of α -linolenic acid content suggests that germination preserves omega-3 fatty acids important for immune regulation, cellular signalling and neurological function. The minimal reduction in linoleic acid indicates that the essential omega-6 fatty acid remained the dominant lipid fraction despite metabolic utilization during germination.

The observed changes may be attributed to activation of endogenous lipases during germination, which hydrolyse stored triacylglycerols to provide energy for developing seedlings. However, the limited duration of germination appears insufficient to cause major depletion of lipid reserves, thereby preserving the characteristic fatty acid composition of foxtail millet. The slight increase in saturated fatty acids such as palmitic and stearic acids may reflect differential utilization of unsaturated fatty acids during early metabolic activity.

Overall, germination had only a modest influence on lipid composition while preserving the predominance of nutritionally desirable unsaturated fatty acids. The maintenance of high linoleic acid together with increased oleic and stable α -linolenic acid contents indicates that germinated foxtail millet remains an excellent source of essential fatty acids. Combined with the improvements in protein digestibility and amino acid composition, these findings demonstrate that germination enhances the overall nutritional quality of foxtail millet without adversely affecting its lipid profile.

3.6 Mineral composition

The mineral composition of raw (RFM) and germinated foxtail millet (TFM) is presented in Table 5 and Figure 7. Germination significantly ($p < 0.05$) influenced the concentration of several macro- and micro-minerals, indicating that sprouting altered mineral distribution and availability within the grain. Calcium content increased markedly from 14.96 ± 0.23 to 41.05 ± 1.45 mg/100 g, representing a 174.39% increase, while iron increased modestly from 5.16 ± 0.08 to 5.50 ± 0.08 mg/100 g (6.50%). In contrast, magnesium decreased from 155.80 ± 0.60 to 94.60 ± 1.90 mg/100 g, manganese from 1.65 ± 0.00 to 1.07 ± 0.01 mg/100 g, zinc from 5.06 ± 0.08 to 3.90 ± 0.05 mg/100 g and phosphorus from 387.60 ± 1.00 to 246.00 ± 1.40 mg/100 g. Sodium and potassium were below the detectable limit (<10 mg/100 g) in both samples.

Table 5: Mineral composition of foxtail millets

Sample	Na	K	Ca	Mg	Mn	Fe	Zn	P
RFM	<10.00	<10.00	$14.96^b \pm 0.23$	$155.8^a \pm 0.60$	$1.65^b \pm 0.00$	$5.16^b \pm 0.08$	$5.06^b \pm 0.08$	$387.60^b \pm 1.00$
TFM	<10.00	<10.00	$41.05^b \pm 1.45$	$94.6^b \pm 1.90$	$1.07^b \pm 0.01$	$5.50^a \pm 0.08$	$3.90^b \pm 0.05$	$246.00^b \pm 1.40$
Mean	-	-	27.99	125.18	1.36	5.33	4.48	316.80
SE	-	-	7.55	17.69	0.16	0.10	0.33	40.88
CD	-	-	15.56	31.82	0.25	1.08	0.44	29.79
CV%	-	-	4.37	2.00	1.46	1.59	0.78	0.74

Note: Values are expressed as mean $\pm$ standard deviation of three determinations.

Means within the same column followed by a common letter do not significantly differ at $p < 0.05$

Unit of measurement in mg/100 g sample

RFM: Controlled foxtail millet

TFM: Test foxtail millet

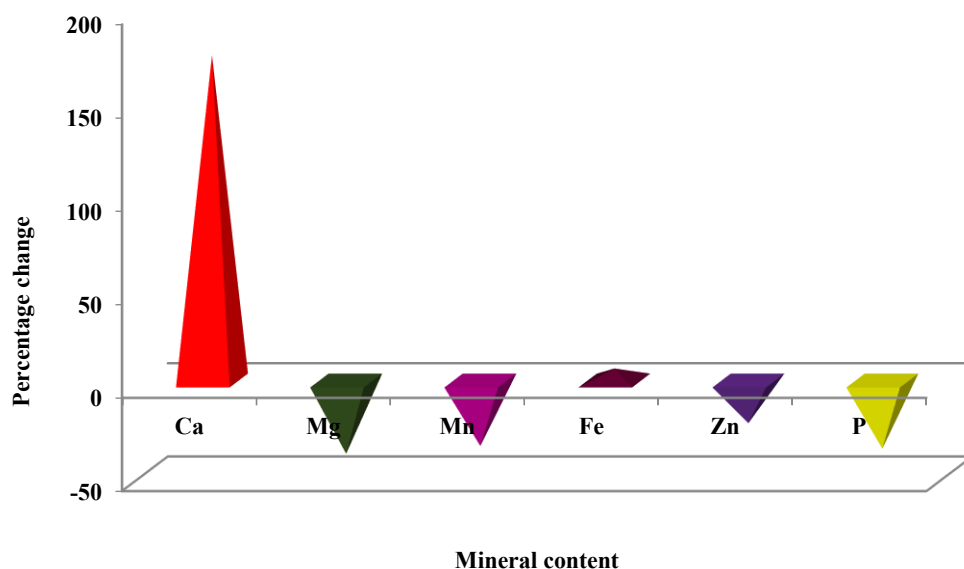


Figure 7: **Percentage change in mineral content of foxtail millets**

The substantial increase in calcium suggests that germination improved either its extractability or analytical availability through biochemical modification of the grain matrix. Germination activates endogenous phytase, which hydrolyses phytic acid and releases minerals previously bound as insoluble phytate complexes. Although reductions in the total concentrations of magnesium, zinc and phosphorus were observed, these changes do not necessarily indicate reduced nutritional value because germination frequently improves mineral bioavailability despite changes in total mineral content. During sprouting, minerals are mobilized from storage tissues to support seedling growth, while water uptake and respiration may also influence their concentration on a dry-weight basis.

Iron showed a slight but significant increase following germination. This finding is nutritionally important because iron deficiency remains one of the most prevalent micronutrient deficiencies worldwide. Enhanced iron availability in germinated millet may therefore improve its nutritional contribution, particularly when incorporated into complementary foods or functional cereal products. Similar observations have been reported by Lestienne et al. (2005), who demonstrated that degradation of phytate during germination improves mineral bioavailability by reducing the formation of insoluble mineral complexes.

Previous studies have reported variation in mineral composition among foxtail millet cultivars and processing methods. Kamara et al. (2009) observed potassium as the predominant mineral in defatted foxtail millet flour, followed by magnesium, calcium and sodium, whereas the present study detected sodium and potassium below the analytical detection limit. Such differences may arise from varietal characteristics, soil conditions, environmental factors and analytical methodologies. Nevertheless, the marked increase in calcium together with maintenance of iron content demonstrates that germination favourably modifies the mineral profile of foxtail millet and enhances its nutritional significance.

3.7 Phytochemical screening

Qualitative phytochemical screening revealed noticeable differences between raw and germinated foxtail millet (Table 6), confirming that germination induced substantial biochemical modifications. Carbohydrates and alkaloids were detected in both samples, whereas proteins were more intensely expressed in germinated millet. Amino acids were detected only in germinated foxtail millet, reflecting extensive proteolysis and synthesis of free amino acids during seed germination. Terpenoids and cardiac glycosides were present in both samples but showed greater intensity after germination, while fixed oils and fats remained detectable throughout the germination process.

Table 6: **Phytochemical screening of foxtail millet**

Phytochemicals	Test	Raw foxtail millet	Germinated foxtail millet
Carbohydrates	Molisch test	++	++
Alkaloids	Mayer's test	+	+
	Wagner's test	++	+

	Hager's test	++	++
Proteins	NaOH and CuSO ₄	+	++
Amino acids	Ninhydrin test	-	+
Flavonoids	With ammonia solution	-	-
Fixed oils and fats	Foam test	+	+
Terpenoids	Chloroform and H ₂ SO ₄	+	++
Cardiac glycosides	Glacial acetic acid and Ferric chloride solution	+	++
Steroids	Liebermann's - Burchard test	-	-
Saponins	Foam test	-	-
Tannins	FeCl ₃ test	-	-
Phlobatannins	With HCl	-	-
Phenols	Ferric chloride test	-	-
	Liebermann's test	-	-
Quinones	With conc. HCl	-	-

Note: + indicate presence, ++ more prominent and - indicate absence of phytochemicals.

All screening tests were carried out in triplicates.

Conversely, flavonoids, steroids, saponins, tannins, phlobatannins, phenols and quinones were not detected under the qualitative conditions employed in this study. The absence of quinones suggests minimal oxidative deterioration during sample preparation and storage. Likewise, the absence of tannins indicates that germination and the preceding soaking process may have reduced soluble tannins through leaching and enzymatic degradation.

The enhanced detection of proteins and amino acids in germinated samples is consistent with the metabolic events occurring during sprouting. Activation of proteases hydrolyses storage proteins into peptides and free amino acids required for embryo growth, thereby increasing their extractability during qualitative analysis. Similarly, increased expression of terpenoids and cardiac glycosides reflects activation of secondary metabolic pathways during germination, which may contribute to improved biological activity of the grain.

Although qualitative tests did not detect phenols or flavonoids, germination has been widely reported to increase the concentration and bioaccessibility of phenolic compounds in cereal grains. Activation of cell wall-degrading enzymes during sprouting disrupts the structural matrix and liberates bound phenolic compounds through hydrolysis of ester linkages. Consequently, free phenolics become more available and contribute to enhanced antioxidant capacity (Duodu 2014; Perales-Sanchez et al. 2014). The discrepancy between qualitative screening and quantitative reports may therefore reflect the limited sensitivity of preliminary phytochemical assays rather than the complete absence of these compounds.

Germination is also recognized as an effective strategy for reducing antinutritional factors present in cereals. Previous studies have demonstrated significant reductions in phytate, tannins and other inhibitory compounds following germination due to activation of endogenous hydrolytic enzymes and leaching during soaking (Chavan and Kadam 1989; Ghorpade and Kadam 1989; Nkama and Ikwelle 1998). These changes enhance nutrient digestibility and mineral bioavailability while improving the functional properties of cereal flours.

Sharma et al. (2015) similarly reported that germination of foxtail millet significantly enhanced dietary fibre, proteins, antioxidants and bioactive compounds while simultaneously reducing antinutritional factors. Likewise, Madhujith et al. (2006) and Shahidi (2009) emphasized that cereal grains contain numerous health-promoting phytochemicals concentrated in the outer layers, and processing methods that preserve or improve their availability enhance the functional value of whole grains. Collectively, these findings support the role of germination as a natural bioprocess capable of improving the phytochemical profile and nutritional functionality of foxtail millet.

CONCLUSION:

The present investigation demonstrates that germination substantially improved the nutritional quality of foxtail millet through coordinated biochemical and physiological modifications. Activation of endogenous hydrolytic enzymes during sprouting altered carbohydrate, protein and lipid metabolism, resulting in significant improvements in dietary fibre, protein digestibility, amino acid composition and selected minerals without adversely affecting the favourable fatty acid profile.

One of the most important nutritional changes observed was the significant increase in crude fibre and total dietary fibre, which enhances the potential health benefits of germinated millet by promoting gastrointestinal health, improving satiety and moderating postprandial glucose responses. Germination also modified starch composition by increasing total sugars and amylose while reducing amylopectin, indicating extensive restructuring of starch granules through amylolytic activity. These changes may contribute to desirable functional properties for food processing and improved glycaemic characteristics.

Protein quality was markedly enhanced following germination, as demonstrated by the substantial increase in in vitro protein digestibility and the considerable enrichment of both essential and non-essential amino acids. Particularly noteworthy were the increases in lysine and methionine, amino acids that are often limiting in cereal proteins. These improvements indicate that germination enhances both protein availability and nutritional balance, making germinated foxtail millet a valuable ingredient for complementary foods and protein-enriched functional products.

Despite moderate changes in mineral composition, the pronounced increase in calcium and maintenance of iron content, together with the expected reduction in phytate-mediated mineral binding, suggest improved mineral utilization. Furthermore, preservation of the predominance of unsaturated fatty acids, especially linoleic and oleic acids, indicates that germination maintains the desirable lipid quality of foxtail millet while enhancing its overall nutritional functionality.

The qualitative phytochemical profile further supports the beneficial effects of germination by demonstrating enhanced detection of proteins, amino acids and selected bioactive constituents. Together with evidence from previous studies showing increased antioxidant potential and reduced antinutritional factors, these findings confirm that germination is an effective, economical and environmentally sustainable processing technique for improving the nutritional and functional properties of foxtail millet.

Overall, the present study demonstrates that controlled germination significantly enhances the nutritional profile of foxtail millet through improvements in fibre content, protein quality, amino acid composition, selected minerals and bioactive constituents while preserving its favourable fatty acid composition. These compositional modifications increase the potential application of germinated foxtail millet in the development of nutrient-dense functional foods, weaning formulations and health-oriented cereal products targeted towards the prevention and dietary management of non-communicable diseases. Further investigations involving quantitative phytochemical analysis, mineral bioavailability, glycaemic response and clinical evaluation will provide additional evidence supporting the utilization of germinated foxtail millet as a functional ingredient in contemporary food systems.

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Authors' contribution JJDS conceptualization, execution, carryout of research work, investigating the result and interpretation, statistical analysis, writing, revising and editing the original draft of manuscript. JSW helped in compilation of data and managed the literature search and approved the final manuscript.

Declarations:

Conflict of interest: The author declare no conflict of interest.

Data availability statement: All data generated or analysed during this study are included in this published article.

REFERENCES

1. Archana, S., & Kawatra, A. (2001). Effect of processing on pearl millet for its utilization as a functional food. *Plant Foods for Human Nutrition*, **56**, 231–245.
2. Cabrejas, M. A. M., et al. (2003). Effect of bioprocessing on dietary fibre in cereals and legumes. *Journal of Agricultural and Food Chemistry*, **51**, 4321–4325.
3. Chavan, J. K., & Kadam, S. S. (1989). Nutritional improvement of cereals by sprouting. *Critical Reviews in Food Science and Nutrition*, **28**, 401–437.
4. Chinma, C. E., et al. (2011). Physicochemical and sensory properties of cookies produced from blends of unripe plantain and defatted sesame flour. *Journal of Food Technology*, **9**, 29–35.
5. Dastjerdi, M. S., et al. (2015). α -Amylase inhibitory activity of cereal and plant extracts and their role in glycemic control. *Journal of Food Biochemistry*, **39**, 1–10.
6. Dhingra, D., Michael, M., Rajput, H., & Patil, R. T. (2012). Dietary fibre in foods: A review. *Journal of Food Science and Technology*, **49**, 255–266.

7. Duodu, K. G. (2014). Effects of processing on phenolic phytochemicals in cereals and legumes. *Cereal Foods World*, **59**, 64–70.
8. Ghorpade, V. M., & Kadam, S. S. (1989). Processing and nutritional improvement of cereals. *CRC Critical Reviews in Food Science and Nutrition*, **28**, 348–400.
9. Hussain, S., et al. (2011). Effect of germination on nutritional quality of cereals. *International Food Research Journal*, **18**, 451–457.
10. Kamara, M. T., Zhu, K., Amadou, I., Tarawalie, F., & Zhou, H. (2009). Nutritional composition of foxtail millet flour. *Food Chemistry*, **112**, 321–327.
11. Kim, J. M., et al. (2009). Physicochemical properties of foxtail millet starch. *Starch/Stärke*, **61**, 509–516.
12. Lestienne, I., et al. (2005). Effects of soaking and germination on phytate degradation and mineral bioavailability. *Journal of Agricultural and Food Chemistry*, **53**, 121–127.
13. Madhujith, T., Shahidi, F., & Izydorczyk, M. (2006). Antioxidant properties of cereal phenolics. *Journal of Agricultural and Food Chemistry*, **54**, 312–318.
14. Mehta, U., & Kaur, S. (1992). *Food Chemistry*. New Delhi: Kalyani Publishers.
15. Nkama, I., & Ikwelle, M. C. (1998). Traditional processing of cereals and nutritional implications. *Plant Foods for Human Nutrition*, **52**, 17–26.
16. Olaerts, H., et al. (2016). Effects of sprouting damage on starch properties of cereals. *Food Chemistry*, **190**, 106–114.
17. Parameswaran, K. P., & Sadasivam, S. (1994). Changes in nutritional composition during germination of proso millet. *Plant Foods for Human Nutrition*, **45**, 97–102.
18. Perales-Sanchez, J. X. K., et al. (2014). Effect of germination on phenolic compounds and antioxidant activity of cereals. *Food Chemistry*, **152**, 1–8.
19. Praveena, B., & Estherlydia, D. (2014). Phytochemical screening and antioxidant potential of cereal grains. *International Journal of Food Science and Nutrition*, **3**, 45–52.
20. Shahidi, F. (2009). Nutraceuticals and functional foods: Whole grains and health. *Food Research International*, **42**, 457–467.
21. Sharma, S., Saxena, D. C., & Riar, C. S. (2015). Effect of germination on nutritional quality and antioxidant properties of foxtail millet. *Journal of Food Science and Technology*, **52**, 870–878.
22. Ushakumari, S. R., et al. (2004). Physicochemical characteristics of foxtail millet starch. *Food Chemistry*, **87**, 281–284.
23. Vayupharp, B., & Laksanalamai, P. (2013). Changes in dietary fibre and antioxidant properties during cereal germination. *Food Chemistry*, **141**, 1236–1241.
24. Zhu, F. (2014). Structure, physicochemical properties and applications of millet starches: A review. *Food Hydrocolloids*, **37**, 52–63.
25. Saleh, A. S. M., Zhang, Q., Chen, J., & Shen, Q. (2013). Millet grains: Nutritional quality, processing and potential health benefits. *Comprehensive Reviews in Food Science and Food Safety*, **12**, 281–295.
26. Taylor, J. R. N., & Emmambux, M. N. (2008). Gluten-free foods and beverages from millets. In *Gluten-Free Cereal Products and Beverages* (pp. 119–148). Academic Press.
27. Devi, P. B., Vijayabharathi, R., Sathyabama, S., Malleshi, N. G., & Priyadarisini, V. B. (2014). Health benefits of finger millet and other millets. *Journal of Food Science and Technology*, **51**, 1021–1040.
28. Amadou, I., Gounga, M. E., & Le, G. W. (2013). Millets: Nutritional composition, health benefits and processing. *Food Science and Nutrition*, **53**, 501–508.
29. Chandrasekara, A., & Shahidi, F. (2011). Bioactivities and antioxidant properties of millet phenolics. *Journal of Functional Foods*, **3**, 144–158.
30. Taylor, J. R. N., Belton, P. S., Beta, T., & Duodu, K. G. (2014). Increasing the utilization of millets through processing and product development. *Comprehensive Reviews in Food Science and Food Safety*, **13**, 122–148.