

## RESEARCH ARTICLE

# Development and evaluation of a jamun-flavored functional yoghurt beverage fortified with kodo millet

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**Abstract:** Millets are often referred to as nutri-cereals due to their inherent therapeutic properties and associated health benefits. Among them, minor millets such as Kodo millet remain underexplored despite their promising functional attributes. Kodo millet possesses anti-diabetic and antioxidant properties, which may reduce the risk of cardiovascular diseases, oxidative stress, certain cancers, and obesity. Similarly, Jamun (*Syzygium cumini*), a fruit used since ancient times, offers comparable health-promoting effects. The present study aimed to develop a functional yoghurt drink combining these two ingredients to complement and enhance their bioactive potential. Kodo millet was subjected to soaking and germination treatments prior to yoghurt preparation. The resulting products were evaluated for physicochemical parameters, antioxidant activity, and sensory attributes. Yoghurt formulated with germinated Kodo millet exhibited a superior nutritional profile, including protein (9.9 %), fat (3.17 %), crude fiber (6.16 %), and ash (3.17 %). Physicochemical characteristics such as pH (4.50), total soluble solids (14.87 °Brix), and acidity (0.16 % lactic acid) were comparable across treatments, although viscosity was significantly higher in yoghurt prepared with untreated millet (180.77 cP). Antioxidant activity was greatest in germinated Kodo millet yoghurt (60.31%), while untreated millet yoghurt displayed the highest total phenolic content (9.05 mg GAE/mL), followed by germinated millet yoghurt (7.83 mg GAE/mL). Sensory

evaluation revealed that the beverage prepared with germinated Kodo millet achieved the highest acceptability scores. Overall, this study highlights the potential for commercializing Kodo millet-Jamun yoghurt beverages as functional foods that provide health benefits and appeal to a broad consumer base, from toddlers to the elderly.

**Keywords:** Antioxidants, Yoghurt, Jamun, Kodo millet

## Introduction

Millets are among the oldest cultivated crops, with a long history of domestication in India where they served as staple foods before the dominance of rice and wheat. In recent years, there has been renewed interest in millets due to their well-documented nutritional and sustainability benefits, bringing focus back to these ancient grains. Among minor millets, Kodo millet (*Paspalum scrobiculatum*) is of particular interest. Although it originated in tropical Africa, India domesticated this crop around 3000 years ago (Bunkar et al.2021) and today remains the primary global producer, cultivating it across 0.08 million hectares (Bhat et al.2018). Kodo millet is considered one of the most drought-resistant cereals, capable of producing good yields within 80–135 days (Saxena et al.2018).

Nutritionally, Kodo millet is superior to many staple grains. It is rich in minerals and fat, with total dietary fiber (6.39 %) markedly higher than that of rice (2.81 %) (Longvah et al.2017). Its protein content is about 8.3 %, predominantly glutenin (Bromilow et al.2017). Crude fiber content (9 %) also exceeds that of wheat (1.2 %) (Chandel et al.2014). On average, Kodo millet provides 353 kcal/100 g, with 66.6 % carbohydrate, 2.4 % minerals, and 1.4 % fat (Chandel et al.2014). In addition to its nutritional profile, Kodo millet demonstrates strong bioactivity. It exhibits high antioxidant potential, with total phenolics of 368 mg catechol equivalents/100 g dry flour and radical scavenging activity of 70 %, compared with 15–53 % for other small millets (Hegde and Chandra, 2005). Its antidiabetic properties are also well established: the grain has a low glycemic index, and its starch content is lower than that of rice flour (Annor et al.2013). Bioactive compounds inhibit  $\alpha$ -glucosidase and pancreatic amylase, thereby reducing postprandial hyperglycemia (Samtiya et al.2021), while aldose

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reductase inhibitors prevent sorbitol accumulation, lowering the risk of diabetic cataracts (Chethan and Malleshi, 2007). Furthermore, Kodo millet is naturally gluten-free, making it suitable for individuals with gluten sensitivity (Bunkar et al. 2021).

The health-promoting effects of Kodo millet extend to reducing oxidative stress, maintaining cellular integrity, lowering cardiovascular disease (CVD) risk, and offering anticancer potential due to its phenolic compounds (Hegde and Chandra, 2005). To further complement these properties, Jamun (*Syzygium cumini*), a fruit widely used in Ayurveda, was incorporated into the present study. Jamun has been traditionally valued for its antidiabetic, anti-ulcer, antibacterial, antifungal, antioxidant, antimicrobial, and radioprotective effects (Kumar et al. 2021). Together, Kodo millet and Jamun provide a promising combination for functional food development.

In this study, Kodo millet grains were subjected to soaking and germination treatments to examine changes in their chemical composition and functional properties compared with untreated samples. A functional yoghurt drink was then formulated using Kodo millet and Jamun. Despite growing recognition of millets in human nutrition, limited research has focused on their application in functional dairy-based beverages (Real et al. 2022; Ponne et al. 2020; Amrutha et al. 2023). Therefore, this study aimed to characterize the physicochemical properties, antioxidant activity, and sensory attributes of the developed yoghurt drink, with a view toward its potential commercialization.

## Materials and Methods

### Sample Procurement

Kodo millet (Miltop Kodri) was purchased from Amazon, an online store, while Jamun fruits, coconut sugar, and spices were procured from the local market in Varanasi, Uttar Pradesh, India and High-methoxyl citrus pectin (Himedia Laboratories, India). Fully ripened dark-purple Jamun fruits (*Syzygium cumini* L.) of a local large-seeded variety were procured from the Varanasi (U.P., India) market. Fruits were sorted, washed, and deseeded prior to extraction. Fresh cow milk required for yoghurt formulation was obtained from the Dairy Farm, Banaras Hindu University (BHU). The starter culture for yoghurt preparation was purchased from the National Collection of Dairy Cultures (NCDC), Dairy Microbiology Division, ICAR-National Dairy Research Institute (NDRI), Karnal, India.

### Product Preparation

For product development, Kodo millet grains were subjected to three treatments. In the first treatment, cleaned grains were soaked overnight in distilled water and then sun-dried to remove surface moisture. In the second treatment, 100 g of millet was steeped in distilled water for 24 h and subsequently allowed to germinate for eight days under controlled conditions. In the third treatment,

millet grains were used without any pre-treatment. Jamun fruits were thoroughly cleaned, deseeded, and washed with distilled water before incorporation into the product.

For yoghurt preparation, fresh cow milk was standardized, pasteurized, and cooled to about 40-42 °C before inoculation with the starter culture. The culture was allowed to ferment until a firm set curd was obtained, which was then blended separately with each of the three millet preparations (soaked, germinated, and untreated) along with Jamun pulp to develop three different functional yoghurt drink formulations. Coconut sugar and selected spices were added to enhance flavor and improve overall acceptability.

### Procedure for yoghurt drink development

Dried Kodo millet grains were weighed and wet-milled with 150 mL of distilled water in a Philips mixer blender to obtain a slurry, which was subsequently boiled and filtered. Jamun fruits, after cleaning and deseeding, were weighed and sieved, and coconut sugar was incorporated during blending to enhance sweetness and provide a low-glycemic, natural alternative to refined sugar. Coconut sugar, being rich in minerals and possessing a lower glycemic index, was selected to complement the antidiabetic potential of Kodo millet and Jamun. It was added at a rate of 5 % (w/v) to ensure both palatability and nutritional enrichment of the beverage. A pectin solution was prepared by mixing equal quantities of pectin powder and distilled water using a hand blender, which served as a stabilizer to improve beverage texture and mouthfeel. Yoghurt was prepared from fresh cow milk by standardization, pasteurization, and inoculation with a starter culture at 40-42 °C, followed by incubation until a firm set was obtained. The yoghurt base was then blended separately with each of the three millet preparations (untreated, soaked, and germinated) along with Jamun pulp, coconut sugar, and pectin solution to obtain three different functional yoghurt drink formulations.

### Determination of pH

The pH of all three yoghurt beverages (untreated millet, soaked millet, and germinated millet formulations) was determined using a digital pH meter (MK-VI SYSTRONIC, Bangalore) following AOAC (2012) guidelines. Measurements were recorded in triplicate.

### Determination of titratable acidity

Titratable acidity, expressed as % lactic acid, was estimated using the standard AOAC (2012) protocol. Each of the three yoghurt drink formulations was analyzed in triplicate.

### Determination of total soluble solids (TSS)

TSS was measured in all samples using a digital refractometer and expressed in °Brix. This analysis was carried out on untreated, soaked, and germinated millet yoghurt beverages.

### Determination of viscosity

Viscosity of all yoghurt drink formulations was analyzed using a Brookfield viscometer (TA-XT Plus, UK). Measurements were performed at 30 °C to standardize the analysis at a temperature relevant to typical consumption and storage conditions, while minimizing temperature-related variability in flow behavior. The viscometer was operated at 50 rpm with torque set to zero, and viscosity was expressed in centipoise (cP).

### Determination of reducing sugar

The reducing sugar content of the final yoghurt beverages prepared from unsoaked, soaked, and germinated Kodo millet was determined using the 3,5-dinitrosalicylic acid (DNSA) method as described by Deshavath et al. (2020). The absorbance was measured at 540 nm using a UV-Vis spectrophotometer (UV-1800, Shimadzu Corporation, Japan).

### Determination of proximate composition

Proximate composition was determined for all three yoghurt drink formulations. Total ash and crude fiber contents were analyzed using AOAC (2012) methods. Protein content was determined by the Kjeldahl method following AOAC (2012) procedures and expressed as percentage protein. The total fat content of the beverages was estimated by the acid-hydrolysis method (AOAC, 2012).

### Analysis of antioxidant properties

The antioxidant properties of untreated, soaked, and germinated millet yoghurt beverages were evaluated by total phenolic content (TPC) and DPPH radical scavenging activity. TPC was determined following Sengar et al. (2021) with absorbance recorded at 765 nm and results expressed as mg gallic acid equivalents per mL. Radical scavenging activity was assessed according to Maizura et al. (2011), with absorbance measured at 517 nm, and values expressed as % inhibition.

$$\text{Antioxidant effectiveness (\%)} = \left[ 100 - \left( \frac{\text{absorbance of sample}}{\text{standard sample absorbance}} \right) \right] \times 100$$

**Table 1:** Chemical Analysis of Kodo Millet based Functional Yoghurt Drink (a, b, c represents comparison of row wise values which have significant difference at 5% level)

Sample	pH (mean ± SD)	Acidity, % LA (mean ± SD)	TSS, °Brix (mean ± SD)
Unsoaked	4.39 ± 0.01 <sup>a</sup>	0.170 ± 0.007 <sup>a</sup>	13.40 ± 0.14 <sup>a</sup>
Soaked	4.45 ± 0.01 <sup>b</sup>	0.127 ± 0.005 <sup>b</sup>	14.53 ± 0.17 <sup>b</sup>
Germinated	4.50 ± 0.01 <sup>c</sup>	0.155 ± 0.007 <sup>c</sup>	14.87 ± 0.12 <sup>c</sup>

### Sensory evaluation of the beverage

Sensory evaluation was performed with 12 semi-trained panellists. Each participant was instructed on the evaluation procedure, and samples were served randomly. The yoghurt beverages were scored for appearance, color, texture, taste, and overall acceptability using a 9-point hedonic scale.

### Statistical analysis

All experiments were conducted in triplicate, and results are expressed as mean ± standard deviation. The experiment followed a Completely Randomized Design (CRD). Data were analyzed using one-way ANOVA followed by Tukey's multiple comparison test at a 95% confidence level ( $p < 0.05$ ) to determine significant differences among treatments. All experiments were conducted in triplicate, and results are expressed as mean ± standard deviation. Data were analysed using MS Excel 2010. One-way analysis of variance (ANOVA) was performed to determine significant differences between samples, and means were compared using Tukey's test at a 95% confidence level ( $p < 0.05$ ).

### Result and Discussion

#### Effect of different treatments of Kodo millet on the pH value of the Yoghurt Beverage

The pH value serves as an important indicator of the acidity or alkalinity of beverages, directly influencing their flavor and microbial stability. A lower pH corresponds to a more acidic and tangy product. In the present study, the mean pH values of the formulated yoghurt beverages ranged from 4.39 to 4.50 (Table 1), confirming their acidic nature, which can be attributed to lactic acid production by starter cultures and the natural acidity of Jamun (Suradkar et al. 2017). Among the treatments, the unsoaked millet formulation exhibited the lowest pH (4.39), while the germinated millet-based beverage recorded the highest value (4.50).

Germination significantly ( $p < 0.05$ ) influenced the pH of the beverages. Earlier studies have reported that prolonged germination leads to a reduction in pH due to increased production of organic acids. During germination, starch is hydrolysed into simple sugars, which are subsequently metabolized into carbon

dioxide and ethanol, thereby lowering the pH (Nefale and Mashau, 2018). In the current study, this trend was also evident, as an extended germination period beyond 48 h showed a negative correlation with pH.

The findings are in line with those of Ponne et al. (2020), who observed a non-significant difference in pH values of yoghurt prepared with pearl millet extract compared to control samples. Thus, the incorporation of Kodo millet, particularly germinated grains, slightly moderated the acidity of the yoghurt beverages without deviating from the typical acidic range expected in fermented dairy drinks.

### Effect of different treatments of Kodo millet on TSS of the Yoghurt Beverage

TSS represent the concentration of dissolved solids in a sample and are critical determinants of the sweetness, texture, and overall palatability of beverages. TSS is also considered an important parameter for ensuring uniformity and consistent product quality. According to FSSAI standards, the TSS of thermally processed fruit beverages should not be less than 10 %. In millet-based functional beverages, previously reported TSS values range from 4.8 to 13.46 °Brix (Danaba et al.2014; Akoma et al.2014).

In the present study (Table 1), TSS values of the developed yoghurt beverages were significantly ( $p < 0.05$ ) influenced by both the incorporation of Jamun and the millet processing techniques. Jamun fruit itself has a reported TSS of 14 °Brix (Suradkar et al.2017), and its inclusion in the beverage formulation contributed to the elevation of TSS. Similarly, germination of Kodo millet increased the availability of soluble sugars, leading to higher TSS values. Geetha and Preethi (2020) reported that germinated Kodo millet-based milk beverages exhibited TSS values of around 15 °Brix, supporting the findings of the current study.

Comparative reports also validate these results. For instance, barnyard millet-incorporated symbiotic yoghurt had a TSS of 11 °Brix (Amrutha et al.2023), while synbiotic beverages fermented from barnyard millet displayed TSS levels in the range of 10-12 °Brix (Joseph et al.2025). The TSS values observed in our study fall within this reported range, highlighting that both germination of millet and inclusion of Jamun significantly improved the soluble solids content and contributed positively to the nutritional and sensory quality of the yoghurt beverage.

### Effect of different treatments of Kodo millet on Titratable Acidity of the Yoghurt Beverage

Titrateable acidity reflects the concentration of organic acids in a beverage and is a critical parameter for determining flavor, microbial stability, and fermentation efficiency. In the present study (Table 1), significant differences ( $p < 0.05$ ) were observed among the formulations. The untreated millet beverage exhibited the highest acidity (0.17 %), followed by the germinated millet beverage (0.16 %), while the soaked millet beverage had the lowest acidity (0.13 %).

The higher acidity in untreated millet beverages may be attributed to the presence of anti-nutritional factors such as phytic acid and tannins, which can influence acid release during fermentation (Samtiya et al.2021). Soaking reduced the acidity levels by leaching out these compounds, thereby lowering the overall titrateable acidity. In contrast, germination enhanced microbial activity, particularly that of lactic acid bacteria (LAB), which hydrolyse starch into fermentable sugars that are subsequently converted into organic acids. Previous studies on germinated finger millet flour have similarly reported that increasing germination time leads to higher acidity, with lactic acid production being the major contributor (Ocheme and Chinma, 2008; Nefale and Mashau, 2018).

The acidity values obtained in this study are consistent with those reported for other millet-based functional yoghurts, such as barnyard millet yoghurt (Amrutha et al.2023) and pearl millet yoghurt (Ponne et al.2020). Overall, the results suggest that soaking reduces acidity through anti-nutrient removal, while germination promotes controlled acid development through microbial fermentation. These findings highlight the role of pre-treatment methods in modulating acidity levels, which can directly influence the sensory acceptability and shelf stability of millet-based yoghurt beverages.

### Effect of different treatments of Kodo millet on Viscosity Measurement of the Yoghurt Beverage

Viscosity plays a critical role in defining the texture and overall appeal of beverages, directly influencing consumer acceptability. Excessively high viscosity can result in a slurry-like consistency, which is generally undesirable, whereas an optimal viscosity ensures a smooth flow characteristic of drinkable yoghurt. In the present study (Table 2), significant differences ( $p < 0.05$ ) were

**Table 2:** Effect of different treatments of Kodo millet on Viscosity of the Beverage, concentration of Reducing sugar in the Beverage and percent Ash Content of the Beverage

Sample	Viscosity (cP)	Reducing Sugar (mg/mL)	Ash (%)
Unsoaked	180.77 ± 0.25 <sup>a</sup>	6.18 ± 0.03 <sup>a</sup>	2.90 ± 0.01 <sup>a</sup>
Soaked	176.23 ± 0.25 <sup>b</sup>	6.52 ± 0.01 <sup>b</sup>	2.84 ± 0.02 <sup>b</sup>
Germinated	175.93 ± 0.19 <sup>c</sup>	7.56 ± 0.02 <sup>c</sup>	3.17 ± 0.02 <sup>c</sup>

observed among treatments, with the unsoaked millet beverage exhibiting markedly higher viscosity compared to the soaked and germinated formulations.

Although the same amount of pectin was added to all samples as a stabilizer, the untreated millet beverage was more viscous. This can be attributed to the presence of highly complex starch granules in unsoaked grains, which tend to bind and retain more water, thereby thickening the product. Additionally, proteins in untreated grains remain in their native, complex forms and can interact with water molecules to form a stronger network structure. By contrast, during germination, starch is hydrolyzed into simpler sugars and proteins undergo partial breakdown into peptides and amino acids, resulting in a reduction in water-binding capacity and thus lower viscosity.

Similar findings have been reported in the literature. Sudha et al. (2016) observed viscosities in the range of 149-166 cP for fermented millet beverages, values that are comparable to those obtained in this study. An increase in apparent viscosity was also reported for symbiotic fermented finger millet yoghurt-like beverages (Real et al.2022), supporting the consistency of our results. Collectively, these findings highlight that grain pre-treatments such as soaking and germination play a crucial role in optimizing beverage viscosity, balancing stability with consumer acceptability.

#### Effect of different treatments of Kodo millet on the concentration of reducing sugar in the Yoghurt beverage

The presence of reducing sugars in food products reflects the breakdown of complex carbohydrates into simpler, more readily available sugars. While reducing sugars contribute to sweetness and influence fermentation, their excess consumption is undesirable, particularly for individuals with elevated blood glucose levels, as these sugars are rapidly absorbed and may cause a glycemic spike.

In the present study (Table 2), the germinated millet yoghurt beverage exhibited significantly higher levels of reducing sugars compared to the soaked and untreated formulations ( $p < 0.05$ ). This increase is attributed to the enzymatic activity during germination, wherein  $\alpha$ -amylase hydrolyzes starch into glucose and other simple sugars. Germination is known to enhance total soluble sugars, resistant starches, and reducing sugars through this conversion process (Omary et al.2012). A similar trend was reported in malting studies on finger millet, where reducing sugar

content increased significantly due to amylase-mediated starch hydrolysis (Banusha and Vasantharuba, 2013).

In addition to germination effects, the incorporation of Jamun also contributed to reducing sugar levels. Jamun fruit contains approximately 10.67% reducing sugars (Suradkar et al.2017), which further elevated the concentration in the beverages. Thus, while germination improved the nutritional profile of Kodo millet beverages by enhancing sugar availability for fermentation, it also led to higher reducing sugar content, a factor that should be considered when targeting diabetic-friendly formulations. Only reducing sugars were quantified in the present study, as they are the primary products of starch hydrolysis during germination and are metabolically relevant during fermentation. The estimation of total sugar and total carbohydrate content was beyond the present scope but will be addressed in future studies to provide a complete carbohydrate profile.

#### Effect of different treatments of Kodo millet on the Ash Content of the Yoghurt Beverage

The ash content provides information on the presence of organic mineral content in the given sample. It is also an indication of purity where a high ash percentage in a sample points to the impurities present. Table 2 summarizes the result obtained for the percentage ash content.

The percentage of ash present in the germinated millet beverage sample was the highest followed by the yoghurt prepared from unsoaked and soaked millet grain ( $p < 0.05$ ). During germination, the anti-nutrients present in the grain are eliminated which leads to the availability of the minerals that were earlier bound to them. This could be a reason for increased ash content in the case of sprouted millet yoghurt beverage. However, in soaked grain beverage the levels of ash content were minimal, the reason could be the soaking time that would have leached some minerals into the water, a possibility that has been revealed in a study where soaking millet grains reduces the amount of zinc and iron (Bindra, 2019). Germination also had variant effects on the ash content where a long germination period caused a pronounced reduction in the nutrient content as depicted in the work of Kumar et al. (2021). The ash content in the unprocessed Kodo grains was high but after processing there was a reduction in its level indicating processing may have caused a decrease in the mineral composition.

**Table 3:** Effect of different treatments of Kodo millet on percent Protein Estimation, percent Fat Content and percent Crude Fiber Content of the Beverage

Sample	Protein (%)	Fat (%)	Crude Fiber (%)
Unsoaked	6.63 ± 0.12 <sup>a</sup>	3.26 ± 0.01	4.27 ± 0.25 <sup>a</sup>
Soaked	7.30 ± 0.22 <sup>b</sup>	3.22 ± 0.02	5.03 ± 0.09 <sup>b</sup>
Germinated	9.90 ± 0.08 <sup>c</sup>	3.17 ± 0.02	6.16 ± 0.16 <sup>c</sup>

### Effect of different treatments of Kodo millet on percent Protein Estimation of the Yoghurt Beverage

The protein content for the samples was between 4.6 % to 7.9 % with the untreated millet yoghurt beverage sample having the least and the germinated millet sample with the highest ( $p < 0.05$ ). Table 3 represents the results obtained in protein estimation.

An explanation for the increased protein content has been ascribed to the release of packed protein in the seed structure when the  $\alpha$ -amylase breaks down the during germination. Due to increased  $\alpha$ -amylase activity during germination, there is a breakdown of the starch granule leading to the release of packed protein in the seed structure, resulting in increased protein content of germinated grains (Hejazi and Orsat, 2016). A study on the effect of germination on proso millets illustrated that soaking overnight and germinating it for 8 days increased the protein content by 16 % (Parameswaran and Sadasivan, 1994). The results are consistent with the findings of barnyard millet incorporated yoghurt (Amrutha et al.2023).

### Effect of Different Treatments of Kodo Millet on the Fat Content of the Yoghurt Beverage

The fat content of the yoghurt beverages showed minor variations among treatments (Table 3). The unsoaked millet beverage recorded a fat content of 3.26%, followed by the soaked (3.22%) and germinated (3.17%) samples. Although the values decreased slightly with soaking and germination, the differences were small and not statistically significant ( $p > 0.05$ ).

Kodo millet and finger millet are inherently low-fat cereals, with typical values ranging from 1.2% to 1.3% (McDonough et al.2000). The slight reduction observed after soaking and germination could be attributed to minimal lipid utilization during metabolic activities associated with sprouting, where stored lipids act as an energy source for enzyme activation and seedling growth (Yenasew and Uрга, 2022). Similar findings were reported by Geetha and Kanchana (2022), who observed comparable fat contents in sprouted and un-sprouted Kodo millet beverages.

Thus, while the fat content exhibited a marginal downward trend due to physiological changes during germination, the overall variation was negligible and not sufficient to be considered statistically or nutritionally significant.

### Effect of Different Treatments of Kodo Millet on the Crude Fiber Content of the Yoghurt Beverage

The crude fiber content of the yoghurt beverages is presented in Table 3. Dietary fibers are indigestible components of plant cell walls that support gut microbiota activity, regulate blood glucose levels, and help reduce cholesterol levels. In the present study, a significant ( $p < 0.05$ ) increase in crude fiber content was observed after soaking and, more prominently, after germination.

Although the absolute fiber fraction of the grain does not increase during germination, the apparent rise in crude fiber on a dry-weight basis can be attributed to the biochemical degradation of soluble carbohydrates, lipids, and certain anti-nutrients, which lowers the total dry mass while leaving cell wall components relatively concentrated. During germination, enzymes such as cellulase, hemicellulase, and pectinase modify the structural polysaccharides, converting some insoluble fiber fractions (cellulose and hemicellulose) into more soluble and fermentable forms (Omary et al.2012). These modifications enhance the physiological functionality of dietary fiber without substantially altering total fiber mass.

Furthermore, soaking initiates enzymatic activation and leaching of low-molecular-weight sugars and soluble solids, leading to a similar concentration effect in the remaining dry matter. Consequently, the proportion of crude fiber appears higher in soaked and germinated samples compared with untreated grains.

Comparable findings have been reported in previous studies: Sharma and Sharma (2021) observed that crude fiber in Kodo millet probiotic drinks increased from 6.8 g (untreated) to 7.5 g (malted), supporting the results of the present study. Overall, these findings indicate that both soaking and germination promote compositional redistribution, enriching the relative fiber fraction and improving the functional properties of the yoghurt beverage.

### Effect of different treatments of Kodo millet on The Total Phenolic Content

Both Kodo millet and Jamun, the two main ingredients of the functional yoghurt beverage, are rich in phenolic compounds known for their strong antioxidant potential (Hegde and Chandra, 2005; Suradkar et al.2017). The results (Table 4) revealed that the unsoaked millet beverage exhibited the highest total phenolic content (TPC), followed by the germinated and soaked millet beverages.

The reduction in phenolic content after soaking can be attributed to the activation of polyphenol oxidase (PPO), which catalyzes the oxidation of polyphenols into quinones, thereby lowering their measurable levels (Hithamani and Srinivasan, 2014). Additionally, soaking leads to the leaching of water-soluble phenolics and the partial degradation of bound phenolic complexes. Similar reductions in phenolic and antinutritional compounds have been reported in other cereals and legumes: phytate content decreased by 4% in sorghum and 21% in maize after soaking (Ibrahim et al.2002), while tannin content in chickpeas was reduced by 22% (Patterson et al.2017).

Germination, on the other hand, induces a more complex biochemical response. During sprouting, hydrolytic enzymes such as esterases and glycosidases cleave phenolic glycosides, releasing previously bound phenolic acids that enhance the free

phenolic pool (Sokrab et al.2012). Concurrently, the biosynthetic pathway for phenolic compounds becomes activated as the germinating grain responds to oxidative and environmental stress, synthesizing new polyphenolic metabolites (Samtiya et al.2020). However, the overall phenolic concentration in the final product may appear lower due to concurrent degradation of antinutritional compounds such as phytates and tannins.

Phytates and tannins, although they possess antioxidant properties, are considered antinutritional factors because of their ability to chelate minerals and bind to proteins, thereby reducing nutrient bioavailability (López et al.2013; Sharma et al.2021). Tannins also contribute to undesirable astringency and reduced palatability. Hence, their partial removal through soaking and germination is nutritionally beneficial, as it enhances protein digestibility and mineral accessibility while retaining an adequate level of bioactive phenols that contribute to the beverage’s antioxidant potential.

Overall, the findings indicate that both soaking and germination modulate the phenolic profile of Kodo millet by reducing antinutritional factors and optimizing the balance between beneficial and inhibitory phenolic compounds, thereby improving the functional and nutritional quality of the yoghurt beverage.

**Table IV.**

**Effect of different treatments of Kodo millet on percent Free Radical Scavenging Activity of the Beverage**

The antioxidant activity of the yoghurt beverages prepared with untreated, soaked, and germinated Kodo millet is presented in Table 4. Free radicals generated in the body as by-products of metabolic and oxidative reactions are known to damage biomolecules and contribute to degenerative diseases such as cancer and cardiovascular disorders. Antioxidants neutralize these reactive species by donating electrons or hydrogen atoms, thereby stabilizing the radicals and preventing oxidative stress.

In the present study, the germinated millet yoghurt beverage exhibited the highest free radical scavenging activity, followed by the soaked and untreated samples. This increase can be attributed to enzymatic activation during germination, which enhances the liberation of bound phenolics and other bioactive compounds, thereby improving antioxidant potential. The contribution of Jamun fruit was also considerable, as it is inherently rich in ellagitannins and anthocyanins, potent natural antioxidants. Previous reports indicate DPPH scavenging activities of 90.71% (Pandey et al.2021) and 95.81% (Suradkar et al.2017) for Jamun extracts, values that underline its strong radical-quenching capacity.

The phenolic compounds present in the fruit pulp and skin are positively correlated with antioxidant efficiency (Luximon et al.2003). In comparison, Kodo millet alone demonstrates moderate antioxidant activity, which increases slightly after malting or germination due to the release of phenolic acids and flavonoids (Sharma and Sharma, 2021). The combined use of germinated Kodo millet and Jamun in the yoghurt matrix therefore resulted in a synergistic enhancement of antioxidant potential.

Overall, the results confirm that germination is an effective pre-treatment to improve the antioxidant activity of millet-based functional beverages, while the inclusion of Jamun further amplifies free radical scavenging due to its high content of phenolic antioxidants such as ellagitannins.

**Effect on the sensory attributes of the Yoghurt beverage due to different treatments of Kodo millet**

A semi-trained panel of 12 judges evaluated the sensory characteristics of the developed yoghurt beverages to determine consumer acceptability. The samples were assessed for color, texture (consistency and mouthfeel), flavor, taste, and overall acceptability using a nine-point hedonic scale.

The inclusion of coconut sugar slightly affected the color of the beverage, imparting a mild brown hue, though the difference was

**Table 4:** Effect of different treatments of Kodo millet on TPC levels, percent Free Radical Scavenging Activity

Sample	Total Phenolic Content (mg GAE/mL)	Antioxidant Activity (%)
Unsoaked	9.06 ± 0.04 <sup>a</sup>	52.54 ± 0.41 <sup>a</sup>
Soaked	6.83 ± 0.06 <sup>b</sup>	40.41 ± 0.30 <sup>b</sup>
Germinated	7.84 ± 0.26 <sup>c</sup>	60.31 ± 0.07 <sup>c</sup>

**Table 5:** Effect of different treatments of Kodo millet on the Sensory Attributes of the Beverage

Sample	Color	Texture	Flavor	Taste	Overall Acceptability
Unsoaked	8.2 ± 0.01 <sup>a</sup>	6.4 ± 0.07 <sup>a</sup>	7.7 ± 0.01 <sup>a</sup>	7.2 ± 0.01 <sup>a</sup>	6.8 ± 0.02 <sup>a</sup>
Soaked	8.5 ± 0.10 <sup>ab</sup>	7.9 ± 0.40 <sup>b</sup>	8.4 ± 0.45 <sup>b</sup>	8.1 ± 0.20 <sup>b</sup>	7.3 ± 0.02 <sup>b</sup>
Germinated	8.7 ± 0.20 <sup>b</sup>	8.3 ± 0.01 <sup>b</sup>	8.6 ± 0.05 <sup>b</sup>	8.3 ± 0.10 <sup>b</sup>	8.3 ± 0.01 <sup>b</sup>

not significant. The mean color scores ranged from 8.2 to 8.7, indicating that all samples were visually appealing. In contrast, significant differences ( $p < 0.05$ ) were observed for texture and taste attributes among treatments. The texture score of the unsoaked millet yoghurt beverage was the lowest, while the germinated sample achieved the highest ratings (Table 5).

The low texture score in the untreated grain beverage can be attributed to its high viscosity and graininess, which resulted in a thick, slurry-like consistency. This defect reduced flowability and made the mouthfeel less pleasant compared to the smoother, more homogeneous consistency of soaked and germinated samples. During soaking and germination, the partial hydrolysis of starch and proteins improves solubility and reduces particle aggregation, thereby enhancing beverage smoothness and drinkability.

Flavor scores for the untreated, soaked, and germinated grain beverages were 7.7, 8.4, and 8.6, respectively. The natural flavor of Jamun effectively masked the inherent bitterness of Kodo millet, producing an overall pleasant taste profile. However, the untreated grain beverage scored lower in taste due to the presence of residual tannins and phytates, which can precipitate proteins and impart mild astringency (Sharma et al. 2021).

The overall acceptability followed the same trend as texture and taste, with the germinated millet yoghurt beverage receiving the highest mean score, followed by the soaked and untreated samples. From a consumer perspective, the untreated beverage would likely be less marketable due to its thicker texture and slightly astringent flavor, whereas the germinated formulation achieved optimal balance between nutrition, flavor, and mouthfeel.

## Conclusion

The germinated Kodo millet–Jamun yoghurt beverage showed superior sensory quality, higher protein, crude fiber, and antioxidant activity compared to soaked and unsoaked samples. Fat content varied only slightly and was not statistically significant. The higher phenolic content in the unsoaked grain was linked to bound tannins and phytates, while germination improved nutritional quality and reduced antinutrients. Incorporation of Jamun enhanced the antioxidant potential, making the beverage a promising functional dairy product with potential health benefits and commercialization prospects.

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