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RESEARCH ARTICLE

Effect of germination on functional properties, flow properties, physico- chemical properties, proximate composition and pasting properties of finger millet

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ABSTRACT

Millets are driven by their health benefits and potential to contribute to food security. Finger millet (*Eleusine coracana* L), commonly referred to as ragi, provides a rich source of essential nutrients, including calcium, dietary fiber, and various health benefits. Germination is the traditional method used to enhance the high nutritional profile and good functional properties of millet flours while reducing anti-nutritional content. Germination improves the acceptability, digestibility, and bioavailability of nutrients. The purpose of this study was to see the effect of germination on functional properties, flow properties, physico-chemical properties, proximate composition, and pasting properties of finger millet flour. Finger millet seeds were cleaned and soaked for 24 h germinated at room temperature and the sample was collected at 0h, 24h, 48 h and 72 h. Non-germinated and germinated samples were dried and milled into flour. The germination treatment on 48 h finger millet flour was optimized based on functional properties such as bulk density, water absorption capacity, oil absorption capacity, dispersibility, swelling power and solubility. There is no significant differences observed in non-germinated finger millet flour and optimized germinated flour of flow properties such as carr index, Hausner ratio, and angle of repose. Based on the results, it was concluded that optimized germinated finger millet flour had increased total titratable acidity and good pasting properties compared to non-germinated finger millet flour. The proximate composition of moisture, protein, fat, ash and fibre content of optimized germinated flour was 9.44%, 8.01%, 2.29%, 2.12% and 4.20% respectively.

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INTRODUCTION

The cereals including millets are derived from the harvested seeds of grass plants (Poaceae). The term “millet” has been in use for approximately 10,000 years and refers to certain grains that have historically served as plant-based food sources for humans (Lu *et al*., 2009). These grains are considered staple foods in many developing countries due to their resilience and ability to thrive in harsh, arid environments (Saleh *et al*., 2013).

Millet is a staple food in many Asian and African countries and is used to make traditional dishes such as idli, dosa, papad, chakli, porridges, bread, and infant snacks. (Chandrasekara *et al*., 2011). Consumer awareness of the nutritional, economic, and environmental benefits of consuming millethas increased (Shah *et al*., 2021). Millets not only provide nutrients but also aid in managing health conditions

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such as diabetes, obesity and hyperlipidemia (Veena., 2003). Furthermore, millets are abundant in essential nutrients, including iron, zinc, and calcium, and have a low glycemic index (Singh *et al*., 2024)

Finger millet *(Eleusine coracana L*, commonly known as ragi, is an ancient cereal grain that has been cultivated for thousands of years (Nakarani *et al*., 2022). In India it is known by various local names such as “umi” in Bihar and “nachni” in Maharashtra which translates to “dancer.” Traditionally the grains were sprouted, dried, gently roasted, pulverized and sieved to prepare for consumption (Ushakumari *et al*., 2004). The grain comes in different colors including brown, light brown and white (Kumar *et al*., 2016)

Finger millet has a low glycemic index which is beneficial in managing diabetes and obesity (Yadav *et al*., 2019). It is also rich in dietary fiber, supporting digestion and potentially lowering the risk of cardiovascular diseases.

Food researchers and developers are continuously investigating methods to enhance the nutritional attributes of foods. To improve the nutritional value of food approaches such as fortification of vital elements may be applied. Biotechnological approaches, fortification and processing methods have all been used to enhance the nutritional value of cereal grains. Nowadays traditional processes such as soaking, germination and fermentation are utilised to improve food’s nutritional value (Shikha *et al*., 2023). Naveen and Sontakke, (2023) reported that traditional processes like fermentation and germination significantly enhance the nutritional value of millet grains and extend the shelf life of flour making these treatments beneficial for various food formulations. Germination is a cost-effective approach to improving the nutritional value and digestibility of finger millet (Udeh *et al*., 2018).

This study aimed to investigate and compare the various properties of germinated and non-germinated finger millet flour. The findings provide valuable insights and recommendations for the incorporation of germinated finger millet flour in food formulation and processing.

MATERIAL AND METHODS

Raw materials

Cleaned finger millet procured from the local market.

METHODS

Preparation of germinated finger millet flour

Collected cleaned grains were washed, drained and dried in shade drying for 24 h at room temperature (Finon-germinated finger millet flour was sieved (100 µm mesh sieve) to produce non-germinated finger millet flour, which served as control. For the germination process, finger millet grains were thoroughly washed and soaked at room temperature for 24 h. After soaking excess water was drained and the grains were evenly spread on clean jute bags lined with a damp cotton cloth. During the germination phase three germination time trials (24 h, 48 h and 72 h) were conducted at room temperature .Water was sprinkled over millet grains during a 4h interval to promote germination. After germination grains were rinsed, drained and dried for 24 h. Dried germinated millet grains were milled and sieved (100 µm mesh sieve) to obtain a uniform size of germinated finger millet flour.

Functional Properties

Bulk density, water absorption capacity, oil absorption capacity, dispersibility, swelling power,, and solubility were measured for non-germinated and germinated finger millet flour samples (24 h, 48 h, and 72 h) following the methodology outlined by Yenasew et al. (2023).

Flow properties

The germinated, non-germinated and optimized germinated finger millet flour samples were examined to determine ion of flow properties (selvaprakash, 2022).

pH and Total Titratable Acidity

The pH and total titratable acidity of non-germinated and optimized germinated finger millet flours were determined following the method described by Sharma (2023).

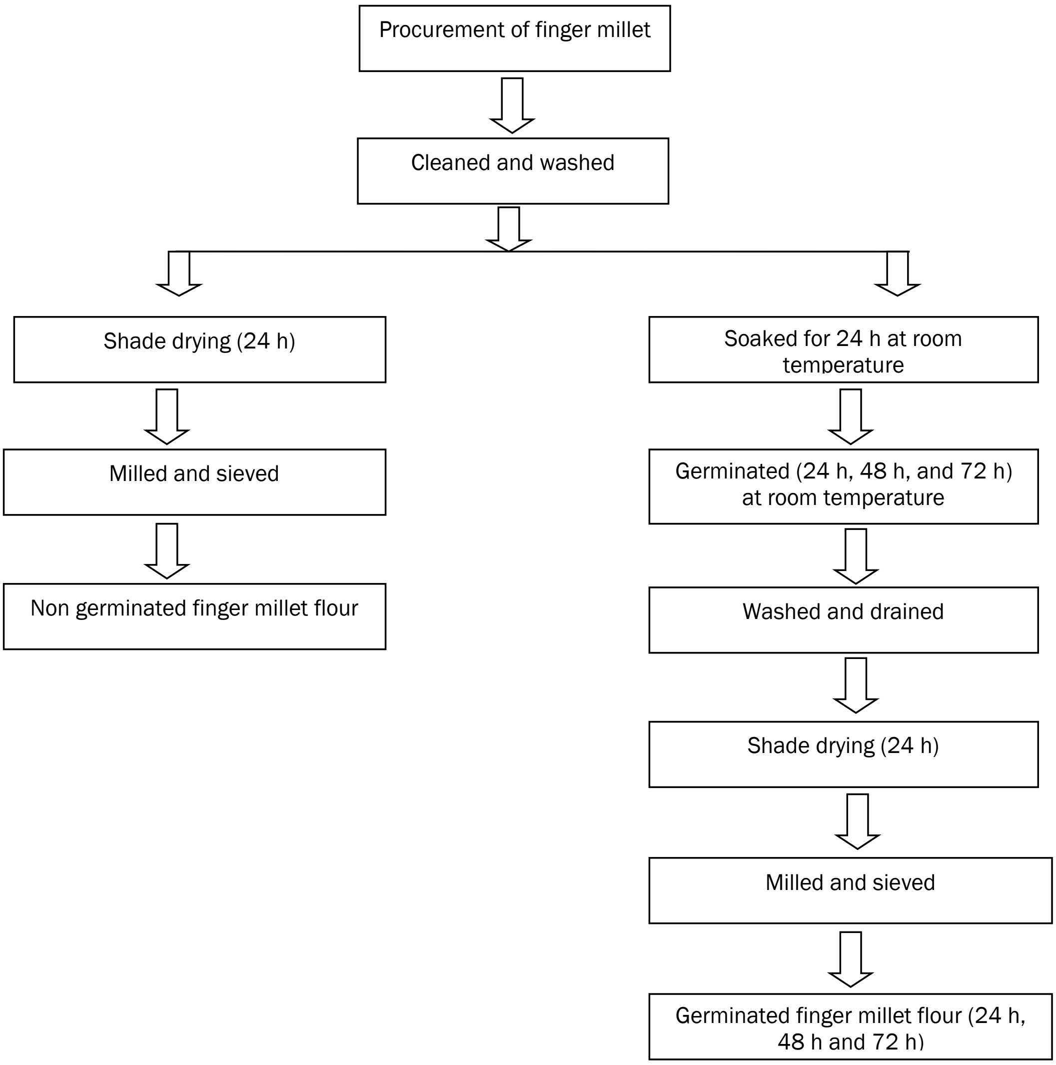
Proximate Composition

The non germinated and optimized germinated finger millet flour samples were analyzed for proximate composition such as moisture, ash, fat, total protein and fiber content, according to AOAC (2010) procedures.

Pasting Properties

The pasting properties of the optimized germinated

Fig 1. Preparation of non germinated and germinated finger millet flour



finger millet flour sample were measured using a rapid visco analyzer following the methodology of Shobana and Malleshi (2007).

RESULTS AND DISCUSSION

Effect of germination on functional properties of germinated finger millets flour

The functional properties of grains are very important in product development. These qualities change during germination, therefore understanding them is critical.. Changes in functional characteristics are primarily caused by variations in carbohydrate and protein composition and structure. Germination has also been shown to reduced starch amylase concentration and proteins with a high molecular weight. Functional properties of germinated finger millet flour such as bulk density, water absorption capacity (WAC), oil absorption capacity (OAC), dispersibility, swelling power and solubility values were shown in table 1.

Bulk density was influenced by energy, density, texture and mouthfeel of flour. Additionally, a variety of factors, including conditions of flour preparation and their storage can impact the bulk density values. The bulk density values of germinated finger millet flour for 0 h, 24 h, 48 h and 72 h were found to be 0.87 g/cm^3, 0.81 g/cm^3, 0.68 g/cm^3 and 0.68 g/cm^3 respectively whereas non-germinated finger millet flour had a higher bulk density. The value of bulk density reduced as germination period increased. Non germinated finger millet flour had a higher bulk density than that of 24-, 48-, and 72-h germinated flour. Simillar bulk density (0.68 g/cm^3) was observed at 48h and 72 h of germination. The result of bulk density of non-germinated finger millet flour showed a significant difference (p < .05) at all the germination period whereas no significant decrease in bulk density at 48h and 72 h of germination finger millet flour.

Table 1: Effect of germination period on functional properties of finger millet flour

Parameter	Germination period(h)				F value
	0	24	48	72	
Bulk Density (g/cm^3)	0.87^c ± 0.01	0.81^b ± 0.02	0.68^a ± 0.01	0.68^a ± 0.02	21.81 **
WAC(g/g)	1.79^a ± 0.02	1.89^b ± 0.01	2.18^c ± 0.01	2.22^c ± 0.12	113.44**
OAC(%)	146.83^a ± 0.52	154.45^b ± 0.59	168.15^c ± 0.43	169.68^c ± 0.54	430.85**
Dispersibility(%)	73.66^a ± 0.38	76.08^b ±0.40	78.01^c ±0.32	78.05^c ±0.50	25.60**
Sweling power(%)	3.05^c ± 0.02	2.82^b ± 0.02	2.41^a ± 0.08	2.40^a ± 0.02	45.85**
Solubility(%)	2.78^a ± 0.01	11.41^b ± 0.28	18.45^c ± 0.33	18.98^c ± 0.37	688.21**

@ Average of 6 trials; Non significant – P > 0.05,*Significant – 0.01 < P≤ 0.05,**Highly significant- P≤0.01; Means bearing different superscripts within colums differ significantly

During germination, bulk density decreased due to the breakdown of complex compounds including proteins and starches into simpler molecules during germination (Ocheme *et al*., 2015). Lower bulk density may be used to soften the grains during soaking, resulting in flour particles after milling (Siddiqua *et al*.,2019). Similar results were obtained by Sharma *et al*., 2023.

Water absorption capacity is defined as the volume that starch occupies after swelling in excess water, maintaining the flour's integrity in aqueous mixtures (Shakirah *et al*., 2022). The values of water absorption capacity for 0 h, 24 h, 48 h and 72 h were found to be 1.79 g/g, 1.89 g/g, 2.18 g/g and 2.22 g/g respectively. The highest (2.22 g/g) and the lowest (1.79 g/g) water absorption capacity values were obtained at 72 h of germination and at 0-h germination, respectively. The result of water absorption capacity of non-germinated finger millet flour showed a significant difference ($p < .05$) at all the germination period. There was a significant increase ($p < .05$) in the water absorption capacity of 48-h and 72-h germination. Similar results are in line with the report of Kumar *et al*. (2021) and Ocheme and Chinma (2008). The water absorption capacity of germinated finger millet flour was higher than that of non germinated finger millet flour. Increased water absorption contributes to improved softness, bulk and uniformity in food products (Siddiqua *et al*., 2019).

The germinated finger millet flour of oil absorption capacity values were 146.83 %, 154.45 %, 168.15% and 169.68 % at 0 h, 24 h, 48 h and 72 h respectively. The result of oil absorption capacity of non-germinated finger millet flour showed a significant difference ($p < .05$) at all the germination period. There was a significant increase ($p < .05$) at 48-h and 72-h germination as compared to ungerminated finger millet flour. Basically, oil absorption capacity increased as the germination period increased, but not significantly. This study results showed a high oil absorption capacity in germinated finger millet flour than non-germinated finger millet flour. This is due to the hydrolysis of starch during germination because the hydrolyzed starch absorbs more water and oil. This may be related to protein solubilization and dissociation, which expose non-polar components during germination. Higher oil absorption value is important to enhance the flavor, taste and lipophilic properties of food products. Simillar results were observed by Sharma *et al*., 2023.

The values of germinated finger millet flour dispersibility were 73.66 %, 76.08 %, 78.01 % and 78.05 % at 0 h, 24 h, 48 h and 72 h respectively. The result of dispersibility of non-germinated finger millet flour showed a significant difference ($p < .05$) at all the germination period. Non germinated finger millet flour had the highest dispersibility value, whereas non germinated had the lowest value at 72 h of germination. However, the dispersibility increased significantly ($p < .05$) at 48-and 72-h germination as compared to non germinated and 24-h germinated finger millet flour. Germinated finger millet flour had high dispersibility values when compared to non germinated finger millet flour. Similar results was obtained by Yenasaw and Urga (2023).

Swelling power of germinated finger millet flour for 0 h, 24 h, 48 h, and 72 h were found to be 3.05 %, 2.82 %, 2.41 % and 2.40% respectively. The swelling power of germinated finger millet flour was significantly reduced (*p* < .05) as germination period increased. The highest swelling power (3.05%) result was obtained from non germinated finger millet flour but the lowest value (2.40%) was recorded at 72-h germination. The result of swelling power of germinated finger millet flour decreased significantly (*p* < .05) as compared to non germinated flour. whereas no significant decrease in swelling power at 48h and 72 h of germination finger millet flour. Similar results was obtained by Nefale and Mashau (2018). Ocheme and Chinma (2008) observed that as germination time increased, fat content decreased, limiting the swelling power of the flour due to starch formation (Horstmann *et al*., 2017).

Values of solublity for 0 h, 24 h, 48 h and 72 h germinated finger millet flour were found to be 2.78 %, 11.41 %, 18.45 % and 18.98 % respectively. Solubility of finger millet flour flour increased significantly (*p* < .05) at all germination periods as compared to non germinated finger millet flour. The souliblity of germinated finger millet flour was significantly increased (*p* < .05) as germination period increased. This might be due to the starch hydrolyzed and increased sugar level during germination. Kumar *et al*, (2021) reported that solubility value increased in germination.

Based on the optimal functional properties, time efficiency and the findings of Rathore *et al*. (2019) reported a reduction in anti-nutritional factors (54% reduction in phytate, 65% reduction in tannins) and an increase in nutrient availability at 48 h of germination, the 48 h germinated finger millet flour was selected for further analysis.

Table 2: Effect of germination on flow properties

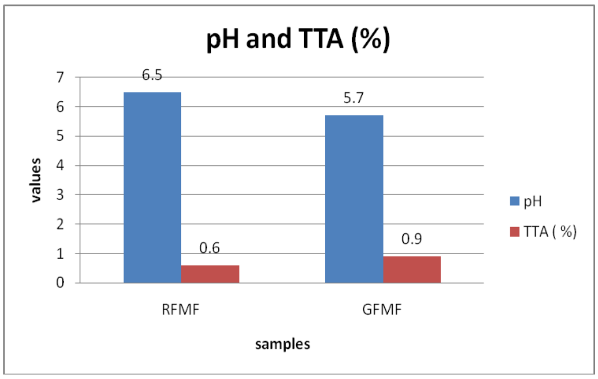
Flow properties	Non germinated finger millet	Optimized Germinated finger millet flour (48 h)
Carr index	11.09	12.01
Hausner ratio	1.09	1.13
Angle of repose (ɵ)	27.70	27.59

Effect of germination on flow properties of finger millet flour

The flow properties of non-germinated finger millet flour and optimized germinated finger millet flour (48 h) values are shown in table 2. The carr index for non germinated and optimized germinated finger millet flour were found to be 11.09 and 12.01 respectively. Carr's index, commonly known as the compressibility index, is a measure of flour flowability; flour with CI less than 15 has high flowability, whereas CI greater than 35 indicates poor flowability. During germination flow properties of carr index value increased than non germinated finger millet flour. Germination causes enzymatic breakdown of carbohydrates and protein, resulting in finer, lighter particles.Germination treatment reduces bulk density and increases particle size heterogeneity, which reduces flowability and increases the Carr Index value. Similar results are obtained by Shingare and Thorat (2013).

The hausner ratio for non germinated and optimized germinated finger millet flour were found to be 1.09 and 1.13 respectively. According to carr (1965), hausner ratio of non germinated and optimized germinated flour were good flow properties. There is a no significant difference between the non germinated and optimized germinated finger millet flour. Germination increases the hygroscopicity of flour due to the presence of hydrolyzed sugars and breakdown of cell walls. This can make the particles more cohesive, which reduces flowability and raises the Hausner ratio. Similar results are obtained by Shingare and Thorat (2013).

Fig 2. Effect of germination on pH and TTA(%)



RFMF – Raw Finger Millet Flour, GFMF-Germinated Finger Millet Flour(optimized)

The angle of repose (□) of non germinated and optimized germinated finger millet flour were found to be 27.70 and 27.59 respectively. Germination leads to enzymatic changes that modify the surface properties of the particles, making them less sticky or cohesive, which also contributes to a lower angle of repose compared to non germinated finger milet flour. Angle of repose indicate the very good flow properties for non germinated and optimized germinated finger millet flour and also increased with the increase in moisture content (Rajasekhar *et al*., 2018).

Effect of germination on pH and total titrable acidity for finger millet flour

The effect of germination on pH and total titratable acidity (TTA) is illustrated in Figure 2. The highest pH value (6.5) was observed in non germinated finger millet flour, while its TTA was 0.6%. In contrast, the optimized germinated finger millet flour showed a pH of 5.7 and a TTA of 0.9%, similar results werefound by Sharma *et al*. (2023). From this result, the pH value of non-germinated finger millet flour was higher than that of optimized germinated finger millet flour. The reduction in pH alongside an increase in TTA may result from the breakdown of complex organic molecules such as lipids, phytin and proteins into simpler compounds during germination. This increased acidity could be attributed to the hydrolysis of these compounds into fatty acids, phosphates and amino acids which may contribute to the improved digestibility of germinated millet flour (Gernah *et al*., 2019). Nefale and Mashau (2018) also reported the content of TTA of finger millet, which increased as the germination period increased.

Effect of germination on proximate composition for germinated finger millet flour

The proximate composition of factors such as moisture, ash, protein, fat and fiber content for non-germinated and optimized germinated (48 h) finger millet flour were presented in Figures 3 and 4. Optimized germinated finger millet flour has a moisture content of 9.44%, which is slightly lower than that of non-germinated finger millet flour (9.78%). During germination water uptake is high and the formation of hydrophilic components results in higher moisture content in germinated finger millet flour compared to its non-germinated finger millet flour. similar results reported by Abioye *et al*. (2018). For long-term flour preservation, a safe limit of ≤10% moisture content has been recommended for grains (Nonogaki *et al*., 2018).

The crude protein content in optimized germinated finger millet flour increased to 8.1% compared to 7.51 % of non-germinated finger millet flour, indicating that germination positively impacts protein levels (Abioye *et al*., 2018). The activity of the protease, which broke down peptides into amino acids, enhanced

Fig 3. proximate composition for non germinated finger millet flour (%)

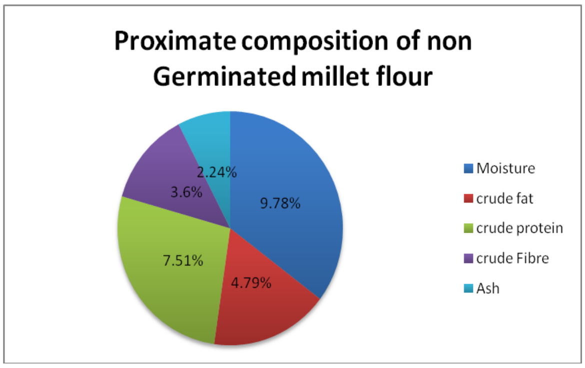
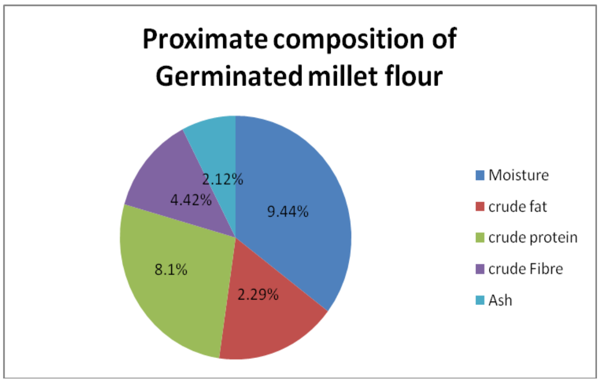


Fig 4. Proximate composition for optimized germinated finger millet flour (%)



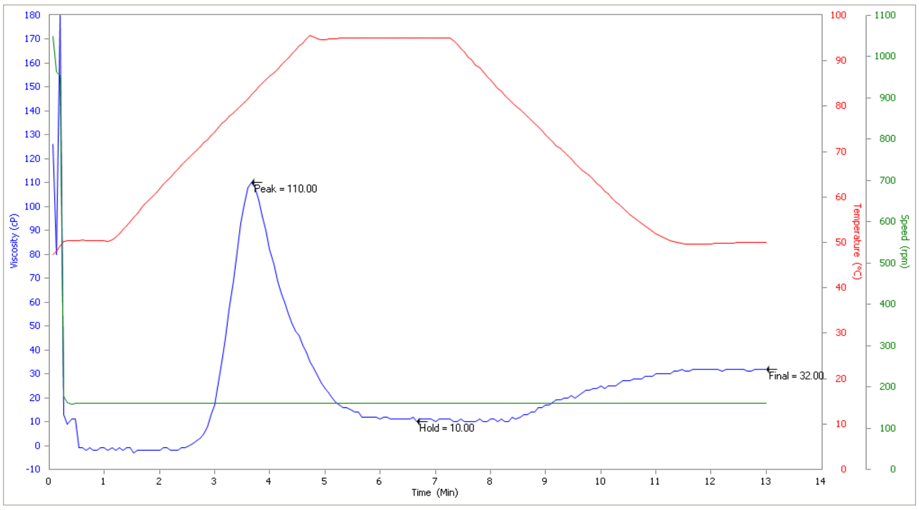
the protein content of germinated finger millet during the germination stage.The crude fat content of non-germinated and germinated finger millet flour was found to be 4.7 % and 2.29%, respectively. From this result it is observed that the crude fat content of optimized germinated finger millet flour value was decreased during germination period due to the increased activity of lipase enzyme. Germinated flour's lower crude fat content may extend its shelf life by reducing rancidity, likely due to the enzymes produced, similar results was finded by Sharma *et al*., 2023.

Crude fibre for non-germinated and optimized germinated finger millet flour were found to be 3.6 %and 4.20 % respectively. while the crude fiber content is notably higher in germinated finger millet flour. Germination leads to the formation of cellulose and hemicellulose, as well as the breakdown of starch, similar to findings by Kumar *et al*. (2021). The ash content for optimized germinated finger millet flour was (2.12%) higher than that of non germinated finger

Table 3: Effect of germination on pasting properties for optimized germinated finger millet flour

Parameter	Non Germinated Finger millet flour	Germinated Finger millet flour (48 h)
Peak viscosity (cp)	2187	109.00
Trough viscosity (cp)	2048	10.00
Breakdown viscosity (cp)	256	99.00
Final viscosity (cp)	1038	32.00
Setback viscosity (cp)	600	22.00
Peak time (min)	7.00	4.00

Fig 5. Effect of germination on pasting properties for optimized germinated finger millet flour



millet flour(2.24%). Germinated grains may have lower ash content due to mineral utilisation during seed sprouting. Kumar *et al*. (2021) obtained a similar result. Overall, the optimized germinated finger millet flour exhibits enhanced nutritional properties compared to non-germinated finger millet flour, demonstrating the beneficial effects of germination.

Pasting characteristics are indices used to predict flour pasting behaviour during and after cooking. The arrangement of amylose and amylopectin in starch granules affects their pasting properties. The pasting properties of the optimized germinated finger millet flour were assessed using a Rapid Visco Analyzer with characteristics such as peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity and peak time summarized in Table 3 and represents figure 5. Peak viscosity means maximum viscosity reached during heating cycle. The peak viscosity (PV) of the non germinated and optimized germinated flour were recorded at 2187 cp and 109 cp respectively. There is a strong correlation between PV and starch damage, with increased starch damage leading to higher PV values (Sanni *et al*., 2004). (Adepehin, 2024).During germination period the peak viscosity value was decreased.

Trough viscosity defined the minimum viscosity after the peak. The trough viscosity of non germinated and optimized germinated finger millet flour were measured as 2048 cp and 10 cp respectively. During germination, enzymatic degradation reduces the amount of intact starch available to form a gel, leading to lower trough viscosity in germinated finger millet flour. similar results obtained by Gull *et al*., 2016. Breakdown viscosity defines the difference between peak and trough viscosity. The breakdown viscosity of non germinated and optimized germinated finger millet flour were measured as 256 cp and 99 cp respectively. Lower breakdown viscosity (BV) indicates greater resistance to heating and shear stress during cooking. The enzymatic activity during germination partially hydrolyzes the starch granules, making them less robust and more prone to disintegration during cooking. This results in reduced viscosity under shear stress, similar result were found by Adepehin, 2024.

The final viscosity (FV) of non germinated and optimized germinated finger millet flour were found to be 1038 cp and 32 cp respectively. The enzymatic modifications during germination decrease the water-binding capacity of starch, which also leads to reduced swelling and lower final viscosity. It reflects the stability of starch during cooking and its ability to form a viscous paste upon cooling. A reduction in starch stability is often associated with high breakdown viscosity (Shimelis *et al*., 2006; Adepehin, 2024). The setback viscosity (SV) of non germinated and optimized germinated finger millet flour were found to be 600 cp and 22 cp respectively. Germination reduces the amylose content through enzymatic breakdown, resulting in lower retrogradation potential and thus reduced setback viscosity. SV is critical in understanding paste stability during cooling and storage, as it indicates the degree of starch retrogradation. Lower SV is associated with decreased starch retrogradation and syneresis, while increased viscosity during cooling may result from starch aggregation (Gull *et al*., 2016). Studies on germinated and fermented pearl millet show that enzyme-driven breakdown of amylose can lead to reduced setback limiting entanglement between starch chains (Nurmomade *et al*., 2024). Setback viscosity reflects how starch molecules behave post-cooking, where reduced temperature promotes hydrogen bonding, amylose-lipid complex crystallization and starch recrystallization.

The peak time of non germinated and optimized germinated finger millet flour were 7min and 4 min respectively. It is reflecting the minimum cooking time required. A similar result was found by Adepehin, 2024. Germination, leads to quicker gelatinization and a lower peak time in germinated finger millet flour compared to non-germinated flour. Germination typically lowers the viscosity of cereal and legume flours due to α-amylase activity, which breaks down starch granules. Reduced viscosity in germinated flours can make porridge suitable for malnourished children, allowing adjustments in flour concentration to increase energy density (Nurmomade *et al*., 2024).

CONCLUSION

This study evaluated the impact of germination on the functional, physico chemical and pasting properties of finger millet flour. Germination led to a notable improvement in nutritional and functional qualities including enhanced protein and fibre content along with desirable changes in water and oil absorption capacities, dispersibility and solubility. The reduction in pH and increase in titratable acidity after germination. Germination improved digestibility due to the breakdown of complex organic molecules. Enhanced pasting properties such as reduced setback viscosity reflect improved gel-forming potential and stability making the germinated flour suitable for various food applications, especially in baked goods and high-energy porridge formulations. The optimized 48 h germination period was effective in enhancing the flour's nutritional profile and functional properties while maintaining manageable processing time and stability. These findings underscore the potential of germinated finger millet flour as a versatile ingredient in the development of functional and gluten-free foods aimed at improving dietary quality and addressing nutritional needs in diverse consumer populations.

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