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EFFECTS OF GERMINATION TIME AND DRYING TEMPERATURE ON CHEMICAL AND SENSORY QUALITY OF FINGER MILLET FLOUR

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Abstract: This study aimed to investigate the impact of germination time and drying temperature on the chemical and sensory properties of finger millet flour. Finger millet was collected, cleaned, soaked in water overnight at room temperature, strained and then spread over the muslin cloth. The germination was carried out at room temperature (27±2 °C) for 24, 48, and 72 h, followed by drying in a cabinet dryer at 80, 90, and 100°C. The dried samples were then milled using a pulp grinder. The effect of germination time and drying temperature on total phenolic content (TPC), antioxidant activity, glucose content, reducing sugars and total sugars was analyzed. The glucose content, reducing sugar and total sugar contents were found to be significantly higher in millet flour germinated for 72 h and dried at 80°C, while TPC and antioxidant activity were slightly lower. The samples were subjected to sensory evaluation in terms of color, smell, taste, flavor and overall acceptance. Germination of finger millet for 48 h followed by cabinet drying at 90 °C resulted in a significant increment of crude protein, crude fat, crude fiber, iron, and calcium contents, whereas moisture and total ash contents were reduced. Sensory analysis showed that flour germinated for 48 h and dried at 90 °C received the highest mean sensory scores among all samples.

Key words: *proximate composition, total phenolics, antioxidant activity, sugars, iron, calcium*

INTRODUCTION

Finger millet *(Eleusine coracana* (L.) Gaertn*)* is a small-seeded cereal grain from the Poaceae family, cultivated and harvested annually. It originated in Ethiopia (Ramashia, Gwata, Meddows-Taylor, Anyasi & Jideani, 2018). This crop is grown in Nepal, Taiwan, China, Japan, India, the United States, and several African countries (Gebreyohannes et al., 2021). It is known as kodo in Nepal, ragi in India, and Kuracan in Sri Lanka. This crop serves as a major staple food in the mid-hills and Himalayan regions of Nepal and India, as well as in eastern and central Africa. In Nepal, it ranks as the fourth most important staple crop after rice, maize, and wheat (Adhikari, Pokharel & Shrestha, 2018). Finger millet is considered beneficial for pregnant women and their fetuses due to its high calcium and iron

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content, which support bone development and help prevent anemia (Kandel, Dhami, Subedi, Shrestha & Bastola, 2019). Finger millet provides numerous health advantages, including the reduction of diabetes, obesity, osteoporosis, anemia, malaria, and diarrhea. These benefits stem from its high content of calcium, iron, and dietary fiber, along with its gluten-free quality (Gebreyohannes et al., 2021). Finger millet comprises approximately 66.6% carbohydrates, 6–13% protein, 2.4% minerals, 1.4% fat, 3.6% fiber, and 2% ash, with calcium content at 0.38% and iron ranging from 25.86 to 39.60 ppm (Bunkar, Goyal, Meena & Kamalvanshi, 2021). In addition, finger millet contains 0.48% phytates, 0.61% tannins (0.61%), 0.3-3% phenolic compounds and trypsin inhibitory factors and is recognised as health beneficial effects, for anti-diabetic, anti-tumorigenic, antiulcer, anti-inflammatory, antioxidant and antimicrobial properties (Mali & Swami, 2023). Finger millet is a valuable source of vitamins and essential amino acids such as histidine, lysine, methionine, and tryptophan.

However, its nutritional benefits are limited by anti-nutritional factors like phytate and oxalates naturally present in the grains. To improve nutrient availability, various processing techniques such as soaking, roasting, heating, germination, and fermentation are applied (Azeez et al., 2022).

Germination is a traditional processing method that enhances the digestibility of cereal grains and legumes by increasing their functional and nutritional qualities. Numerous studies have shown that germination improves the chemical composition and nutritional value of various cereals, including millet, rice, and wheat (Nefale & Mashau, 2018).

Germination is a natural process occurring during seedling development, where new cells are formed. Its primary purpose is to activate natural hydrolytic enzymes that remain inactive in the raw seed. This enzymatic activation facilitates the seed's growth and development (Ayernor & Ocloo, 2007). Studies investigating the impact of germination on legumes indicate that this process enhances the digestibility of proteins and dietary fibers, reduces antinutritional factors such as tannins and phytates, and augments the bioavailability of minerals and vitamins (Azeez et al., 2022). Germination enhances antioxidant and functional properties, modifies structure, reduces anti-nutritional factors (ANFs), softens the kernel, and improves overall nutritional quality (Chinma, Abu, Asikwe, Sunday & Adebo, 2021). Drying is employed to remove excess moisture and volatile substances from food materials. This process involves the simultaneous transfer of heat and mass (Annavarapu & Kaumudi, 2018).

Drying induces several physical and chemical changes, including cell membrane denaturation, alteration of enzymatic activity, oxidation of color and vitamins, and acceleration of Maillard reactions (Mali & Swami, 2023). Previous studies have reported that germination significantly increases total phenolic content, flavonoids, and antioxidant activity in finger millet flour (Abioye, Ogunlakin, & Taiwo, 2018). Similarly, Kumar, Kaur, Gupta, Gat and Kumar (2021) demonstrated that varying germination times (12–96 h) altered the physicochemical composition and mineral content of finger millet, suggesting its potential for functional food applications. Comparative work on millet and other grains has also shown that germination improves glucose and reducing sugar levels due to enzymatic hydrolysis of starch (Sneha et al., 2023).

Drying conditions, however, play a critical role in preserving or degrading bioactive compounds. While germination has been extensively studied, systematic evaluation of drying temperatures in combination with germination time remains limited. Most prior research has focused either on germination alone or on drying methods without integrating both factors. This gap is particularly important because drying at elevated temperatures may reduce phenolic compounds and antioxidant activity, yet optimal drying is necessary for flour stability and shelf life.

Therefore, the present study aims to analyze the interactive effects of germination duration (24, 48, and 72 h) and cabinet drying temperatures (80, 90, and 100 °C) on the chemical properties of finger millet flour, specifically total phenolic content, antioxidant activity, glucose, reducing sugar, and total sugar. By addressing germination and drying parameters simultaneously, this research provides novel insights into optimizing processing conditions for enhancing the nutritional and functional quality of finger millet flour.

MATERIALS AND METHODS

Materials

A common variety of finger millet *(Elusine coracana* L.*)* was collected from the local market of Dharan. Equipment and analytical grade reagents required were utilized from Dharan Multiple Campus laboratory.

Finger millet grains were first winnowed with woven bamboo trays (nanglo, in Nepali language). In this step, husk, immature grains and light particles were removed, while heavier particles such as specks and stones were separated by gravity. Cleaned millet of 1.5 kg in 3 lot was soaked in water (millet: water =1:3) overnight at room temperature (27±2 ℃).

Light materials present in the sample were skimmed off. Agitation was done to clean the seeds again. Straining the water, the steeped millet was spread over the muslin cloth with the thickness of 0.75±0.25 cm and was covered by wet muslin cloth. Each experimental condition was replicated three times to ensure reliability of the results.

Germination of finger millet

Finger millet was allowed to germination as per the method mentioned by Nefale and Mashau (2018) with minor modification. The finger millet grains were evenly spread and covered with muslin cloth then sprayed with water every six hours to maintain moisture. They were kept in a well-ventilated room at 27±2 °C to promote germination. During this time, the grains were regularly mixed to ensure uniform moisture and temperature distribution. Rootlets appeared after 24 h, and germination was monitored at intervals of 24, 48, and 72 h.

Drying and milling of finger millet

Germinated finger millet was dried continuously in a cabinet dryer at 80, 90, and 100 ℃ until the grain moisture content reached 11±1%, ground using an electric blender and sieved with 100µm stainless steel sieve and then packed in low-density polyethylene bags and stored at room temperature 27±2 °C for further analysis as described by Ocheme and Chinma (2008) with minor modification.

Proximate analysis of raw millet and dried millet flour

Proximate composition of finger millet was determined described by Ranganna (1986). Moisture content of the sample was determined by using a hot air oven. Crude fat was determined by solvent extraction method. Crude protein was determined indirectly by measuring total nitrogen content using micro-Kjeldahl method. A conversion factor of 6.25 was applied to calculate crude protein content. Total ash content of the sample was determined by dry ashing method. For crude fiber, moisture and fat-free sample were boiled consecutively with 1.25% H_2SO_4 solution and 1.25% NaOH solution, for 30 min under a reflux condenser. After each treatment, the samples were thoroughly washed with boiling water to remove acid and alkali residues. Carbohydrate content was calculated by subtracting the sum of moisture, protein, fat, ash, and crude fiber from the total sample weight (100).

Determination of iron and calcium content

Iron content was determined by colorimetry described by Ranganna (1986). Briefly, ash obtained by dry ashing was treated with 25 mL of 10% HCl and dissolved by heating for 5 min. The solution was filtered and transferred to a 100 mL volumetric flask and the volume was adjusted with distilled water. Into three separate stoppered measuring cylinders, pipette the solutions as given below. In each of the above cases, make up the volume to 15 mL with water. Three tubes were prepared as blank, standard and sample and their absorbance were taken at 480 nm. Measure the color at 480 nm setting the blank at 100% transmission. Calcium content was determined by volumetric method described in Ranganna (1986). The ash obtained by dry ashing was treated with 25 mL of 10% HCl and dissolved by heating for 5 min. The solution was filtered and transferred to a 100 mL volumetric flask and volume made up using distilled water. Pipette out 20-100mL aliquot to a 250 mL conical flask then 10 mL of saturated ammonium oxalate and 2 mL of methyl orange indicator were added, followed by a few drops of dilute acetic acid until a faint pink color appeared.

$$\text{Iron (mg/100g)} = \frac{\text{OD of sample} \times 0.1 \times \text{Total volume of ash solution} \times 100}{\text{OD of standard} \times 5 \times \text{Weight of sample taken for ashing}}$$

The mixture was left overnight, filtered through Whatman No. 42, and washed with water until the filtrate was free of oxalate. The filter paper was broken with a glass rod, washed with hot dilute sulfuric acid, and the volume was adjusted to 100 mL with distilled water. A 25 mL aliquot was pipetted into three conical flasks, warmed to 80 °C, and titrated with 0.01 N $KMnO_4$ until a persistent pink endpoint was reached. For one flask, after reaching the endpoint, the previously used filter paper was added, and titration was repeated.

$$\text{Calcium (mg/100g)} = \frac{T \times N \times 20 \times V}{v \times W}$$

where,

T = Titre,
N = Normality of KMnO4 solution,
V = Total volume of the ash solution,
v = Vol of ash solution taken for estimation,
W = weight of the sample taken for ashing.

Analysis of bioactive components

Total phenolic content (TPC)

The determination of total phenol content was conducted following the procedure described by Sadasivam and Manikam (2008) using Folin-Ciocalteau reagent. To conduct the assay, 0.5 mL of the extract was mixed with 1 mL of Folin-Ciocalteau reagent and incubated at room temperature for 15 minutes. Then, 2.5 mL of saturated sodium carbonate was added, followed by further 30-minute incubation at room temperature. The absorbance was measured at 650 nm using a spectrophotometer and quantified against a standard curve. Results were expressed as mg GAE per 100 g of sample

Antioxidant activity

The method outlined by Hawa, Satheesh and Kumela (2018) with minor modifications was employed to assess the antioxidant activity of the samples. The control sample (A control) was made by adding 0.28 mL of DPPH solution (0.1 mM, in 95% methanol) to a 10 mL conical flask, and then diluting it with methanol to the necessary volume. 0.28 mL of the DPPH solution and 0.28 mL of the test sample (sample A) were used in the preparation and poured into a 10 mL conical flask. The mixture was then diluted with methanol to the necessary level. Following repeated inversions, the mixture was incubated for 30min at ambient temperature in a darkened area. The absorbance was calculated with the aid of a spectrophotometer set at 517 nm, in comparison to the control sample. The radical scavenging activity was estimated as a decrease in DPPH absorbance and was calculated using the following equation:

The percentage DPPH radical scavenging activity was calculated as follows:

$$\%\ \text{Radical scaven. act.} = \frac{\text{Abs. control} - \text{Abs. sample}}{\text{Abs. control}} \times 100$$

Analysis of glucose, reducing sugar and total sugar content

Glucose content was determined by glucose oxidase method described by Sadasivam and Manikam (2008). Firstly, Glucose oxidase peroxidase reagent was made dissolving 25mg O-dianisidine completely in 1mL of methanol and 49 mL of 0.1M phosphate buffer (pH 6.5) were added. Then add 5 mg of peroxidase and 5 mg of glucose oxidase to the above prepared O-dianisidine solution. 100 mg glucose was dissolved in 100 mL distilled water. 10 mL of this stock was diluted to 100 mL to obtain the working standard solution. Briefly, 0.5mL millet powder extract taken in a test tube and 0.5 mL distilled water and 1mL glucose oxidase peroxidase reagent were added. The working standard solution was pipette out and transferred into a series of test tubes by 0.2, 0.4, 0.6, 0.8 and 1 mL and made up volume to 1 mL with distilled water and 1 mL of glucose oxidase-peroxidase reagent were added in all series of test tube. All the tubes were incubated at 35 for 40 min. After 40 min 2 mL of 6N HCl were added to terminate the reaction and measured the absorbance using UV-Visible spectrophotometer at 540 nm. A standard graph was constructed to calculate the amount of glucose present in the sample and expressed as mg/g. Reducing sugar and total sugar were determined by Lane and Eynon method as described in Ranganna (1986).

Sensory evaluation

Sensory evaluation was carried out using hedonic test (1 = poor and 5 = excellent) at 5-point scale as described by Ranganna (1986). Ten semi-trained panelists were participated including faculties and staff from Dharan Multiple Campus. Firstly, information was provided to each panelist about the types of formulated samples to be tested. Panelists took part in sensory evaluation willingly, and they

were not forced. Each panelist was provided with 5 g of the test sample, 100 mL of warm boiled water, a spoon, and a sensory score card. The parameters for sensory evaluation were: color, smell, taste, flavor and overall acceptability. After the data were tabulated, the sensory sheets were destroyed. The researchers did not release or disclose any participant-related data to the public in any journals, reports, or presentations. Panelists were made aware of how their data would be used, and they agreed to it – typically through verbal consent procedures.

During the evaluation, participants' privacy and autonomy were protected, ensuring transparency and ethical integrity in the research process. No vulnerable populations (e.g., children, individuals with diminished physical or intellectual capacity, socially or economically vulnerable, or institutionalized individuals) were involved in the study.

Statistical analysis

ANOVA (Analysis of Variance) was used to analyze the data of sensory evaluation and physicochemical composition. IBM SPSS Statistic version 27 was used to analyze data and Tukey's HSD test was done to discern the significant differences among sample means using 5 % level of significance and Microsoft Excel 19 was used to draw diagrams and tabulate data.

RESULTS AND DISCUSSION

Chemical composition of raw finger millet

The chemical composition of raw finger millet is shown in Table 1. Shrestha and Karki (2018) reported moisture content in the range of 13.4–14.5%, whereas the values obtained in this study were lower than those documented by Sarwar (2010). Low moisture content is advantageous, as it ensures prolonged edibility and nutritional quality by reducing susceptibility to microbial growth, enzymatic activity, and chemical degradation (Cacatian & Guittap, 2018). Moisture levels of ≤10% are considered a safe threshold for extended flour preservation (Azeez et al., 2022). The crude protein content of finger millet was lower than that reported by Sarwar (2010), but higher than the values found by Mali and Swami (2023), and within the range documented by Shrestha and Karki (2018). The fat content was higher than that reported by Sarwar (2010) and comparable to Shrestha and Karki (2018). The relatively low fat content of finger millet is important, as it contributes to storage stability by reducing the risk of rancidity (Cacatian & Guittap, 2018). Lande, Thorats and Kulthe (2017) reported an ash content of 1.91%, which is higher than the value listed in the food composition table by DFTQC (2012). Elevated ash levels are generally indicative of poor milling practices and the presence of silica in millet (Ranganna, 1986). The fiber content observed was greater than the values reported by (Lande et al., 2017; Mali & Swami, 2023). The iron concentration in finger millet was comparable to that reported by Lande et al. (2017), who found 13.57 mg/100 g. Similarly, the calcium content fell within the range documented by Shrestha and Karki (2018) who reported 344.9–398 mg/100 g. Variations in iron and calcium levels may be attributed to varietal differences, environmental conditions, or agronomic practices employed during cultivation (Ramashia et al., 2018).

Effects of germination time and drying temperature on chemical composition of finger millet flour

The influence of germination time and drying temperature on total phenolic content, glucose, total sugars, reducing sugars, and antioxidant activity in finger millet flour was assessed. The

Table 1.
Chemical composition of raw finger millet

Parameters	Values
Moisture (% wb)	13.60±0.20
Crude protein (% wb)	7.30 ± 0.26
Crude fat (% wb)	1.75 ± 0.03
Total ash (% wb)	3.29 ± 0.05
Crude fiber (% wb)	3.90 ± 0.09
Carbohydrate (by difference)	70.16 ± 0.03
Iron (mg/100g wb)	12.80 ± 0.02
Calcium (mg/100g, wb)	370.03 ± 1.79

Values in the table are the mean of triplicate measurements ± S.D.

germination was carried out for 24, 48 and 72 h and drying temperature was 80 ℃, 90 ℃ and 100 ℃ respectively for each sample. Data are presented in Table 2 (TPC, glucose content and antioxidant activity) and Table 3 (content of reducing sugars, total sugars and sucrose).

Effect on TPC

Phenolic compounds in cereals and legumes are integral components of dietary fiber, occurring predominantly in association with cell wall structures (Salawu, Bester & Duodu, 2014).

The highest total phenolic content was observed in millet germinated for 72 h and dried at 100 °C, reaching 33.4 mg GAE/100 g, with significant differences noted as presented in Table 2. A similar trend was reported by Kruma et al. (2016). The increase in total phenolics can be attributed to enzyme activation during germination, which promotes the synthesis of phenolic compounds (Salawu et al., 2014). Furthermore, the rise in polyphenols with prolonged germination may result from an increased proportion of seed coat at later stages, due to carbohydrate depletion (Kumar et al., 2021).

In the case of the sample germinated for 24 h, a slight increase in drying temperature initially resulted in only a modest reduction in total phenolic content (TPC), up to a certain threshold, beyond which a sharp decline was observed (Table 2). A similar trend was reported by Pandidurai, Amutha, Kanchana, Vellaikumar and Prabhakaran (2022).

Table 2.
Effect on germination time and drying temperature on TPC, glucose content and antioxidant activity of finger milllet

Parameters	**Germination time** (h)	**Drying temperature**		
		80°C	**90**°C	**100**°C
TPC (mg GAE/100 g)	24	25.55±0.99^{a}	32.06±2.43^{a}	23.57±1.00^{a}
	48	29.82±2.00^{b}	32.43±1.64^{a}	25.2±1.27^{a}
	72	27.23±10^{a}	31.83±1.64^{a}	33.4±2.00^{b}
Glucose content (mg/100 g)	24	212.9±14.04^{a}	88.9±10.00^{a}	179.3±18.22^{a}
	48	509.1±50.00^{b}	290.6±22.00^{b}	235.3±23.90^{a}
	72	812.3±40.87^{c}	274.5±35.00^{b}	329.1±30^{b}
Antioxidant activity (%)	24	73.19±0.89^{a}	85.11±2.23^{a}	85.83±0.98^{a}
	48	83.44±1.98^{a}	74.65±1.41^{b}	87.62±0.87^{b}
	72	76.40±2.10^{b}	81.20±2.80^{b}	82.62±1.43^{b}

Values in the table are arithmetic mean of triplicate samples ± S.D. Values in the column having different letters are significantly different at 5 % level of significance

Table 3.
Effect on reducing sugar, sucrose and total sugar

Parameters	**Germination time** (h)	**Drying temperature**		
		80°C	**90**°C	**100**°C
Red. sugars before inversion (%)	24	1.09±0.06^{a}	1.09±0.04^{a}	0.58±0.08^{a}
	48	1.72±0.09^{b}	1.5±0.06^{b}	1.05±0.09^{b}
	72	2.09±0.20^{c}	1.61±0.05^{b}	1.84±0.16^{c}
Sucrose (%)	24	0.34±0.04^{a}	0.17±0.02^{a}	0.53±0.02^{a}
	48	0.42±0.04^{a}	0.5±0.05^{b}	0.36±0.02^{b}
	72	0.73±0.01^{b}	0.61±0.04^{c}	0.73±0.06^{c}
Total sugars (%)	24	1.43±0.04^{a}	1.27±0.03^{a}	1.11±0.02^{a}
	48	2.14±0.16^{b}	1.98±0.07^{b}	1.37±0.19^{a}
	72	2.82±0.2^{c}	2.22±0.09^{c}	2.57±0.06^{b}

Values in the table are arithmetic mean of triplicate samples ± S.D. Values in the column having different letters are significantly different at 5 % level of significance

The lower initial TPC values may be attributed to the activation of polyphenol oxidase (PPO) at temperatures up to 80 °C, leading to oxidative degradation of polyphenols. The subsequent increase in TPC with moderate temperature elevation is likely due to the thermal deactivation of PPO, which is unstable and loses activity above 90 °C (Prathapan, Lukhman, Arumughan, Sundaresan & Raghu, 2009).

The pronounced decline in TPC at higher temperatures can be explained by non-enzymatic oxidation of polyphenols. In general, thermal processing tends to reduce TPC (Wang et al., 2013). Statistical analysis confirmed significant differences ($p < 0.05$) in TPC as a function of germination time and drying temperature.

Effect on glucose content

The glucose content of finger millet flour was highest in the sample germinated for 72 h and dried at 80 °C in a cabinet drier, reaching 812.3 mg/100 g (Table 2). For the 24 h germinated samples, glucose content ranged from 88.9 to 212.9 mg/100 g, while for the 48 h germinated samples it varied between 235.3 and 509.1 mg/100 g. In the 72 h germinated samples, values ranged from 274.5 to 812.3 mg/100 g across drying temperatures of 80, 90, and 100 °C. The significant increase in soluble sugars, surpassing sucrose levels, can be attributed to the activation of invertase, which hydrolyzes sucrose into glucose and fructose during germination (Nkhata, Ayua, Kamau & Shingiro, 2018). Overall, glucose content appears to rise with longer germination periods.

Similar increases in glucose following germination have been reported in soybean and peanut (Megat, Azrina & Norhaizan, 2016). Statistical analysis confirmed significant differrences ($p < 0.05$) in glucose content as influenced by germination time and drying temperature.

Effect on antioxidant activity

The antioxidant activity, expressed as radical scavenging activity (RSA), of finger millet flour was highest in the sample germinated for 48 h and dried at 100 °C (Table 2). This indicates that antioxidant activity increases with germination time, likely due to the rise in ascorbic acid content during germination (Kumar et al., 2021). Hydrolytic enzymes active during germination modify endosperm components, enhancing antiradical properties. The enzymatic release of bound phenolics contributes to higher total phenolic content (TPC) and improved antioxidant capacity during malting (Kumar et al., 2021). Additionally, thermal degradation of insoluble and bound phenolic compounds may further elevate antioxidant activity (Wangcharoen & Gomolmanee, 2013). Statistical analysis revealed significant differences ($p < 0.05$) in antioxidant activity as influenced by germination duration and drying temperature.

Effect on total reducing sugar, sucrose and total sugar content

The reducing sugar content before inversion of finger millet flour was found to be the highest in sample germinated for 72 h and dried at 80 °C in a cabinet drier (Table 3). The greatest changes in starch and sugar content of finger millet were observed after 48 h of germination, likely due to elevated amylase activity between 48 and 72 h (Kumar et al., 2021). The increase in total and reducing sugars can be attributed to enhanced enzymatic activity that converts starch into simpler sugars and oligosaccharides (Ocheme & Chinma, 2008). Statistical analysis revealed significant differences ($p < 0.05$) in reducing sugar content prior to inversion, depending on germination duration and drying temperature.

Several studies have demonstrated that reducing sugar levels in finger millet increase by 13–15 times during sprouting, imparting a sweet taste (Shrestha & Karki, 2018). During this process, starch is hydrolyzed into dextrins and short-chain sugars through the activity of α-amylase (Shrestha & Karki, 2018; Krapf et al., 2020). These short-chain sugars exhibit reducing potential and contribute to the overall reducing sugar content (Krapf et al., 2020). Krapf et al. (2020) further reported that prolonging germination time leads to a progressive increase in reducing sugar levels. Similarly, Banusha and Vasantharuba (2013) observed a significant rise in amylase activity when germination was extended from 24 to 72 h in rice, chickpea, cowpea, and mungbean.

Germination time exhibited a positive linear relationship with sugar content (Kumar et al., 2021). Sucrose levels increased progressively with longer germination periods. Post-germination drying at higher temperatures effecti-

vely halted enzymatic activity, thereby preserving the elevated sucrose concentrations generated during germination (Karki, Dangal, Pokharel, Dhakal & Timsina, 2024). Similarly, the highest total sugar content in finger millet flour was observed in the sample germinated for 72 h and dried at 80 °C in a cabinet drier, while the lowest value was recorded in the sample germinated for 24 h and dried at 100 °C. The increase in total sugar content with extended germination is primarily attributed to enhanced enzymatic hydrolysis of starch reserves into simpler sugars, which serve as energy sources for seedling growth. This process involves the conversion of starch into glucose, maltose, and other soluble sugars, facilitating seedling development (Aoki et al., 2006). Urbano et al. (2005) reported that germination induces metabolic changes in seeds, whereby carbohydrate reserves in the form of starch and oligosaccharides are hydrolyzed, leading to elevated sugar levels. Furthermore, Martín-Cabrejas et al. (2008) noted that increased α-galactosidase activity during germination cleaves α-1,6-galactosidic linkages, thereby contributing to higher total sugar content.

Sensory evaluation of finger millet flour

Color

The mean sensory scores for the color of germinated millet flour differed significantly ($p < 0.05$), as shown in Fig. 1. The sample germinated for 48 h and dried at 90 °C received the highest score for color, while the sample germinated for 72 h and dried at 100 °C had the lowest. The observed changes in flour color are attributed to Maillard reactions between starch and proteins during drying following germination. Extending the germination period significantly increased the yellowness of the flour, while darker shades in some samples were likely due to browning reactions occurring during drying (Nefale & Mashau, 2018). Panelists preferred the sample germinated for 48 h and dried at 90 °C because of its yellow appearance, which corresponded to the highest sensory score. At higher drying temperatures and longer durations, pigments shifted toward a slightly brownish hue (Asgar, Musaddad, Rahayu & Levianny, 2022).

Odor

Statistical analysis indicated that variations in germination time and drying temperature had a significant effect ($p < 0.05$) on the odor of the flour samples (Fig. 2). The sample germinated for 48 h and dried at 90 °C received the highest mean sensory score for odor. Finger millet is typically characterized by green, oat-like notes along with woody and phenolic undertones, contributing to its grainy odor. Millets are also rich in phenolic acids, which are known to influence off-flavors and aromas in foods (Sarker, 2015).

Taste

Statistical analysis revealed that germination time and drying temperature had a significant effect ($p < 0.05$) on the taste of the flour samples (Fig. 3). The sample germinated for 48 h and dried at 90 °C received the highest sensory score for taste, whereas the sample germinated for 48 h and dried at 80 °C had the lowest. Finger millet is often associated with a bitter taste and lingering aftertaste, a finding consistent with (McSweeney, Duizer, Seetha-raman & Ramdath, 2016). Similarly, sorghum varieties with higher phenolic content have been rated as more bitter and astringent by trained panels (Kobue-Lekalake, Taylor & De Kock, 2007). Phenolic acids are known contributors to bitterness and astringency, and changes in their levels during germination – whether increasing or decreasing – can have a marked impact on the sensory properties of millet (Sarker, 2015).

Flavor

Statistical analysis demonstrated that germination time and drying temperature had a significant effect ($p < 0.05$) on the flavor of the flour samples. The sample germinated for 48 h and dried at 90 °C received the highest sensory score for flavor, while the sample germinated for 72 h and dried at 100 °C had the lowest. The mean sensory scores for flavor across samples are presented in Fig. 4. Flavor development was influenced by various aromatic compounds naturally present in millet. Previous studies have identified aldehydes, alcohols, and ketones as contributors to grassy, husky, and nutty notes in millet (Wang et al., 2013). The increase in free sugars during germination also enhanced sweetness in the flavor profile. Panelists perceived a green, vegetation-like aroma, which, along with branny notes, intensified with longer germination periods. Conversely, starchy flavor diminished as germination time increased (Sarker, 2015).

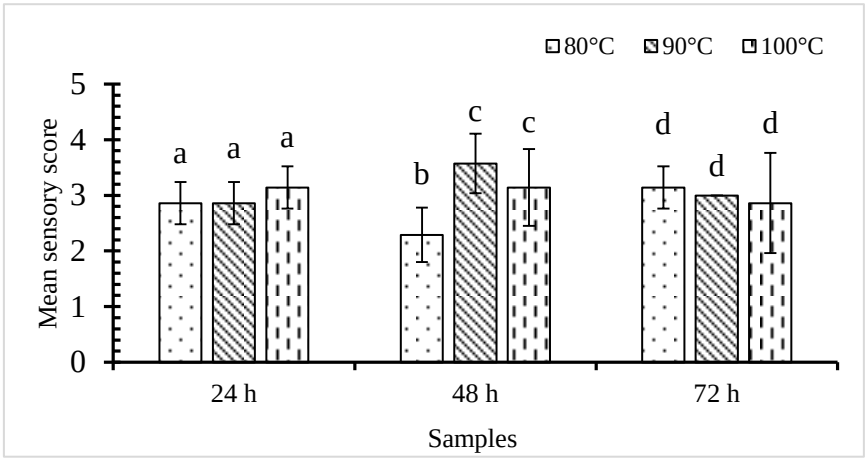

Figure 1. Mean sensory scores for color of different flour samples. Values represent the mean of three determination. Bar sharing the different letters are significantly different ($p<0.05$)

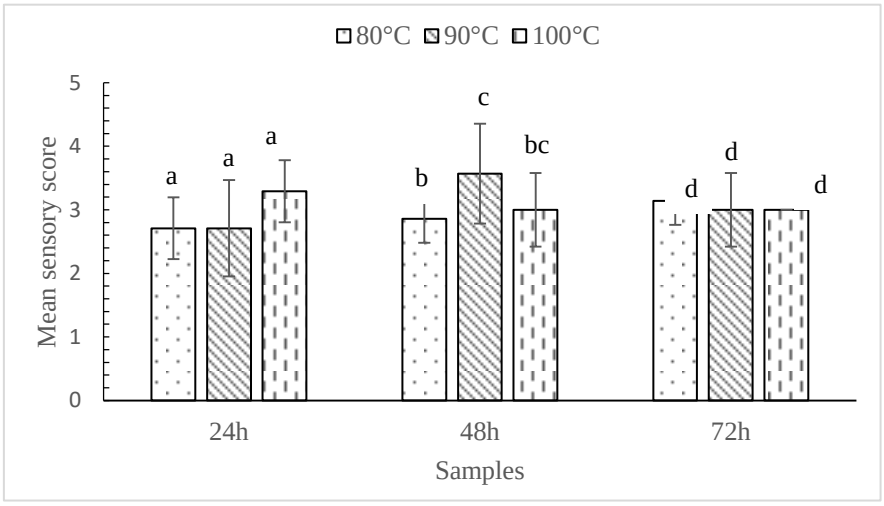

Figure 2. Mean sensory scores for odor of different flour samples.Values represent the mean of three determination. Bar sharing the different letters are significantly different ($p<0.05$)

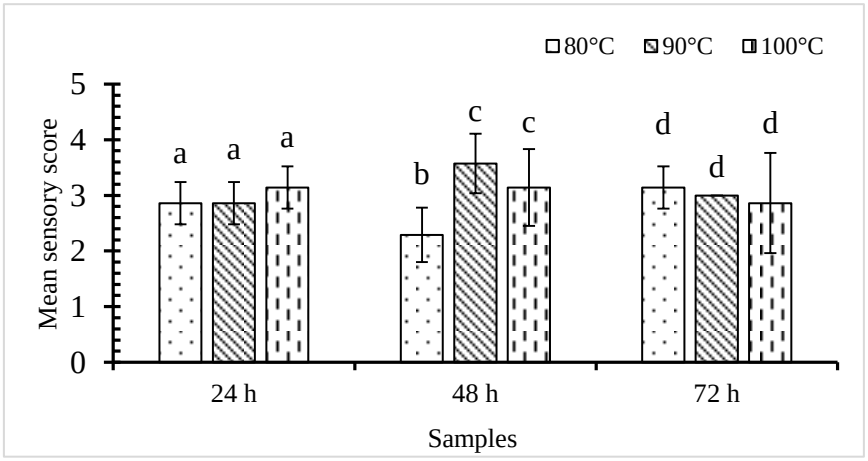

Figure 3. Mean sensory scores for taste of different flour samples. Values represent the mean of three determination. Bar sharing the different letters are significantly different ($p<0.05$)

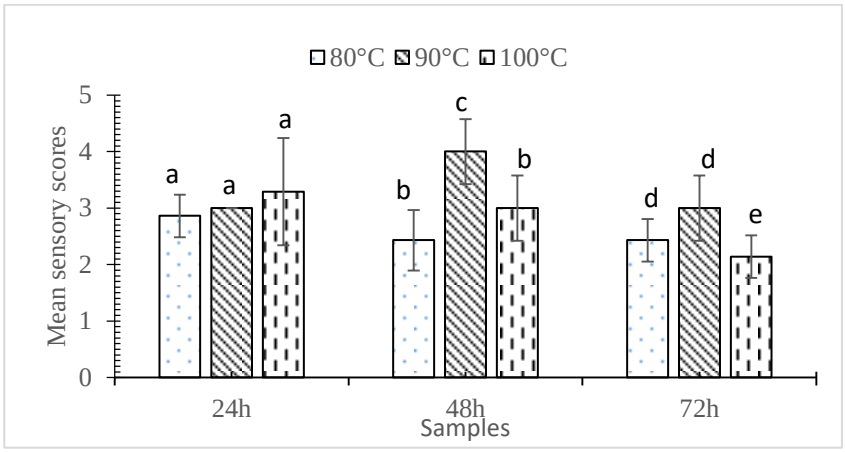

Figure 4. Mean sensory scores for flavor of different flour samples. Values represent the mean of three determination. Bar sharing the different letters are significantly different ($p<0.05$)

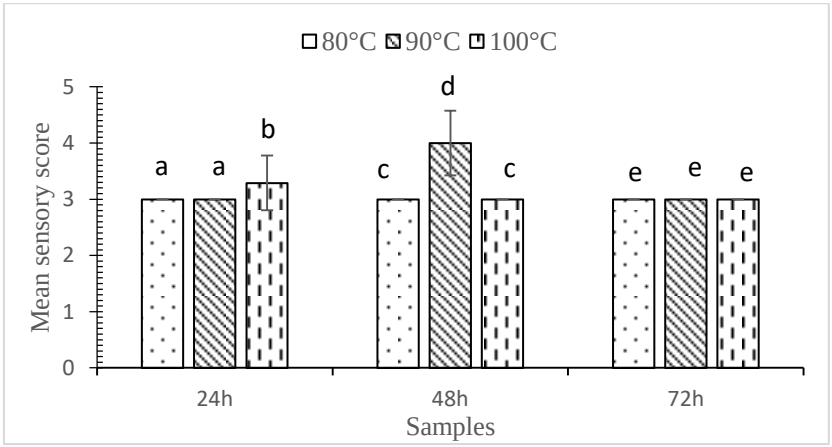

Figure 5. Mean sensory scores for overall acceptability of different flour samples. Values represent the mean of three determination. Bar sharing the different letters are significantly different ($p<0.05$)

Table 4
Chemical composition of the raw and treated finger millet flour with the best characteristics

Parameters	**Raw millet flour**	**Best treated raw millet flour**
Moisture (%, wb)	13.60±0.20[a]	11.0±0.20[b]
Crude protein (%, db)	8.40±0.16[a]	11.0±0.10[b]
Crude fat (%, db)	2.02±0.02[a]	2.64±0.16[b]
Total ash (%, db)	3.80±0.04[a]	4.20±0.03[b]
Crude fiber (% db)	4.51±0.07[a]	4.67±0.07[b]
Carbohydrates (by difference) (% db)	81.20±0.24[a]	78.46±0.50[a]
Iron (mg/100g db)	7.80±0.20[a]	10.23±0.02[b]
Calcium (mg/100g db)	370.03±1.79[a]	394.87±3.55[b]

Values in the table are arithmetic mean of triplicate samples ± S.D. wb-wet base; db-dry base.

Overall acceptability

Statistical analysis revealed that germination time and drying temperature had a significant effect ($p < 0.05$) on the overall acceptability of the flour samples. The sample germinated for 48 h and dried at 90 °C achieved the highest overall acceptance score. Panelists preferred this sample, which outperformed others in

sensory evaluation, likely due to improvements in color, aroma, taste, and flavor.

Consequently, finger millet flour germinated for 48 h and dried at 90 °C in a cabinet drier was found to be significantly superior in overall acceptability based on sensory characteristics.

Comparison of the untreated and the best-ranked treated finger millet

The findings of this study indicate that the most favorable treatment for finger millet was germination for 48 h followed by drying in a cabinet drier at 90 °C. The proximate composition, including iron and calcium content, was compared with that of raw millet flour (Table 4). The moisture content of germinated flour was lower than that of raw millet, likely due to hydration during soaking and germination (Nefale & Mashau, 2018). Changes in sorption isotherms during germination may also increase water uptake (Lande et al., 2017). Sarwar (2010) reported a moisture content of 10% for both malted and unmalted finger millet flour.

Protein content increased significantly ($p < 0.05$) in germinated samples compared to raw millet, consistent with findings by Abioye et al. (2018). This rise is attributed to enzyme protein synthesis and compositional changes resulting from degradation of other constituents during germination (Mali & Swami, 2023). Enhanced protease activity during germination hydrolyzes peptide bonds, increasing free amino acids and overall protein content (Iswarya & Narayanan, 2016; Nkhata et al., 2018). Nitrogen utilization for embryo development may also contribute to improved protein quality (Chauhan & Sarita, 2018).

Fat content also increased significantly ($p < 0.05$) in germinated flour which confirms the findings reported by Chauhan and Sarita (2018). This rise is likely due to carbohydrate depletion, with sugars serving as energy for the growing embryo, thereby elevating fat levels (Kumar et al., 2021). Conversely, ash content decreased significantly in germinated flour compared to raw millet, consistent with Yenasew and Urga (2022). Mineral leaching during steeping and washing, utilization of minerals in sprouting metabolism, and loss of bran during removal of roots and shoots may explain this reduction (Kumar et al., 2021).

Crude fiber content increased significantly ($p < 0.05$) in germinated flour, in agreement with Chauhan and Sarita (2018). This may be due to starch loss, adherence of root and shoot parts after deculming (Kumar et al., 2021) and synthesis of cellulose and hemicellulose during germination (Yenasew & Urga, 2022). Adhikari and Acharya (2016) reported similar increases in malted sorghum compared to unmalted. Carbohydrate content remained relatively stable, likely due to the balance between depletion of reserves and accumulation of free sugars (Sarker, 2015). Yenasew and Urga (2022) reported that the carbohydrate was found maximum in millet germinated at 72 h and minimum in case of germination carried out for 24 and 48 hr. Variations in carbohydrate levels across germination times may reflect changes in moisture, fat, protein, ash, and fiber (Derbew & Moges, 2017).

Iron content increased significantly in germinated flour, consistent with findings in germinated pearl millet (Iswarya & Narayanan, 2016). Calcium content also rose significantly ($p < 0.05$), similar reported by (Chauhan & Sarita, 2018). This increase may result from degradation of organic dry matter during germination (Kumar et al., 2021) and oxalic acid interference (Proietti, Moscatello, Famiani & Battistelli, 2009).

CONCLUSIONS

The study demonstrated that germination time and drying temperature exert a significant influence on the nutritional, functional, and sensory properties of finger millet flour. Extended germination combined with moderate drying conditions enhanced glucose content, resistant starch, and total sugar levels, while shorter germination under higher drying temperatures favored antioxidant activity and polyphenol retention. Sensory evaluation further indicated that intermediate germination coupled with optimized drying conditions yielded superior overall acceptability.

These results highlight the importance of carefully selecting germination duration and drying parameters to maximize both health-promoting compounds and consumer preference in finger millet flour.

AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, D.B.K. and B.A.; Investigation, formal analysis, validation, writing-original draft prepration, N.G.; Writing-review and editing, P.K.; Supervision, D.B.K.

DATA AVAILABILITY STATEMENT

Data contained within the article.

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CONFLICT OF INTEREST

The authors report no conflicts of interest for this research work. No unethical work was done in research to maintain integrity, trust, and the validity of scientific findings.

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UTICAJ VREMENA KLIJANJA I TEMPERATURE SUŠENJA NA HEMIJSKI I SENZORSKI KVALITET BRAŠNA OD PROSA (FINGER MILLET)

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Sažetak: Ova studija imala je za cilj da ispita uticaj vremena klijanja i temperature sušenja na hemijska i senzorna svojstva brašna od prosa (finger millet). Zrna prosa su sakupljena, očišćena, potopljena u vodi preko noći na sobnoj temperaturi, procedjena i zatim raspoređena po muslinskoj tkanini. Klijanje je sprovedeno na sobnoj temperaturi (27±2 °C) tokom 24, 48 i 72 sata, nakon čega je usledilo sušenje u komori za sušenje na 80, 90 i 100 °C. Osušeni uzorci su potom samleveni u mlinu za pulpu. Analiziran je uticaj vremena klijanja i temperature sušenja na ukupni sadržaj ukupnih fenola (TPC), antioksidativnu aktivnost, sadržaj glukoze, redukujućih šećera i ukupnih šećera. Utvrđeno je da su sadržaji glukoze, redukujućih šećera i ukupnih šećera značajno viši u brašnu od prosa klijanom 72 sata i sušenom na 80 °C, dok su TPC i antioksidativna aktivnost bili nešto niži. Uzorci su podvrgnuti senzornoj evaluaciji u pogledu boje, mirisa, ukusa, arome i ukupne prihvatljivosti. Klijanje prosa tokom 48 sati, praćeno sušenjem na 90 °C, dovelo je do značajnog povećanja sadržaja sirovih proteina, sirovih masti, sirovih vlakana, gvožđa i kalcijuma, dok su sadržaji vlage i ukupnog pepela smanjeni. Senzorna analiza je pokazala da je brašno klijano 48 sati i sušeno na 90 °C dobilo najviše prosečne senzorne ocene među svim uzorcima.

Ključne reči: *hemijski sastav, ukupni fenoli, antioksidaciona aktivnost, šećeri, gvožđe, kalcijum*

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