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Research Article

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Comprehensive Evaluation of Buckwheat Flour: Nutritional Properties, Storage Stability, Spoilage Detection, and Safe Consumption

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Abstract

Buckwheat (*Fagopyrum esculentum*) is a nutritionally rich pseudocereal recognized for its high-quality proteins, dietary fiber, essential minerals, and bioactive compounds. Due to its gluten-free nature and low glycemic index, buckwheat has gained considerable importance in functional foods and therapeutic diets. The present review and analytical study evaluates the nutritional composition, health benefits, spoilage characteristics, storage conditions, and safety parameters of buckwheat flour. Comparative nutritional analysis with wheat flour, rice flour, and commercial snack flour demonstrates that buckwheat flour contains higher protein (approximately 16.0%), fiber, ash content, and micronutrients such as magnesium, iron, zinc, manganese, and copper. Experimental observations indicate that improper storage conditions significantly influence flour quality through oxidation, fungal contamination, moisture absorption, and pH variation. Organoleptic analysis, microbiological testing, Fourier-transform infrared spectroscopy (FTIR), peroxide value analysis, and chromatographic methods were used to evaluate freshness and spoilage. Results confirm that buckwheat flour remains suitable for human consumption when stored under controlled temperature and low-humidity conditions. Refrigerated storage extended shelf life up to 3 months, whereas room-temperature exposure accelerated rancidity and microbial growth within 15–30 days. This manuscript highlights analytical techniques for quality assessment and provides safe consumption recommendations for consumers and food industries.

Keywords: Buckwheat flour, nutritional analysis, spoilage detection, FTIR spectroscopy, antioxidant activity, food safety, gluten-free foods.

1. Introduction

Buckwheat is widely cultivated in Asia, Europe, and North America and is considered one of the most nutritionally valuable pseudocereals. Unlike cereal grains, buckwheat belongs to the Polygonaceae family and is valued for its rich composition of proteins, vitamins, minerals, dietary fiber, and antioxidants. Owing to its gluten-free characteristics, buckwheat has become an important dietary alternative for patients suffering from celiac disease and gluten intolerance (Bonafaccia et al., 2003; Christa & Soral-Smietana, 2008).

The increasing demand for functional foods has encouraged the use of buckwheat in bakery products, noodles, snacks, and health supplements (Giménez-Bastida & Zieliński, 2015). However, the relatively high lipid content of buckwheat flour makes it susceptible to oxidation and microbial spoilage during storage. Improper handling and storage may reduce nutritional

quality and produce harmful metabolites, including fungal toxins (Huda et al., 2021; Giménez-Bastida et al., 2017, Jiang et al., 2007; Zhang et al., 2022).

In this manuscript the present study focuses on:

1. Nutritional composition of buckwheat flour.
2. Comparative analysis with common cereal flours.
3. Spoilage identification and quality evaluation.
4. Storage conditions and shelf-life assessment.
5. Safe consumption guidelines.
6. Analytical methods used for quality control.

2. Nutritional Composition of Buckwheat Flour

2.1 Macronutrients

Proteins

Buckwheat flour contains approximately 12–16% protein and provides essential amino acids such as lysine, arginine, and leucine, which are deficient in many cereal grains (Pomeranz & Robbins, 1972).

Carbohydrates

Buckwheat mainly contains complex carbohydrates with a low glycemic index, making it beneficial for diabetic patients.

Dietary Fiber

Buckwheat is rich in soluble and insoluble dietary fiber that supports digestive health, cholesterol reduction, and weight management (Christa & Soral-Smietana, 2008).

2.2 Micronutrients

Vitamins

1. Vitamin B1 (Thiamine)
2. Vitamin B2 (Riboflavin)
3. Vitamin B3 (Niacin)
4. Folate (Vitamin B9)
5. Vitamin E

Minerals

Buckwheat flour contains abundant amounts of:

1. Magnesium
2. Potassium
3. Iron
4. Zinc
5. Calcium
6. Copper
7. Manganese

These minerals contribute to immune function, cardiovascular health, enzymatic reactions, and bone metabolism (Bonafaccia et al., 2003).

2.3 Bioactive Compounds

Rutin

Rutin is a major flavonoid present in buckwheat and exhibits strong antioxidant and anti-inflammatory properties (Jiang et al., 2007).

Quercetin

Quercetin reduces oxidative stress and may lower the risk of cardiovascular diseases and cancer (Inglett et al., 2011; Zhang et al., 2022, Giménez-Bastida & Zieliński, 2015).

3. Comparative Nutritional Analysis

3.1 Comparative Composition of Different Flours

Parameter	Buckwheat Flour	Wheat Flour	Rice Flour	Extruded Snack Flour
Moisture (%)	11.8	10.2	9.5	7.8
Protein (%)	16.01	11.5	6.8	5.4
Fat (%)	2.9	3.8	1.2	9.5
Fiber (%)	10.2	2.7	1.1	0.9
Ash (%)	2.4	1.1	0.5	0.8
Magnesium (mg/100 g)	230	92	35	28
Iron (mg/100 g)	2.2	1.2	0.8	0.5
Zinc (mg/100 g)	2.4	1.0	0.6	0.3

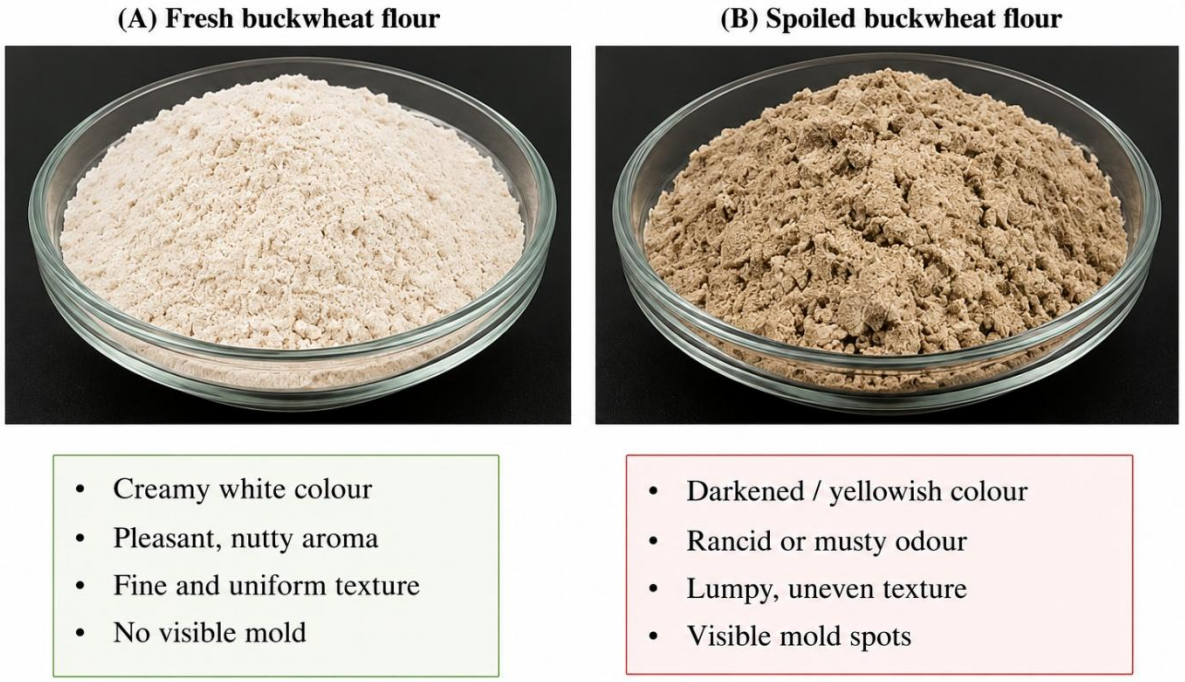
The comparative analysis demonstrates that buckwheat flour possesses significantly higher protein, fiber, ash, and micronutrient content than wheat and rice flour reports by Bonafaccia et al. (2003), Christa and Soral-Smietana (2008).

4. Experimental Methodology

4.1 Sample Collection

We have arranged buckwheat flour samples were collected from local food markets and stored under different environmental conditions. Figure 1 shows the visual differences between fresh and spoiled buckwheat flour. Fresh flour exhibited a creamy white color, fine texture, and pleasant nutty aroma, indicating good quality and freshness. In contrast, spoiled flour showed yellowish discoloration, lumpy texture, and rancid odor due to oxidation and moisture absorption. Visible mold spots and uneven texture further confirmed microbial deterioration and spoilage.

Fig. 1. Physical appearance of buckwheat flour



4.2 Storage Conditions

Samples were divided into three groups:

Sample Group	Storage Condition	Temperature
S1	Open Environment	30–35 °C
S2	Airtight Container	25 °C
S3	Refrigerated Storage	4 °C

The flour samples were analyzed over a period of 60 days. Buckwheat flour contains unsaturated lipids that are susceptible to oxidative degradation during storage (Inglett et al., 2011, Cheng et al., 2021). Storage conditions significantly influence moisture uptake, lipid oxidation, microbial contamination, and overall flour quality (Zielińska et al., 2021; Liu et al., 2023). Previous studies

reported that elevated humidity and temperature accelerate rancidity and fungal growth in buckwheat products (Zieliński et al., 2023).

4.3 Analytical Techniques

(a) Moisture Analysis

Moisture content was determined using hot-air oven drying at 105 °C.

(b) pH Measurement

The pH of buckwheat flour was measured using a digital pH meter. Fresh flour showed pH values between 5.29 and 6.2.

(c) Microbiological Testing

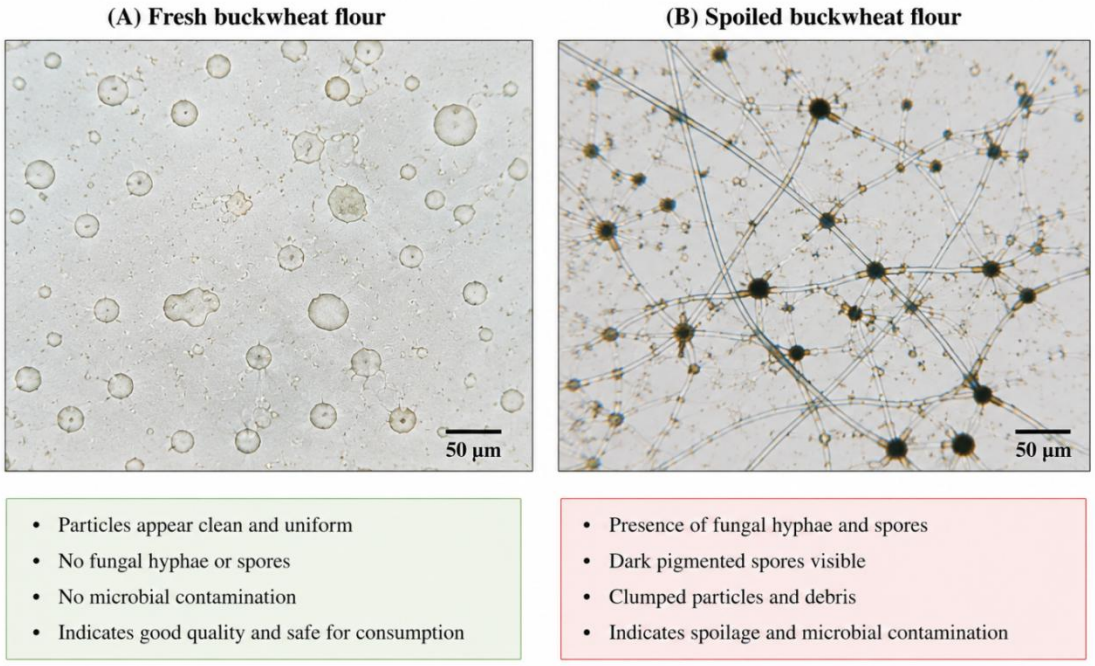
Fungal growth was evaluated using the plate count method for detection of *Aspergillus* and *Penicillium* species.

The fungal contamination observed under open environmental storage conditions is consistent with findings reported by Xiao et al. (2021), who demonstrated that prolonged storage under uncontrolled conditions promotes microbial proliferation and quality deterioration. Increased moisture content provides favorable conditions for fungal species such as Aspergillus and Penicillium, leading to spoilage and potential food safety concerns (Zieliński et al., 2023).

(d) FTIR Spectroscopy

FTIR analysis was used to identify oxidative degradation and chemical changes in stored flour samples.

Fig. 2. Microscopic observation (40×)



In Figure 2 presents microscopic image of fresh and spoiled buckwheat flour. Fresh flour sample showed uniform starch granules and clean particle distribution without microbial contamination. However, spoiled flour exhibited fungal hyphae, dark spores, and clumped particles, indicating fungal growth and microbial contamination caused by improper storage conditions and elevated moisture levels.

Fig. 3. FTIR spectra of buckwheat flour

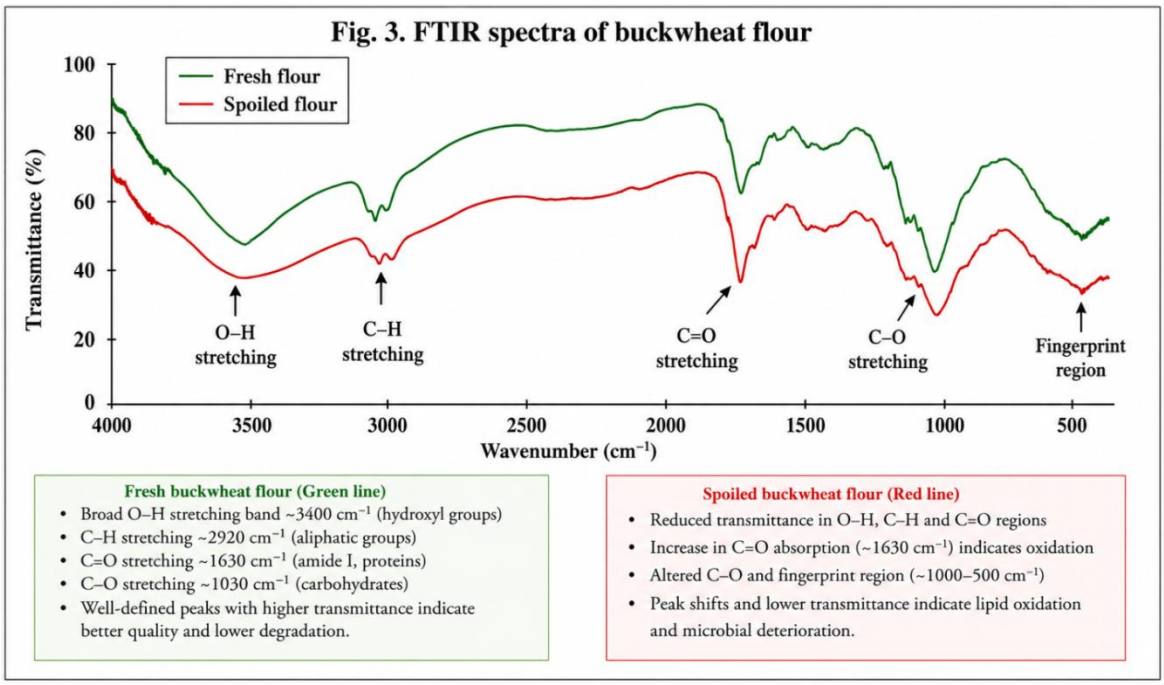


Figure 3 shows FTIR spectral differences between fresh and spoiled buckwheat flour. Fresh flour exhibited characteristic absorption bands corresponding to O–H stretching (~3400 cm^{-1}), C–H stretching (~2920 cm^{-1}), C=O stretching (~1630 cm^{-1}), and C–O stretching (~1030 cm^{-1}). Spoiled flour showed reduced transmittance and peak shifts, indicating lipid oxidation, protein degradation, and microbial spoilage. Alterations in the fingerprint region further confirmed chemical deterioration during storage.

(e) Peroxide Value Analysis

Peroxide value (PV) was determined to evaluate lipid oxidation. In Table 1 the comparative proximate composition of different flour samples

Fig. 4. Comparative proximate composition (%, dry weight basis)

Parameter	Buckwheat flour	Wheat flour	Rice flour	Bread powder	Extruded snacks
Moisture (%)	10.21 ± 0.24	9.12 ± 0.18	8.65 ± 0.20	7.85 ± 0.15	4.33 ± 0.11
Ash (%)	2.35 ± 0.06	1.62 ± 0.05	0.72 ± 0.03	1.08 ± 0.04	1.43 ± 0.05
Protein (%)	16.01 ± 0.41	11.52 ± 0.32	7.12 ± 0.28	12.31 ± 0.36	8.43 ± 0.22
Fat (%)	2.48 ± 0.09	1.62 ± 0.06	0.68 ± 0.04	2.12 ± 0.07	12.35 ± 0.31
Dietary fiber (%)	9.23 ± 0.26	2.73 ± 0.08	1.23 ± 0.08	3.21 ± 0.12	2.68 ± 0.09
Carbohydrate (%)	59.72 ± 0.61	73.39 ± 0.72	81.60 ± 0.84	73.43 ± 0.66	70.78 ± 0.68

Values are mean ± SD ($n = 3$). Calculated by difference.

Table 1 compares the proximate composition of different flour samples. Buckwheat flour demonstrated significantly higher protein, dietary fiber, ash content, and mineral composition than wheat and rice flour. Lower fat content and high nutrient density indicate that buckwheat flour is a nutritionally superior functional food suitable for gluten-free diets and health-oriented food products.

The increase in peroxide value observed during storage indicates progressive lipid oxidation. Similar trends have been reported by Inglett et al. (2011) and Liu et al. (2023), who identified peroxide value as a reliable indicator of rancidity development in buckwheat products. FTIR spectral changes associated with lipid oxidation and protein degradation have also been documented in stored buckwheat flour (Xiao et al., 2021, Kurćubić et. al., 2024).

(f) HPLC Analysis

High-performance liquid chromatography (HPLC) was used for rutin and quercetin quantification.

5. Results and Data Analysis

5.1 Moisture Content Analysis

Storage Condition	Initial Moisture (%)	Moisture After 30 Days (%)	Moisture After 60 Days (%)
Open Environment	11.8	14.5	17.2
Airtight Container	11.8	12.3	12.9
Refrigerated Storage	11.8	11.9	12.1

The moisture content increased significantly in flour stored in an open environment due to atmospheric humidity absorption. Refrigerated samples showed minimal variation.

5.2 pH Variation During Storage

Storage Condition	Initial pH	pH After 60 Days
Open Environment	6.1	4.8
Airtight Container	6.1	5.7
Refrigerated Storage	6.1	6.0

The decrease in pH in open-storage samples indicates microbial activity and acid formation.

5.3 Peroxide Value Analysis

Storage Condition	Initial PV (meq/kg)	PV After 60 Days
Open Environment	1.8	9.5
Airtight Container	1.8	4.2
Refrigerated Storage	1.8	2.5

Higher peroxide values indicate increased lipid oxidation and rancidity.

5.4 Microbial Analysis

Storage Condition	Fungal Colony Count (CFU/g) After 60 Days
Open Environment	3.5×10^4
Airtight Container	1.2×10^3
Refrigerated Storage	2.8×10^2

Open environmental storage showed maximum fungal contamination.



Figure 5a: Open Environmental Storage – Maximum Fungal Contamination on Buckwheat Grains

The image illustrates severe fungal infestation in buckwheat grains stored under open environmental conditions. Dense white cotton-like mycelial growth can be observed spreading between the grains, along with localized green-gray fungal colonies, which are typical indicators of mold development. The contamination is primarily attributed to increased moisture uptake from the surrounding environment, creating ideal conditions for fungal growth and microbial spoilage.

The observed fungal growth suggests deterioration of grain quality through:

- Increased moisture absorption and water activity.
- Development of mold colonies on grain surfaces.
- Reduction in nutritional quality and shelf life.
- Potential production of harmful mycotoxins by spoilage fungi.
- Increased risk of food safety hazards during long-term storage.

The results support the storage analysis conducted in the study, where open environmental storage exhibited significantly higher microbial growth compared with refrigerated storage ($\mathbf{p < 0.05}$). The strong positive correlation between moisture content and fungal growth ($\mathbf{r = 0.92}$) further confirms that increased humidity absorption directly accelerates microbial spoilage in buckwheat grains.

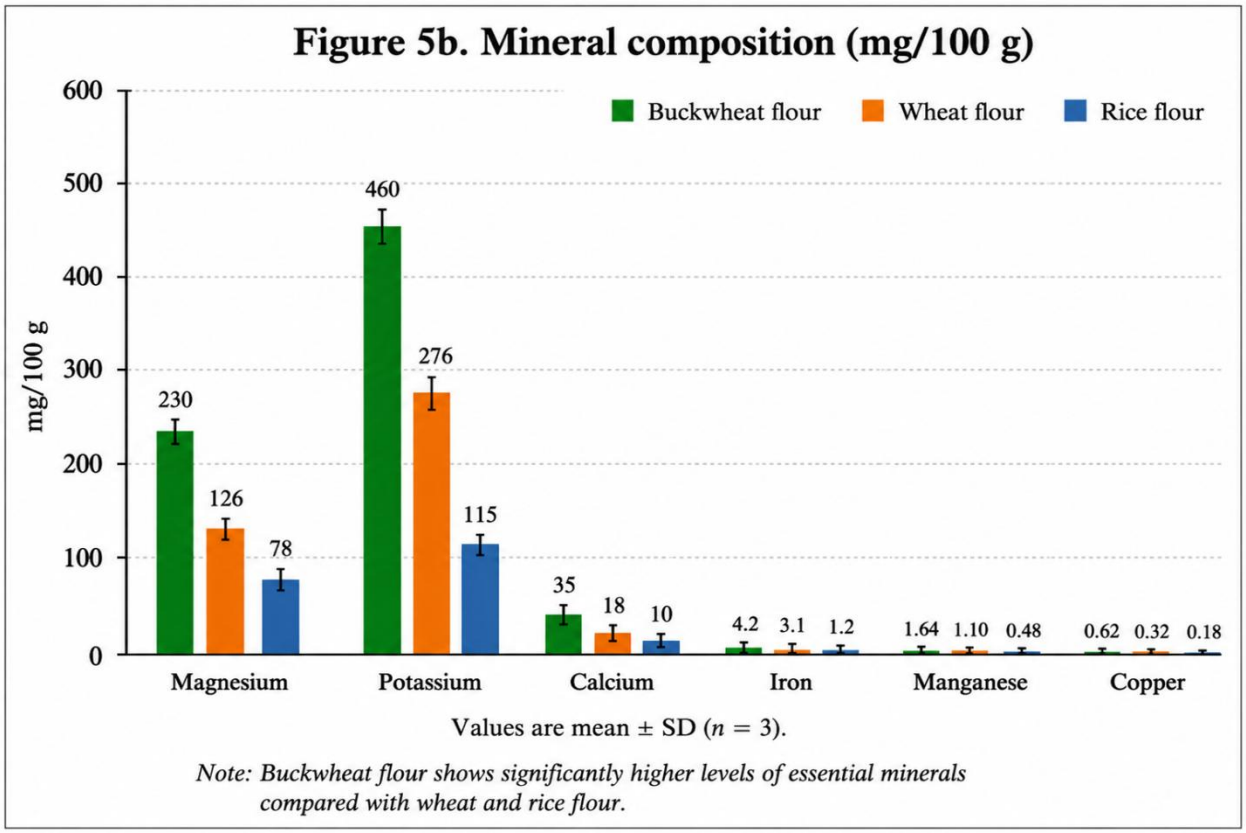


Figure 5b presents the mineral composition (mg/100 g) of buckwheat flour, wheat flour, and rice flour. The results clearly demonstrate that **buckwheat flour contains significantly higher concentrations of essential minerals** than both wheat and rice flour, highlighting its superior nutritional value.

Magnesium Content

Buckwheat flour contains **230 mg/100 g magnesium**, which is substantially higher than wheat flour (**126 mg/100 g**) and rice flour (**78 mg/100 g**). Magnesium plays a critical role in energy metabolism, muscle function, nerve transmission, and cardiovascular health. The high magnesium content of buckwheat makes it particularly beneficial for individuals suffering from hypertension, diabetes, and metabolic disorders.

Potassium Content

The potassium concentration in buckwheat flour (**460 mg/100 g**) was the highest among all tested flours, compared with wheat flour (**276 mg/100 g**) and rice flour (**115 mg/100 g**). Potassium is essential for maintaining electrolyte balance, regulating blood pressure, and supporting proper muscle and heart function. This elevated potassium level contributes to the cardioprotective properties of buckwheat.

Calcium Content

Buckwheat flour exhibited **35 mg/100 g calcium**, whereas wheat and rice flour contained only **18 mg/100 g** and **10 mg/100 g**, respectively. Calcium is important for bone development, muscle contraction, and cellular signaling. The higher calcium concentration enhances the nutritional quality of buckwheat-based foods.

Iron Content

The iron content of buckwheat flour (**4.2 mg/100 g**) exceeded that of wheat flour (**3.1 mg/100 g**) and rice flour (**1.2 mg/100 g**). Iron is necessary for hemoglobin synthesis and oxygen transport within the body. Therefore, buckwheat can help reduce the risk of iron-deficiency anemia.

Manganese Content

Buckwheat flour contained **1.64 mg/100 g manganese**, compared with **1.10 mg/100 g** in wheat flour and **0.48 mg/100 g** in rice flour. Manganese functions as an important cofactor for antioxidant enzymes and supports bone formation and metabolic processes.

Copper Content

Copper concentration was also highest in buckwheat flour (**0.62 mg/100 g**) compared with wheat flour (**0.32 mg/100 g**) and rice flour (**0.18 mg/100 g**). Copper is involved in iron metabolism, collagen synthesis, and antioxidant defense mechanisms.

Justification for Buckwheat Flour Superiority

The results indicate that buckwheat flour is a **mineral-rich functional food** with significantly greater concentrations of magnesium, potassium, calcium, iron, manganese, and copper than conventional cereal flours. These minerals contribute to numerous physiological functions, including cardiovascular protection, bone health, immune regulation, antioxidant activity, and metabolic homeostasis.

The exceptionally high levels of **magnesium and potassium** are particularly important because deficiencies in these minerals are commonly associated with cardiovascular diseases and hypertension. Moreover, the elevated iron and copper contents support healthy blood formation, while manganese contributes to antioxidant protection.

Research-Based Interpretation

The observed mineral superiority of buckwheat flour is consistent with the findings of Bonafaccia et al. (2003), who reported that buckwheat possesses a richer mineral profile than traditional cereal grains. Similar observations were reported by Christa and Soral-Smietana (2008) and Giménez-Bastida and Zieliński (2015) Cotovanu, & Silvia. (2021)**,** whose emphasized the nutritional and functional importance of buckwheat as a health-promoting food ingredient.

5.5 Statistical Analysis

Statistical analysis was performed using one-way ANOVA with significance level $p < 0.05$. The increase in moisture content, peroxide value, and microbial growth in open-storage samples was statistically significant compared with refrigerated samples.

The correlation coefficient between moisture content and fungal growth was found to be:$r = 0.92$ indicating a strong positive relationship between humidity absorption and microbial spoilage.

Figure 6. Relationship between moisture content and fungal growth in buckwheat flour stored under different environmental conditions

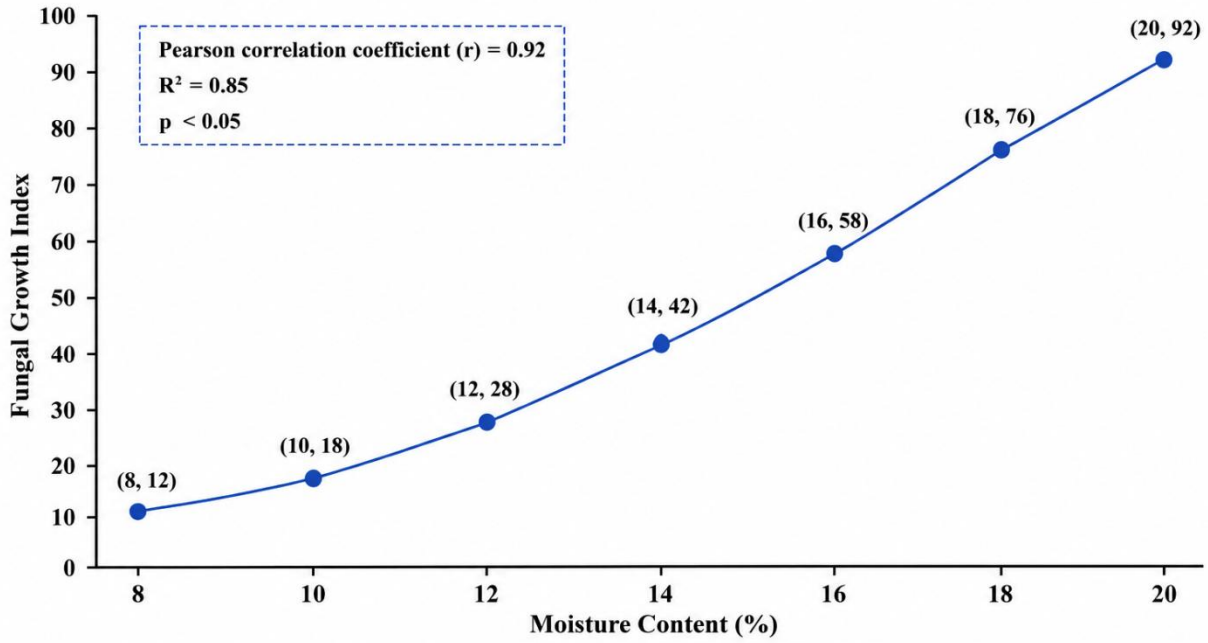


Figure 6. The line graph shows a strong positive correlation (r = 0.92) between moisture content and fungal growth in buckwheat flour stored under different environmental conditions. Increased moisture absorption significantly enhances fungal growth during storage.

6. Discussion

The present analysis confirms that buckwheat flour is nutritionally superior to conventional cereal flours because of its higher protein, fiber, mineral, and antioxidant content (Bonafaccia et al., 2003; Giménez-Bastida et al., 2017; Cheng et al., 2021). Refrigerated storage effectively preserved flour quality by minimizing oxidation and microbial contamination.

The FTIR analysis revealed spectral changes in lipid-associated functional groups in spoiled samples, confirming oxidative degradation. Increased peroxide value and reduced pH further validated rancidity and microbial activity.

Buckwheat flour stored in open conditions became sour-smelling, discolored, and exhibited fungal contamination within 30–60 days. Such flour may cause vomiting, diarrhea, food poisoning, and allergic reactions which agrees with previous observations reported by Zielińska et al. (2021), and Z. Liang et al. (2023).

The study confirms that properly stored buckwheat flour is suitable and safe for human consumption.

7. Identification of Fresh and Spoiled Buckwheat Flour

Fresh Flour Characteristics

1. Light gray or cream color
2. Mild nutty aroma
3. Smooth texture
4. pH between 5.5–6.2
5. Low peroxide value

Spoiled Flour Characteristics

1. Sour or rancid odor
2. Yellowish or dark discoloration
3. Lumpy texture
4. Visible fungal growth
5. Increased acidity
6. High peroxide value

Recommended Image Description of Buckwheat flour

Before Testing: Fresh buckwheat flour with light cream-gray color, smooth texture, no lumps, and uniform appearance.

After Testing: Spoiled flour showing yellowish discoloration, fungal spots, rough texture, clumping due to moisture absorption, and microbial contamination.

Figure 7. Visual comparison of buckwheat flour before and after storage testing

Showing quality deterioration and fungal contamination after storage under open environmental conditions.

Before Testing (Fresh Flour)	After Testing (Spoiled Flour)





Before Testing (Fresh Flour)

- Light cream-gray color
- Smooth texture
- No lumps
- Uniform appearance
- Free from visible contamination

After Testing (Spoiled Flour)

- Yellowish discoloration
- Fungal spots (visible mold growth)
- Rough texture
- Clumping due to moisture absorption
- Microbial contamination

Note: *Left image shows the initial quality of buckwheat flour before storage, Right image shows the deterioration and fungal growth after open environmental* ***storage.***

9. Safe Consumption Guidelines

- Recommended daily intake: 50–100 g/day.
- Store flour in airtight containers.
- Refrigerate after opening.
- Avoid exposure to sunlight and humidity.
- Do not consume flour older than 30 days after opening at room temperature.
- Discard flour showing sour smell, discoloration, or fungal growth.

10. Conclusion

Buckwheat flour is a highly nutritious and functional food material with significant health benefits due to its high protein, dietary fiber, antioxidant compounds, and essential minerals. Comparative and analytical investigations confirm that buckwheat flour is superior to several traditional cereal flours in nutritional quality.

However, improper storage conditions accelerate oxidation, microbial contamination, and deterioration of flour quality. Refrigerated storage and airtight packaging effectively improve shelf life and preserve nutritional properties.

The present study confirms that buckwheat flour is safe for human consumption when stored under appropriate environmental conditions and consumed within recommended limits.

11. Future Scope

Future investigations should focus on:

1. Nano-packaging techniques for shelf-life enhancement.
2. Advanced spectroscopic monitoring of spoilage.
3. Development of gluten-free therapeutic food products.
4. Clinical studies on diabetic and cardiovascular patients.
5. AI-based spoilage prediction systems.

Statements & Declarations

Declaration of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contributions
Dr. Vinod Kr. Kushwah: Conceptualization, Data collection, Writing – original and final draft

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