



Germination as A Strategy To Enhance Nutritional, Physical, and Sensory Quality of Legume- and Cereal-Based Multigrain Pita Bread

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Abstract

Germination is known to modify the bioavailability of nutrients and enhance the antioxidant potential of grains. In this research, pita bread made from germinated grains (GGB) was compared to non-germinated (NGB) counterparts to assess changes in nutritional profile, antioxidant capacity, and phenolic compound levels. Physical properties such as crumb porosity, dough density, and oil and water retention capacities were also evaluated to understand the influence of germination on bread texture and structure. Sensory evaluation panel assessed consumer acceptance, flavor, texture, and aroma. No significant differences were observed between GGB and NGB in most physical and nutritional attributes, except for a higher oil retention capacity in NGB. Germination influenced lipid absorption without affecting dough density or water absorption. Both GGB and NGB exhibited significantly greater antioxidant capacity compared to commercial bread (CB), with notable bioactive compounds, such as p-tyrosol and vanillic acid, present in GGB and NGB but absent in CB. Sensory evaluations indicated that bread made with sprouted grains offers similar acceptability



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to commercial bread, with enhanced flavor and texture that may improve consumer appeal. According to JAR analysis, attributes like crumb porosity and acid flavor were critical to GGB's acceptability, while adjustments in the brown color of NGB could further improve its appeal. These findings suggest that germinated grains enhance bread's nutritional and antioxidant qualities without compromising baking performance and may improve sensory attributes, making them a promising addition to multigrain bread formulations.

Abbreviations

GGB	Germinated grains bread
NGB	Non-germinated bread
CB	Control bread
E_g	Specific gravity of the mass
WHC	Water holding capacity
OHC	Oil holding capacity
B_L	baking loss
TPC	Total phenolic compounds
N.N.E.	Non-nitrogenous extract
EAG	Gallic Acid Equivalent
N.D	Not detected.

Introduction

Chile is one of the countries with the highest bread consumption in Latin America, averaging 95 kg per capita per year (approximately 250 g per person per day). Globally, it ranks third after Germany (106 kg/capita/year) and Turkey (150 kg/capita/year).¹⁻³ According to Valenzuela, Quiral, Zavala, Villanueva and Atalah (2014), bread accounts for 16% to 23% of monthly household expenditures, depending on the socioeconomic group, with higher spending observed in lower socioeconomic levels.⁴

The main ingredient in bread production is refined wheat flour due to its technological properties, such as producing high volume, light color, uniform porosity, and a soft crumb. However, refined wheat flour has a high glycemic index and lacks vitamins, minerals, lysine, dietary fiber, and antioxidant components prior to fortification.⁵ In Chile, wheat flour is fortified with thiamine, riboflavin, niacin, iron, and folic acid as part of a program aimed at improving the nutritional quality of bread.⁶ However, the added micronutrients may undergo physicochemical changes during storage and processing, which can affect their stability and the program's overall effectiveness.⁶⁻⁸

The use of whole wheat flour in bread production significantly reduces these nutritional deficiencies.⁸ Health-conscious consumers are favoring foods with fewer additives to reduce the risk of diet-related diseases and promote general wellness.⁵ In this context, bread has been widely used as an effective vehicle for incorporating nutrients that improve dietary quality.^{9,10}

An emerging trend in the development of healthier foods is the use of germinated grains. The process boosts both the nutrient and bioactive content of grains and positively affects their flavor and physical-chemical properties.^{11,12} Although commonly applied to legumes and some cereals, germination has attracted renewed interest for its potential to enhance both the nutritional profile and functional characteristics of foods.¹³ During germination, grains may accumulate higher levels of bioactive molecules such as vitamins, gamma-aminobutyric acid (GABA), and polyphenols, which have been linked to improved cardiovascular function and decreased inflammatory response.¹⁴ Moreover, studies on foods made with germinated legumes, such as lentils and fava beans, have demonstrated therapeutic effects, including improved iron bioavailability in anemic patients and pharmacological activity in diseases like Parkinson's.¹⁵⁻¹⁷

Although numerous studies have demonstrated that germination enhances the nutritional profile and antioxidant capacity of individual grains,^{11,12} there is a lack of specific research on its impact on multigrain baked products, such as pita bread. Furthermore, the influence of germination on sensory properties and consumer acceptance has not been extensively explored in this product category.

Considering that adding cereal and legume flours alters the technological performance of wheat flour as well as nutritional properties of bread, this study addresses these gaps by evaluating the differences in nutritional and antioxidant profiles between pita bread made with germinated grains (GGB) and non-germinated grains (NGB), the impact of germination on physicochemical properties, and the consumer acceptance and preference of multigrain pita bread made with beans, millet, rye, wheat, and lentils.

Materials & Methods

Materials

The grains (cereals and pulses) and other materials (salt, oil, sugar, and yeast) used to make the flour and bread were sourced from local supermarkets.

Germination and Flour Preparation

Germinated grains were obtained following the procedure described by Montemurro, Pontonio, Gobbetti and Rizzello (2019).¹⁸ Grains (wheat, broad beans, lentils, millet, and rye) were kept in a 0.1% NaClO solution (1:5 w/v) for 30 min and then washed with distilled water. After that, the grains were immersed in tap water during 24 h at 20 °C (seed:water ratio, 1:5, w/v). For grain germination, drained seeds were kept in the dark at 20 °C. During storage in darkness, tap water was sprayed over the grains every 12 hours for 5 minutes. At the same time, the seeds were manually tossed every 24 h. The germination time varied depending on the seed type and was determined based on how quickly the grains reached an appropriate rootlet length (approximately 3/4 of the average seed length). Once germinated, the seeds were washed three times using distilled water to then be dried in an oven at 30 °C for 48 h, without separating the rootlets from the grains. The drying conditions applied in this study are similar to those utilized in the industrial malting of barley, which are recognized to lead to increased enzymatic activity. All treated seeds were converted into flour by milling, sieved with a sieve (80 µm mesh), and then stored at -40 °C until use.¹⁸⁻²⁰ The flour used in the manufacture of bread was prepared by combining flour from all germinated grains (Germinated Grain Flour, or GGF from now onwards) in equal proportions. In addition, flour from non-germinated grains (NGF, or Non-Germinated Flour from now onwards) was prepared to compare the results.

Formulation and Preparation of Multigrain Pita Bread

The multigrain pita bread was formulated and prepared based on the method proposed by Yousif, Nhepera, and Johnson (2012), incorporating certain modifications.¹⁹ Two formulas were developed with different types of flour: from germinated grains (GGB, or Germinated Grain Bread) and non-germinated grains (NGB, or Non-Germinated Bread) (Table 1). The formula was made without additives (no ascorbic acid and reduced amount of sugar) to study the behavior of the flour, without other source of bias.¹⁰

Table 1: Pita bread formulations

Ingredients	Type of Pita Bread	
	GGB	NGB
GGF (g)	450	-
NGF (g)	-	450
Water (g)	157	157
Yeast (g)	3	3
Oil (g)	6	6
Salt (g)	4	4
Sugar (g)	3	3

To prepare both types of bread (GGB and NGB), the yeast was previously rehydrated at 38°C for 15 minutes in 10 ml of water mixed with 1 g of sugar. The flour and the rest of the ingredients were mixed with the hydrated yeast in an orbital mixer (Aura mixer, FDV, China) for 5 minutes. The dough was fermented at 30 °C for 20 min. Then the dough was stretched to give it a uniform thickness (1 cm) and loaves of equal size were cut with a 10 cm diameter mold. The baking conditions were: 180 °C for 12 minutes in a conventional oven. Immediately afterwards, the breads were cooled to room temperature on metal racks, packaged in airtight plastic bags, and kept at 4°C until use (no more than 24 hours).

Physical Characterization

Specific gravity of the mass (GE): It was calculated by dividing the density of the dough by the density of water.²⁰

$$G_E = \frac{\text{Dough density} \left(\frac{g}{cm^3} \right)}{\text{Water density} \left(\frac{g}{cm^3} \right)} \dots(1)$$

Moisture loss during baking: The product was weighed at the time of baking and 1h after baking to calculate the weight loss with the following equation:²¹

$$BL(\%) = \left[\frac{(B-C)}{IW} \right] \times 100 \quad \dots(2)$$

Where BL is the weight of the product after baking and IW is the initial water content of the dough.

Water holding capacity (WHC) and oil holding capacity (OHC) of flour: WHC and OHC of the samples were assessed based on the procedure outlined by Arora (2023), as referenced by Aider, Sirois-Gosselin, and Boye, with minor adjustments.²² One gram of flour was combined with 10 ml of distilled water, and the mixture was left to rest at room temperature for 30 minutes. It was then centrifuged at 3000 rpm for another 30 minutes. The WHC was calculated using the following formula:²³

$$WHC \left(\frac{g}{g} \right) = \frac{(M_1 - M_0)}{M_0} \quad \dots(3)$$

Where M_0 is the initial weight of the samples and M_1 is the final weight of the samples. For oil absorption, authors repeated a similar procedure using sunflower oil instead of water. The oil holding capacity (OHC) was calculated with the same equation.²³

Nutritional Characterization

The determination of protein, fat, and ash, and moisture content in the bread samples was carried out following the Official Methods of Analysis (AOAC, 2006), with some modifications.²³ The characterization was carried out on the GGB and NGB samples. Additionally, a sample of commercial pita bread (CB) was analyzed for comparative purposes as a control both for the proximal analysis and for the total polyphenol content and the polyphenolic profile.

Total Phenols, Phenolic Profile, and Radical Scavenging activity Determination

To extract the sample, one gram of bread was combined with 25 mL of ethanol and agitated using a shaker. The mixture was then centrifuged, collected, and filtered. The determination of total phenolic content and DPPH radical scavenging capacity followed the protocol outlined by Aljahani (2022).²³

The polyphenol profile was analyzed using a high-performance liquid chromatography system coupled with a diode array detector (HPLC-DAD Primaide, Hitachi High Technology America, Inc., Dallas, USA). The analysis was performed on a Kromasil® C18 column. The mobile phases consisted of 1% formic acid in water (Phase A) and acetonitrile (Phase B). Separation was achieved at a flow rate of 1 mL/min, with an injection volume of 10 μ L.²⁴

Sensory Evaluation

The sensory evaluation of the GGB, NGB and CB formulations was carried out with ninety-seven panelists each. Three coded samples of each product type (GGB, NGB, CB) were presented in randomized order at room temperature. Participants were asked to rinse their mouths with water between each sample tasting. The sensory evaluation protocol was approved by the Scientific Ethics Committee of the Universidad Adventista de Chile. Panelist group was conformed by untrained staff and students over 18 years of age from the same University. All participants signed an informed consent before taking part in the study. The consent procedure complied with the ethical standards and regulations in force in Chile. They were also screened to ensure that they liked and regularly consumed pita bread and did not have any allergies to grains.²⁵ Evaluation was carried out based on acceptability of appearance, texture, flavor, and overall preference using a hedonic 9-point scale (1 = dislike extremely, 9 = like extremely).²⁶ Additionally, just-about-right (JAR) scales were employed to evaluate the intensity and suitability of other parameters.²⁷

Statistical Analysis

Physicochemical and sensorial data were replicated three times, and results were expressed as means with their corresponding standard deviation. Jamovi software (Jamovi, v.2.3, Sidney, Australia) was used to analyze data by means of one-way ANOVA and Tukey's procedure at $P < 0.05$.^{28–31} To identify significant differences in the preference ranking data, Friedman's test was applied.

Results

Physical Characterization

Table 2 provides information on the physical characteristics of the types of pita bread (GGB and NGB) made for the research.

Table 2: Physical characteristics of GGB and NGB

Sample	Moisture content (%)		Baking loss (%)		SG		WHC (g/g)		OHC (g/g)	
GB	35,0	±9 ^a	34,3	±5.2 ^a	1,4	±0.1 ^a	2,6	±0.9 ^a	3,2	±0. ^a
NGB	35,3	±9 ^a	38,5	±8.1 ^a	1,4	±0.2 ^a	3,2	±0.2 ^a	7,5	±0.7 ^b

Values are expressed as mean ± standard deviation (n = 3). Different lowercase letters within the same column denote statistically significant differences between the two samples (p < 0.05).

Moisture content, moisture loss during baking, and specific gravity were similar in both GGB and NGB. No statistically significant differences were observed between the samples (p < 0.05). The WHC values, corresponding to the grams of water absorbed per gram of sample, did not vary significantly between GGB and NGB (p < 0.01). It is worth noting that a statistically significant difference in oil-holding capacity (OHC) was observed between the two bread samples (p < 0.01). The NGB bread showed more than double the oil-holding capacity compared

to the GGB sample. Other physical characteristics did not show significant differences between the two types of bread.

Nutritional Characterization

Table 3 presents the proximal analysis for samples GGB, NGB and CB. No significant differences were found in the results, except for the calorie value, which indicates that germination did not produce substantial variations in its nutritional composition.

Table 3: Proximate analysis for germinated bread (GGB), non-germinated (NGB) and commercial bread (CB) samples

Proximate analysis	GGB	NGB	CB
Moisture (%)	36.70±2.01 ^a	36.94±1.98 ^a	35.88±2.1 ^a
Protein (%)	8.82±2.40 ^a	8.59±1.21 ^a	8.78±2.02 ^a
Lipids (%)	2.56±0.70 ^a	3.02±0.66 ^a	3.89±0.59 ^a
N.N.E. (%)	47.69±1.99 ^a	47.05±2.21 ^a	47.78±1.67 ^a
Ash (%)	2.64±1.01 ^a	1.85±0.97 ^a	2.05±0.89 ^a
Fibre (%)	1.59±0.74 ^a	2.55±0.89 ^a	1.62±0.68 ^a
Calories (Kcal)	249.08±10.3 ^a	249.74±11.1 ^a	261.25±12.56 ^b

Results are presented as mean values along with their respective standard deviations (n = 3). Within each row, different lowercase letters indicate statistically significant differences among the samples (p < 0.05).

Total Phenols, Phenolic Profile, and Radical Scavenging Activity Determination

Table 4 shows data for TPC, individual phenolic compounds, and antioxidant capacity. The results of TPC and DPPH were significantly different (p < 0.001 and p < 0.05, respectively). The polyphenol content had a maximum value in the NGB sample, followed by GGB and CB. Regarding the antioxidant capacity (DPPH), the GGB and NGB samples showed a higher significative concentration compared to CB.

Concerning the individual phenolic compounds, the content of p-tyrosol and vanillic acid showed a significant difference between data (p < 0.05). These compounds were only detected in the GGB and NGB samples. The 4-hydroxybenzoic compound was found in greater quantity in the NGB sample than in GGB, although this difference was not enough to imply a significant difference (p > 0.05). The compounds 3,4-DHP glycol and trans-ferulic

acid were only detected in NGB, while gallic acid and 2,6-dimethoxyphenol were only detected in CB. No other phenolic compounds were found in the analyzed samples.

Table 4: Content of total polyphenols, DPPH antioxidant capacity and profile of phenolic acids and derivatives in CB, GGB and NGB samples

	CB	GGB	NGB
Total polyphenols (mg EAG/100g)	19.8±0.3 ^a	33.9±0.2 ^b	180.6±1.5 ^c
DPPH (µmol Trolox/100g)	54.7±2.7 ^a	198.2±17.1 ^b	180.6±2.5 ^b
Phenolic acids and derivatives (mg/100 g)			
4-hydroxybenzoic acid	N.D	0.888±0.119 ^a	1.114±0.351 ^a
3,4-DHP glycol	N.D	N.D	32.950±1.888
gallic acid	0.433±0.016	N.D	N.D
p-tyrosol	N.D	0.816±0.093 ^a	0.733±0.075 ^b
vanillic acid	N.D	0.133±0.013 ^a	0.224±0.015 ^b
2,6-dimethoxyphenol	0.032±0.007	N.D	N.D
trans-ferulic acid	N.D	N.D	0.158±0.035

Data represent mean ± standard deviation values. Values are expressed as means ± standard deviation. Different lowercase letters within the same row indicate statistically significant differences between samples ($p < 0.001$ or $p < 0.05$).

Sensory Evaluation

Sensory Properties

Figure 1 shows the results of the sensory attributes evaluated for GGB, NGB and CB (appearance, taste, texture, flavor, color, overall liking, preference ranking). A significant difference ($p < 0.05$) in the flavor attribute was noted between GGB and NGB, but not between them with CB, which is positive since these breads based on beans, lentils, millet,

wheat and rye would have an aroma as acceptable to the consumer as commercial bread. In the case of GGB (6.5), the aroma attribute received a higher score than CB (5.9), while in the case of NGB (5.7), the score was lower. GGB presented a better flavor and texture score compared to the other samples, although no significant differences were detected ($p > 0.05$).

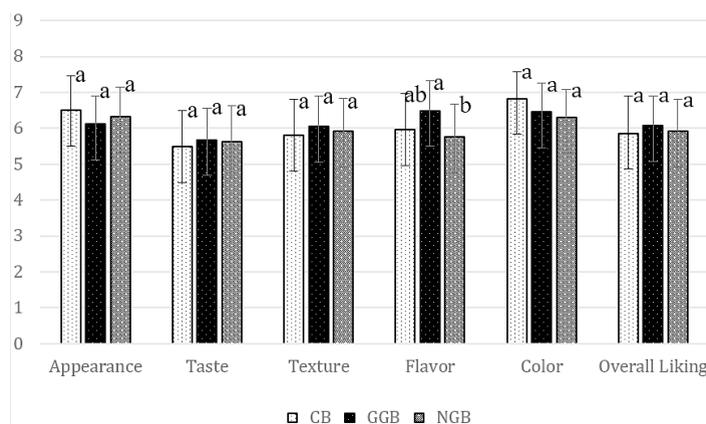


Fig. 1: Sensory properties of bread made from germinated grains (GGB), non-germinated grains (NGB) and commercial bread (CB). Black bar/white dots (GGB), gray bar/white dots (NGB), and white bar/black dots (CB). Statistically significant at $p < 0.05$, where a and b indicate significance difference in bar

JAR Analysis (“Just-about-right”)

The results of the JAR analysis are seen in Figure 2 (A, C, and E). The statistical analysis showed significant differences in the “pulse-like taste” attribute between GGB and CB ($p < 0.001$).

Regarding the crumb porosity attribute, significant differences are found between the NGB and CB samples ($p < 0.001$), as well as in the crumb color attribute ($p < 0.05$).

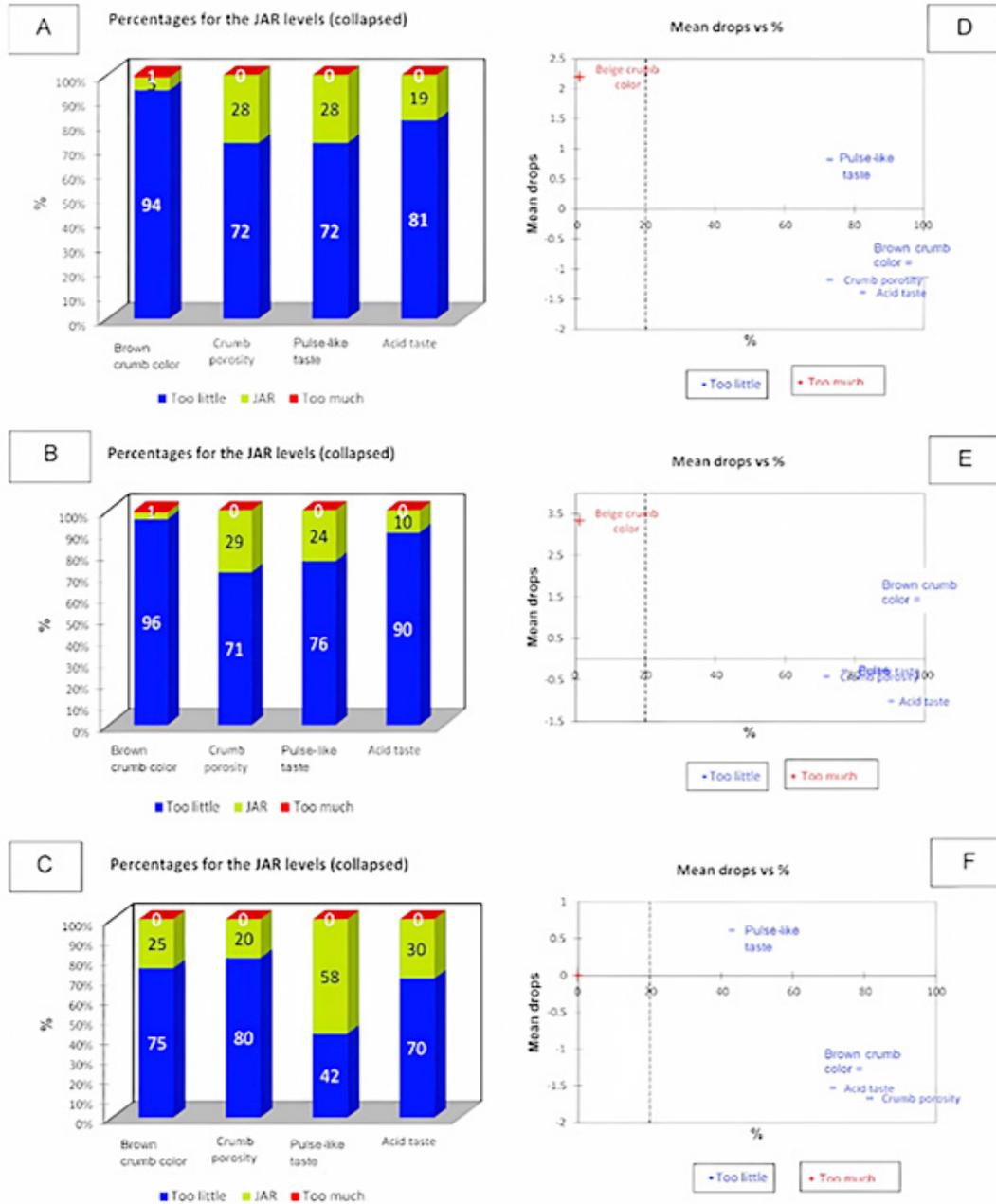


Fig. 2: JAR (Just-About-Right) score and penalty distribution (Mean drops) according to each evaluated attribute (brown crumb color, crumb porosity, legume flavor and acid flavor), for germinated bread, GGB (A and B), non-germinated bread, NGB (C and D) and commercial bread, CB (E and F)

Regarding the percentage values for the JAR levels, more than 70% of the participants consider that all bread samples (NGB, GGB, and CB) show “too little acid” taste. Similarly, for the “pulse-like taste”, 72% and 76% of the participants consider that the GGB and NGB samples, respectively, present a “too little pulse-like” taste. Regarding the attribute “crumb porosity”, 71% or more of the participants chose “too little” in all samples.

In the case of the attribute “crumb color”, a percentage of participants of 96% in NGB, and 94% in GGB considered that the color of the crumb was “too light” brown. While in CB, that value was reduced to 75%.

Penalty Analysis (Mean Drops)

Figure 2 shows the distribution of penalties for the different attributes (brown crumb color, crumb porosity, legume flavor and acid flavor) in the three samples (GGB, NGB, CB). According to Fernández-Segovia, García-Martínez, Fuentes-López (2018), the influence of the attribute on the general acceptance of the product is significant when the value of the mean drop is greater than 1 and less than -1 and also when less than 20% of the evaluators give different scores to JAR (indicated in lines dashed in Figure 2).²⁸ In all samples, a high percentage of panelists described the attributes studied as “too little.” However, when performing the penalty analysis, not all of them would influence the acceptability, since the value of mean drop <1.

Discussion

Physical characterization

These findings indicate that germination could influence the lipid absorption capacity of bread, which agrees with previous studies in germinated flour from sorghum, wheat, and millet.^{29–31} Other properties such as the density of the dough and its water absorption capacity were not changed. According to previous studies, it may be due to physicochemical modifications during germination. Also, lentil protein presence contributed to the increased oil-holding capacity because of the functionality of their proteins.^{30–33}

Nutritional Characterization

All grains used in GGB and NGB can significantly contribute to the protein content of the bread samples, since pulses and cereals used have

a protein content range from 8% to 25%.^{30,34,35} As for the CB, grains and seed used may have also contributed to its protein content. Regarding lipids, the higher OHC of non-germinated flour may influence the slightly higher lipid content of NGB compared to GGB. According to some studies, grain germination may reduce fat content in bread due to lipolytic enzymes action, which can decompose lipids present in the grains, resulting in a decrease in fat content in sprouted grains.³⁶ Ash content represents the mineral salt content present in the bread. There was a slightly higher mineral content in GGB compared to NGB, which might be due to the activation of various enzymes in the grain during germination.³⁷ These enzymes can break down compounds such as phytic acid, which is primarily bound to certain minerals like calcium, iron, zinc, and magnesium. The breakdown of phytic acid during germination can release these minerals, thereby increasing the ash percentage.³⁸ Additionally, during the germination process, an increase in the seed's metabolic activity occurs. This can lead to the mobilization and redistribution of minerals within the grain, potentially resulting in an increase in the content of certain minerals, such as potassium and magnesium.^{36,38}

Total Phenols, Phenolic Profile, and Radical Scavenging Activity Determination

Most studies indicates that germination increase TPC and antioxidant activity (AoxA).^{39–41} It was expected a higher amount of TPC in the pita bread from germinated grains. However, the TPC content in the case of the NGB sample was higher than that of the GGB sample. This could be attributed to interference from other compounds with reducing properties, such as certain amino acids like tryptophan and tyrosine.⁴² All the grains used in the preparation of the different bread samples are rich sources of tryptophan and tyrosine. Indeed, lentils and beans are the grains with the highest tryptophan and tyrosine content, followed by wheat, millet and rye.^{42–44} Non-phenolic compounds may interfere with TPC quantification by reducing the Folin-Ciocalteu reagent, potentially leading to an overestimation of total phenolic content—an acknowledged limitation of this spectrophotometric technique.⁴⁵ Also, some studies indicates that germination activates enzymes that hydrolyze phenolic compounds, converting them from insoluble to soluble forms, which may lead to a net decrease in total phenolic content.⁴⁶

Regarding antioxidant capacity (AoxA), germination led to an increase in AoxA, while simultaneously decreasing TPC.⁴⁷ Additionally, GGB demonstrated a higher antioxidant capacity, suggesting that germination can enrich bakery products with bioactive compounds. These findings are consistent with previous research,¹⁹⁻²¹ which suggests that sprouting may be an effective strategy to improve the nutritional and antioxidant quality of bakery products. In terms of clinical practice, these results support the promotion of the consumption of germinated grain-based baked goods as a healthier and more nutritious option.

Meral and Köse (2018) suggest that the differences in gallic acid content are directly proportional to the fermentation time, so the difference between CB and GGB (ND) or NGB (ND) could be related to a variation in fermentation time.⁴⁸ Tian, Ehmke, Miller, and Li (2019) suggest that the flavonoid content, phenolic acids and antioxidant activity of germinated flour are lower.⁴⁹ According to their study, 4-hydroxybenzoic acid has greater tolerance to germination, it does not degrade completely, which agrees with what was observed in the GGB sample and not in the CB. The opposite happened with ferulic acid, the main phenolic acid in wheat, which was only detected in NGB. Shahidi and Ambigaipalan (2015) found that during the germination process in wheat samples the trans-ferulic acid content decreased, probably due to the decomposition of the cell wall in the seeds.⁵⁰ This agrees with the results obtained in this study. Xiang, Yuan, Du, Zhang, Li and Beta (2023) suggest that the vanillic acid content in millet increases its concentration with germination.⁵¹ This differs from the results shown in Table 4, where it is found in lower quantities in GGB than in NGB; while in the CB it was not detected. Several studies also suggest that hydroxybenzoic acid decreases considerably with germination.^{47-48,50} According to this study, hydroxybenzoic acid is also found in decreased values in GGB compared to NGB and CB.

Sensory Evaluation

Better flavor and texture score of GGB compared to the other samples could have contributed to its higher overall acceptance score. The grain germination process could generate changes in the chemical and enzymatic composition, which affected the flavor and aroma attribute of the bread.⁴⁰ During germination, compounds such as aldehydes, volatile

fatty acids and other metabolites are produced that contribute to the aroma of bread.^{40,51}

. In the case of GGB (Fig. 2D), the attributes of crumb porosity and sour taste are important in acceptability because they met the two established conditions. In the case of NGB (Fig. 2E), only the “too little” brown attribute was considered important for a future adjustment of the formulation. With respect to CB, (Fig. 2F), the attributes “too little” acid taste and crumb porosity present a mean drop >1. It is possible that the low score obtained in the flavor attribute as well as the significant differences found in the flavor attribute of the samples may be related to the JAR value of the “acid taste” in them.⁵²

While this study provides valuable insights into the impact of germination on the nutritional, antioxidant, physicochemical, and sensory properties of multigrain pita bread, certain limitations should be considered when interpreting the findings: variability in the germination process, batch-to-batch consistency and scalability, and untrained panel of consumers for sensory evaluation. These limitations highlight the need for continued research to optimize germination conditions, validate sensory findings across different consumer segments, and assess the commercial scalability of using germinated grains in bakery products.

Conclusion

In general, no statistically significant differences were detected in most physical and nutritional characteristics between GGB and NGB, except for a higher oil retention capacity in NGB and a slight difference in calorie content. Germination appears to impact lipid absorption without altering other aspects such as dough density and water absorption. Both GGB and NGB showed significantly higher antioxidant capacity than CB, with notable differences in specific bioactive compounds like p-tyrosol and vanillic acid, which were present in both GGB and NGB but not in CB.

Sensory evaluations revealed that bread made with sprouted grains has comparable acceptability to commercial bread, with improvements in flavor and texture that may enhance product appeal. Certain attributes, such as crumb porosity and acid flavor, significantly impact the acceptability of GGB, as they meet the threshold criteria for influencing consumer

preference. In contrast, only the "too little" brown color attribute is important for NGB, suggesting that adjustments in these specific sensory characteristics could improve the acceptability of each bread type. These findings suggest that incorporating germinated grains can enrich bread with bioactive compounds, enhancing its nutritional and antioxidant qualities without negatively impacting its baking properties and potentially improving its sensory attributes. However, challenges related to batch consistency, scalability, and cost-effectiveness must be addressed for commercial viability. Future research should focus on optimizing germination conditions, standardizing production processes, and evaluating the stability of bioactive compounds during storage. Additionally, consumer acceptance studies across diverse markets and clinical trials to validate health benefits would further support its commercialization.

These findings contribute to the development of innovative, health-oriented bakery products aligned with current consumer trends.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

Data available on request from the authors. The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Ethics Statement

This study was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki. All procedures involving human participants were approved by the Scientific Ethics Committee of the Universidad Adventista de Chile.

Informed Consent Statement

Informed consent was obtained from all participants prior to their inclusion in the study. Participation was voluntary, and participants were informed of their right to withdraw at any time without any consequences. The data collected were anonymized to ensure confidentiality and used exclusively for research purpose.

Clinical Trial Registration

This research does not involve any clinical trials.

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Author Contributions

- **Francesca Contreras-Castro:** Data Collection, Statistical Analysis, Writing – Original Draft
- **Karina Riveros-Becerra:** Data Collection, Statistical Analysis, Writing – Original Draft
- **Isidora Jimenez-Vargas:** Data Collection, Statistical Analysis, Writing – Original Draft
- **Pamela R. Toledo-Merma:** Writing – Review & Editing
- **Reynaldo J. Silva-Paz:** JAR Analysis
- **Marcela Jarpa-Parra:** Conceptualization, Methodology, Funding Acquisition, Supervision, Review - Final Draft.

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