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Effect of Seaweed Powder on Rheological Properties of Dough and Quality of Germinated Brown Rice Bread

My Duyen Nguyen Dang*, **Thanh Tung Pham**

Ho Chi Minh City University of Technology and Education, Vietnam

*Corresponding author. *Email:* myduyen@hcmute.edu.vn

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ABSTRACT

This study investigated the effect of seaweed powder on the rheological properties of dough and the quality of germinated brown rice bread. Germinated brown rice flour was replaced with seaweed powder at levels of 10%, 20%, 30%, and 40% (w/w). Rheological properties of the dough, including viscoelasticity, deformation resistance, and deformation recovery, were evaluated. The effects of seaweed powder on bread quality attributes, such as loaf volume, specific volume, texture, and sensory characteristics, were also determined. The results showed that seaweed powder significantly affected the rheological properties of the dough and the quality of the bread. Dough moisture content decreased, while viscosity and elasticity increased with increasing levels of seaweed powder. The storage modulus (G') was higher than the loss modulus (G"), indicating a predominantly elastic behavior. Deformation resistance and recovery also increased with increasing seaweed powder substitution. Furthermore, increasing seaweed powder substitution led to a decrease in specific volume and an increase in crumb firmness, chewiness, and resilience. Crumb cohesiveness and springiness decreased with increasing seaweed powder content. Sensory evaluation revealed that bread with 20% seaweed powder substitution was the most preferred. This study suggests that supplementing germinated brown rice bread with 20% seaweed powder can improve its nutritional value while maintaining acceptable sensory qualities.

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1. Introduction

Recent research has shown significant interest in exploring wheat flour alternatives for bread production [1]. Compared to traditional wheat bread, germinated brown rice bread offers superior nutritional benefits (protein, fiber, vitamins, etc.) and improved digestibility due to the germination process, which activates enzymes that break down complex compounds. Demirkesen and Ozkaya [2] reported that germinated brown rice flour is a suitable grain for gluten-free bread production due to its desirable characteristics such as natural flavor, low allergenicity, and potential health benefits for the elderly. However, the lack of gluten-forming proteins in germinated brown rice flour can result in bread with a crumbly texture, poor color, and undesirable defects in crust, volume, texture, and flavor [3]. To improve the texture of germinated brown rice bread, it is essential to develop a strong gel network that provides the desired viscosity and elasticity. Although milk, soy, and egg proteins have been utilized to improve the quality of gluten-free bread, these methods present certain limitations [4]. Recent research on gluten-free products suggests that seaweed has significant potential as a functional food ingredient for improving dough properties and bread quality. Seaweed is a rich source of polysaccharides, proteins, lipids, minerals, and vitamins. Furthermore, seaweed contains bioactive compounds with antibacterial and antifungal properties beneficial for bread preservation. The presence of antioxidants (polyphenols) in seaweed may also reduce oxidative stress, potentially extending the shelf life of bread [5], [6]. Therefore, the aim of this research is to investigate the feasibility of using seaweed as a wheat flour replacement in bread production, focusing on its impact on dough rheology, bread quality, and sensory characteristics.

2. Materials and Methods

2.1. Materials

The seaweed powder used in this study was produced from dried Miyuk seaweed (Godbawee brand, South Korea). The dried seaweed was finely ground and sieved through a 20 cm diameter sieve with a 0.5 mm mesh size to obtain a fine powder with uniform particle size. The moisture content of the seaweed powder was determined to be 8.9% using an XM 50 infrared moisture analyzer (Precisa XM 50, Switzerland).

2.2. Bread Production

Germinated brown rice bread with added seaweed powder was produced according to the following process (Figure 1):

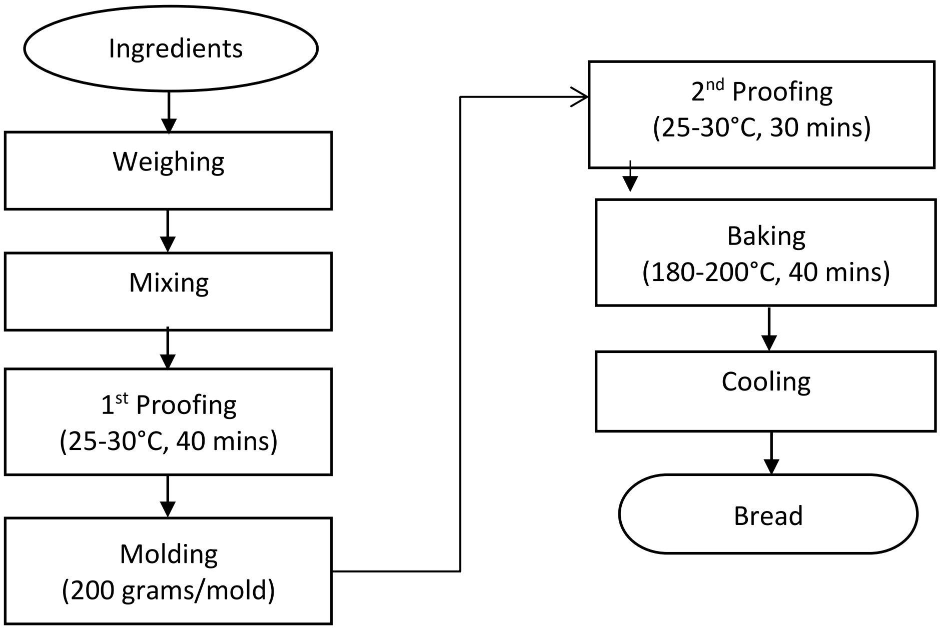


Figure 1. *The process flowchart of bread-making.*

2.3. Rheological Analysis of Dough

The rheological properties of the dough were evaluated using a HAAKE RheoStress 1 rheometer (Thermo Scientific, USA) equipped with a parallel plate geometry (diameter of plate: 35mm, the gap between two plates: 1mm). Dynamic oscillatory tests were conducted at a constant temperature of 25°C. The storage modulus (G') and loss modulus (G") were determined by applying a dynamic strain sweep at frequencies ranging from 1 to 50 Hz at a controlled shear stress is of 5 Pa [7]. G' represents the elastic behavior of the dough, while G" represents the viscous behavior [8].

2.4. Bread Quality Analysis

2.4.1. Specific Volume

The specific volume of the bread was calculated as the ratio of loaf volume to loaf weight, as described by Al-Saleh and Brennan [9]:

$$v = \frac{V}{m} \text{ (cm}^3\text{/g)}$$

where: V is loaf volume (cm^3) and m is loaf weight (g).

2.4.2. Textural Analysis

Textural properties of the bread crumb were measured using a CT3-Brookfield texture analyzer (Ametek Brookfield, USA) with TA-AACC36 probe. A two-cycle compression test was performed using a flat-faced cylindrical probe with a diameter larger than the sample. The probe compressed the sample at a defined speed, and the force required for compression was recorded. The measurement parameters are set as follows: test type set to “compression”, target value of 40%, trigger load of 5 g, test speed of 1.0 mm/s, with 2 cycles.

Textural properties of the bread crumb were defined: hardness (g): force required for a pre-determined deformation; springiness (mm): rate at which a deformed sample returns to its original size and shape; chewiness (g): energy needed to disintegrate a semisolidfood until it is ready to swallow; gumminess (g): energy needed to disintegrate a semi solidfood until it is ready to swallow; cohesiveness (no unit): strength of internal bonds in the sample [9]. Data were analyzed using TA.XTPlus Texture Analyzer software.

2.4.3. Nutritional Analysis

The energy content and carbohydrate content of the bread samples were analyzed according to FAO methods [10]. Protein content was determined using the Kjeldahl method [11]. Lipid content was determined using the Soxhlet method [10]. Polyphenol content was analyzed according to ISO 14502 – 2005 [12]. Soluble fiber content was analyzed according to AOAC method 991.43 [13].

2.4.4. Sensory Evaluation

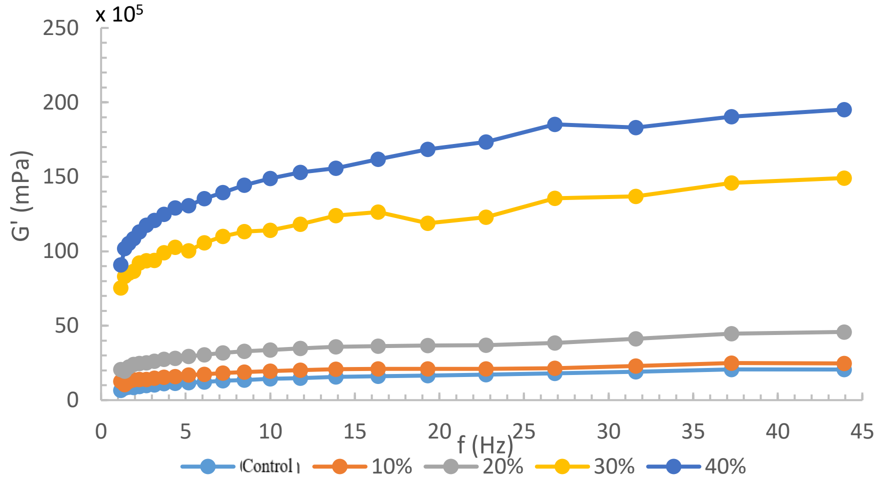
A hedonic scoring test was conducted to evaluate the consumer acceptance of the bread samples. The sensory evaluation involved a panel of 79 individuals who assessed specific attributes, including texture, color, aroma, taste, and overall liking. Each sensory attribute was rated on a 9-point hedonic scale, where a score of 1 represented "dislike extremely," and a score of 9 indicated "like extremely." This scale allows for a quantitative assessment of consumer preferences, with higher scores reflecting greater acceptance [14].

2.4.5. Statistical Analysis

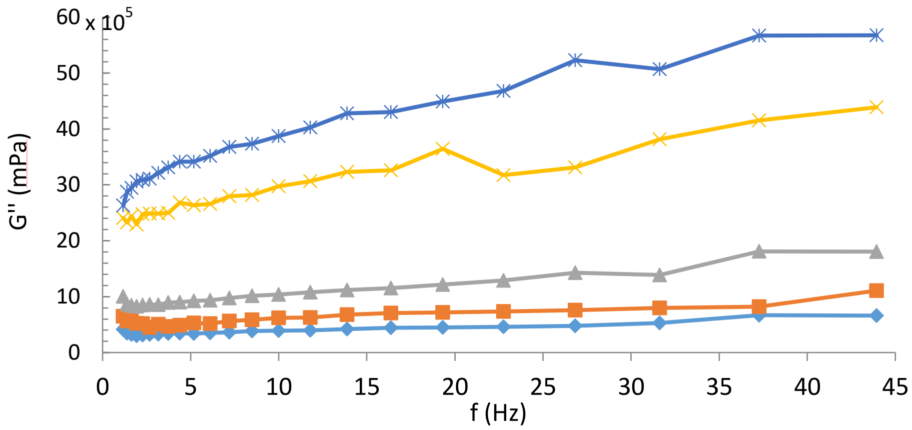
Data were analyzed using analysis of variance (ANOVA). Standard deviation, correlation coefficients, and graphs were generated using SPSS and Excel 2016 software.

3. Results and Discussion

3.1. Effect of Seaweed Powder on Rheological Properties of Germinated Brown Rice Dough



a) Storage Modulus (G')



b) Loss Modulus (G")

Figures 2. *Effect of Seaweed Powder Substitution on Viscoelastic Moduli of Germinated Brown Rice Dough.*

Figures 2 presents the results of the dynamic oscillatory tests. All dough samples exhibited a higher storage modulus (G') than loss modulus (G") (G' > G") across all frequencies, indicating that the germinated brown rice dough had predominantly elastic (solid-like) behavior. This characteristic contributes to improved dough handling and gas retention capacity. These findings are consistent with previous studies on the rheological properties of gluten-free rice dough by Guarda et al., [15] and Ronda et al., [16]. Both G' and G" showed an increasing trend with increasing frequency (from 0 to 50 Hz). This can be explained by the fact that at higher frequencies, the rate of deformation applied to the dough increases, while the time for the dough to relax decreases. This leads to increased viscous flow and a higher G". Conversely, the shorter time for stress relaxation at higher frequencies reduces stress sagging and increases the amount of energy stored (G') [17].

Figures 2 also demonstrates the significant impact of seaweed powder substitution on dough rheology. Both G' and G" increased with increasing levels of seaweed powder (from 0 to 40%), indicating that seaweed powder enhances both the elastic and viscous properties of the gluten-free dough. The dominance of G' over G" at all seaweed powder concentrations suggests that the elastic behavior is more pronounced with increasing seaweed powder content. This effect can be attributed to the high fiber content of seaweed powder, particularly the presence of alginate in the soluble fiber fraction [18]. Soluble fiber increases water absorption capacity through hydrogen bonding within the dough matrix and interactions with free -OH groups on polysaccharide chains [19]. Additionally, the hydrophilic hydroxyl groups in alginate contribute to increased viscosity and water holding capacity, leading to reduced dough moisture content [20]. This, in turn, enhances dough elasticity and resistance to deformation [21]. Furthermore, fiber and alginate can interact with the starch gel network, promoting stronger bonds between starch granules and reducing their mobility, which further contributes to increased dough elasticity [22]. Mir et al., [23] also reported that hydrocolloids can improve food texture by increasing G' and G", enhancing rheological properties, and increasing elasticity in rice flour-based bread dough. Therefore, substituting germinated brown rice flour with seaweed powder improved the rheological properties of the gluten-free dough by enhancing its elasticity and promoting a more dominant elastic behavior over viscous behavior. This resulted in a less sticky and more manageable dough that is easier to shape during processing.

3.2. Effect of Seaweed Powder on Specific Volume of Germinated Brown Rice Bread

According to Table 1, the loaf weight of the germinated brown rice bread increased from 164.98 g to 172.48 g with increasing seaweed powder substitution. This can be attributed to the high water absorption capacity of the fiber and hydrophilic compounds in seaweed powder. These components form hydrogen bonds with water molecules, enhancing moisture retention in the baked bread and leading to a gradual increase in loaf weight [24].

Table 1. *Loaf Weight, Loaf Volume, and Specific Volume of Germinated Brown Rice Bread.*

Substitution level (%)	Loaf weight (g)	Loaf volume (cm3)	Specific volume (cm3/g)
0	164.98 ± 0.11^{a}	368.33 ± 2.89^{a}	2.24 ± 0.02^{a}
10	167.58 ± 1.23^{b}	367.67± 2.52^{ab}	2.23 ± 0.01^{ab}
20	168.92± 0.81^{bc}	367.70 ± 0.58^{abc}	2.17 ± 0.03^{c}
30	170.28 ± 0.99^{d}	334.00 ± 11.36^{c}	1.96 ± 0.02^{d}
40	172.48 ± 0.85^{e}	316.67 ± 4.93^{d}	1.80 ± 0.06^{e}

*Different letters within a row indicate significant differences ($p < 0.05$)

The analysis also revealed a decrease in loaf volume from 368.33 cm^3 to 316.67 cm^3 with increasing seaweed powder substitution. However, there was no statistically significant difference between the control and the samples with 20% and 30% seaweed powder substitution. The development of gluten-free bread structure is influenced by several factors, including hydration and swelling of dough components, fermentation, and CO_2 retention within the gel network formed during protein denaturation and starch gelatinization. These factors ultimately affect the loaf volume of the baked bread [25]. Seaweed powder contains hydrocolloids, which absorb water and may hinder moisture loss during baking, potentially reducing loaf expansion and volume [26]. At higher substitution levels, the insoluble fiber fraction in seaweed powder can disrupt the starch gel network, restricting moisture release during baking and further reducing loaf expansion and height, leading to a decrease in loaf volume [25]. As the loaf weight increased and loaf volume decreased with increasing seaweed powder substitution (from 0 to 40%), the specific volume of the bread decreased accordingly. This result is consistent with previous studies on the effect of seaweed on the physical properties of gluten-free bread [27].

3.3. Effect of Seaweed Powder Substitution on the Texture of Germinated Brown Rice Bread

The textural analysis of the bread samples (Table 2) revealed that substituting germinated brown rice flour with seaweed powder (10% to 40%) increased crumb firmness compared to the control (0%). Conversely, crumb cohesiveness and springiness decreased with increasing seaweed powder substitution. These differences were statistically significant ($p < 0.05$) for samples with 20% or more seaweed powder. This can be attributed to the influence of insoluble fiber in seaweed powder on the density (g/cm^3) of the bread. Increased bread density leads to higher firmness and reduced springiness and cohesiveness [28]. As shown in Table 1, the specific volume decreased with increasing seaweed powder substitution, indicating a corresponding increase in bread density. Consequently, the crumb became denser and firmer with higher seaweed powder content. The study also showed that chewiness and resilience increased with crumb firmness. This is because chewiness is calculated as the product of firmness and cohesiveness, while resilience is calculated as the product of firmness, cohesiveness, and springiness. This increase in chewiness and resilience could help overcome the common drawback of gluten-free bread, which tends to be dry and crumbly, potentially improving its shelf life.

Table 2. *Textural Properties of Bread Crumb.*

Substitution level (%)	Hardness (g)	Cohesiveness	Springiness (mm)	Gumminess (g)	Chewiness (g)
0	391.33±8.75^{a}	0.9354±0.01^{d}	0.70±0.01^{d}	366.00±6.72^{a}	256.89±2.42^{a}
10	417.66±11.40^{a}	0.9242±0.02^{bc}	0.70±0.04^{bc}	385.83±2.02^{b}	268.25±2.84^{b}
20	651.33±15.04^{b}	0.9061±0.07^{b}	0.69±0.03^{b}	590.16±11.18^{c}	407.40±7.59^{c}
30	734.33±35.92^{c}	0.9046±0.01^{b}	0.68±0.01^{a}	664.00±24.24^{d}	449.22±13.35^{d}
40	1190.83±52.35^{d}	0.8724±0.01^{a}	0.68±0.03^{a}	1038.66±39.86^{e}	702.20±29.67^{e}

*Different letters within a row indicate significant differences ($p < 0.05$)

3.4. Sensory Evaluation of Germinated Brown Rice Bread

According to Table 3, the hedonic scoring test revealed that the germinated brown rice bread with 20% seaweed powder substitution was the most preferred, receiving an average score of 6.7. The least preferred sample was the one with 40% seaweed powder, which received a score of 5.8 due to its excessive saltiness. At the 20% substitution level, the bread exhibited a characteristic green hue imparted by the seaweed powder. The distinctive aroma and flavor of the seaweed also helped mask the yeasty and eggy off-notes often associated with germinated brown rice bread. However, at higher substitution levels, consumer preference declined. This was likely due to the strong seaweed flavor and saltiness overpowering the desirable bread flavor. Furthermore, the increased crumb firmness and reduced springiness (Table 2) resulted in a dense texture that was less appealing. Based on the sensory evaluation and the analysis of crumb texture and loaf volume, the bread with 20% seaweed powder substitution was selected for further nutritional analysis.

Table 3. *Sensory Evaluation of Germinated Brown Rice Bread with Seaweed Powder.*

Substitution level (%)	Texture	Color	Aroma	Taste	Overall acceptance
10	6.03 ± 2.59^{b}	6.4 ± 2.12^{ab}	5.90 ± 2.79^{ab}	6.19 ± 2.54^{b}	6.25 ± 2.24^{ab}
20	6.54 ± 1.51^{c}	6.81 ± 1.57^{b}	6.33 ± 2.27^{b}	6.63 ± 1.88^{c}	6.80 ± 1.93^{c}
30	6.47 ± 1.8^{ab}	6.47 ± 2.19^{ab}	5.99 ± 1.94^{ab}	6.29 ± 2.44^{ab}	6.42 ± 1.94^{bc}
40	6.43 ± 2.30^{ab}	$6. 43 \pm 2.92^{a}$	5.61 ± 2.65^{a}	5.65 ± 2.51^{a}	5.82 ± 2.84^{a}

*Different letters within a row indicate significant differences ($p < 0.05$)

3.5. Nutritional Composition of Germinated Brown Rice Bread with 20% Seaweed Powder Substitution

As shown in Table 4, 100g of germinated brown rice bread with 20% seaweed powder substitution provides 275 kcal, which is higher than the energy provided by traditional white bread (268 kcal/100g). Although the germinated brown rice bread has a lower carbohydrate content, its higher fat content (7.79%) contributes to the increased energy value. It is important to note that the fat in the germinated brown rice bread with seaweed powder primarily consists of palmitic acid and linoleic acid, both of which are essential fatty acids found in germinated brown rice flour. These fatty acids play crucial roles in various bodily functions, including vitamin absorption, metabolic processes, and hormone balance (Ikram et al., 2021). Furthermore, the germinated brown rice bread with seaweed powder is a good source of dietary fiber (3.62%), polyphenols (57.0 mg/100g), and Gamma-Aminobutyric Acid (23.7 mg/100g). While the protein content is lower than that of traditional white bread due to the absence of gluten protein in germinated brown rice flour, the protein present is a mixture of plant-based proteins with a high content of essential amino acids, such as glutamic acid, alanine, and glycine [29].

Table 4. *Nutritional Composition of Germinated Brown Rice Bread with 20% Seaweed Powder Substitution*.

Parameters	Unit	Germinated brown rice bread	White bread
Energy	kcal/100g	275	268
Carbohydrate	g/100g	45.4	53
Protein	g/100g	5.71	9.8
Fat	g/100g	7.79	1.8
Total Fiber	g/100g	3.62	1.98
Soluble Fiber	g/100g	1.49	-
Polyphenols	mg GAE/100g	57.0	-
Gamma-Aminobutyric Acid	mg/100g	23.7	-

4. Conclusions

This study demonstrated that the addition of seaweed powder to germinated brown rice bread significantly affected the dough's rheological properties. This, in turn, influenced the specific volume, crumb texture, and overall acceptability of the bread. The germinated brown rice bread with 20% seaweed powder substitution received the highest sensory scores for texture, color, aroma, taste, and overall liking. Furthermore, the incorporation of seaweed powder enhanced the nutritional value of the final product. 100g of germinated brown rice bread with seaweed powder provides 275 kcal, with 45.4% carbohydrates, 5.71% protein, 7.79% fat, and 3.62% total dietary fiber. It also contains 0.057% polyphenols and 23.7 mg/kg of Gamma-Aminobutyric Acid. These results highlight that the combination of germinated brown rice flour and seaweed powder improves the nutritional quality of the bread compared to traditional white bread.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request

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Nguyen Dang My Duyen received the B.S and M.S. degrees from the Ho Chi Minh City University of Technology (BKU), Ho Chi Minh City, Vietnam, in 2003 and 2016. She is currently a lecturer with the Department of Food Technology, Ho Chi Minh City University of Technology and Education (HCMUTE), Vietnam. Her research interests include cereal, bread, pasta, modified starch.

Email: myduyen@hcmute.edu.vn. ORCID: https://orcid.org/0009-0009-2146-2937

Pham Thanh Tung received his B.S. degree in Food Science and Technology from Nong Lam University (Ho Chi Minh City, Vietnam) in 2015 and his M.S. degree in Product Development from Kasetsart University (Bangkok, Thailand) in 2018. He is currently a Ph.D. candidate in Food Science at the Hungarian University of Agriculture and Life Sciences (Budapest, Hungary). His research focuses on starch, fiber, and related product development. From 2019 to 2021, he lectured at Ho Chi Minh City University of Technology and Education (Vietnam). Email: tungpt@hcmute.edu.vn. ORCID: https://orcid.org/0000-0002-7911-6430