



Physico-chemical properties of sandwich bread formulated with sweet potato–yeast blends

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ABSTRACT

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Consumer demand for nutritious and healthy goods made from plant-based functional foods is expanding. This study replaced a portion of the wheat flour in sandwich bread recipes with a mixture of white-fleshed sweet potato (WFSP) and orange-fleshed sweet potato (OFSP), ranging from 10% to 25%, based on five sandwich bread recipes. A Box-Behnken Design model was created with three factors: WFSP (5–10%), OFSP (10–15%), and instant dry yeast (0.3–0.5%). Response Surface Methodology was used to optimize input variables for the optimal expansion volume and β -carotene content in sandwich bread processing. Among the five developed formulations, formula A3, replacing 20% of the sweet potato flour mixture (7.5% WFSP, 12.5% OFSP, 80% wheat flour), was selected due to its favorable textural features and higher levels of fiber, resistant starch, total polyphenol content, and β -carotene content (3.56%, 3.59%, 12.87 mg GAE/g, and 17.21 μ g/g, respectively) compared to the control sample A0. Furthermore, the optimal conditions for producing sandwich bread with WFSP, OFSP, and instant dry yeast were identified as 10%, 15%, and 0.5%, respectively. Under these conditions, the bread expanded by 5.63 times and contained 24.13 μ g/g of β -carotene. The findings demonstrate the potential for incorporating WFSP and OFSP in sandwich bread manufacturing. The effective utilization of low-cost sweet potato raw materials not only enhances the nutritional and functional value of the product by adding natural colors but also reduces reliance on imported raw materials, thereby supporting the long-term development of the country's sweet potato value chain.

Contribution/Originality: This is one of the few research studies that have successfully exploited and integrated sweet potato varieties in Vietnam, focusing on high quality and low cost. The research partially replaces wheat flour in bread-making recipes and combines it with yeast to create a familiar and popular product within culinary culture.

1. INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is cultivated extensively in Vinh Long province, Vietnam, which is the largest sweet potato-growing area in the Mekong Delta, known for its many famous sweet potato varieties. This tuber has evolved into an economically significant agricultural crop and is now regarded as one of the seven most important staple food crops worldwide. Among the sweet potato varieties, OFSP grown in Vinh Long province has been

comprehensively evaluated and demonstrated to possess superior nutritional properties (Dung, Giau, Van Hao, Minh, & Thuy, 2024). Besides, WFSP are rich sources of polyphenols and have high antioxidant activity.

In food processing, blending, or the process of combining two or more ingredients to form a homogeneous product, is used to improve functional characteristics and nutritional value. Steamed bread with purple-fleshed sweet potato (PFSP) powder demonstrated increased color, polyphenol content, and antioxidant activity (Cui & Zhu, 2022). Wang et al. (2021) also found that the combination might improve the texture of extruded rice products. The addition of 20% PFSP powder to wheat flour in the making of noodles was highly received by consumers and improved their nutritional composition (Uthai, Suktanarak, Chetyakamin, & Thamrongchot, 2022). Using OFSP powder to partially replace wheat flour in the noodle production formula resulted in a product with good flavor, texture, and acceptance, as well as increased nutritional value. When yellow maize and orange-fleshed sweet potato flours were used to replace wheat substitutes in the bread production formula, the product had superior nutritional value (especially in terms of carbohydrate, fiber, fat, ash, calcium, and β -carotene, the precursor of vitamin A), as well as good flavor and acceptance (Bibiana, Grace, & Julius, 2014). Investigated how steamed PFSP powder affects the physicochemical qualities of sandwich bread. The results demonstrated that PFSP supplementation had a substantial effect on the bread's color and anthocyanin concentration. Sandwich bread with 33% PFSP exhibited a lovely purple color, enhanced expansion over the control sample, and improved overall product quality with higher fiber content and antioxidant activity.

The combination of several colored sweet potato cultivars has the potential to yield a range of items, including noodles, vermicelli, steamed bread, bread, and cakes. Sweet potato flours can be blended in various amounts to create products with better nutritional content and acceptable sensory quality. However, while the majority of studies have focused on the effects of purple sweet potato powder on processed wheat flour products (Hu, Zhou, Zhang, Zhou, & Zhang, 2023; Shan, Zhu, Peng, & Zhou, 2013; Uthai et al., 2022), very few studies have examined the quality characteristics of processed products derived from different colored sweet potatoes that are combined to fully exploit their valuable bioactive compounds. The use of a combination of sweet potato powder (orange and white flesh) and tuber form (steamed and shaped) in sandwich bread compositions is still relatively limited in research. This addition has a variety of effects on the product's physicochemical characteristics. Therefore, the presence of instant dry yeast plays a significant role. Instant dry yeast helps bread rise and feel airy. It works by creating carbon dioxide gas, which is trapped in the dough, causing it to expand and lighten. Yeast not only increases volume but also improves flavor, texture, crumb structure, color, and overall quality of baked foods. Properly combining yeast, flour, and water provides sufficient soluble protein and sugar for fermentation. In general, 2% yeast is often mixed with 100% flour in bread recipes (Mondal & Datta, 2008). As the yeast concentration increases, so does the volume of the dough. Yeast is therefore an important ingredient in bread manufacturing. It also acts as a catalyst for fermentation, which converts dense dough into a well-risen loaf of bread. When flour, water, and yeast are combined, enzymes in the yeast and flour convert large starch molecules into simple sugars. Yeast metabolizes these simple carbohydrates, producing carbon dioxide and ethyl alcohol, which form bubbles in the dough. The dough contains a strong, elastic gluten network; carbon dioxide becomes trapped within the air bubbles and causes the dough to inflate. The dough swells as more and smaller carbon dioxide-filled air bubbles form (Swami, Thakor, & Murudkar, 2015).

This study investigates the physico-chemical properties of sandwich bread produced by blending proportions of OFSP and WFSP powder, replacing part of the wheat flour, together with the addition of fleshy parts of both sweet potato varieties and instant dry yeast to finally establish a theoretical and practical basis for the effective use of naturally colored sweet potato forms to develop food products with a higher nutritional value.

2. MATERIAL AND METHODS

2.1. Preparation of Sweet Potato and its Powder

OFSP and WFSP tubers were collected from a growing site in Vinh Long Province, Vietnam. After harvesting, they were transported to Can Tho University's laboratory. The tubers were then processed to remove damaged and

diseased specimens. The tubers of good quality were washed, peeled, cut into 1 x 1 x 1 cm cubes, and frozen at -20°C for future research. OFSP and WFSP flesh cubes were cooked for 3 minutes before performing the experiment. Additionally, the OFSP and WFSP powders used in this investigation were prepared according to established protocols.

2.2. Preparation of Sandwich Bread

In addition to the flour (wheat flour - Bakers' Choice and self-prepared OFSP and WFSP powders), the other ingredients used in the sandwich bread recipe are fixed, including: 27 g of margarine (Tuong An, Vietnam), 27 g of sugar, 2.7 g of salt, 117 g of fresh milk (TH True Milk, Vietnam), 1.8 g of yeast (Lesaffre - Red Saf-instant Dry Yeast, France), and 54 g of eggs.

The mass of wheat flour, OFSP powder, and WFSP powder was manufactured as shown in Table 1, with the control sample (recipe A0) containing only wheat flour. In recipes A1 to A4, sweet potato powder (OFSP powder and WFSP powder) replaced some of the wheat flour, with percentages ranging from 10% to 25%. The flour/powder ingredients (wheat and sweet potatoes) were modified so that the total weight of each batch was 490.5 g.

An automatic bread machine (PETRUS PE9600, China) was used with a 165°C baking temperature. The overall mixing, proofing, and baking time was approximately 3 hours and 20 minutes. The sandwich bread was evaluated for moisture, expansion volume, hardness, color, and bioactive components (TPC and β -carotene).

Table 1. Recipes for making sandwich bread with different combinations of wheat flour, OFSP, and WFSP powder.

Ingredients (g)	A0	A1	A2	A3	A4
Wheat flour	261	235	222	209	196
WFSP powder	0	6.5	13	19.5	26
OFSP powder	0	19.5	26	32.5	39

Note: With A0 as the control sample (all wheat flour), the sandwich bread recipes with the ratio of WFSP powder: OFSP powder: wheat flour (%): A1 is 2.5:7.5:90, A2 is 5.0:10:85, A3 is 7.5:12.5:80, and A4 is 10:15:75.

2.3. Experimental Design Using Supplementation Amounts of WFSP, OFSP (Pieces), and Instant Dry Yeast

The previous experiment's data was utilized to create a formulation with OFSP and WFSP powder ratios, substituting a portion of the wheat flour. The acquired data was optimized using the Box-Behnken design (BBD) and response surface methodology (RSM). The concentrations of WFSP and OFSP tuber flesh, and instant dry yeast ranged from 5-10%, 10-15%, and 0.3-0.5%, respectively. The low and high levels of each element were coded as -1 and +1, respectively, with zero being the central value (Table 2). The study's dependent variables included expansion volume and β -carotene content. BBD was applied with 18 trials, with 6 runs taking place at the central points, each trial repeated 3 times. RSM from Statgraphic (XV.I) software was applied to optimize the factors.

Table 2. Independent variables with range and factor level.

Variables	Coded	Range and levels		
		-1	0	+1
WFSP flesh (%)	X ₁	5	7.5	10
OFSP flesh (%)	X ₂	10	12.5	15
Instant dry yeast (%)	X ₃	0.3	0.4	0.5

2.4. Physicochemical Properties

Hardness. The TA.XTplusC-Texture Analyzer (Stable Micro Systems, England) was used to assess hardness (g force). A bread loaf was cut into 2 cm thick slices and placed on the texture analyzer platform. The sliced bread was compressed with a cylindrical probe under 50% strain. Bread thickness and diameter were used to calculate the spread factor (Hussain, Anjum, Butt, Khan, & Asghar, 2006).

Color values (L^* , a^* and b^*) were read from a Hunter Lab Colorimeter (Color Flex, USA).

Expansion volume (times) was calculated through the volume ratio of the sandwich bread before baking and after finishing the product (Thuy et al., 2023).

The proximate composition of sandwich bread, including moisture, protein, lipid, fiber, and ash content, was determined according to the AOAC (2005) standard method, while carbohydrates were analyzed using (AOAC, 1980). *Resistant starch (RS)* was analyzed according to the method published by McCleary, McNally, and Rossiter (2002). *Total polyphenol content (TPC)* was measured in mg GAE/g by Folin-Ciocalteu assay (Philpott, Gould, Lim, & Ferguson, 2004). *β -carotene content ($\mu\text{g/g}$)* was determined according to the method of Fikselová, Šilhár, Mareček, and Frančáková (2008).

2.5. Scanning Electron Microscopy

Scanning electron microscopy (SEM) was conducted using a Hitachi S-4800 scanning electron microscope (Japan), as described by Zambelli et al. (2018).

2.6. Statistical Analysis

The trials were conducted three times, and the results are presented as mean $\pm$ standard deviation (STD). The regression equations were calculated by fitting a quadratic polynomial model to the experimental mean data using Statgraphic XV.I software. The statistical significance of the model terms was determined through an analysis of variance at a 5% confidence level. The coefficients of determination (R^2) were used to evaluate the model's ability to accurately describe the response variables.

3. RESULTS AND DISCUSSION

3.1. Effect of Partial Replacement of Wheat Flour with OFSP and WFSP Powder Blends on Sandwich Bread Quality

3.1.1. Physicochemical Properties of Sandwich Bread

The results in Table 3 reveal that altering the flour combination in the formulas resulted in a considerable change in moisture content. The sandwich bread baked from recipe A4 had the lowest moisture content (31.80%), while the sample from recipe A0 had the highest (35.36%). Thus, as the amount of mixed flour used increases, the moisture content of the bread sample decreases, which does not impair the bread's deliciousness when eaten but also has the potential to lengthen the product's shelf life. Meng, Xu, Wu, and Feng (2022) found that as the amount of orange-fleshed sweet potato flour increased, the flour's water absorption capacity increased first, then decreased, possibly due to differences in the content and size of starch and dietary fiber granules among varieties, as well as the number of hydroxyl groups in the fiber.

Table 3. Physicochemical properties of sandwich bread prepared by replacing a part of wheat flour with OFSP and WFSP powder according to different recipes.

Parameters	Formulas				
	A0	A1	A2	A3	A4
Moisture content (%)	35.36 ^e	34.55 ^d	33.40 ^c	32.54 ^b	31.80 ^a
Expansion volume (times)	4.66 ^d	4.10 ^c	3.90 ^{bc}	3.77 ^b	3.30 ^a
Hardness (g force)	13.23 ^a	19.97 ^b	35.28 ^c	39.85 ^d	46.50 ^e
L*	60.45 ^a	62.78 ^b	63.57 ^{bc}	64.28 ^c	68.09 ^d
a*	8.61 ^a	9.73 ^b	10.33 ^c	11.43 ^d	11.88 ^d
b*	31.02 ^a	49.60 ^b	53.13 ^c	55.32 ^d	59.16 ^a
TPC (mg GAE/g)	1.52 ^a	6.54 ^b	9.54 ^c	12.87 ^d	15.43 ^e
β -carotene ($\mu\text{g/g}$)	1.16 ^a	9.65 ^b	15.69 ^c	17.21 ^d	20.68 ^e

Note: Mean values in the same row followed by different superscript letters (a, b, c, d, e) are significantly different ($P \leq 0.05$).

L*, a*, b* denote color values the CIELAB system (L*: lightness, a*: green–red, b*: blue–yellow).

The expansion of sandwich bread varied significantly among the prepared samples (Table 3), with sample A0 having the highest expansion (4.66 times) and sample A4 having the lowest (3.30 times). Mitiku, Abera, Bussa, and

Abera (2018) published similar findings, demonstrating that replacing wheat flour with sweet potato flour in increasing quantities reduced loaf growth when compared to the control sample. The bread recipe's ratio of WFSP and OFSP powder made the dough drier, and as a result, reduced the loaf's rise. It is suggested that the inclusion of sweet potato powder reduces the amount of gluten in the gluten-starch matrix. As a result, the gluten-starch matrix loses its ability to retain the gas generated during baking and disintegrates. Gluten serves as the bread's skeleton, trapping CO₂ generated during fermentation and allowing the dough to rise. The use of gluten-free powder lowered the amount of CO₂ contained in the dough and prevented the sandwich bread from rising excessively (Makinde & Akinoso, 2014). Steam generated during baking increased the pressure within the gas bubbles, causing the loaf to collapse (Mills, Wilde, Salt, & Skeggs, 2003). Wang, Sun, Zhou, and Chen (2012) also found that adding dietary fiber to wheat generally reduces the activity of gluten proteins by slowing and weakening dough expansion.

The usage of WFSP and OFSP powder in sandwich bread formulas had a significant impact on the product's hardness. The hardest sample was A4 (46.50 g force), while the softest was A0 (13.23 g force) (Table 3). The findings were quite similar to those published by Cao, Zhang, Guo, Dong, and Li (2019), who discovered that steamed bread with more than 30% potato pulp content reduced starch-gluten interaction and had discontinuous network structures. Sweet potato lacks gluten protein; therefore, adding high levels of sweet potato powder reduced the amount of gluten protein, which resulted in the formation of a strong three-dimensional network structure inside the dough that made it more difficult to hold air, and made the bread have a tight tissue structure and thus increased hardness (Cao et al., 2019). Furthermore, the increase in hardness may be due to an increase in dietary fibres from OFSP flour (Van Hal, 2000), which would interfere with the gluten network, resulting in a decrease in bread volume (Morris & Morris, 2012).

All L*, a*, and b* values for the sandwich bread samples offered in the recipes were significantly different (Table 3). Sample A0 had the lowest L* value (60.45), while sample A4 had the highest (68.09). As the sweet potato powder replacement ratio grows, the L* value tends to increase as well. Adding extra sweet potato powder, particularly WFSP powder, to a wheat flour mixture tends to increase the L* value because it has a lighter hue than wheat flour. Similarly, the L* value range tendencies rose when white sweet potato inulin extract was introduced and soy flour was substituted for white bread (Yudhistira, Saputri, & Prabawa, 2022).

The b* value, which indicates the recipe's yellowness, increased dramatically from 31.02 (A0) to 59.16 (A4) as the sweet potato powder ratio increased. The use of WFSP and OFSP powder blends in the recipe produced a brighter, orange-yellow loaf. There was a favorable association between the b* (yellowness) value and β -carotene concentration. The orange-yellow color of sweet potato powder is caused by the presence of carotenoid pigments, which impact the red-green hue (Van Hal, 2000). Pasqualone, Caponio, and Simeone (2004) similarly, a favorable connection was found between b* and carotenoids in durum wheat semolina.

In addition, increasing the replacement ratio of WFSP and OFSP flour also increased the TPC and β -carotene contents of sandwich bread (Table 3). TPC and β -carotene were measured lowest in sandwich bread sample A0 (1.52 mg GAE/g – 1.16 μ g/g) and highest in sample A4 (15.43 mg GAE/g – 20.68 μ g/g). When replacing part of the wheat flour with a mixture of WFSP and OFSP powder, a natural source of carotenoids (mainly from OFSP) was added to the dough. Therefore, the higher the proportion of OFSP powder added to the dough, the higher the β -carotene content in the product. Similarly, TPC increased with increasing the proportion of WFSP and OFSP powder because WFSP and OFSP have high TPC, thus increasing the source of phenolic compounds for bread compared to using only refined wheat flour (which is low in phenolics). Meng et al. (2022) found that the amount of TPC and β -carotene in bread varied depending on the flour variety used. Similarly, replacing wheat flour with white-fleshed sweet potato flour combined with corn starch enhanced the TPC of the shortbread biscuits by over 50% (Ozgolet, Belkacemi, & Arici, 2025). Furthermore, the orange sweet potato contains a significant concentration of phenolic chemicals that have antioxidant properties (Oluniyo, Omoba, Awolu, & Olagunju, 2021). The refined wheat flour does not contain β -carotene (Calderón de la Barca et al., 2022), so using OFSP as a measure to supplement this content

and contribute to reducing vitamin A deficiency in the diet of the community. According to Alam, Rana, and Islam (2016), OFSP are a promising plant source of β -carotene, which can be transformed into vitamin A. Thus, while the partial substitution of sweet potato flour altered the physical and chemical features of the sandwich bread, the alterations were favorable to the product, as mentioned previously. From the planned formulations, formulation A3 (7.5% WFSP powder: 12.5% OFSP powder: 80% wheat flour) demonstrated a considerable improvement in quality, resulting in a food product with human health advantages.

3.1.2. Sandwich Quality Assessment (Comparison of Control Sample with Sample Taken from Recipes)

The data in Table 4 show that replacing some of the wheat flour with a combination of WFSP and OFSP powders altered the quality of the sandwich bread. The carbohydrate content of the sandwich bread from recipe A3 (7.5% WFSP powder: 12.5% OFSP powder: 80% wheat flour) was found to be 41.07%, lower than that of the control product (44.69%). Kidane, Abegaz, Mulugeta, and Singh (2013) discovered that wheat flour is the primary source of carbohydrate content in bread. Sweet potatoes are high in fiber, whereas refined wheat flour has had its bran and germ removed and is very low in fiber.

Therefore, replacing part of the wheat flour with sweet potato flour mixture significantly increased the total fiber content of the formula. The results are quite similar to previous publications (Elkatry et al., 2023; Kidane et al., 2013). Sweet potatoes have a low glycemic index despite their high carbohydrate content (Waidyarathna, Ekanayake, & Chandrasekara, 2021). This demonstrates the benefits of employing sweet potato powder mixes for bread production, including reduced digestibility and additional beneficial components. The A3 sandwich bread sample contained less moisture and fat than the A0 sample. The protein and ash contents did not differ between the two samples.

Increased use of sweet potato powder in the formulation reduces fat content. This was owing to the decreased fat content of OFSP powder compared to wheat flour, as stated by Lyimo, Gimbi, and Shayo (2007). Furthermore, sample A3 contains 1.28 times more total fiber than sample A0 (Table 4). This is most likely due to the fact that refined wheat flour contains a lot of digestible amylopectin but very little resistant starch (RS). As a result, substituting a sweet potato flour mix for some of the wheat flour adds a natural source of RS to the recipe, raising the overall RS content of the bread. The fiber level of the A3 product was practically identical to that of wheat flour bread enhanced with green vegetable powder (1.8–4.0%), as reported by Odunlade et al. (2017). High-fiber foods are indicated for both healthy diets and gastrointestinal problems such as duodenal ulcers, inflammatory bowel disease, irritable bowel syndrome, diverticular disease, constipation, and hemorrhoids.

Table 4. Nutritional value of sandwich bread from A0 (Control sample) and A3 (7.5% WFSP powder, 12.5% OFSP powder, 80% wheat flour).

Parameters	Formula A0	Formula A3
Moisture content (%)	35.36 ^b ± 0.40	31.80 ^a ± 0.20
Protein (%)	11.90 ^a ± 0.48	11.62 ^a ± 0.15
Carbohydrate (%)	44.69 ^b ± 0.30	41.07 ^a ± 0.25
Lipid (%)	3.50 ^b ± 0.18	2.25 ^a ± 0.21
Total fiber (%)	2.78 ^a ± 0.17	3.56 ^b ± 0.13
Ash (%)	2.01 ^a ± 0.15	2.49 ^a ± 0.12
RS (%)	1.02 ^a ± 0.16	3.59 ^b ± 0.15
TPC (mg GAE/g)	1.52 ^a ± 0.10	12.87 ^b ± 0.15
β -carotene (μ g/g)	1.16 ^a ± 0.10	17.21 ^b ± 0.52

Note: Mean values in the same row followed by different superscript letters (a, b) are significantly different ($P \leq 0.05$).

Sample A3 had a somewhat greater RS content (3.59%) than sample A0 (1.02%), as seen in Table 4. Sweet potatoes contain complex carbohydrates, including resistant starch (RS), which is resistant to digestion in the small intestine and acts as dietary fiber (Rosell, Quizhpe, Ayuso, Peñalver, & Nieto, 2024). Brites, Trigo, Carrapiço, Alviña, and Bessa (2011) discovered that raising the RS content of bread greatly decreases the glycemic curve, frequently reversing the insulinogenic effect of wheat flour-based bread. Sample A3 showed considerably higher levels of TPC

and β -carotene (12.87 mg GAE/g and 17.21 μ g/g, respectively) compared to sample A0 (1.52 mg GAE/g and 1.16 μ g/g). Thus, using WFSP and OFSP powders in sandwich bread production has the potential to improve bread's nutritional composition and qualities. OFSP powder is particularly rich in β -carotene, which the body converts into vitamin A, helping to improve eye health and immunity. Both OFSP and WFSP powders can increase the fiber content of bread and reduce sugar absorption in the body. Moreover, the addition of these flours also had a positive effect on the texture of bread, and the color of the product was more vibrant.

3.1.3. Scanning Electron Microscopy (SEM) of Sandwich Bread

Figure 1 depicts scanning electron micrographs of two sandwich samples: control sample A0 and sample A3. The gluten structure and dense pore distribution of the bread can be seen, and the porous sponge microstructure demonstrates that the gluten structure creates a solid form. Specifically, control sample A0's gluten network (Figure 1a) is highly formed, with a few conspicuous starch particles. During the mixing procedure, the gas battery initially introduces dough (Scanlon & Zghal, 2001).

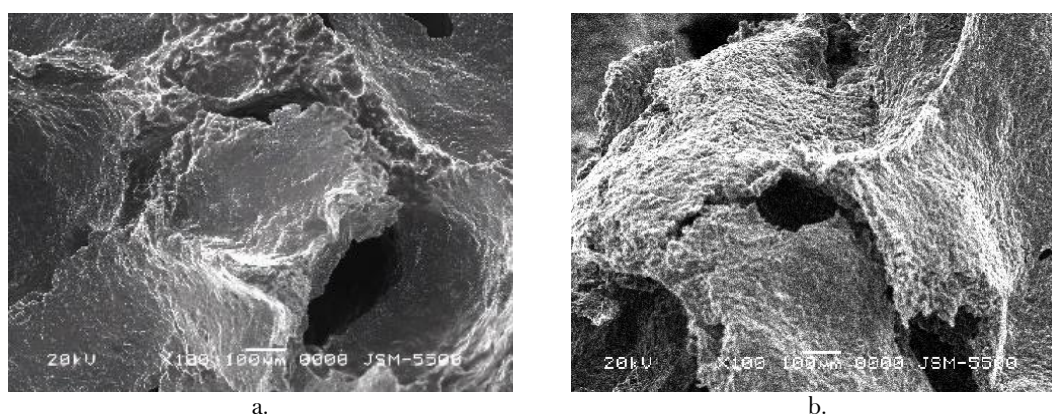


Figure 1. SEM (Magnification $\times 100$) of sandwich bread (a) Sample A0 (control sample) and (b) Sample A3 (7.5 % WFSP powder: 12.5 % OFSP powder: 80 % wheat flour).

Meanwhile, sample A3 (Figure 1b) shows a compact and continuous matrix with reduced dimensions; nonetheless, the creation of the gluten network in these samples may be slightly interrupted due to the lower gluten content after replacing part of the wheat flour. Similar to the study by Liu, Duan, Mao, and Yu (2020), when the amount of flaxseed flour increased, the wet gluten concentration of the mixed powder decreased because the gluten content was diluted and gluten structure formation was avoided. Liu, Mu, Sun, Zhang, and Chen (2016) further explained that using a large proportion of potato flour in bread improved the surface connectivity between starch granules and gluten, making gluten strands in the dough difficult to observe.

3.2. Effects of WFSP Flesh, OFSP Flesh and Instant Dry Yeast Supplementation on the Expansion Volume and B-Carotene Content of Sandwich Bread

3.2.1. Expansion Volume

Analysis of variance (ANOVA) revealed that WFSP flesh (X_1), OFSP flesh (X_2), instant dry yeast (X_3), and X_1X_1 all had significant effects on expansion volume ($P < 0.05$) (Supplement 1). Meanwhile, the effects of X_1X_2 , X_1X_3 , X_2X_2 , X_2X_3 , and X_3X_3 on expansion volume were non-significant ($P > 0.05$). The lack-of-fit test was designed to examine whether the chosen model was appropriate to describe the observed data. The P-value of lack-of-fit in the ANOVA table was greater than 0.05 (0.6927), indicating that the model fit the observed data with a confidence level of 95.0%. The R^2 statistic indicates that the fitted model accounted for 96.01% of the variation in expansion volume. The R^2 adjusted statistic is quite high (95.19%), indicating that it is better to compare models with different independent variables. The estimate's standard error indicates that the residuals have a standard deviation of 0.14. As previously

discussed, the interactions X_1X_2 , X_1X_3 , X_2X_2 , X_2X_3 , and X_3X_3 were removed from the model because they make no meaningful contribution to its correctness. As a result, a novel model for assessing the relationship between expansion volume and influencing factors has been developed.

The regression equation showing the relationship between expansion volume and independent variables was established as seen in Equation 1, with $R^2 = 95.22\%$ and $SEE = 0.14$.

$$Y_1 = -1.453 + 0.402X_1 + 0.074X_2 + 8.138X_3 - 0.021X_1^2 \quad (1)$$

Where Y_1 is expansion volume (times), X_1 is WFSP flesh concentration (%), X_2 is OFSP flesh concentration (%), and X_3 is instant dry yeast concentration (%).

The expansion of a loaf of bread is an essential indicator of the bread crumb structure, as well as the interior's lightness and airiness. A low expansion value denotes a dense, tight, and poorly expanded crumb structure (Nwosu, Owuamanam, Omeire, & Eke, 2014). The response surface plot in Figure 2 demonstrates that WFSP flesh, OFSP flesh, and instant dry yeast all have an effect on expansion volume. When the added WFSP and OFSP flesh contents were fixed at 7.5% (Figure 2a) and 12.5% (Figure 2b), respectively, the expansion volume increased as the instant dry yeast concentration increased, reaching a maximum of 5.47 times with 15% OFSP flesh and 5.56 times with 9.65% WFSP flesh, both at an instant dry yeast concentration of 0.5%.

It is also shown that as the amount of yeast added to Gac aril-supplemented bread increased, the expansion volume also increased, reaching a maximum at a yeast concentration of 0.5%. Instant dry yeast concentration is used to leaven bread. It works by converting sugar into carbon dioxide, causing the dough to rise and become light and airy (Swami et al., 2015). The yeast concentration is increased, then the volume of dough also increases. If the yeast content is insufficient, the fermentation of starch molecules is inadequate, as is the creation of carbon dioxide, preventing the gluten network structure from fully expanding. On the contrary, when the yeast concentration is too high, the expansion force of carbon dioxide generated during fermentation exceeds the endurance of the gluten network structure, causing some internal structural damage and negatively affecting the bread's expansion volume and texture (Wang, Han, Zhang, & Li, 2024).

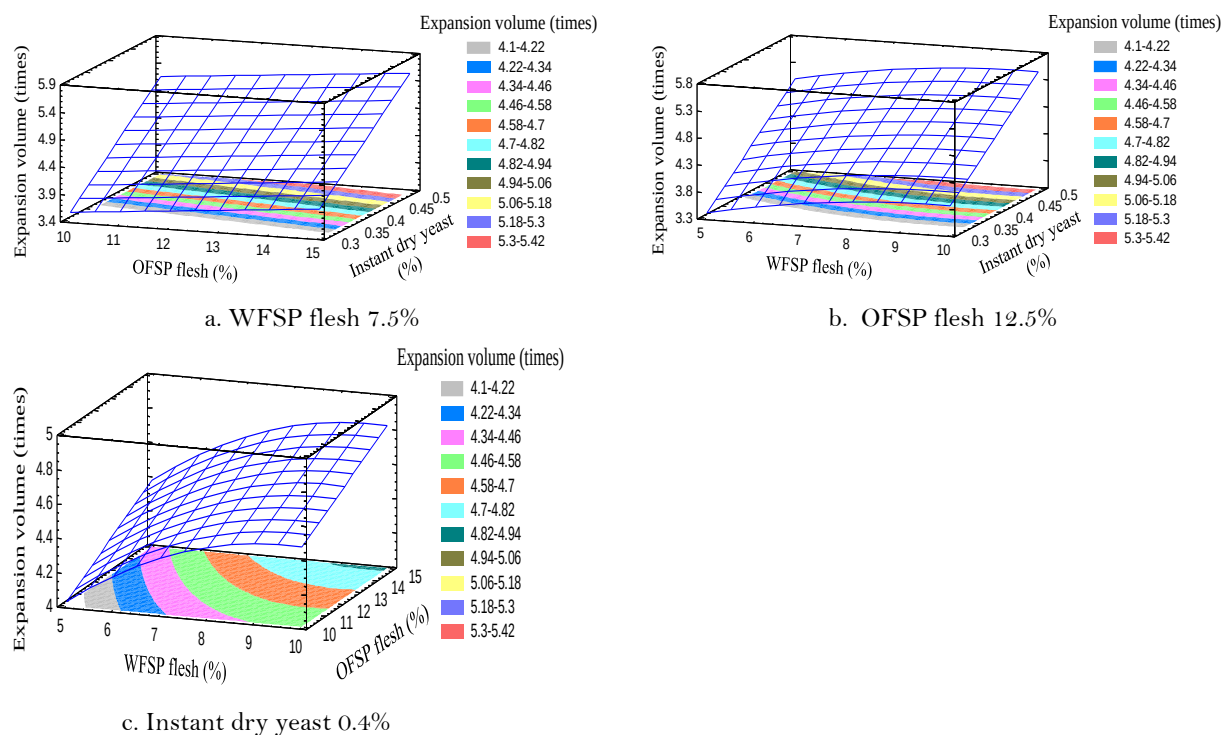


Figure 2. The response surface plot of expansion volume: a. 7.5% WFSP flesh, b. 12.5% OFSP flesh, c. 0.4% instant dry yeast.

When the instant dry yeast concentration was 0.4% (Figure 2c), the expansion volume rose and reached its peak of 8.84 times when WFSP flesh and OFSP flesh concentrations were added at 9.65% and 15%, respectively. The addition of steamed WFSP and OFSP flesh to sandwich bread produced a moister but not soggy dough, allowing the yeast to operate better and generate a superior crust during baking while still retaining shape and expansion. This pattern is remarkably similar to the research by Cao et al. (2019); the addition of potato pulp and steamed purple sweet potato to the bread doubled its volume. Using Statgraphics software (version XV.I) to calculate the ideal response value, the results showed that the expansion volume reached a maximum of 5.65 times when WFSP flesh, OFSP flesh, and instant dry yeast concentrations were introduced at 9.65%, 15%, and 0.5%, respectively.

3.2.2. β -Carotene Content

The ANOVA table dividing the variation for β -carotene content into separate parts for each effect is presented in Supplement 2. In this case, four effects with P-values < 0.05 are identified, including X_1 , X_2 , X_3 , and X_2X_3 . The lack-of-fit test was also conducted, and since their P-value in the ANOVA table is > 0.05 (specifically 0.5292), the model fits the observed data well at the 95% confidence level. The R^2 statistic indicates that the model accounts for 96.47% of the variation in β -carotene content. The adjusted R^2 value, which is more appropriate for comparing models with different numbers of independent variables, was 95.74%. The SEE revealed that the residuals had a standard deviation of 0.34.

Because the interactions X_1X_1 , X_1X_2 , X_1X_3 , X_2X_2 , and X_3X_3 made no meaningful contributions to the model (P values > 0.05), they were eliminated. Using multiple regression analysis, a model was created to assess the impact of variables on β -carotene content (Equation 2) with $R^2 = 96.00\%$ and $SEE = 0.34$.

$$Y_2 = 11.70 + 0.17X_1 + 0.52X_2 - 20.93X_3 + 1.79X_2X_3 \quad (2)$$

Where Y_2 is β -carotene content ($\mu\text{g/g}$), X_1 is WFSP flesh concentration (%), X_2 is OFSP flesh concentration (%), and X_3 is instant dry yeast concentration (%).

Figure 3 displays a response surface plot illustrating the impact of several parameters on the β -carotene content in sandwich bread. When WFSP flesh was supplied at a fixed concentration of 7.5% (Figure 3a), β -carotene content rose from 16.8–24.0 $\mu\text{g/g}$ as OFSP flesh concentration was supplemented, since β -carotene was largely found in OFSP (Dung et al., 2024). Malavi et al. (2022) found that replacing wheat flour with OFSP purée improved the β -carotene content of bread.

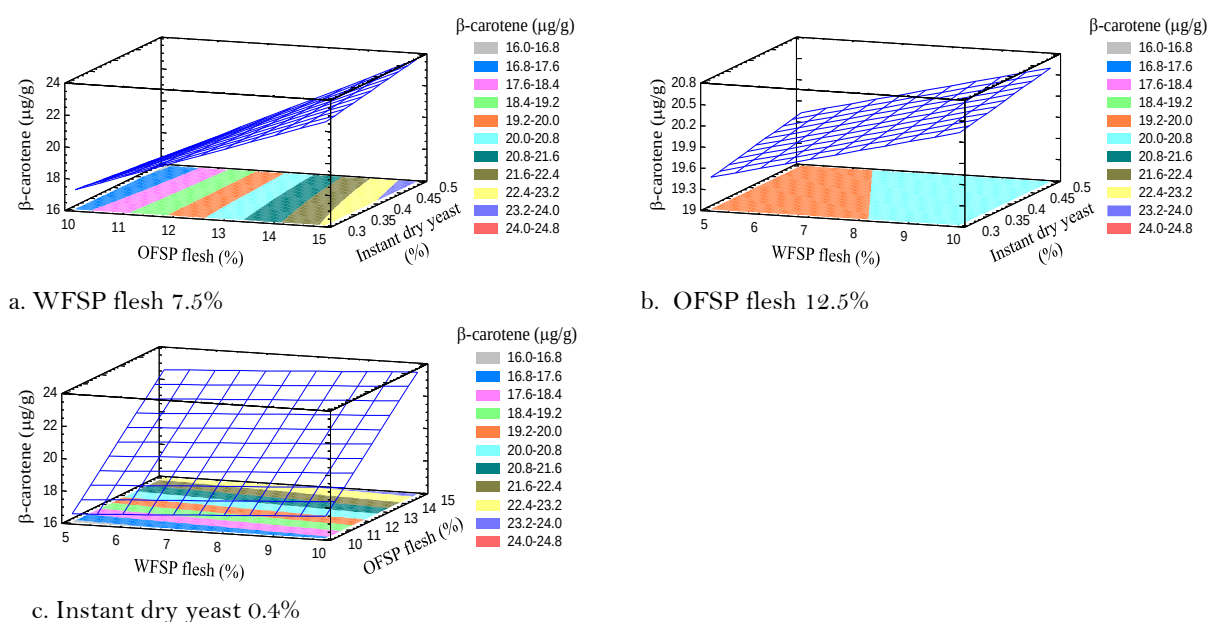


Figure 3. The response surface plot of β -carotene: a. 7.5% WFSP, b. 12.5% OFSP, c. 0.4% instant dry yeast.

OFSP flesh is used as a functional additive in bread to boost the product's provitamin A content. In Figure 3b, OFSP flesh concentration was fixed at 12.5%. Using instant dry yeast did not significantly modify the β -carotene content of sandwich bread, as confirmed in Thuy et al. (2023) investigation. Furthermore, when instant dry yeast concentration was set at 0.4% (Figure 3c), OFSP flesh concentration dramatically increased β -carotene content. WFSP flesh concentration also contributed to an increase in the β -carotene content of the product, but to a much lesser extent, because β -carotene was also present in WFSP at a low content (Kammona, Othman, Jaswir, & Jamal, 2015). Abidin, Jutomo, and Harini (2019) found that using white-fleshed sweet potato flour in biscuit formulations increases the product's β -carotene concentration. The optimal response value was calculated using Statgraphics software (version XV.I) based on the obtained results. The study found that adding WFSP flesh, OFSP flesh, and instant dry yeast at 10%, 15%, and 0.5% concentrations resulted in the highest β -carotene level (24.13 $\mu\text{g/g}$).

3.2.3. Simultaneous Optimization

The obtained responses of expansion volume and β -carotene content were optimized using Statgraphics software (version XV.I) to produce maximum expansion volume and β -carotene content during sandwich bread preparation. The multiple regression method revealed a satisfactory relationship between the response surfaces, with the objective function being the maximum expansion volume and β -carotene content. The concurrent optimization points of all circumstances, as well as the responses, were illustrated by superimposing contour plots (Figure 4). The results showed that the optimal circumstances with WFSP flesh, OFSP flesh, and instant dry yeast concentration were 10%, 15%, and 0.5%, respectively, utilizing Optimize Desirability (Statgraphics Centurion XV.I), with a desirability of 0.97. Under these settings, the expansion volume and β -carotene content reached their optimum values of 5.63 times and 24.13 $\mu\text{g/g}$, respectively, as indicated by asterisks (*) and presented concurrently in Figure 4a, 4b and 4c.

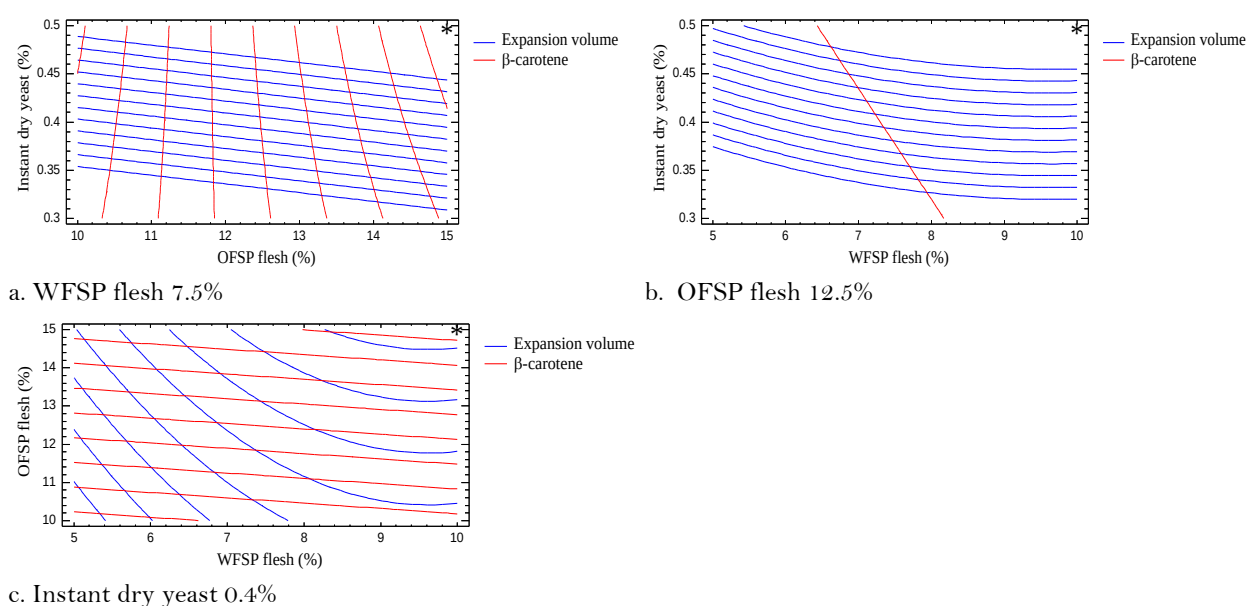


Figure 4. Overlap plots between expansion volume (times) and β -carotene content ($\mu\text{g/g}$) of sandwich bread.

To ensure that the prediction models' best values were accurate, a validation study was conducted using the recommended optimal values, which included 10% WFSP flesh, 15% OFSP flesh, and 0.5% instant dry yeast concentration. Under optimal conditions, sandwich bread expanded by 5.72 times and contained 23.41 $\mu\text{g/g}$ of β -carotene. The determined values were nearly identical to the expected results, with only a slight deviation (1.57-2.98%), within the permitted limit ($<5\%$).

4. CONCLUSIONS

The physicochemical properties of sandwich breads prepared with partial replacement of wheat flour with OFSP powder and WFSP powder in the formulation, together with the addition of white and orange sweet potato (in flesh), and the impact of yeast on the overall quality were evaluated. SEM images of sandwich bread samples revealed considerable changes in microstructure between the tested samples. The BBD experimental design with RSM was successfully used to model and optimize the parameters of WFSP flesh, OFSP flesh, and instant dry yeast. The study found that incorporating WFSP flesh, OFSP flesh, and instant dry yeast affected the expansion, TPC, and β -carotene content of sandwich bread. The regression equations obtained by the model in this study were extremely trustworthy and could be utilized to regulate product quality on a practical production scale. This study's findings demonstrated the potential for mixing WFSP and OFSP (powder and flesh forms) in sandwich bread making. The effective exploitation of sweet potato raw materials not only contributes to the creation of nutritionally valuable products but also maximizes available local resources at a low cost and aims for the long-term development of this agricultural product across the country.

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