PHYSICOCHEMICAL PROPERTIES OF COMPOSITE FLOUR AND QUALITY OF BREAD SUPPLEMENTED WITH HEAT-MOISTURE TREATED MUNG BEAN POWDER

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SUMMARY

This study aimed to develop wheat-based bread supplemented with heat-moisture treated mung bean powder and to measure the physicochemical properties of the composite flour and bread quality. The addition of modified mung bean powder increased the gelatinization temperature but reduced other pasting properties, swelling index, and solubility. Bread supplemented with modified mung bean powder exhibited a darker color, smaller size, and higher hardness value. Along with the additional increments of the heat-moisture treated mung bean powder into dough, these substituted breads contained lower amounts of rapidly digestible starch (56.39-63.32%) and higher concentrations of resistant starch (17.18-27.00%) as compared to those of wheat-based one (65.38% and 13.32% respectively). Thus, the heat-moisture treated mung bean powder, containing high resistant starch content, potentially reduced the amount of rapidly digestible starch and increased the percentage of resistant starch in the final product. Although the organoleptic profiles of the substituted bread were scored lower than those of the control bread, the composite bread made from 90% wheat flour and 10% heat-moisture treated mung bean powder achieved the highest overall acceptability among the three substituted breads. As a result, this product could be recognized as a "low-carb" bread beneficial for human health.

Keywords: Bread quality, digestibility, heat-moisture treatment, low-carb bread, mung bean powder, physicochemical properties.

INTRODUCTION

Mung bean (*Vigna radiata*) is a highly-consumed legume crop, grown extensively from the lowlands to the mountainous regions in numerous Asian countries (Hou *et al.,* 2019). It is valued for its nutritional content, providing a well-balanced source of protein, amino acids, dietary fiber, minerals, vitamins, and a significant number of bioactive compounds (*Gan et al.,* 2017). Mung bean is also a key source of resistant starch (RS) in human diets (Duyen *et al.,* 2020), as starch accounts for over half of the mung bean's total weight, with amylose making up about 40% of the total starch. Studies have shown that heat-moisture treatment can significantly enhance the RS content in mung beans (Li, Gao, 2010). These modified mung beans can be eaten directly as seeds, sprouts, or in various processed forms. They are commonly used in soups, congee, and to improve the nutritional value of noodles, confectionery, and various snacks (Hou *et al.,* 2019). Using affordable staples like mung bean to supplement wheat flour (WF) can boost the nutritional quality of wheat-based products.

Wheat-based foods, such as bread, contain large amounts of quickly digestible starch, causing an undesirable spike in blood sugar levels after eating (Tien *et al.,* 2018). Therefore, there is a growing interest in developing carbohydrate-rich foods that are healthier for consumers while maintaining the quality of the bread. According to Hung et al. (2014), adding fiber often leads to lower quality bread, with reduced loaf volume, firmer crumb, and darker appearance compared to bread made from white flour. In contrast, RS provides health benefits similar to dietary fiber and improves the physicochemical properties of food during processing (Tien *et al.,* 2018). Replacing WF study tackled this issue by incorporating heat-moisture treated mung bean powder into bread dough, substituting 10%, 20%, and 30% of the WF. The study also examined the physicochemical properties of the composite flour and the quality of the bread.

MATERIALS AND METHODS

Materials

Mung bean (DX208, SSC, Vietnam), all-purpose wheat flour (Meizan, Vietnam), refined sugar (Bien Hoa, Vietnam), salt (Thanh Phat, Vietnam), and instant dry yeast (Mauripan, Vietnam) were purchased in Coop-mart supermarket.

Enzymes including α-amylase from *Aspergillus oryzae* (30 U/mg) and amyloglucosidase from *Aspergillus oryzae* (300 U/mL), and other chemicals were supplied by Sigma-Aldrich Company (St. Louis, Mo, USA).

Methods

Preparation of heat-moisture treated mung bean powder

Heat-moisture treated mung bean powder (HMT-MBP) was produced based on the modified method of Li and Gao (2010). Mung bean seeds were dehulled after being soaked in distilled water at room temperature for 3 hours, dried in an oven at 50^oC for 24 hours, milled, and then sieved through 250-mesh into fine powder. The obtained powder was mixed well with water to achieve moisture levels of 30%, stabilized at room temperature for 24 hours, heated at 100^oC for 6 hours, dried at 50^oC to the uniform moisture content of 10%, milled, and then sieved through 250-mesh. The final product, HMT-MBP, was collected for the preparation of composite flour and the bread-making procedure.

Preparation of composite flour and baking process

HMT-MBP was utilized to substitute WF at diverse concentrations to formulate the composite flour for baking bread. These replacement levels of HMT-MBP consisted of 10% (10MBF), 20% (20MBF), and 30% (30MBF). Additionally, bread using 100% WF was designated as WFB, while 10MBB, 20MBB, and 30MBB indicated bread prepared from 10MBF, 20MBF, and 30MBF, respectively.

All ingredients including 100 g of the composite flour of WF and HMT-MBP, 6 g of sugar, 1.5 g of salt, 2 g of yeast, and 62.6 mL of water were mixed well to form a dough, which was fermented at 30^oC with a relative humidity of 85% for 90 minutes and a requirement of kneading every 30 minutes. The fermented output was divided into several small pieces, which were molded, later proofed at 38^oC for 33 minutes with the relative humidity of 90 minutes, shaped, and finally baking oven at 180^oC for 20 min. The final products, breads, were packed in plastic containers and further analysed.

Physicochemical properties of composite flour

A micro visco-amylograph (Brabender GmbH & Co. KG, Germany) was applied to evaluate the pasting properties of composite flour according to the procedure described by Tien et al. (2019). The data was automatically recorded and expressed as gelatinization temperature (GT), maximum viscosity (MV), trough viscosity (TV), final viscosity (FV), breakdown (BD), and setback (SB). Furthermore, swelling and water solubility indexes of composite flour were measured based on the method described by Tien et al. (2019).

Quality of bread

The *in vitro* digestibility of bread was manipulated based on the method of Tien et al. (2019) and expressed as rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). In this assay, the combination of α-amylase (1400 U/mL) and amyloglucosidase (13 AGU/mL) was first employed, and amyloglucosidase (50 AGU/mL) was then applied to hydrolyze to release glucose.

The color attributes of bread crumb and crust were identified using the Chroma meter PCE-CRM 40 and exhibited as L*, a*, and b* values. The rapeseed displacement approach was conducted to estimate the volume of bread. The textural properties including hardness, springiness, and gumminess of breads were determined by a textural analyzer according to the operating conditions instructed by Tien et al. (2019). A five-point hedonic rating scale was performed by 30 untrained panelists, which was used to score breads in terms of color, appearance, texture, odor, flavor, and overall acceptability.

Statistical analysis

All measurements were manipulated in triplicates. One way analysis of variance with Tukey's multiple-range test to compare the averages of results at $p < 0.05$.

RESULTS AND DISCUSSIONS

Physicochemical properties of composite flour

Table 1. Physicochemical properties of composite flour

Samples	GT	MV	TV	FV	BD	SB	Swelling index (g/g)	Solubility (g/g)
WF	57.57 ± 1.19^c	964 ± 6^a	950 ± 25^a	1050 ± 56^a	418 ± 20^a	413 ± 12^a	6.49 ± 0.12^a	4.65 ± 0.56^a
10MBF	59.77 ± 0.47^b	916 ± 17^a	846 ± 44^b	965 ± 16^{ab}	380 ± 14^b	352 ± 10^b	5.57 ± 0.20^b	3.64 ± 0.58^{ab}
20MBF	62.23 ± 0.49^a	876 ± 6^b	742 ± 32^c	911 ± 69^b	357 ± 6^{bc}	328 ± 2^c	5.17 ± 0.03^{bc}	2.66 ± 0.59^{bc}
30MBF	63.5 ± 0.46^a	773 ± 41^b	632 ± 13^d	782 ± 19^c	329 ± 13^c	311 ± 8^c	4.78 ± 0.30^c	1.34 ± 0.59^c

[1] HMT-MBP, Heat-moisture treated mung bean powder; WF, wheat flour; 10MBF, composite flour prepared from 90% WF and 10% of HMT-MBP; 20MBF, composite flour prepared from 80% WF and 20% of HMT-MBP; 30MBF, composite flour prepared from 70% WF and 30% of HMT-MBP.

[2] GT, gelatinization temperature (°C); MV, maximum viscosity (BU); TV, trough viscosity (BU); FV, final viscosity (BU); BD, breakdown (BU); SB, setback (BU).

[3] Data followed by the same superscript letter in the same column was not significantly different ($p > 0.05$).

The physicochemical properties of the composite flours are shown in Table 1. The gelatinization temperature (GT) of the bread increased with higher levels of HMT-MBP substitution, while other pasting properties, the swelling index, and solubility decreased. This outcome can be attributed to differences in protein and amylose content. Protein denaturation and starch crystallization occur during heat-moisture treatment and baking, leading to the formation of protein-starch complexes. The more these complexes are formed, the less free starch remains, resulting in a higher pasting temperature. Additionally, the lower maximum and final viscosities of the composite flours are mainly due to reduced swelling and collapsing of the short-chain molecules in mung bean flour created during heat-moisture treatment (Tien *et al.,* 2019). The decrease in the swelling index of the composite flours could be due to the rearrangement of starch crystallites, the formation of amylose-amylopectin complexes, and the effective acceleration of molecular rearrangement and formation of starch-lipid complexes after treatment. Furthermore, the reduction in solubility of the composite flours might be due to the internal rearrangement of granular starch structures, the generation of amylopectin branches, and the presence of amylose-lipid complexes (Zavareze, Dias, 2011).

Physical characteristics of bread

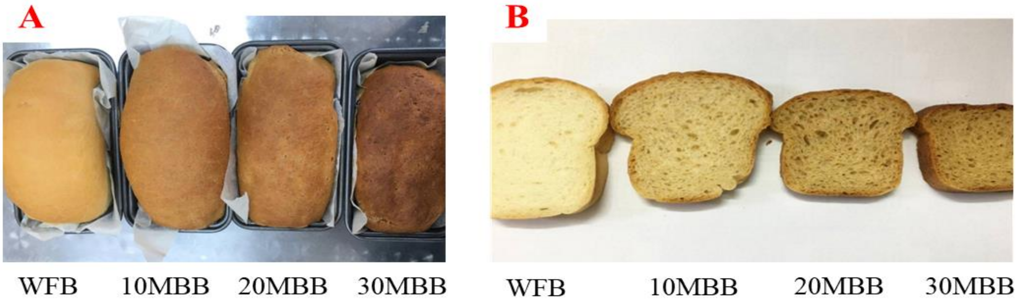

Figure 1. Photograph (A) and cross-sectional image (B) of substituted bread

[1] WFB, bread made from WF; 10MBB, composite bread made from 10MBF; 20MBB, composite bread made from 20MBF; 30MBB, composite bread made from 30MBF; Abbreviations of 10MBF, 20MBF, and 30MBF are the same as in Table 1.

Figure 1 shows the appearance and cross-sectional view of the substituted bread, while Table 2 presents the color attributes of the crust and crumb. The shape of all substituted breads was similar to WFB, but they exhibited a rougher surface and darker crust and crumb color. The intensity of roughness and color increased with higher levels of HMT-MBP substitution. These results were consistent with the decreased L* values and increased a* and b* values of the crust and crumb shown in Table 2. The darker color of the bread supplemented with HMT-MBP can be attributed to the high protein content of mung bean. Higher protein and starch levels in the recipe increase the likelihood of melanoidin formation through the Maillard reaction, resulting in a darker brown color.

Table 2. Color attributes of crust and crumb bread

Samples	Crust			Crumb		
	L	a	b	L	a	b
WFB	46.96 ± 1.61^{a}	44.37 ± 2.64^{a}	25.01 ± 1.31^{a}	50.92 ± 0.12^{a}	15.69 ± 4.47^{c}	11.88 ± 2.52^{d}
10MBB	36.80 ± 1.60^{b}	53.99 ± 7.32^{a}	36.76 ± 2.27^{b}	46.25 ± 1.16^{b}	28.65 ± 2.63^{b}	27.00 ± 0.26^{c}
20MBB	31.10 ± 0.96^{c}	53.99 ± 7.32^{ab}	43.21 ± 2.76^{c}	39.20 ± 1.00^{c}	38.52 ± 2.06^{a}	33.21 ± 2.92^{b}
30MBB	29.43 ± 0.13^{c}	64.64 ± 2.16^{b}	60.53 ± 1.46^{d}	39.10 ± 1.93^{c}	40.25 ± 0.78^{a}	40.00 ± 2.25^{a}

[1] Abbreviations are the same as in Figure 1.

[2] Data followed by the same superscript letter in the same column was not significantly different ($p > 0.05$).

The volume of the substituted bread is shown in Table 3. The substitution of HMT-MBP significantly reduced the bread's volume. This finding is consistent with Figure 1B, where the bread size decreased with higher concentrations of HMT-MBP added to WF. The reduction in bread volume can be attributed to the lack of gluten in

HMT-MBP. Previous research has confirmed that the reduced elasticity and lower extensibility of the dough are due to the decreased gluten content in the composite flour (Tien *et al.,* 2018).

Table 3. Volume and textural properties of substituted bread

Samples	Volume (cm^3)	Textural properties		
		Hardness (N)	Stringiness (mm)	Gumminess (N)
WFB	827.9 ± 2.6^{a}	2.88 ± 0.03^{d}	15.23 ± 0.35^{a}	1.89 ± 0.03^{d}
10MBB	751.1 ± 1.2^{b}	6.47 ± 0.36^{c}	13.87 ± 0.34^{b}	2.54 ± 0.27^{c}
20MBB	642.4 ± 2.3^{c}	7.80 ± 0.78^{b}	12.82 ± 0.13^{c}	3.23 ± 0.32^{b}
30MBB	499.5 ± 2.5^{d}	13.11 ± 0.68^{a}	10.97 ± 0.32^{d}	5.35 ± 0.17^{a}

[1] Abbreviations are the same as in Figure 1.

[2] Data followed by the same superscript letter in the same column was not significantly different ($p > 0.05$).

Table 3 also presents the textural properties of the substituted bread, including hardness, springiness, and gumminess. The addition of HMT-MBP significantly increased the hardness and gumminess of the bread while reducing the springiness. These results are consistent with previous research described by Tien *et al*., (2018). The changes in the textural properties of the bread can be explained by gluten-starch interactions and starch retrogradation. Solubilized amylose and short-chain molecules in HMT-MBP retrograde more easily during the baking and cooling process, leading to increased stiffness and hardness (Tien *et al.,* 2018). Additionally, the gel formed by short-chain molecules leached from heat-moisture treated starch is stronger than the amylose leached from wheat starch, resulting in higher gumminess.

***In vitro* digestibility of bread**

Table 4. *In vitro* digestibility of substituted bread

Samples	RDS	SDS	RS
WFB	65.38 ± 0.77^{a}	21.92 ± 0.67^{a}	13.32 ± 0.81^{d}
10MBB	63.32 ± 1.29^{a}	17.19 ± 0.24^{b}	17.18 ± 0.64^{c}
20MBB	59.23 ± 0.59^{b}	17.58 ± 0.26^{b}	23.86 ± 0.35^{b}
30MBB	56.39 ± 1.27^{b}	14.61 ± 0.90^{c}	27.00 ± 0.53^{a}

[1] Abbreviations are the same as in Figure 1.

[2] RDS, rapidly digestible starch; SDS, slowly digestible starch; RS, resistant starch.

[3] Data followed by the same superscript letter in the same column was not significantly different ($p > 0.05$).

In vitro digestibility of substituted bread is expressed as concentrations of RDS, SDS, and RS and is demonstrated in Table 4. Along with rising substituted levels of HMT-MBP, RS content of substituted bread improved significantly, and the percentages of RDS and SDS reduced remarkably. The result was consistent with previous studies. The suitable explanation for the above results could be due to the high RS content of HMT-MBP. Li and Gao (2010) confirmed that heat-moisture treatment favorably improved the amount of RS in mung bean flour. Thus, the more HMT-MBP was added to dough, the higher the RS content existed in substituted bread. Furthermore, some amylose and short-chain molecules of wheat and mung bean starch were able to re-associate and then gelatinize during baking and retrograde afterward, resulting in the newly formed RS in bread (Hung *et al.,* 2005).

The *in vitro* digestibility of the substituted bread, expressed as concentrations of rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS), is shown in Table 4. As the levels of HMT-MBP increased, the RS content in the substituted bread significantly improved, while the percentages of RDS and SDS markedly decreased. This result aligns with previous studies. The likely explanation for these findings is the high RS content in HMT-MBP. Li and Gao (2010) confirmed that heat-moisture treatment significantly increases the RS content in mung bean flour. Therefore, the more HMT-MBP added to the dough, the higher the RS content in the substituted bread. Additionally, some amylose and short-chain molecules from wheat and mung bean starch can re-associate, gelatinize during baking, and retrograde afterward, leading to newly formed RS in the bread (Hung *et al.,* 2005).

Organoleptic profiles of bread

Table 5. Organoleptic profiles of substituted bread

Samples	Appearance	Color	Aroma	Taste	Texture	Overall acceptability
WFB	4.37 ± 0.62^{a}	4.67 ± 0.48^{a}	4.73 ± 0.45^{a}	4.67 ± 0.61^{a}	4.70 ± 047^{a}	4.50 ± 0.57^{a}
10MBB	3.53 ± 0.78^{b}	3.77 ± 0.68^{b}	3.13 ± 1.01^{b}	4.20 ± 0.85^{a}	4.70 ± 0.47^{a}	3.50 ± 0.63^{b}
20MBB	4.50 ± 0.57^{a}	4.37 ± 0.72^{a}	2.70 ± 0.88^{b}	3.13 ± 0.94^{b}	3.50 ± 1.28^{b}	3.23 ± 0.63^{bc}
30MBB	2.63 ± 056^{c}	3.50 ± 0.68^{b}	2.63 ± 0.85^{b}	2.20 ± 0.76^{c}	2.37 ± 0.77^{c}	2.90 ± 0.80^{c}

[1]Abbreviations are the same as in Figure 1.

[2]Data followed by the same superscript letter in the same column was not significantly different ($p > 0.05$).

The organoleptic profiles of the substituted bread are shown in Table 5. WFB received high ratings, with an average score of over 4.5 out of 5 for all sensory attributes, except for appearance, which scored 4.37. The substitution of HMT-MBP significantly reduced the scores for all sensory attributes of the substituted bread. Although 20MBB had lower scores for aroma, taste, and texture compared to 10MBB, its appearance and color were rated higher among the three substituted breads. Consequently, the overall acceptability of 20MBB, while lower than that of WFB, was not statistically different from 10MBB.

CONCLUSION

HMT-MBP was successfully produced and mixed with WF to create various concentrations of composite flour for bread-making. The mixture of WF and HMT-MBP had higher gelatinization temperatures compared to WF alone, but lower values for other pasting properties, swelling index, and solubility. HMT-MBP contributed to a darker color, smaller size, and higher hardness value in the substituted bread. Additionally, bread made from WF and HMT-MBP had higher RS content but received moderate scores for all sensory attributes. Consequently, composite bread made from 90% WF and 10% HMT-MBP was considered a "low-carb" bread beneficial for human health.

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NGHIÊN CỨU CÁC TÍNH CHẤT LÝ HÓA CỦA BỘT PHỐI TRỘN VÀ CHẤT LƯỢNG CỦA BÁNH MÌ BỔ SUNG BỘT ĐẬU XANH XỬ LÝ NHIỆT-ẨM

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TÓM TẮT

Mục tiêu của nghiên cứu này nhằm phát triển sản phẩm bánh mì sử dụng bột đậu xanh xử lý nhiệt-ẩm thay thế một phần bột mì và xác định các tính chất lý hóa của bột phối trộn cũng như chất lượng bánh mì. Việc bổ sung bột đậu xanh xử lý nhiệt-ẩm làm tăng nhiệt độ hồ hóa nhưng giảm các tính chất hồ hóa khác, cũng như chỉ số trương nở và độ hòa tan. Bánh mì bổ sung bột đậu xanh xử lý nhiệt-ẩm có màu tối hơn, kích thước nhỏ hơn và độ cứng cao hơn. Cùng với việc bổ sung thêm bột đậu xanh đã được xử lý nhiệt-ẩm vào bột nhào, những loại bánh mì thay thế này chứa lượng tinh bột tiêu hóa nhanh thấp hơn (56,39-63,32%) và nồng độ tinh bột kháng cao hơn (17,18-27,00%) so với của loại làm từ lúa mì (lần lượt là 65,38% và 13,32%). Vì vậy, bột đậu xanh xử lý nhiệt-ẩm có chứa hàm lượng tinh bột kháng cao cho nên sản phẩm bánh mì có lượng tinh bột tiêu hóa nhanh thấp hơn hàm lượng tinh bột kháng cao hơn so với mẫu bánh mì đối chứng. Mặc dù các chỉ số cảm quan của bánh mì có bổ sung bột đậu xanh được đánh giá thấp hơn so với mẫu bánh mì đối chứng, nhưng bánh mì làm từ 90% bột mì và 10% bột đậu xanh xử lý nhiệt-ẩm đạt được độ chấp nhận tổng thể cao nhất trong số ba loại bánh mì bổ sung bột đậu xanh. Kết quả là, sản phẩm này có thể được sử dụng như là loại bánh mì ít carbohydrate có lợi cho sức khỏe con người.

Từ khóa: Chất lượng bánh mì, khả năng tiêu hóa, xử lý nhiệt-ẩm, bánh mì ít carbohydrate, bột đậu xanh, tính chất lý hóa.

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