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TABLE OF CONTENTS PAGE

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Characterization of hot air drying and microwave vacuum drying of okra powder and application in bread

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Abstract
This research aimed to develop okra powder and applied into bread. Fresh okras were pretreated by blanching and further subjected to hot air drying (HA) at 70°C and microwave vacuum drying (MV) at 3 W/g, -600 mmHg. Results showed that MV reduced the drying time by about 75% compared to HA. The color *a** and *b** values of the okra powder from MV were lower than from HA and were more closed to fresh okra. Moreover, total polyphenolic content and free radical scavenging by DDPH of MVsamples were higher than HA samples. Blanching okra before drying preserves its color, while sample without blanching leads to a faster drying process. However, unblanced okra powder retain a greater amount of total phenolic content. Specific volume of the bread substituited with 1% okra powder was higher when compared to the control formula ($P<0.05$). The addition of the okra powder reduced bread's hardness and enhanced the bioactive compound in the bread. The okra powder had the potential to reduce the glycaemic index (GI) of bread from 59.1 to 54.9, which could be considered as medium to low GI food.

Keywords: Okra; Drying; Microwave vacuum drying; Hot air; Blanching; Bread; Glycemic index

1. Introduction

Okra (*Abelmoschus esculentus*) is a plant in the Malvacae family. It is an important vegetable plant grown in many parts of the world. It is rich in bioactive compounds, mainly mucus-forming polysaccharides and phytochemicals (Nampuak and Tongkhao, 2020). This mucilage is a highly hydrophilic substance that can react with water and swell, resulting in dissolution and dispersion in water. Therefore, mucilage is used to modify and improve food quality regarding stability and textural improvement, as well as acting as a gelling agent, thickener, and emulsifier. Thus, it can be considered a food additive (Noorlaila *et al*., 2015).

Drying is a processing method used for preserving and producing powdered products. However, conventional hot air drying (HA) causes the product to lose its color and nutritional quality. Microwave vacuum drying (MV) is a promising drying method to improve the quality and efficiency of production. Microwaves can deeply penetrate food material. Thus, the water in the food evaporates rapidly from inside to outside, resulting in a shorter drying time (Monteiro *et al*., 2021). However, only few studies reported using MV to dry okra. Xu *et al*. (2020) compared the drying rate and quality attributes of okra obtained by MV, HA, and freeze drying. They discovered that MV could reduce processing time and retain color and nutrition such as total phenolic and flavonoid contents. Moreover, many researchers suggested that blanching treatment before drying is an effective method for inactivating enzymes that deteriorate products during processing (Monteiro *et al*., 2021). However, blanching treatment changes the tissue structures of samples. This is critical because the tissue structure affects the texture and bioactive compounds in samples. The application of okra powder by MV as an ingredient has not been well established. Therefore, it is interesting to study the drying method and blanching before drying to produce okra powder as a functional food ingredient, especially in bread.

Bread is a highly nutritious food consumed worldwide (Rodge *et al*., 2012). The growing consumer demand for healthier foods drives "healthy bread" research by adding dietary fiber, micronutrients, and antioxidants. Therefore, many studies use vegetables mixed in bread to increase their nutritional value. In addition, consumers are interested in the glycaemic index (GI) value of food. The GI value is an indicator that measures the quality of carbohydrates in foods based on how quickly blood glucose levels rise following digestion (Cabral *et al*., 2022). Foods with high GI release glucose rapidly increase into the blood, and foods with low GI tend to release glucose levels slowly and steadily. White bread is a food with a high GI value because it is easily digested. However, consumers want low-GI bread for their health benefits. Therefore, the food industry has tried to develop the lower GI bread. Wee and Henry (2020) summarized that adding functional ingredients such as polysaccharides reduced the digestion rate of the food, resulting in a lowering of the expected GI value. Marachai *et al.* (2013) applied the lablab flour for loweing the GI in macaroni. Phimolsiripol *et al.* (2017) found that the addition of 10% of the crude malva nut gum showed a significant decrease *in vitro* starch digestion, resulting in lower GI of bread from 98 of the control (100% wheat flour) to 73.

As mentioned above, MV has a high possibility to improve the quality of okra powder, and the effect of okra powder on baked products has not been fully investigated. Therefore, this research aimed to investigate the physicochemical properties of okra powder from HA and MV. In addition, the impact of optimized okra powder on some physicochemical properties, predicted glycemic index (*p*GI), and sensory properties of wheat bread was determined.

2. Materials and Methods

2.1 Materials

Fresh okra was bought from a local market in Chiang Mai, Thailand. The average dimensions of okra were 6 cm long with a dark green color. Commercial wheat flour (White Swan, United Flour Mill Co., Ltd., Thailand), instant dry yeast (Saf-instant®Gold, Lesaffre, Indonesia), white refined sugar (Mitr Phol, Mitre Phol Co., Ltd., Thailand), milk (Meiji, CP-Meiji Co., Ltd, Thailand), unsalted butter (Allowrie, KCG Corporation Co., Ltd.), salt and egg were purchased from a local market. All chemicals used in the experiments were purchased from Union Science Co., Ltd. (Chiang Mai, Thailand).

2.2 Preparation of microwaved okra powder

The fresh okra was rinsed with tap water. The okra pods were cut into 1 cm lengths, then blanched in boiling water for 2 min, then immediately soaked in cold water (4°C) to prevent overcooking. The unblanched okra was used as a control.

The unblanched and blanched okra samples were dried using a microwave vacuum dryer (March Cool Industry, Bangkok, Thailand) compared with a hot air oven (model 600, Memmert, Schwabach Germany). One hundred grams of okra was subjected to the microwave vacuum dryer at 3 W/g. For HA, the sample (1 kg) was dried at 70°C. The dried samples were powdered by an ultra-centrifuge mill (Retsch ZM 200, Haan, Germany). In this way, four different types of okra powder were obtained, namely unblanched with hot air okra powder (UH), blanched with hot air okra powder (BH), unblanched with microwave vacuum okra powder (UM), and blanched with microwave vacuum okra powder (BM). All powders were packed in laminated aluminum foil bags (PET/ALU/LLDPE) until analysis within 3 days.

2.3 Drying characteristics

For the hot air dryer, 1 kg of sample was distributed in the sample tray. The HA was carried out at 70°C with 1 m/s air velocity. All the samples were dried until the moisture content was about 5%. The moisture content of samples was analyzed using the standard methods (AOAC, 2000) every 60 min, and the moisture content was used to determine the drying curves. For MV, 100 g of okra sample was dried for a specified period. Okra samples were continuously dried for 30, 45, 75, 90, 105 and 120 min. The moisture ratio during drying was expressed as Eq. 1:

$$\text{Moisture ratio} = \frac{X_i \quad X_e}{X_0 \quad X_e} \tag{1}$$

where X_0 and X_i = the moisture content (kg water/kg dry solid) at initial time 0 and time t, X_e = the equilibrium moisture content (kg water/kg dry solid).

Fick's second law was applied to determine the effective diffusivity (D_{eff}). The D_{eff} of water in the okra sample was estimated using the modified Crack's equation as shown in Eq. 2 (Akter *et al*., 2022).

$$\frac{X_i X_e}{X_0 - X_e} = \frac{8}{\pi^2} \sum_{n-1}^{\infty} \frac{1}{(2n-1)^2} \exp(-\frac{(2n-1)^2 \pi^2 D_{eff}}{4L^2} t) \tag{2}$$

where D_{eff} = the effective moisture diffusivity (m^2/s), L= the half thickness of the okra (0.5×10^{-3} m), t = drying time (s), X_i = the moisture content (kg water/kg dry solid) at time X_e = the equilibrium moisture content (kg water/kg dry solid).

2.4 Physicochemical properties of okra powder

The color CIE L^*, a^*, and b^* values of okra powder were measured using a colorimeter (CR-410, Konica-Minolta, Tokyo, Japan) equipped with a light source illuminant D65 and 10°C for observation.

Water holding capacity (WHC) was measured following the methods of Van der Sman *et al*. (2013) with slight modification. Briefly, 0.1 g of the sample was mixed with 10 mL of distilled water and shaken before incubation for 24 h. The mixture was centrifuged at 770 ×*g* for 30 min. Then the weight of the supernatant was measured. The WHC was calculated by the different weights of sediment and sample as a g water/g sample.

Swelling capacity (SC) was measured according to the method of Yu *et al*. (2012). Two grams of the sample were added to the calibration and the initial occupied bed volume (V_1) was recorded. Then, 100 mL. of distilled water was added to the powder and allowed to stand for 24 h at 30°C until complete swelling. The bed volume was recorded (V_2) and SC was calculated as SC = (V_2-V_1)/mass of the sample (mL/g).

For the viscosity of the okra suspension, okra powder was diluted in distilled water at 1%, 3%, 5%, 7%, and 9% concentration for 1 h. The viscosity of the okra suspension was measured using a Brookfield Viscometer (CAP1000 Viscometer, Massachusetts, USA). All measurements were made using the No. 4 spindle.

2.5 Total phenolic compound (TPC) and DDPH radical scavenging assay

The total phenolic compound was determined following the method of Surin *et al*. (2020). In this study, 0.5 mL of the extract was mixed with 2.5 mL of Folin-Ciocalteau reagent. Immediately, 2.0 mL of 7.5% Na_2CO_3 was added. Then, the mixture was incubated in the dark place for 30 min and the absorbance was read at 765 nm using a UV-Vis spectrophotometer (UV-2101PC, Shimadzu, Japan). Gallic acid (0.01-0.06 mg/mL) was used as a standard. The TPC was expressed as mg of gallic acid equivalents (GAE) per 100 g dry sample.

For the DPPH assay (Nadon *et al*., 2023), the okra powder was dissolved in distilled water at final concentrations of 1, 2, 3, 4 and 5 mg powder/mL. Two mL of the sample solutions were mixed with 2 mL of 0.25 mmol DPPH solution. The mixture solution was kept in the dark at 30°C for 30 min. The absorbance of the mixture was measured at 550 nm using the spectrophotometer. The DPPH radical scavenging activity was calculated IC_{50}. The IC_{50} value was determined from a plot of the scavenging activity versus extract concentration, reflecting the concentration of antioxidants required to decrease by 50% the initial DPPH radical concentration.

2.6 Bread-making process

The unblanched with microwave vacuum-dried okra powder was further studied in bread due to its high WHC and total phenolic content. Wheat flour was replaced with okra powder at different levels (0%, 1%, 3%, and 5%). Bread-making ingredients included 52 g of wheat flour, 29.5 g of water, 5.6 g of milk, 5.6 g of butter, 2.8 g of sugar, 0.2 g of salt, 0.6 g of yeast, 1.8 g of vanilla flavor, and 1.9 g of yolk. Wheat flour, yeast, and water were mixed to become dough. Then, the doughs were proofed at 30°C for 30 min. The other ingredients were mixed in a kitchen aid (5KSM175PSBCB, Hobart Manufacturing Co., USA). The dough was placed in molds and proofed again for 30 min, and then baked in an oven (Model KTO-16, Kluay Nam Thai Trading Group Co.Ltd., Bangkok, Thailand) at 180°C for 60 min. After baking, the loaves were removed from the mold, allowed to cool, and stored in sealed polyethylene bags at 25°C. The experiment was conducted in duplicate.

2.7 Physical properties of bread

Moisture of bread was analyzed according to the approved method 44-15.02 (AACC, 2015). Bread volume was determined by the method 10-05.01 (AACC, 2015). The specific volume was calculated as the ratio of bread volume to its mass. Crumb color CIE L^*, a^* and b^* values were measured using the colorimeter. Crumb texture was measured with a TA.XT plus texture analyzer (Stable Microsystems, Surrey, UK). Briefly, samples were cut into 2 × 2 × 2 cm. and placed on the sample platform. Texture Profile Analysis (TPA) tests were performed using a 25 mm cylinder probe at the speed of 5 mm/s to penetrate up to 50% of the sample. Hardness, adhesiveness, cohesiveness, springiness, cohesiveness, and chewiness were calculated from the TPA curves.

2.8 *In vitro* starch digestibility and predicted GI of bread

The *in vitro* GI test was determined following the method described by Phimolsiripol *et al.* (2017). 500 g of sample was incubated at 37°C with 1 mL of alpha-amylase (250U per mL of carbonate buffer, pH 7) for 15 s. Then, the mixture of 2.5 mL of pepsin solution and 2.5 mL of 0.02 M HCl was added. The solution was incubated in a water bath shaker at 37°C for 30 min. After that, the sample was neutralized with 0.02 M NaOH. The pH was adjusted with 0.2 M Na acetate buffer (pH 6). The solution was mixed with 5 mL of pancreatin (2 mg/mL in Na acetate buffer) and amyloglucosidase (28 U/mL in Na acetate buffer. The solution was incubated in a water bath at 37°C for 10, 20, 30, 45, 60, 90, 120, 150, 180, 210 and 240 min. The glucose released was measured with a glucometer (Accu-Chek Performa, Roche Diagnostics GmbH, Mannheim, Germany). The predicted glycemic index (*p*GI) was calculated using the value at 90 min from the fitted digested starch curve *vs* time (hydrolysis index, HI) using the method of Goni *et al.* (1997): pGI = 0.803 HI_{90} + 39.21. The curve was fitted following the method described by Mahasukhonthachat *et al.* (2010). The glycemic index ranks food on a scale from 0 to 100. Generally, there were three categories of foods based on their GI values: low GI foods (<55), medium GI foods (56-69), and high GI foods (>70) (Eleazu, 2016).

2.9 Sensory evaluation of bread

Fifty untrained panelists assessed four bread formulations. Each sample, weighing twenty grams, was presented in plastic bags labeled with random three-digit codes. The presentation order was randomized. The panelists used a 9-point hedonic scale to rate overall liking, appearance, color, odor, flavor, softness, and sweetness.

2.10 Statistical analysis

Analysis of variance (ANOVA) in the statistical package SPSS (version 17.0) was performed to analyze the experimental data. Duncan's multiple range tests were used to find the multiple comparisons of mean values with the significance set at $P<0.05$.

3. Results and Discussion

3.1 Effect of blanching and dehydration process on drying characteristics

The drying curves of okra at different treatments are shown in Fig 1. The moisture ratio continued to decrease with the increase in drying time. Considering HA, the results demonstrated that the proportion of moisture content decreased rapidly in the beginning. It was because the water contained within the food moved to the surface at a similar rate to the movement of the water's surface to the hot air. However, at the end of drying, a small reduction in the proportion of moisture content was observed. This was due to the movement rate of water within the food to the surface by capillary force being lower than the rate of evaporation of water into the surrounding air (Doymaz *et al.*, 2023).

For MV, the moisture ratio decreased rapidly when compared with HA, resulting in faster drying time. Thus, the drying times required to reduce the moisture content in the sample to less than 5% were 90 and 120 min for unbalanced and blanched samples, respectively. The drying rate of MV depended on the energy absorption of the sample. It did not depend on the heat transfer from the inside to the surface of the sample. Therefore, using a microwave caused the samples to absorb more energy, resulting in reduced drying time compared to hot air drying (Marzuki *et al.*, 2021). Similarly, Bai-gew *et al.* (2015) reported that MV could reduce 90% of the drying time compared to HA in durian powder. Considering pretreatment, the moisture ratio of the blanched okra samples was higher than the unblanched samples, resulting in longer drying times. This is because okra produces mucilage, which is polysaccharide, gums, and pectin that prevent water movement and water evaporation to the surface (Zaharuddin *et al.*, 2014).

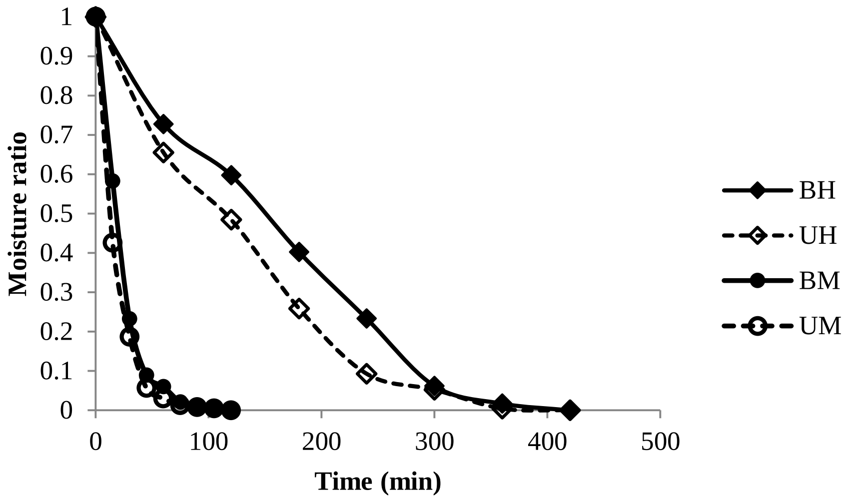

Fig 1 Drying curves under various drying conditions of okra; BH- Blanched and HA, UH- Unblanched and HA, BM- Blanched and MV, UM- Unblanched and MV.

As per Fick's model, the D_{eff} of unblanched okra dried in the hot air dryer and microwave vacuum dryer were 0.2369 × 10^{-8} and 1.1913 × 10^{-8} m^2/s, respectively (Table 1). The D_{eff} of blanched okra dried in the hot air dryer and microwave vacuum dryer were 0.1822 × 10^{-8} and 1.7822 × 10^{-8} m^2/s.The MV improved the D_{eff} of the okra compared to HA. In the vacuum system of MV, the pressure in the drying chamber was decreased. Therefore, the difference between the vapor pressure in the product and chamber was increased, resulting in increased water mass diffusion (Therdthai and Northongkom, 2011). Considering the pretreatment before drying, it was found that the blanching decreased the moisture diffusion coefficient because blanching at high temperatures could extract the polysaccharides with thick and slimy textures. Therefore, it obstructed the distribution of water in the sample.

Table 1 The D_{eff} and other parameters of okra drying conditions.

Drying method	**Pretreatment**	**D_{eff} (m^2/s)**
HA	Blanched	0.1822×10^{-8}
	Unblanched	0.2369×10^{-8}
MV	Blanched	1.0729×10^{-8}
	Unblanched	1.1913×10^{-8}

3.2 Effect of blanching and dehydration process on the color of okra powder

The blanching and drying method had a significant effect ($P<0.05$) on the L^*), a^* and b^* values of okra powder (Table 2). After the MV, L^* and b^* were increased, whereas a^* was significantly decreased ($P<0.05$). The okra powder became a lighter green color. This was due to the MV system having lower oxygen and lower temperature, which could preserve the color of the sample from auto-oxidized pigment and thermal color loss (Bai-Ngew *et al.*, 2011). The change of L^* value is related to the Maillard reaction leading to the formation of brown pigment during the drying process. Browning increased with an increase in drying time and temperature.

HA has more oxygen and moisture content in a system, as a result, the Maillard reaction was facilitated during drying. (Qing-gou *et al.*, 2006).

Considering pretreatment, blanching caused a slightly darker color value with significantly lower *L**values (P<0.05) in HA. However, there were no significant differences in MV (P≥0.05). Moreover, blanching before drying could enhance the green color (reduction in *a**) and a more yellow tone (increase in *b**). It was due to blanching inactivates chlorophyllase and polyphenol oxidase (PPO) responsible for senescence and rapid loss of green color (Koca *et al.*, 2007).

Table 2 Color values of okra powder with different drying conditions.

Drying method	Pretreatment	*L**	*a**	*b**
HA	Blanched	66.83[c] ± 0.11	-2.58[a] ± 0.06	20.57[c] ± 0.16
	Unblanched	68.26[b] ± 0.12	-2.33[a] ± 0.22	18.81[d] ± 0.16
MV	Blanched	69.91[a] ± 0.22	-11.57[c] ± 0.23	24.91[a] ± 0.07
	Unblanched	69.89[a] ± 0.52	-4.98[b] ± 0.11	23.37[b] ± 0.13

The mean ± standard deviation values in the same column with different letters are significantly different (P<0.05).

3.3 Effect of blanching and dehydration process on water holding capacity (WHC) and swelling power (SC)

The WHC and SC were important features associated with water absorption of products usually rich in protein or fiber, which often affected the viscosity of the food (Duarte *et al.*, 2016). The result found that the WHC value of okra powder was in the range of 4.01-4.63 g water/g sample (Table 3). The drying condition and blanching process did not affect the ability to absorb water (P≥0.05). However, MV has a slightly higher WHC. This may be related to rapid heating and decreasing of the pressure chamber, which increases the pressure gradient. This phenomenon has the potential to enhance the expansion of internal structure, resulting in a more porous structure (Nimmanpipug and Therdthai, 2013), thereby facilitating improved water absorption. However, MV and blanching did not affect the swelling capacity (P≥0.05). The SC value was in the range of 35.62 to 39.70 mL/g, which was higher than other vegetables, e.g., carrot (22-29 mL/g) (Chantaro *et al.*, 2008), cabbage (16-21 mL/g), and lime (13-15 mL/g) (Jongaroontaprangsee *et al.*, 2007). This was possible due to polysaccharide mucilage in okra powder was highly hydrophilic that could interact and entrap with water between the polymer chains and branches (Noorlaila *et al.*, 2015).

Table 3 WHC value and swelling capacity value of okra powder with different drying conditions.

Drying method	Pretreatment	WHC[ns] (g water/g sample)	SC[ns] (mL/g)
HA	Blanched	4.52 ± 0.18	35.62 ± 0.88
	Unblanched	4.51 ± 0.19	36.92 ± 0.68
MV	Blanched	4.63 ± 0.21	38.13 ± 2.20
	Unblanched	4.53 ± 0.13	39.70 ± 2.68

[ns] value shown as mean ± standard deviation within the same column are not significantly different (P≥0.05).

3.4 Effect of blanching and drying process on okra powder's suspension viscosity

Okra is a mucilaginous vegetable used to thicken dishes such as soup or stews (Dantas *et al*, 2021). The increased concentration of okra powder significantly increased viscosity (P<0.05), as shown in Table 4. As for the pretreatment, blanching resulted in a slight decrease in viscosity. It was due to a change in the structure of the polymer into a random coil structure upon heating, resulting in less molecule combination followed by a decrease in the viscosity of the solution (Noorlaila *et al*. 2015). Considering the drying method, MV obtained higher viscosity compared with HA at the same concentration (P<0.05). It might be due to the rapid evaporation of MV, resulting in increased pressure inside the okra samples, and also enhancing the plant tissue cracking. Therefore, polysaccharides can be dissolved in the water much better and easier than HA. Similarly, Shah and Seth (2011) found that okra mucilage was isolated in high yields and less time by the developed microwave method than conventional heating.

Table 4 Viscosity of suspension (cP) in different concentrations of okra powder.

Okra powder (%)	HA		MV	
	Unblanched	Blanched	Unblanched	Blanched
1	16.37^{c} ± 1.07	15.17^{c} ± 2.10	39.33^{a} ± 2.51	35.28^{b} ± 3.01
3	98.76^{c} ± 3.92	96.57^{c} ± 2.54	166.13^{a} ± 0.99	150.87^{b} ± 5.78
5	305.52^{b} ± 8.50	264.52^{c} ± 12.54	406.00^{a} ± 12.53	387.00^{b} ± 5.14
7	441.00^{b} ± 18.7	400.21^{d} ± 10.24	683.70^{a} ± 54.9	610.87^{a} ± 31.01
10	632.30^{c} ± 27.1	550.78^{d} ± 10.28	1049.70^{a} ± 1.15	987.14^{b} ± 10.78

The mean ± standard deviation values in the same row with different letters are significantly different (P<0.05).

3.5 Effect of blanching and dehydration process on total phenolic compound (TPC) and DPPH radical scavenging activity

The differences in TPC content and DPPH values among samples were significant (P<0.05) (Table 5). The TPC content of unblanched okra powder was in the range of 341.05–452.40 mg GAE/100g sample. Considering drying conditions, the TPC of okra dried by MV was significantly (P<0.05) higher than that of okra dried by HA. This was probably because the use of a vacuum in MV allowed water to evaporate at lower temperatures, and the presence of less oxygen reduced the potential oxidation, which resulted in the preservation of the total phenolic compound (Leusink *et al.*, 2010). This coincided with Wojdylo *et al.* (2014) who reported that the TPC content of microwave vacuum-dried strawberries was higher than that of hot air-dried samples and freeze-dried samples. After blanching, the TPC content decreased to 341.05 and 421.69 mg GAE/100 g samples for HA and MV, respectively. The reduction might be due to the degradation of phenolic compounds by heat or their leaching out from the tissues into the blanching water (Bamidele *et al.*, 2017). Irondi *et al.* (2017) found that blanching at 80°C for 10 min resulted in decreasing flavonoids and phenolic contents. This was because high temperature may have disrupted the cell wall, thereby leading to the leaching of soluble matters into the blanching water.

Regarding antioxidant activity, DPPH radical scavenging activity was analyzed and reported as IC_{50} value. IC_{50} value was also known as the half-maximal inhibitory concentration. A lower IC_{50} value means better % inhibition (Graham *et al.*, 2017). The IC_{50} value of the okra powder ranged from 0.19 – 0.68 mg/mL (Table 5). The drying process significantly affected the inhibition (P<0.05). The MV samples had a lower IC_{50} value than the HA samples (P<0.05), indicating a high free radical scavenging power on the DPPH assay. It was confirmed that the increased total phenolic content might contribute to the high antioxidant activity (Roshanak *et al.*, 2016). According to Hihat *et al.* (2017), microwave drying created high vapor pressure and temperature inside the sample, resulting in the degradation of the plant cell wall. Therefore, more phenolics were released, exhibiting a high antioxidant capacity.

Table 5 Total phenolic compound (TPC) and DPPH radical scavenging activity of okra powder with different drying conditions.

Drying method	Pretreatment	TPC (mg GAE/100 g sample)	IC_{50} DPPH (mg/mL)
HA	Blanched	$341.05^{d} \pm 5.06$	$0.68^{a} \pm 0.11$
	Unblanched	$361.20^{c} \pm 6.04$	$0.53^{a} \pm 0.05$
MV	Blanched	$421.69^{b} \pm 13.46$	$0.22^{b} \pm 0.06$
	Unblanched	$452.40^{a} \pm 8.02$	$0.19^{b} \pm 0.03$

The mean ± standard deviation values in the same column with different letters are significantly different (P<0.05).

3.6 Physicochemical properties of bread

The addition of 0, 1, 3 and 5% okra powder into wheat flour resulted in a significant difference in the color values of the bread crumb (P<0.05). The increased percentage of okra powder decreased the *L** and *a** value and increased the b* value. The 5% okra powder bread showed the highest dark green color with 56.93, -1.08, and 26.06 for *L**, *a**, and *b**, respectively (Table 6). The addition of okra powder significantly decreased in moisture content of bread from 35.29 to 30.11% (P<0.05). It was due to okra powder could be used as a natural hydrocolloid (Tufaro *et al*., 2022). Increasing the hydrocolloid concentration might transform free water to bound water by reducing the mobility of water molecules (Maleki and Milani, 2013) resulting in a reduction of water evaporation during the cooking phase.

For specific volume, the result shows that the bread with 1% okra powder had more specific volume than the control (0%) (P<0.05). Due to proper hydrocolloid content in the system, it could strengthen the dough structure during fermentation, resulting in better gas retention during the baking process (Culetu *et al.,* 2021). However, the addition of 3% and 5% okra powder resulted in bread with a lower specific volume than the control. It was due to the water in the system being bound to okra fibers, so less water was available for starch-gluten network development leading to an underdeveloped gluten-network and reduced specific volume (Xu *et al.*, 2020).

The textural properties of bread samples are given in Table 7. The effects of okra powder addition on the textural of bread were determined to be significant (P<0.05). The addition of okra powder resulted in a significantly lower hardness and chewiness (P<0.05), indicating that the bread had a softer texture. It could be because okra powder contains mucilage and gum, which are polysaccharides like hydrocolloids. When okra powder dissolved in water, a highly viscous mucilage solution was obtained which has been proven to be a soft dough (Machine *et al.*, 2020). Since hardness is one of the parameters used in calculating the chewiness, the higher chewiness values evaluating the result considered hard to chew. Due to the structure that softens with okra powder, a decrease in chewiness was observed.

Table 6 Moisture content, specific volume, and color of bread.

Okra powder (%)	Moisture content (% w.b.)	Specific volume (cm^3/g)	*L**	*a**	*b**
0 (Control)	$35.29^a \pm 0.70$	$3.56^b \pm 0.20$	$70.92^a \pm 4.77$	$-0.55^a \pm 0.25$	$17.66^c \pm 0.15$
1	35.19a ± 0.16	$4.80^a \pm 0.17$	$66.26^a \pm 2.42$	$-0.87^{ab} \pm 0.04$	$18.98^c \pm 0.01$
3	32.42b ± 0.25	$3.23^b \pm 0.35$	$57.13^b \pm 1.58$	$-0.66^{ab} \pm 0.21$	$24.32^b \pm 0.51$
5	$30.11^c \pm 0.16$	$3.13^b \pm 0.20$	$56.93^b \pm 0.58$	$-1.08^b \pm 0.15$	$26.06^a \pm 0.45$

The mean ± standard deviation values in the same column with different letters are significantly different (P<0.05).

Table 7 Textural properties of bread containing okra powder.

Okra powder (%)	Hardness (g.force)	Adhesiveness (g.sec)	Cohesiveness	Springiness	Chewiness (g.force)
0 (Control)	11.61^{a}±0.29	5.84^{a}±0.32	0.997^{a}±0.024	0.979^{a}±0.013	11.34^{a}±0.25
1	11.39^{ab}±0.51	5.88^{a}±0.46	0.996^{a}± 0.071	0.975^{a}±0.010	11.06^{ab}±0.48
3	11.43^{ab}±0.32	6.05^{a}±1.03	0.997^{a}± 0.040	0.979^{a}±0.017	11.16^{a}±0.32
5	9.38^{b}±1.46	5.94^{a}±0.74	0.995^{a}± 0.012	0.975^{a}±0.011	9.10^{b}±0.41

The mean ± standard deviation values in the same column with different letters are significantly different (P<0.05).

3.7. Predicted glycemic index (*p*GI) of bread containing okra powder

Several *in vitro* assays have been proposed to evaluate the rate of starch hydrolysis. Fig 2 shows the digested starch curve during incubation time. The result showed that increased okra powder in bread tended to decrease the digested starch. A first-order kinetics model of Mahasukhonthachat *et al.* (2010) was generated to calculate the digestion rate constant (k), predicted digested starch at 90 min (H_{90}). Then, the predicted glycemic index (*p*GI) was calculated using the method of Goni *et al.* (1997).

In vitro starch digestibility showed that increased okra powder in bread from 0% to 5% tends to reduce *p*GI (Table 8). The addition of 5% okra powder decreased (P<0.05) *p*GI by about 7% compared to the control bread and was classified as low GI (<55). However, the addition of 1 and 3% okra powder was still considered as medium GI (55<GI<70), similar to the control (0%). For the bread containing okra, wheat flour replacement by okra powder leads to a dilution in the starch. Xu *et al.* (2020) reported that oligomeric catechins and flavanol derivatives which have phenolic content in okra have been shown to possess inhibitory properties of pancreatic alpha-amylase activity. Moreover, Phimolsiripol *et al.* (2017) reported that the inclusion of dietary fiber may reduce the accessibility of alpha-amylase to starch. As a result, the individual's blood sugar response is reduced.

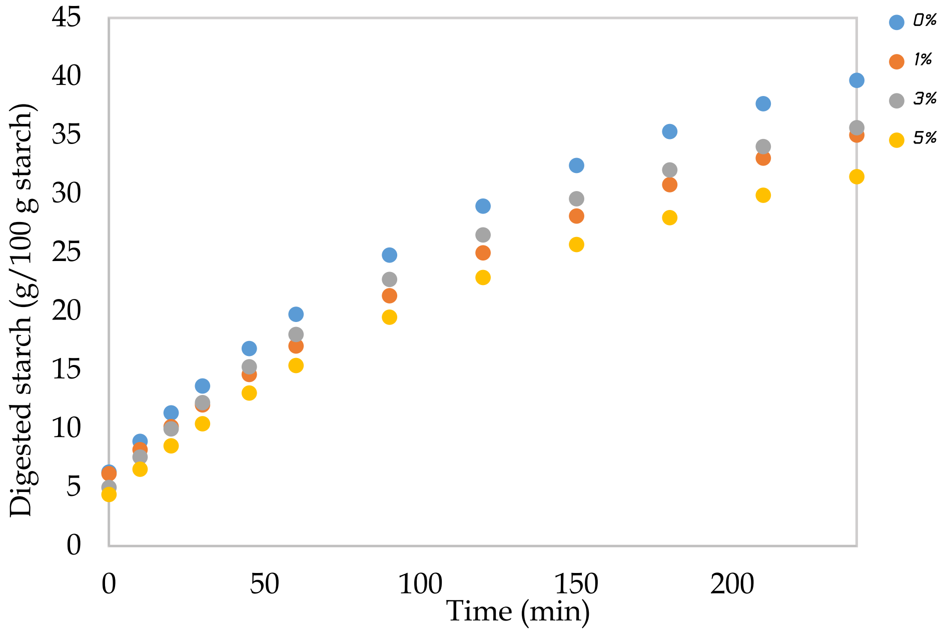

Fig 2 Digested starch curve of bread under different okra powder level.

Table 8 Model parameters hydrolysis index (HI) and predicted glycemic index (*p*GI) of bread containing different okra powder levels.

Okra powder (%)	D_0	D_∞	*k* (min^{-1})	H_{90}[a]	*p*GI[b]
0 (Control)	6.32	42.96	0.006	24.79	59.12
1	6.17	40.33	0.005	21.33	56.34
3	5.01	37.37	0.007	22.74	57.47
5	4.41	34.52	0.006	19.51	54.87

[a] Predicted digested starch at 90 min using the modified first-order kinetic model of Mahasukhonthachat *et al.* (2010).
[b] Predicted GI using the equation of Goni *et al.* (1997) as GI = 0.803 H_{90} + 39.21.
Mean value of *p*GI with the different letters in the same column are significantly different (P<0.05).

3.8 Sensory properties of bread

In studies of new products, sensory acceptance of the final product by consumers is very important. Sensory attributes of bread samples, including appearance, crumb color, odor, flavor, texture, and overall liking, are shown in Table 9. The results show that the bread using 1% okra powder obtained the highest score of all parameters. Therefore, it was confirmed that the bread with 1% okra powder was successful in terms of visual, texture, and taste properties. However, it was observed that when okra powder was increased to 3% and 5%, all characteristics had significantly decreased (P<0.05). This is because okra powder had a green leafy odor and green color, resulting in bread with a strong rank flavor and dark color, which panelists did not accept the products. In addition, the bread had dense and flat loaf, resulting in lower liking scores for appearance and softness.

Table 9 Sensory properties and predicted glycemic index (*p*GI) of bread containing different okra powder.

Okra powder	Appearance	Color	Odor	Flavor	Softness	Overall liking
0 (Control)	$7.2^{a} \pm 1.2$	$7.3^{a} \pm 1.1$	$6.8^{a} \pm 1.2$	$6.7^{a} \pm 1.4$	$7.2^{a} \pm 0.8$	$7.0^{a} \pm 1.0$
1	$7.3^{a} \pm 0.8$	$7.4^{a} \pm 0.9$	$7.0^{a} \pm 0.6$	$6.7^{a} \pm 1.0$	$7.2^{a} \pm 0.8$	$7.1^{a} \pm 0.8$
3	$5.8^{b} \pm 1.4$	$6.0^{b} \pm 1.1$	$6.1^{b} \pm 1.3$	$5.5^{b} \pm 1.2$	$5.6^{b} \pm 1.6$	$5.7^{b} \pm 1.1$
5	$5.6^{b} \pm 1.4$	$5.8^{b} \pm 1.4$	$5.8^{b} \pm 1.0$	$5.3^{b} \pm 1.3$	$5.4^{b} \pm 1.1$	$5.3^{b} \pm 1.2$

The mean ± standard deviation values in the same column with different letters are significantly different (P<0.05).

4. Conclusion

To sum up, it was found that the MV resulted in a shorter drying time. Moreover, MV dried at lower oxygen and temperature resulted in an okra powder with a brighter green color, higher total phenolic compound, and antioxidant activities. Blanching was an effective pre-treatment in terms of color deterioration; however, it decreased the drying rate and decreased the total phenolic content. Therefore, the unblanching followed by the MV was selected to improve the okra powder quality. The applications of okra powder in bread were studied. Based on the physical attributes, the addition of 1% okra powder presented the highest specific volume and texture properties which were similar to the control (0%) with a light green color. Regarding GI test, the *p*GI values of the bread with okra powder was lower than that of the control, which can be considered as a medium GI food. However, the formulations containing 1% of the okra powder obtained the highest score of sensory. Further studies should be conducted in order to study the other drying techniques to produce okra powder and to explore combinations with other hydrocolloid in formula development of low GI bread.

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References

AACC International. 2015. Approved Methods of Analysis. 9th edn. St. Paul, MN: AACC International.

Akter, F., Muhury, R., Sultana, A., Deb, U. K. 2022. A comprehensive review of mathematical modeling for drying processes of fruits and vegetables. International Journal of Food Science. 2022: 6195257.

AOAC. 2000. Official Methods of Analysis, 17th ed. The Association of Official Analytical Chemists. Maryland. USA.

Bai-Ngew, S., Therdthai, N. and Dhamvithee, P. 2011. Characterization of microwave vacuum-dried durian chips. Journal of Food Engineering. 104(1): 114-122.

Bai-Ngew, S., Therdthai, N., Dhamvithee, P. and Zhou, W. 2015. Effect of microwave vacuum drying and hot air drying on the physicochemical properties of durian flour. International Journal of Food Science and Technology. 50(2): 305-312.

Bamidele, O. P., Fasogbon, M. B., Adebowale, O. J. and Adeyanju, A. A. 2017. Effect of blanching time on total phenolic, antioxidant activities and mineral content of selected green leafy vegetables. Current Journal of Applied Science and Technology. 24(4): 1-8.

Cabral, D., Fonseca, S. C., Moura, A. P., Oliveira, J. C. and Cunha, L. M. 2022. Conceptualization of rice with low glycaemic index: Perspectives from the major European consumers. Foods. 11(14): 2127.

Chantaro, P., Devahastin, S. and Chiewhan, N. 2008. Production of antioxidant high dietary fiber powder from carrot peels. LWT-Food Science and Technology. 41(10): 1987-1994.

Culetu A, Duta D.E., Papageorgiou, M., Varzakas, T. 2021. The role of hydrocolloids in gluten-free bread and pasta; Rheology, characteristics, staling and glycemic index. Foods. 10(12): 3121.

Dantas, T.L., Alonso Buriti, F. C., Florentino, E. R. 2021. Okra (*Abelmoschus esculentus* L.) as a potential functional food source of mucilage and bioactive compounds with technological applications and health benefits. Plant. 10(8): 1683.

Doymaz, I., Tunckal, C. and Göksel, Z. 2023. Comparison of drying kinetics, energy efficiency and color of dried eggplant slices with two different configurations of a heat pump dryer. Energy sources, Part A: Recovery, Utilization and Environmental Effects. 45(1): 690-707.

Duarte, Y., Chaux, A., Lopez, N., Largo, E., Ramirez, C., Nunez, H., Simpson, R and Vega, O. 2016. Effects of blanching and hot air drying conditions on the physicochemical and technological properties of yellow passion fruit (*Passiflora edulis* Var. Flavicarpa) by-products. Journal of Food Process Engineering. 40(3): E12425.

Eleazu C. O. 2016. The concept of low glycemic index and glycemic load foods as panacea for type 2 diabetes mellitus; prospects, challenges and solutions. African Health Science. 16(2): 468-479.

Goni, I., Garci-Alonso, A. and Suara-Calirto, B. 1997. Starch hydrolysis procedure to estimate glycemic index. Nutrition Research. 17: 427-437.

Graham, J. O., Agbenorhevi, J. K., Kpodo, F. M. 2017. Total phenol content and antioxidant activity of okra seeds from different genotypes. American Journal of Food and Nutrition. 5(3): 90-94.

Hihat, S. Remini, H. and Madani, K. 2017. Effect of oven and microwave drying on phenolic compounds and antioxidant capacity of coriander leaves. International Food Research Journal. 24(2): 503-509.

Irondi, E. A, Akintunde, J. K., Agboola, S. O., Boligon, A. A. and Athayde, M. L. 2017. Blanching influences the phenolics composition, antioxidant activity, and inhibitory effect of Adansonia digitate leaves extract on amylase, glucosidase and aldose reductase. Food Science and Nutrition. 5(2): 233-242.

Jongaroontaprangsee, S., Chokanaporn, W., Devahastin, S., Tritrong, W., Methacanon, P. and Chiewchan, N. 2007. Effects of drying temperature and particle size and hydration properties of dietary fiber powder from lime and cabbage by-products. International Journal of Food Properties. 10(4): 887-897.

Koca, N., Karadeniz, F. and Burdurlu, H. S. 2007. Effect of pH on chlorophyll degradation and colour loss in blanched green pea. Food Chemistry. 100(2): 609-615.

Leusink, G. J., Kitts, D. D., Yaghmaee, R. and Durance, T. 2010. Retention of antioxidant capacity of vacuum microwave dried cranberry. Journal of Food Science. 75(3): C311-C316.

Machine, A. P., Massingue, A. A., Ngome, M. T., Balane, S. G., Munguambe, A. A., Armando, E. J. and Asaam, S. 2020. Physicochemical and sensory properties of bread with sweet potato flour (*Ipomea batatas* L.) as partial replacer of wheat flour supplemented with okra hydrocolloids. African Journal of Food Science. 14(11): 385-394.

Mahasukhonthachat, K., Sopade, P. A., Gidley, M. J. 2010. Kinetics of starch digestion in sorghum as affected by particle size. Journal of food engineering. 96(1): 18–28.

Maleki, G. and Milani, J. 2013. Effect of guar gum, xanthan gum, CMC and HPMC on dough rheology and physical properties of barbari bread. Food Science and Technology Research. 19(3): 353-358.

Marachai, W., Kwangpan, S. and Phimolsiripol, Y. 2013. Glycemic index and certain qualities of macaroni containing lablab flour *(Dolichos lablab*). Food and Applied Bioscience Journal. 1(3): 146-159.

Marzuki, S. U, Pranoto, Y., Khumsap, T., Nguyen, L. T. 2021. Effect of blanching pretreatment and microwave-vacuum drying on drying kinetics and physicochemical properties of purple-fleshed sweet potato. Journal of food science and technology. 58(8): 2884-2895.

Monteiro Oshima, T., Kato, K., Imaizumi, T. 2021. Effects of blanching on drying characteristics, quality, and pectin nanostructures of dried cut-persimmons. LWT. 143. 111094.

Nadon, S., Leksawasdi, N., Jantanasakulwong, K., Rachtanapun, P., Ruksiriwanich, W., Sommano, S. R., Mousavi Khaneghah, A., Castagnini, J. M., Barba, F. J. and Phimolsiripol, Y. 2023. Antioxidant and antimicrobial properties and GC-MS chemical compositions of Makwaen pepper (*Zanthoxylum myriacanthum*) extracted using supercritical carbon dioxide. Plants. 12(11): 2211.

Nampuak, C. and Tongkhao, K. 2020. Okra mucilage powder: a novel functional ingredient with antioxidant activity and antibacterial mode of action revealed by scanning and transmission electron microscopy. International Journal of Food Science and Technology. 55(2): 569-577.

Nimmanpipug, N and Therdthai, N. 2013. Effect of osmotic dehydration time on hot air drying and microwave vacuum drying papaya. Food and Applied Bioscience Journal. 1(1): 1-10.

Noorlaila, A., Siti Aziah, A., Asmeda, R., Norizzah, A.R. 2015. Emulsifying properties of extracted Okra (*Abelmoschus esculentus* L.) mucilage of different maturity index and its application in coconut milk emulsion. Internation Food Research Journal. 22(2): 782-787.

Phimolsiripol, Y., Siripatrawan, U., Teekachunhatean, S., Wangtueai, S., Seesuriyachan, P., Surawang, S., Laokuldilok, T., Regenstein, J.M., Henry, C. J. K. 2017. Technological properties, *in vitro* starch digestibility and *in vivo* glycaemic index of bread containing crude malva nut gum. International Journal of Food Science and Technology. 52: 1035-1041.

Qing-guo, H., Min, Z., Mujumdar, A. S., Wei-Hua D. and Jin-Cai, S. 2006. Effects of different drying methods on the quality changes of granular edamame. Drying Technology. 24(8): 1025-1032.

Rodge, A.B., Sonkamble, S.M., Salve, R.V. and Hashmi, S.I. 2012. Effect of hydrocolloid (Guar Gum) incorporation on the quality characteristics of bread. Journal of Food Processing and Technology. 3(2): 133-120.

Roshanak, S., Rahimmalek, M. and Goli, S. A. H. 2016. Evaluation of seven different drying treatments in respect to total flavonoid, phenolic, vitamin C content, chlorophyll, antioxidant activity and color of green tea (*Camellia sinensis* or C-assamica) leaves. Journal of Food Science and Technology. 53(1): 721-729.

Shah, B. N. and Seth, A. K. 2011. Microwave assisted isolation of mucilage from the fruits of *Abelmoschus esculentus*. Journal for Drugs and Medicines. 3(1): 54-57.

Surin, S., You, S., Seesuriyachan, P., Muangrat, R., Wangtueai, S., Jambrak, A., Phongthai, S., Jantanasakulwong, K, Chaiyaso, T. and Phimolsiripol, Y. 2020. Optimization of ultrasonic-assisted extraction of polysaccharides from purple glutinous rice bran (Oryza sativa L.) and their antioxidant activities. Scientific Reports. 10(1): 10410.

Therdthai, N. and Northongkom, H. 2011. Characterization of hot air drying and microwave vacuum drying of gingerroot (Boesenbergia pandurate). International Journal of Food Science and Technology. 46(3): 601-607.

Tufaro, D., Bassoli, A. and Cappa, C. 2022. Okra (*Abelmoschus esculentus*) powder production and application in gluten-gree bread: Effect of particle size. Food and Bioprocess Technology .15: 904-914

Van der Sman, R. G. M., Paudel, E., Voda, A. and Khalloufi, S. 2013. Hydration properties of vegetable foods explained by Flory–Rehner theory. Food Research International. 54(1): 804-811.

Wee, M. S. M. and Henry, C. J. 2020. Reducing the glycemic impact of carbohydrates on foods and meals: Strategies for the food industry and consumers with special focus on Asia. Comprehensive Reviews in Food Science and Food Safety. 19(2): 670-702.

Wojdylo, A., Oszmianski, J. and Teleszko, M. 2014. Antioxidant property and storage stability of quince juice phenolic compounds. Food Chemistry. 152: 261-270.

Xu, K., Guo, M., Roman, L., Pico, J., Martinez, M. M. 2020. Okra seed and seedless pod: Comparative study of their phenolics and carbohydrate fractions and their impact on bread-making. Food Chemistry. 317: 126387.

Xu, Y., Xiao, Y., Lagnika, C., Li, D., Liu, C., Jiang, N., Song, J. and Zhang, M. 2020. A comparative evalution of nutritional properties, antioxidant capacity and physical characteristics of cabbage (*Brassica oleracea var. Capitate var L.*) subjected to different drying methods. *Food Chemistry*. 309: 124935.

Yu, S., Ma, Y., Menager, L. and Sun, D. 2012. Physicochemical properties of starch and flour from different rice cultivars. Food Bioprocess Technology. 5(2): 626-637.

Zaharuddin, N.D., Noordin, M. I. and Kadivar, A. 2014. The use of *Hibiscus esculentus* (Okra) gum in sustaining the release of propranolol hydrochloride in a solid oral dosage form. Biomed Research International. 20114: 735891.