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EFFECT OF POMELO [*CITRUS MAXIMA* (BURM.) MERR] ALBEDO POWDERS ON SOME QUALITY AND DIGESTIBLITY PROPERTIES OF PIZZA BASE

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Abstract

Using fruit byproducts to partially replace wheat flour in pizza and baked goods is a growing trend. Pomelo albedo powders (PAP) containing 73.7 % of total digestible fiber were added to pizza dough at 5 %, 10 %, 15 %, and 20 % (w/w). The study assessed changes in physico-chemical properties, structure, appearance, volume, color, and digestibility. Results show that adding appropriate PAP content maintained key properties of pizza base (PB) while increasing fiber content. Dough volume decreased with higher PAP, lowest at 20% and closest to control at 5 %. Water holding capacity rose with more PAP. Dough color darkened with increased PAP ratio. No significant effects on par-baked PB, but crust color varied. Higher PAP negatively impacted specific volume and increased mass loss. PAP disrupted hole structure, with denser areas at 15 % and solid appearance at 20 %. Higher PAP decreased digestibility, but up-to 15 % PAP was accepted sensory and provided viable fiber for pizza. These results indicated that 15 % PAP enriched into the pizza base is selected as the optimal level for pizza dough production.
Keywords: pizza base; pomelo; soluble dietary fiber; texture; *in vitro*.

ВПЛИВ АЛЬБЕДО ПОРОШКІВ ПОМЕЛО [*CITRUS MAXIMA* (BURM.) MERR] НА ДЕЯКІ ПОКАЗНИКИ ЯКОСТІ ТА ЗАСВОЮВАНОСТІ ОСНОВИ ДЛЯ ПІЦИ

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Анотація

Використання побічних продуктів переробки фруктів для часткової заміни пшеничного борошна в піці та хлібобулочних виробах є зростаючою тенденцією. Порошки альбедо помело (ПАП), що містять 73.7 % загальної кількості перетравної клітковини, додавали до тіста для піци у кількості 5 %, 10 %, 15 % та 20 % (мас.). У дослідженні оцінювали зміни фізико-хімічних властивостей, структури, зовнішнього вигляду, об'єму, кольору та засвоюваності. Результати показують, що додавання відповідного вмісту ПАП зберігає ключові властивості основи для піци (ОП), водночас збільшуючи вміст клітковини. Об'єм тіста зменшувався зі збільшенням вмісту PAP, найнижчий за 20 % і найближчий до контролю за 5 %. Водоутримуюча здатність зростала зі збільшенням вмісту ПАП. Колір тіста темнішав зі збільшенням вмісту ПАП. Не було помічено значного впливу на випечену ОП, але колір скоринки змінювався. Вищий вміст ПАП негативно вплинув на питомий об'єм і збільшив втрати маси. ПАП порушував структуру пор, з більш щільними ділянками за 15 % і твердою консистенцією за 20 %. Підвищений вміст ПАП знижував засвоюваність, але до 15 % сприймався органолептично і забезпечував життєздатну клітковину для піци. Ці результати свідчать про те, що оптимальним рівнем збагачення основи для піци є 15 % ПАП, що додається до тіста для піци.
Ключові слова: основа для піци; помело; розчинні харчові волокна; текстура; *in vitro*.

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Introduction

In recent years, health-conscious baked goods such as pizza have gained popularity among consumers who seek to adopt a healthier lifestyle. Pizza has become a popular choice for various generations in Asia. However, the primary ingredient used to make the pizza base contains an excessive amount of starch and lacks fibers. By blending wheat and non-wheat flours, additional fibers can be incorporated while reducing starch content. This innovative approach addresses issues with bakery products that cannot be resolved by using solely wheat flour.

The flattened disc-shaped pizza base is composed of wheat flour, water, salt, and lipid in varying ratios depending on the formula. However, it is crucial for the flour to contain a high-quality protein with a quantity of approximately >12 % w/w to form the gluten network. When appropriate mechanical force and other ingredients such as oil and salt are present, a perfect formation of gluten network can be achieved which confers elasticity and toughness enabling it to hold gas during fermentation, incubation and baking process [1]. Therefore, using yeast as a leavening agent requires flour with elevated protein content for creating an ideal pizza base.

Incorporating alternative sources into wheat flour can introduce a range of beneficial compounds, including vitamins, minerals, dietary fibers, and phytochemicals found in plants [2]. While this can enhance the functional properties of food products, it may also impact various aspects of the final outcome. Therefore, optimizing a balance between sensory attributes and targeted supplementation is crucial for successful implementation.

Pomelo (*Citrus maxima*) is cultivated worldwide, but it holds a special place in South Asia, particularly in China, Vietnam and Thailand. According to FAO statistics, the global yield of pomelo stands at approximately 9.3×10^6 tons with China, Vietnam and Thailand contributing over 2×10^5 tons in 2019 [3]. Following fresh processing, a significant quantity of pomelo peel is discarded which includes a high volume of albedo – comprising around 30–40 % of the fruit's weight [4; 5]. This albedo section contains an abundant fiber content consisting of cellulose, pectin and hemicellulose accounting for roughly 93 % of the total carbohydrate content along with small quantities of lipids, proteins and ash as well as phenolic compounds like naringin and limonin [6]. Meanwhile, the utilization of by-products from pomelo peels not only results in value-added products but also helps reduce environmental hazards [4].

Citrus albedo powder has versatile uses, such as replacing fat in cakes, fortifying bread flour, and enhancing fiber content in fruit cakes to improve nutrition and reduce diabetes risk [7; 8]. Recent research by Taglieri et al. [9] explored fortifying bread with cooked purple potato flour and citrus albedo, particularly from pomelo and grapefruit, for bakery applications. Incorporating debittered albedo into wheat flour at varying levels influenced physicochemical properties and sensory attributes. Reshmi et al. [10] studied starch digestibility and predicted glycemic index in bread with pomelo fruit segments, finding reduced glycemic index values and increased resistant starch fractions.

Numerous studies have demonstrated that citrus albedo powder contains a substantial amount of soluble fiber, making it an excellent ingredient for bread and bakery flour blends. However, the formulation must be further optimized by determining the appropriate percentage of albedo addition to enhance quality characteristics and functional properties [9; 11]. The use of flour blends with albedo powder is particularly beneficial for individuals who are dieting, attempting to lose weight or experiencing allergies associated with traditional flours. The significance of this research goes beyond developing innovative products as it improves human dietary value by incorporating fiber-rich ingredients – especially when used in pizza production. Currently, there is limited information on how pomelo albedo compares with traditional products used in pizza bases.

The present study endeavors to investigate the viability of incorporating pomelo albedo powder into wheat flour at varying levels, while simultaneously assessing several physico-chemical and sensory characteristics of the resultant pizza base. An *in vitro* evaluation was also conducted to determine the effects of blending.

Experimental part

Materials and methods

Preparation of the pomelo albedo powder

The Vietnamese green peel pomelo (*Citrus maxima*) used in this study was purchased at the local farm at Hamlet 5, Binh Loi Commune, Vinh Cuu District, Dong Nai Province, Vietnam. The utilization of intact green-skinned grapefruit

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involves the careful crushing of its flesh to achieve a uniform texture. The harvesting period spanned from July through December of 2023. During this time, analyses were conducted to determine the physical and chemical composition of the harvested produce. These analyses included measurements for moisture content (%) (AOAC, 2000), mass (kg), diameter (cm), and Brix levels (°Bx) in accordance with Le and Jittanit [12]. The average size of the albedo is 8×15 cm, while the average thickness is about 2 cm. The albedo was cleaned, chopped, and soaked in a 10 % NaCl salt solution at 60 °C with a ratio of albedo/brine of 1 : 5 for 60 min. Then it was rinsed with water, squeezed to drain the water using a manual screw press (MECDBT, Vietnam), and convectively dried at 90 °C until the moisture content reached 10 %–13 %. The dried pomelo pulp was ground and finely sieved using a 70 mesh (hole diameter of 212 μm) sieve. The resulting PAP was stored in an airtight container at room temperature.

Scheme of the experiment and preparation of the pizza base

Commercial wheat flour (14 % moisture, 0.5 5% ash, and 38 % gluten) originated from Australian hard wheat (AH1), and it was produced by Interflour Vietnam Ltd., Vietnam. Bread improver (27.5–32.5 % wheat flour, 24–25 % calcium carbonate, 20–21 % tapioca starch, 17–18 % Mono- and Di- Glycerides of fatty acids, 4–5 % fungal α-amylase and protease, 2.5–3.5 % ascorbic acid was provided by AB Mauri Vietnam), instant yeast (Saf-instant Red label, Lesaffre Vietnam), and soybean oil was supplied by Meizan (Meizan CLV Ltd., Vietnam). Sugar and salt were procured from local market.

Six pizza base formulations were evaluated, as detailed in Table 1. The PAP component was incorporated into the formulation at varying percentages ranging from 0 % to 20 % by weight, corresponding to bread flour amounts of 100 %, 95 %, 90 %, 85 %, and 80 %. Water content was adjusted accordingly to achieve ratios of 60g (%), 75 g (%), 100 g (%), 114 g (%) and 123 g (%). In addition, other ingredients such as sugar (2.0 %), salt (1 %), bread improver (0.5 %), and soybean oil (5 %) were included in the recipe.

Table 1

Pizza base formula

Ingredients	Pomelo albedo powder (PAP) ratio				
	CT0	CT5	CT10	CT15	CT20
Bread flour (g)	100	95	90	85	80
PAP (g)	0	5	10	15	20
Sugar (g)	2	2	2	2	2
Salt (g)	1	1	1	1	1
Bread improver (g)	0.5	0.5	0.5	0.5	0.5
Instant yeast (g)	3	3	3	3	3
Soybean oil (g)	5	5	5	5	5
Water (g)	60	75	100	114	123

All the ingredients of each formula were combined using a dough mixer (HMJ-A35M1 – 120W, Bear Electric Appliance Co.,Ltd, China) for a duration of 10–12 min. The dough was rolled and left to rest for 20 min at room temperature. Then it was divided into 120 g portions using a fixed flat disc aluminum mold (18 cm diameter). The pizza dough was proofed in a UN cabinet (UN55, Memmert, Germany) at 30 °C (85 % RH) for 1 h. Finally, the proofed pizza base was partially baked at 180° C for 12 min using a TO-38iA – 1380W oven (Fujiyama, Japan). For the complete baking process, the pizza base (PB) was baked at 220 °C for 15 min. All of the samples were cooled for 1 h at room temperature prior to undergoing subsequent analysis.

Determination of chemical properties

Moisture content was determined by the hot air drying method [13], crude protein content (N×6.25) by the Kjeldahl method [14], total lipids by the diethyl ether soxhlet extraction method [15], ash content by the kiln ashing method (Daihan) at 700 °C [16], gluten content by the near-infrared method (NIR) (INFRANEO, Chopin Technologies, France), and total fiber, soluble fiber, and insoluble fiber content by the enzyme method [17]. Total carbohydrate content was calculated using the formula 100 − (% protein + % lipid + % ash + % moisture). The results have been expressed as g/100 g of dry matter.

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Determination of dough volume expansion

Dough volume expansion was determined according to the method of Wu et al. [18]. After mixing all ingredients, the dough was divided into small portion of 50 g, and these were shaped into rolls. The samples were then put into a 250 mL glass cylinder and placed in a bulk proof cabinet at 30 °C, 75–80% RH, for 120 min. The dough volume expansion was monitored and recorded at the 30, 60, 90, and 120 min time points.

Determination of specific volume

The volume of the pizza (mL) was determined by the sesame seed displacement method, adjusted from AACC method 10-05.01 [19]. The specific volume has been calculated as the ratio of the PB volume to the mass of the PB according to the following formula [20]:

$$\text{SV}\ (\text{cm}^3/\text{g}) = \frac{\text{V}_{\text{loaf}}}{\text{W}_{\text{loaf}}}$$

Where: SV is the specific volume, V_{loaf} is the PB volume after baking, and W_{loaf} is the weight of the PB after baking.

Determination of color

The color of the dough and PB after baking was randomly measured at five different locations on the surface of each sample using a CS-10 colorimeter (CHNSpec Co. Ltd., Shenzhen, China), with the system color CIE L*a*b*. Colors are defined on the basis of three-axis color coordinates, with (L*) representing lightness, (a*) green to red, and (b*) blue to yellow.

Determination of water-holding capacity

Water-holding capacity (WHC) was determined based on the modified method of Marchini et al. [21]. Around 15 g of dough was mixed with 285 mL of distilled water in a 500 mL beaker and stirred for 10 min at 20 rpm with a magnetic stirrer. Next, the solution was evenly divided into centrifuge tubes and rotated at 5,000 rpm for 30 min. Finally, the supernatant was removed, and WHC (g water/g dough) was calculated according to the following formula:

$$\text{WHC} = \frac{[(\text{Mass of tube and pellet} - \text{Dried tube mass}) - \text{pellet mass (g)}]}{\text{Dough mass (g)}}$$

Crumb cell ImageJ analysis

After baking, the PB samples underwent analysis of their internal structure through imaging. The PB was horizontally sliced to remove surface debris, and images of crumb were captured using a 12 MP camera within a square box under fixed lighting conditions. The camera was positioned 20 cm away from the sample, and the images were saved in HEIC format. Subsequently, the captured images were cropped to a size of 10×10 cm using GIMP software (version 2.10.32) and saved as JPG files. The processed image was then opened in ImageJ software (version 1.53k, National Institutes of Health, USA), converted to grayscale (8-bit), and the threshold was adjusted using Otsu's algorithm [22].

The analysis results have been converted to mm, with a conversion value of 1 mm equal to 11.81 pixels. Analytical data was presented using the following parameters: number of cells or alveolar, total area of cells, mean cell size (the average diameter of cells, mm), porosity (the ratio of total area of cells to area of the slice, %), and cell circularity. According to Rosell et al., [23], the formula for calculating circularity has been presented as follows:

$$\text{Circularity} = \pi \times 4 \times \frac{\text{Area}}{\text{Perimeter}^2}$$

In vitro starch digestibility

This experiment was performed based on the enzymatic hydrolysis method of Pereira et al. [24], with modifications. First, the sample was pureed and finely sieved (0.5 mm) 0.5 g of the sample was placed in a 50 mL glass tube, mixed with 17.5 mL of sodium acetate buffer of pH 5.0 with $CaCl_2$, and then closed). Subsequently, the mixture was incubated in a 50 °C environment for 5 min, while being stirred at a speed of 170 rpm. Following this, 2.5 mL of a combination of enzymes, α-amylase (4,000 U/5 mL) and Gluco-amylase (1,700 U/5 mL), was added. The sample underwent heating at 50°C and stirring at 170 rpm for a duration of 180 min. Samples of 1 mL of hydrolysate were then extracted at intervals of 0, 20, 40, 60, 90, 120, and 180 min into glass tubes, where they were combined with a 20 mL solution containing 50 mM acetic acid. Subsequently, the solution was filtered using Newstar 102 filter paper and subjected to analysis for reducing sugars with a DNS reagent. The quantity of starch hydrolyzed at 20, 120, and 180 min was utilized in determining the starch indices, rapidly digestible starch (RDS), slowly digestible starch (SDS), and total starch (TDS).

Enzyme α-amylase (4,000 U/5 mL) (*Aspergillus oryzae*, Cool Chemical, China), Gluco-amylase (1,700 U/5 mL) (Angel, China), sodium acetate (99.5 % purity), calcium chloride (99.5 %

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purity), and diethyl ether (99.7 % purity) were supplied by Unionchem (Unionchem Co. Ltd., China); D-Glucose (99.7 % purity). DNS (99.8 % purity) were purchased from Sigma-Aldrich Chemie Co. Ltd, USA.

The amount of starch hydrolyzed was calculated according to the following formula:

$$\%\ \text{Starch hydrolyzed} = \frac{\text{Reducing sugar mass} \times 0.9}{\text{Sample mass}} \times 100$$

Where 0.9 is the coefficient of conversion from glucose to starch.

Determination of reducing sugars

The reducing sugar was determined according to the study of Saqib and Whitney [25]. Around 1 mL of the reducing sugar solution was put in a test tube before 4 mL of the DNS reagent was added. Next, the test tube was placed in a boiling water bath for 5 min, followed by rapid cooling to 25 °C. The sample was measured for optical absorbance at 540 nm using UV-Vis spectrophotometer UH-5300 (Hitachi, Japan). Calibration curves were prepared using a D-glucose solution at a concentration of 2 mg/mL [26].

Glycemic index

The kinetics of starch degestion was estimated by non-linear equations as follow [24]:

$$\text{C} = \text{C}_{\infty}(1 - \text{e}^{-\text{kt}})$$

Where C is the percentage of starch hydrolyzed at time t, C_{∞} is the percentage of starch hydrolyzed after 180 min, k is the kinetic constant, and t is the corresponding time (min).

Then the area under the curve (AUC) was determined by the amount of starch hydrolyzed over time. The hydrolysis index (HI) was calculated as the ratio of the AUC of each sample to the AUC of the control sample.

$$\text{AUC} = \text{C}_{\infty}(\text{t}_{\infty} - \text{t}_0) + \left[\frac{\text{C}_{\infty}}{\text{k}}(\text{e}^{-\text{kt}_{\infty}} - \text{e}^{-\text{kt}_0})\right]$$

Where AUC is the area under the curve, C_{∞} is the percentage of starch hydrolyzed after 180 min, t_{∞} is the final time (180 min), t_0 is the initial time (0 min), and k is the kinematic constant

The HI value of each sample was used to predict the corresponding glycemic index (pGI) according to the following equation:

$$\text{pGI} = 39{,}6207 + 0.5498 \times \text{HI}$$

Determination of pizza base texture

The texture profile analysis (TPA) of PBs were determined by CT3 texture meter (Brookfield, USA) using a 4,500 g load cell sensor, and the TA11-1000 cylindrical probe of 25.4 mm in diameter. The following settings were employed: two presses mode with initial press speed of 2 mm/s, measuring speed of 1 mm/s, press of 20 % of the sample height and rest for 30 seconds between two presses [20; 27]. The PB was cut into 5×5 cm cubes for measurement. Hardness is the maximum force in the first press; the parameters gumminess, springiness, chewiness, and cohesiveness are also given in the software [28].

Sensory evaluation

For sensory evaluation, fully baked PBs were taken and allowed to cool at room temperature (25 °C) within 1 hour and cut into 2×5 cm pieces. This assessment involved sixty sensory panelists (3rd and 4th year students specializing in food technology). The samples were assigned random three-digit codes, and a sample presentation sequence was established to prevent any bias. Each panelist evaluated five samples simultaneously, assessing them for color, taste, texture, and overall acceptability using a nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely). Panelists were instructed to rinse their palates with filtered water before and between sample evaluations. The sensory session was overseen by a coordinator to ensure adherence to specific protocols and maintain the highest quality standards.

Data analysis

The experiment was arranged in triplicate. The results were subjected to statistical analysis of variance (ANOVA) using Statgraphics Centurion 16.2 (USA) and Excel software with a significance level of 5 %.

Results and discussion

Chemical properties of wheat flour and PAP

The chemical properties of wheat flour and PAP are presented in Table 2. They show that the total carbohydrate content has a negligible difference between wheat flour and PAP. However, the protein content of wheat flour is high (13.46 ± 0.04 g/100 g), while PAP is 4.21 ± 0.32 g/100 g. On the other hand, the TDF in PAP was high, accounting for 73.7 g/100 g, of which soluble dietary fiber (SDF) accounted for 24.1 %

and insoluble dietary fiber (IDF) accounted for 49.6 %, and there was no occurrence of this ingredient in wheat flour. This result was similar to those in the studies of Gamonpilas et al. [6] and Sharma et al. [29]. In 2015, Wang et al. [30] also demonstrated that *Citrus grandisi Marc.* contains the highest SDF content (93.05 ± 0.68%) when comparing the physicochemical properties of fiber on five different citrus fruits. The analysis results of Table 2 show that albedo is a very rich source of fiber and this is suitable for use in the low-caloric pizza production.

Table 2

Chemical properties of wheat flour and pomelo albedo powder (PAP)

Chemical parameter	Wheat flour	PAP
Moisture (g/100 g)	13.68 ± 0.05	12.84 ± 0.21
Total carbohydrate (g/100 g)	82.41 ± 0.17	78.99 ± 0.53
Lipid (g/100 g)	3.53 ± 0.12	2.78 ± 0.33
Ash (g/100 g)	0.6 ± 0.03	1.31 ± 0.05
Protein (g/100 g)	13.46 ± 0.04	4.21 ± 0.32
Gluten (g/100 g)	35.25 ± 0.26	-
TDF (g/100 g)	-	73.7 ± 0.14
Soluble dietary fiber (SDF) (g/100 g)	-	24.10 ± 0.73
Insoluble dietary fiber (IDF) (g/100 g)	-	49.60 ± 0.59

Changes in volume of dough for different formula

The effect of PAP ratio on dough rise is shown in Fig. 1. The results show a significant difference in swelling volume over time at the addition ratios of PAP. Most of the dough samples at 0 min had a volume of about 50 mL and increased with prolonged proofing time. Generally, the volume of the dough decreased as the PAP content increased. However, the dough rise with 5% PAP added (CT5) showed no significant difference (P > 0.05) compared to the control sample (CT0) at 30, 60, and 90 min intervals, but a notable difference emerged after 120 min of incubation. The noticeable reduction in volume expansion observed when substituting with 10 % PAP. This could be attributed to the diminished CO_2 retention capacity resulting from the reduced yeast activity in the flour mixture with lower gluten content. A similar observation was made in Wu's study [18] involving a 10 % sweet potato puree blend.

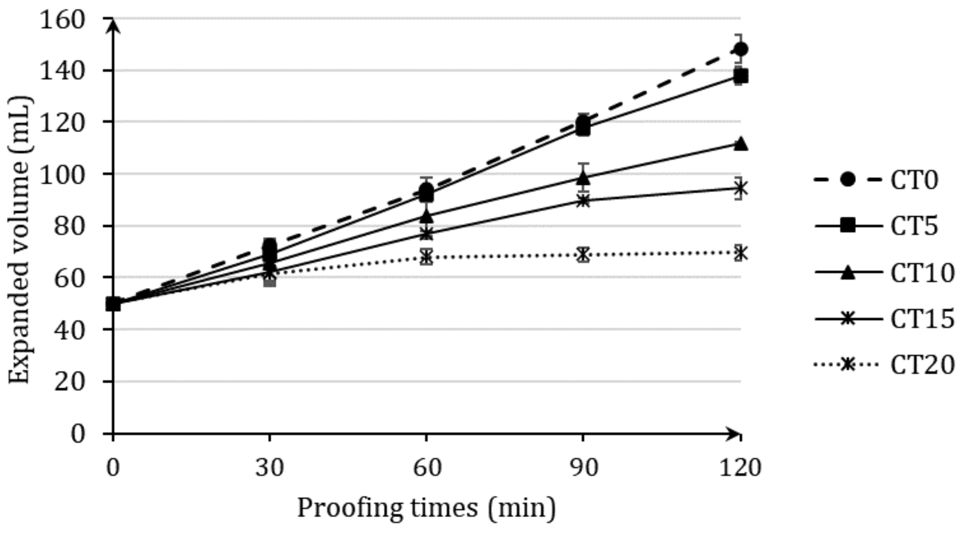

Fig.1. Effect of pomelo albedo powder (PAP) enrichment on pizza dough expansion

Note: CT0 = control sample; CT5 = 5% PAP, CT10 = 10% PAP, CT15 = 15% PAP, CT20 = 20% PAP

During the 120 min incubation period, the dough volume of samples CT0 and CT5 expanded more rapidly compared to the other samples. Samples CT10 and CT15 exhibited a slower increase in dough volume, and CT15 showed the slowest trend; the difference in volume at 90 and 120 min was not statistically significant ($P < 0.05$). The lowest rise in volume was observed in the CT20 sample. The dough volume of the 20 % PAP sample increased within the initial 30 min but remained nearly unchanged for the remainder of the period. The findings indicate that incorporating 5 % PAP results in dough quality most closely resembling that of the control sample.

Changes in color and WHC of dough

The results from Table 3 show that WHC is directly proportional to PAP content. This value has no significant difference between CT0 and CT5 ($P > 0.05$). However, during the experiment, the amount of water needed to be added to the formula for 5 % PAP was more than the control sample, which was 15 g water/100 g flour. The remaining samples had significantly increased WHC values compared with the control samples according to the ratio of PAP addition, specifically for CT0 sample 1.03 ± 0.05 g water/g flour; there was an increase of 1.39 ± 0.23 g water/g powder. Similarly, the CT15 sample increased to 1.83 ± 0.21 g water/g flour, and the CT20 sample was 2.29 ± 0.12 g water/g flour. The high WHC was contributed by the chemical properties of the albedo. Carbohydrates have a higher propensity to absorb water compared to proteins due to their hydrophilic nature, which allows them to hold onto water molecules more effectively. In this study, a higher water holding capacity (WHC) was noted in the formula containing a higher proportion of PAP. This enhanced WHC may result from a decrease in protein content in the formula on one hand, while simultaneously increasing the carbohydrate content, specifically total dietary fiber (TDF), including soluble dietary fiber (SDF) and insoluble dietary fiber (IDF). On the other hand, in addition to their hydrophilic nature, these substances can also demonstrate physical effects whereby a higher concentration of PAP can lead to the creation of numerous interstitial spaces. This formation of a matrix can effectively retain water within it [31; 32]. Nevertheless, the higher mass loss post-baking may be attributed more to the physical effects of the substances rather than their hydrophilic nature. This observation is supported by the findings presented in the subsequent section of this study.

Table 3

Effect of pomelo albedo powder (PAP) levels on WHC and color of dough

Parameters	Sample				
	CT0	CT5	CT10	CT15	CT20
WHC (g water/g flour)	1.03 ± 0.05^{a}	1.01 ± 0.06^{a}	1.39 ± 0.23^{b}	1.83 ± 0.21^{c}	2.29 ± 0.12^{d}
L*	84.96 ± 0.61^{d}	84.23 ± 1.17^{cd}	83.76 ± 0.75^{bc}	83.17 ± 0.61^{b}	82.23 ± 0.49^{a}
a*	0.93 ± 0.99^{b}	0.01 ± 0.68^{a}	0.12 ± 0.386^{a}	0.22 ± 0.19^{a}	-0.19 ± 0.03^{a}
b*	13.70 ± 0.48^{a}	15.37 ± 0.99^{bc}	14.79 ± 0.1^{b}	14.96 ± 0.38^{b}	15.62 ± 0.34^{c}

Note: $^{a, b, c, d}$ mean that there is a statistically significant difference between the values by row ($P < 0.05$)

The color of the dough with the L*, a*, b* scale is shown in Table 3. The L* value decreases linearly with the PAP ratio ($P < 0.05$), which means the color of the dough darker when increase PAP ratio. The control sample CT0 has the highest brightness (84.94 ± 0.61), and the sample CT20 has the lowest brightness (82.23 ± 0.49). There was no notable distinction in the a* value among the formulas containing PAP, but a significant variance was observed when compared to CT0. A decreasing value of a* means that the samples are bluer, specifically CT20 (−0.19 ± 0.03), compared to the control sample CT0 (0.93 ± 0.99). The b* parameter, on the other hand, represents blue (−b*) to yellow (+b*). The dough with the largest b* value is CT20 (15.62 ± 0.34), which is more yellow than the CT0 sample with the smallest b* value (13.70 ± 0.48). Consistent with findings from prior research, the incorporation of fruit powder into bread had varying effects on color, which could be significant or insignificant, depending on the amount added and the presence of color pigments in the powder [33].

Color, specific volume, and mass loss of the PB after baking

The value of L*, a*, b* of the crust surface are shown in Table 4. The results show a clear difference in color between before and after baking. The L* value of PB is lower than that of the dough, which indicates a darker color after baking. This value increased gradually from CT0 (70.86 ± 1.49) to sample CT15 (74.83 ± 0.56) and decreased at CT20 (69.07 ± 0.43). This process provides a high amount of heat that changes the overall color of the PB.

The addition of PAP continually affected the color of the baked product. It can be said that when replacing 5 % with 15% PAP, the color of the crust becomes brighter. However, when increasing to 20 % PAP, the color darkens. The a* values also show differences but are not linear. Similar to dough, the a* value tends to decrease when replacing more PAP: the highest at CT0 (−0.92 ± 0.73) and the lowest at CT10 (−1.94 ± 0.41). This shows that the color of the PB tends to turn green because of the baking process. For the b* value, a significant difference was found between samples CT15 (17.78 ± 0.68) and CT20 (19.75 ± 1.05), with $P < 0.05$. On the other hand, a significantly higher b* of PB indicates that the crust has turned yellow at the end of baking. The color change may be due to the Maillard reaction or caramelization when exposed to high temperatures [34]. Overall, the total color remained relatively consistent across all PAP samples. Previous research on rye bread by Mustafa et al. [35] has also shown little color difference between the adjusted samples after baking.

Table 4

Effect of pomelo albedo powder (PAP) levels on color of the par-baked pizza base

Parameters	Sample				
	CT0	CT5	CT10	CT15	CT20
L*	70.86 ± 1.49[b]	72.69 ± 0.57[c]	72.24 ± 1.09[c]	74.83 ± 0.56[d]	69.07 ± 0.43[a]
a*	−0.92 ± 0.73[c]	−1.31 ± 0.77[bc]	−1.94 ± 0.41[a]	−1.79 ± 0.26[ab]	−1.73 ± 0.16[ab]
b*	19.53 ± 1.38[ab]	19.13 ± 2.57[ab]	18.37 ± 1.57[ab]	17.78 ± 0.68[a]	19.75 ± 1.05[b]

Note: [a, b, c, d] mean that there is a statistically significant difference between the values by row ($P < 0.05$)

The increase of the PAP ratio had a negative effect on the specific volume (SV) of PB (Fig. 2). The experiments have shown that SV is high at CT0 (4.53 ± 0.09 cm^3/g) and low at CT20 (1.43 ± 0.08 cm^3/g). Smaller specific volumes indicate that PB has expanded poorly during baking. This was proportional to the recorded bulk proof volume. Similar to dough expanded volume, this may be due to the dilution of gluten content combined with the interference of lignans and fiber on the gluten network [36]. This phenomenon has also occurred in several previous studies. According to Begum et al. [20], who used banana bract fiber powder in bread, showing that the largest specific volume was for the control sample (5.83 cm^3/g) and markedly decreased when adding fiber powder from 4 g/100 g (5.46 cm^3/g). Wang et al. [27] also confirmed that the cake volume was reduced with increasing chestnut flour content (2 % CCP reduced by 10.8 %; 6 % CCP decreased by 23 %) compared with the control sample (6.38 mL/g). In the realm of baked goods, specific volume and structure are crucial factors that impact consumer purchasing decisions [37]. A PB product with a generous volume is likely to be more appealing to consumers.

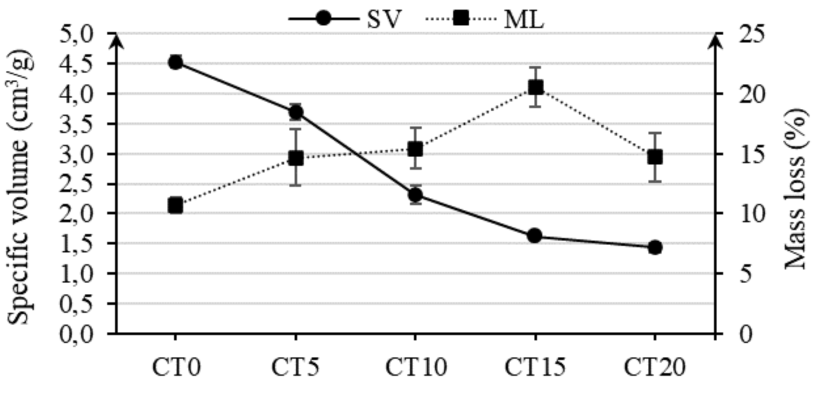

Fig. 2. Effect of pomelo albedo powder (PAP) levels on specific volume (SV) and mass loss (ML) of the par-baked pizza base

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The results show that ML tended to increase with the addition of PAP in Fig. 2. Specifically, the CT0 sample had the lowest (10.71 ± 0.63 %) and highest increase at 15 % PAP (20.51 ± 1.68 %). There was a nonsignificant difference in the WL value at samples CT5, CT10, and CT20. In general, PAP made PB lose more weight when baking than the control sample CT0, and the change between samples with PAP was not statistically different ($P < 0.05$). Although PAP had good water absorption and increased dough mass, the ML during baking was high. This could be attributed to the decrease in flour mass, causing a reduction in the extent of starch gelatinization due to the baking temperature. Consequently, the water content was not retained and instead evaporated from the mixture.

Texture analysis of the par-baked pizza base

Table 5 shows the effect of PAP ratio after baking on the texture of PB. The results show that adding PAP from 5 % to 15% reduced hardness (ranging from 1.09 to 1.83 N); at the 20 % PAP sample, this value increased (15.22 ± 1.38N) and was higher than CT0 (2.23 ± 0.13N). At CT20, the highest gumminess and chewiness were 13.2 ± 1.18 N and 12.3 ± 0.83 N, respectively. This trend is similar to that of hardness. The main reason may be that addition of PAP led to dilution of gluten netwok and under the baking process, the gluten network was more weakened resulting in the poor air retention, and volume expansion leading to increased hardness [27; 38]. On the other hand, addition of PAP caused the brick pores structure , when baking at high temperatures, the water is largely evaporated [32]. Previous study by Chen et al. [39] also showed that a five fold increase in hardness was observed when 20% mango peel powder was added to the bread, while the values of cohesiveness and springiness have no difference ($P > 0.05$). The results indicate that the addition of PAP at the appropriate level did not lose the important structural properties of PB but provided a significant amount of fiber. Thereby, based on the suitability of the PB product, which is not too hard and has good elasticity, 10–15 % PAP was selected.

Table 5

Effect of pomelo albedo powder (PAP) levels on the texture profile of the par-baked pizza base

Attributes	Sample				
	CT0	CT5	CT10	CT15	CT20
Hardness (N)	2.23 ± 0.13^{b}	1.83 ± 0.09^{ab}	1.15 ± 0.03^{ab}	1.09 ± 0.05^{a}	15.22 ± 1.38^{c}
Cohesiveness*	0.9 ± 0.06^{a}	0.91 ± 0.08^{a}	0.89 ± 0.14^{a}	1.0 ± 0.06^{a}	0.87 ± 0.01^{a}
Springiness*	0.96 ± 0.03^{a}	0.97 ± 0.01^{a}	0.94 ± 0.05^{a}	0.98 ± 0.02^{a}	0.93 ± 0.02^{a}
Gumminess (N)	2.0 ± 0.1^{b}	1.66 ± 0.1^{ab}	1.02 ± 0.17^{a}	1.09 ± 0.03^{ab}	13.2 ± 1.18^{c}
Chewiness (N)	1.91 ± 0.14^{b}	1.62 ± 0.11^{ab}	0.95 ± 0.19^{a}	1.07 ± 0.03^{a}	12.3 ± 0.83^{c}

Note: $^{a, b, c, d}$ mean statistical difference by row ($P < 0.05$), while * means that the difference is negligible by row ($P > 0.05$)

Crumb cell analysis and In-vitro test

Crumb cell analysis. The influence of PAP ratio on PB intestinal structure through cross-sections has been shown in Fig. 3. Detailed parameters obtained when processed by the ImageJ software are also presented in Table 6.

The analysis findings revealed a gradual decrease in the number of cells as the PAP ratio increased. The addition of PAP disrupted the formation of a uniform hole structure in the PB, indicating that the weakened gluten network hindered the trapping of CO_2 during dough fermentation. As depicted in Fig. 3, an increase in PAP from CT5 to CT15 resulted in areas with dense structures and uneven holes, with irregular distribution, while CT20 exhibited a nearly solid appearance without a porous structure. A study by Sun et al. [37] demonstrated a similar trend when raw and fermented maize gluten feed were incorporated into bread. Corresponding with the results in Table 6, the cell count was highest at CT0 (4206.67 ± 302.49) with a decrease as PAP content increased and lowest at CT20 (376.33 ± 26.69). Furthermore, the total cell area tended to decrease from the highest value at CT0 (3742.60 ± 678.98 mm^2) to the lowest at CT20 (780.15 ± 207.17 mm^2), resulting in an increase in the average cell size. A circularity value closer to 1 indicates a more desirable cross-sectional structure in CT0 compared to samples containing PAP, although values for samples CT5 to CT20 were approximately between 0.78 and 0.80.

Premium-quality PB typically exhibits small air holes and uniform distribution, a lower cell count suggests gas escape during fermentation due to hole formation in the gluten network [40].

Table 6

Analysis of internal cross-sectional structure of pizza base

Parameters	Sample				
	CT0	CT5	CT10	CT15	CT20
Total number of cells	4206.67 ± 302.49[e]	1843.00 ± 179.22[c]	2284.00 ± 120.88[d]	1286.67 ± 174.57[b]	376.33 ± 26.69[a]
Total area of cells (mm^2)	3742.60 ± 678.98[d]	2966.23 ± 336.76[c]	2435.64 ± 204.73[bc]	2078.15 ± 233.55[b]	780.15 ± 207.17[a]
Mean cell size (mm)	0.89 ± 0.14[a]	1.63 ± 0.36[bc]	1.07 ± 0.07[ab]	1.62 ± 0.05[bc]	2.09 ± 0.58[c]
Porosity (%)	37.43 ± 6.79[d]	29.66 ± 3.37[c]	24.36 ± 2.05[bc]	20.78 ± 2.34[b]	7.80 ± 2.07[a]
Circularity	0.84 ± 0.01[c]	0.79 ± 0.01[ab]	0.80 ± 0.00[b]	0.78 ± 0.01[a]	0.79 ± 0.01[b]

Note: [a, b, c, d] mean statistical difference by row ($P < 0.05$)

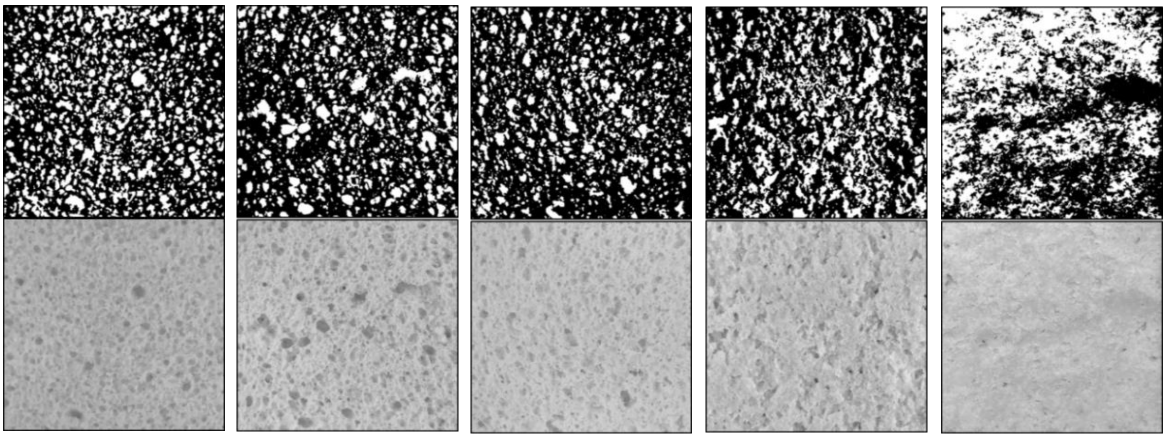

Fig. 3. Internal cross-section of PB at difference scales of PAP.
Note: 0 % (CT0), 5 % (CT5), 10 % (CT10), 15 % (CT15), and 20 % PAP (CT20)

In vitro starch digestibility

The *in vitro* test of PB containing PAP is shown in Table 7. The results show no significant difference in RDS between samples CT0 and CT5 (from 45.28 % to 55.41 %) as well as between CT10 and CT15 and CT20 (from 22.51 % to 28.92 %). Since then, it has been shown that the ability to digest PB when increasing the percentage of PAP has a positive effect on health. Meanwhile, about 85.25 ± 3.825 % starches were digested in the control sample, while this number was lower in the formulation containing PAP (from 41.08 % to 60.72 %). Total digestibility of TDS was inversely proportional to the concentration of supplemental PAP. However, the SDS index reached the highest at CT0 (23.53 ± 10.95 %) and had a significant difference compared with the remaining samples. This has been shown to inhibit starch digestion and maintain stable blood sugar, prolonging satiety and reducing the stimulation of energy intake [41]. Most of the kinematic constant k is comparable between samples, which is approximately 0.04, with the R^2 coefficient at the highest CT0 indicating that the sample is stable in this assay. Although within safe limits, at CT0, however, the pGI index reached the highest value (94.6 ± 0.0 mg/dL), while this value tended to decrease with the addition of PAP and was inversely proportional to the concentration. The slower starch digestion in the PAP samples could be affected by the added fiber content (Table 2), which binds to and forms a sheath on the starch granules that slows the penetration of digestive enzymes, making the substrate enzyme reaction limited, leading to changes in some physicochemical and rheological properties of PB [40, 42]. Furthermore, the phenolic group components present in albedo have the ability to inhibit the activity of enzymes [42]. Previous publications have also shown a similar trend when adding fiber to bread [41].

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Table 7

Starch digestibility of pizza base

Parameter	Sample				
	CT0	CT5	CT10	CT15	CT20
RDS (%)	55.41 ± 15.79[b]	45.28 ± 1.94[b]	28.92 ± 1.01[a]	22.51 ± 9.65[a]	28.25 ± 7.5[a]
SDS (%)	23.53 ± 10.95[c]	6.28 ± 0.79[a]	12.98 ± 1.57[b]	17.96 ± 3.14[bc]	6.79 ± 2.71[a]
TDS (%)	85.25 ± 3.82[c]	60.72 ± 6.96[b]	49.03 ± 2.99[a]	50.28 ± 8.99[a]	41.08 ± 1.49[a]
k*	0.04 ± 0.01[a]	0.04 ± 0.02[a]	0.02 ± 0.0[a]	0.02 ± 0.01[a]	0.04 ± 0.02[a]
R^2	0.96 ± 0.02	0.86 ± 0.09	0.86 ± 0.01	0.92 ± 0.02	0.89 ± 0.04
pGI (mg/dL)	94.6 ± 0.0[d]	78.78 ± 4.49[c]	71.29 ± 1.97[ab]	72.24 ± 5.51[b]	66.14 ± 0.93[a]

Note: [a, b, c, d] mean statistical difference by row ($P < 0.05$), while * means that the difference is negligible by row ($P > 0.05$)

Sensory evaluation

The sensory evaluation results of PBs are depicted in Fig. 4 CT5 and CT10 showed a marginal difference in appearance scores (6.82 ± 0.85 and 6.77 ± 0.87, respectively), while CT15 reached the highest level of 7.83 ± 0.64. In terms of color and texture, most panelists rated the samples with a high acceptance level exceeding 6. Notably, these ratings surpassed 7 at CT15. The addition of PAP from 5 % to 15 % did not yield noticeable differences as the average scores remained consistent. CT20 exhibited the lowest values across all attributes, with 6.42 ± 0.64 for color and only 5.87 ± 1.05 for flavor. This could be attributed to the bitter taste in PAP (due to naringin, hesperidin, or essential oils) reaching a taste detection threshold at 20 %, resulting in lower scores. The results suggest that CT15 is the most suitable addition level for PBs based on sensory acceptability.

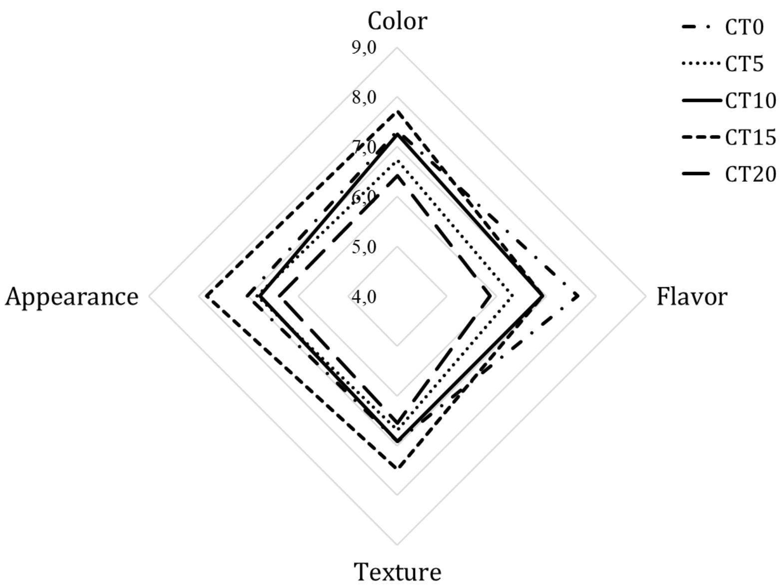

Fig. 4. Sensory evaluation of baked pizza base

Conclusion

The results show that adding PAP at the right level maintained PB's key properties while increasing fiber content. Dough volume decreased with higher PAP content, lowest at CT20 and closest to control at 5 % PAP (CT0). Water holding capacity (WHC) rose with more PAP. Dough color darkened linearly with PAP ratio, affecting crust color post-baking. Specific volume decreased with higher PAP, while ML increased. Hardness decreased from 5 % to 15 % PAP but spiked at 20%. Gumminess and chewiness were insignificantly affected. PAP disrupted hole structure, denser at CT15 and solid at CT20. Digestibility decreased with more PAP. PAP can replace some flour in PB for added fiber, with sensory scores consistent up to 15 % PAP, differing at CT20.

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