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Quality Characteristics of Pregelatinized Cassava Flour and Its Application in Frozen Dough for Artisan Pizza

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Abstract: Cassava has played a significant role in Indonesia, serving as a cultural identifier and symbol of tradition. It has undergone various modern adaptations by transforming into pregelatinized cassava flour (PCF). This study reports on the characteristics of PCF produced by small entrepreneurs, evaluates the suitability of PCF frozen dough for fusion dishes like PCF-pizza, and assesses consumer acceptability of PCF-pizza. PCF-pizza combined the elements of Indonesian ethnic cuisine, such as cassava, with the popular Western dish of pizza. For these purposes, a PCF producer was interviewed, followed by PCF sampling, which was then further formulated into a dough. The dough was developed in a laboratory, and it was stored in a freezer at a temperature of -20 + 2 ^{o}C for 0, 14, and 28 days. An artisan baker was intensively coached to develop the dough for the production of PCF-pizza, which was then delivered to the end consumer. Standard methods were applied to analyze the PCF characteristics. A questionnaire was used to explore the consumers acceptability of the PCF-pizza. The study revealed that PCF has suitable characteristics for dough preparation of PCF-pizza. The dough could expand and form pores upon baking, indicating that the dough protected the yeast cells during frozen storage. The PCF frozen dough, stored for 14 days, was still suitable for producing PCF-pizza. Consumers accepted the PCF-pizza texture, taste, and aroma, and the price was feasible for the artisanal bakery industry. This study demonstrated that the scientific and technological innovation of PCF, supported by public investment, presents opportunities for improved cassava utilization, thereby encouraging the development of smallholder agro-industries.

Keywords: Cassava; flour; fusion dish; pregelatinized; PCF-pizza

1. Introduction

Cassava (*Manihot esculenta* Crantz) played an important role in Indonesian culinary traditions, serving as a cultural identifier and symbol of traditions [1–3]. This tuber was incorporated into many traditional foods, savory snacks, and sweet desserts. This tuber crop can be grown in various types of agroecosystems throughout the archipelago and can become an income-generating crop. Cassava has several attributes that make this crop attractive for both economic and health reasons[4]. Cassava is processed into starch to be utilized as an ingredient in the food industry, such as tapioca pearls, mochi, etc. Currently, cassava has undergone various modern adaptations by the food industry. The development of pregelatinized cassava flour (PCF) is a breakthrough in cassava transformation. The process involves washing, peeling, chipping, heat or extrusion treatment, and fine grinding [5]. This processing helped reduce post-harvest loss of cassava and even out fluctuations in seasonal supply. The cassava flour has been incorporated into the development of high-fiber, low-sugar snacks [6], artificial rice [7–9], a matrix for turmeric encapsulation [10], and noodles [11–12]. It was also blended with rice flour and sago starch to produce gluten-free wafers [13].

In Malang, East Java, Indonesia, there is a type of staple food made from dried cassava (also known as gaplek), which is ground into flour and then steamed or boiled. This type of food is popular as Tiwul and is a beloved ethnic dish that showcases the region's rich culinary heritage. Pizza is a popular and versatile dish that originated in Italy but has become beloved worldwide. Pizza is incredibly adaptable, allowing for endless combinations of flavors and styles to suit personal tastes and regional preferences. It was reported that pizza dough was successfully developed from PCF [14–15]. The use of PCF for pizza was a fusion that combines elements of Indonesian ethnic cuisine with the popular Western dish. This fusion dish was named PCF-pizza, which was produced as an artisanal food product. An artisan food product was all about high-quality, handcrafted, traditional, and locally sourced ingredients. Currently, artisanal food products are rapidly being produced by smallholder enterprises worldwide. Despite these facts, the potential for commercializing PCF-pizza has not been fully tapped due to a lack of appropriate information concerning PCF technology and its characteristics, as well as the acceptability of PCF-pizza. On the other hand, frozen dough has been widely applied in the bakery industry, which is reported to enhance productivity, streamline operations, and improve product quality. This study is distinctive in documenting the production of PCF by small-scale entrepreneurs, characterizing its properties, and demonstrating its application in frozen dough for an innovative product, PCF-pizza. The work uniquely integrates local cassava-based ingredients with a globally popular dish, highlighting both scientific innovation and socio-cultural value. The objectives of this study were to report the characteristics of PCF produced by small entrepreneurs, to assess the suitability of PCF for preparing frozen dough, and to evaluate the consumers' acceptability of PCF-pizza produced by an artisanal bakery.

2. Materials and Methods

2.1. Materials

Sweet cassava was supplied by a farmers' association in Warungkiara District, Sukabumi Regency, West Java Province. PCF was produced by a small entrepreneur (PT Infiad Indonesia) at Cigombong District, Bogor Regency, West Java Province. PCF-pizza was produced by the artisanal baking shop of Roti Boss at Kendal Payak District, Malang Regency, East Java Province. Figure 1 shows the area covered in this study. All baking ingredients, such as yeast, sugar, and margarine, were purchased from the local market. Chemicals of analytical grade, such as HCl, H_2SO_4, and PDA, were purchased from Indonesian distributors.

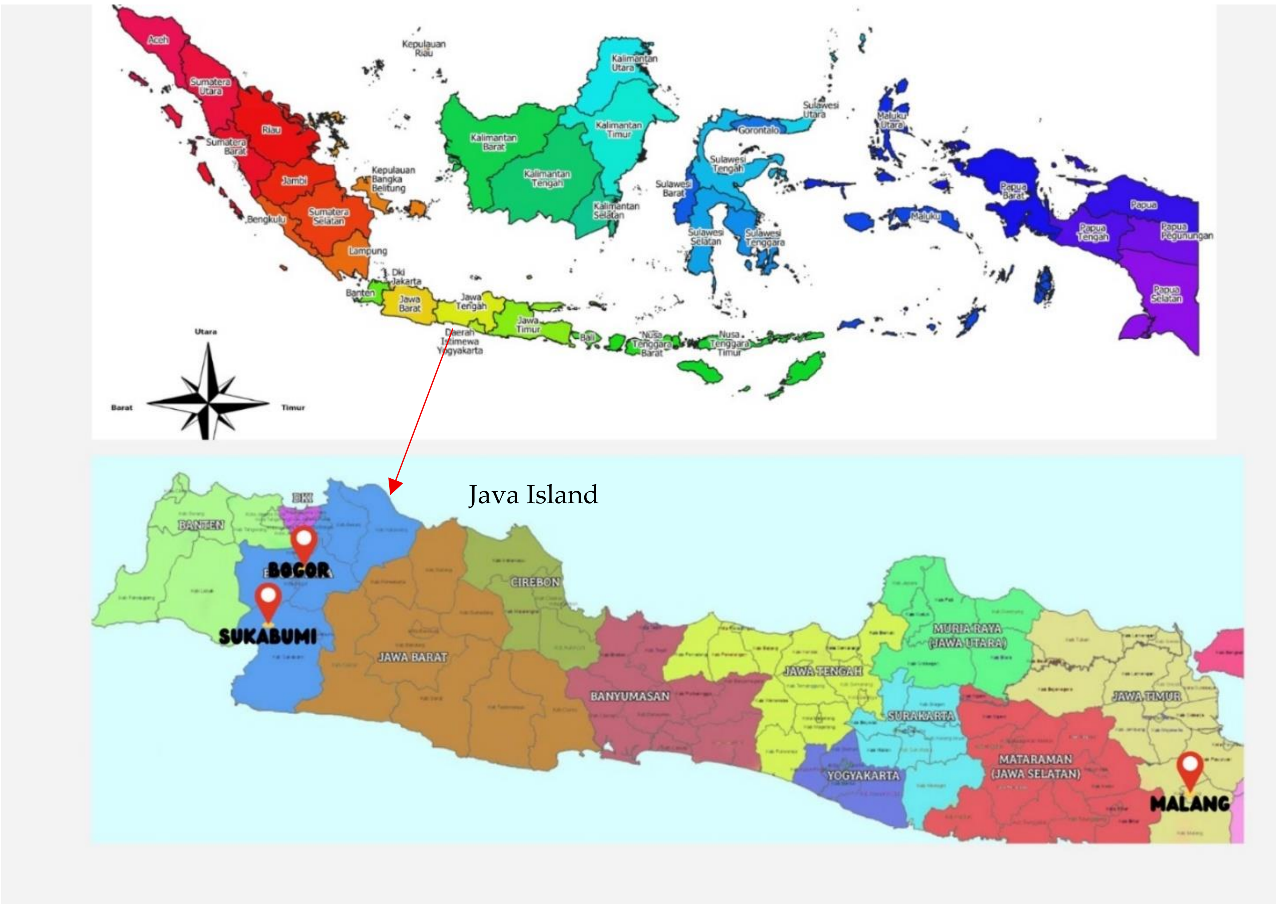

Figure 1. Geographical map of the study area

2.2. Survey and sampling of PCF

A survey conducted at PT Infiad Indonesia (Bogor, West Java) documented the PCF production technology, including descriptions of the machinery and its functions. PCF was taken for sample analysis and pizza formulation. It was packed in high-density polyethylene (HDPE) bags, placed in carton boxes, and delivered by car to the laboratory and an artisanal bakery. The ethical clearance No. 402/KE.01/SK/06/2023 was approved by the Ethics Commission on Social and Humanities, National Research and Innovation Agency, Republic of Indonesia.

2.3. Preparation of PCF-Based Dough and Artisanal Production of PCF-pizza.

The PCF (produced by PT Infiad Indonesia) was blended with rice flour and sago starch, with a weight proportion of 5:4:1, respectively. The basic recipe of the dough consisted of 200 g blended PCF flour, 3 g of xanthan gum, 0.6 g of bread improver, 3 g of yeast, 20 g of sugar, 40 g of margarine, 25 g of full-cream milk powder, 50 g of whole egg, and 250 mL of water. All ingredients were mixed in a bread maker machine (RB Bread RB250C). Mixing for 15 minutes, fermentation-proofing, and resting for 2 hours were automatically established by the machine. The dough was placed in a covered plastic container and immediately stored in a freezer at a temperature of -20 + 2 °C. After frozen storage for 0, 14, and 28 days, the dough was thawed at 25 °C for 1 hour. The dough was divided into 50 g pieces, molded, and then baked in a baking oven for about 10-15 minutes at 220 °C + 10 °C. The artisan baker of Roti Boss was asked to join in this study. She was selected due to her regularity, quantity in production, and experience with cassava flour utilization. She was intensively coached to produce PCF-pizza. The production process was followed step by step, from the dough preparation to the finished food (Figure 2). The baker was located in Malang, East Java Province.

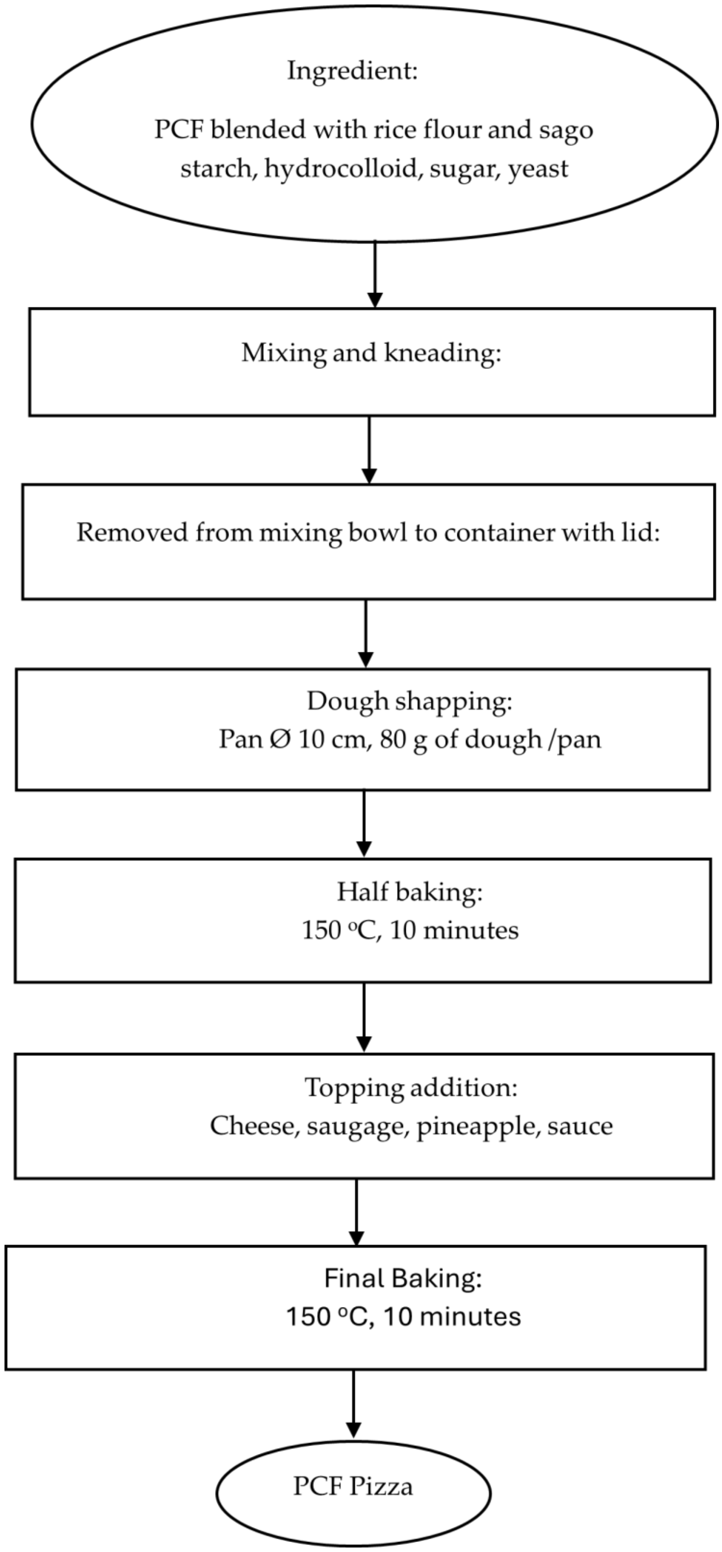

Figure 2. Overview of the production of PCF-Pizza

2.4. Physicochemical and Sensory Analysis

The national standard method, SNI 7622:2011 [17], was used for the analysis of moisture content, fat, protein, and microbiological contaminants. The polarized light microscope and Scanning Electron Microscope

(Zeissevoima-10) were applied to the observed starch granule of PCF [18]. The particle distribution was analyzed on a set of sieves [19]. The pasting properties were recorded by Rapid Visco Analyzer (Perten, Newport Scientific, Australia) [20]. Dough was analyzed for the viability of yeast (PDA method) and baking volume [14]. A picture was taken to observe crumb formation after the dough was baked. Sensory evaluation was conducted on PCF-pizza produced by an artisanal baker. A form was distributed to 69 of the selected consumers who attended the Roti Boss bakery shop. They were asked to evaluate the quality attributes of PCF-pizza in terms of color, texture, and taste. The evaluation was carried out in 3 categories (1: Dislike, 2: Neutral, 3: Like). They were also asked to state the reason for preferring PCF-pizza and the maximum price they were willing to pay for PCF-pizza.

2.5. Data Analysis

A single treatment factor was applied in the experiment on frozen dough storage. The data were analyzed using a two-way ANOVA with a single factor for the storage period, followed by Duncan's multiple range test at the $P < 0.05$ level. Data on consumer evaluation and the socio-economic characteristics of consumers were summarized, and descriptive statistics (percentages) were generated using Excel pivot tables.

3. Results and Discussion

3.1. Production technology and characteristics of PCF

Cassava flour contains starch, fiber, sugars, and small amounts of lipids and other components. It has different properties compared to cassava starch, which forms a more cohesive paste when cooked. Pregelatinized flour is flour that has undergone partial or complete gelatinization. The typical method for the pre-gelatinization process includes spray drying, extrusion, and drum drying [21]. This means that the starch in the flour was heat-treated with the availability of suitable water. According to Indonesian Regulation Number 13/2023 [22], PCF was categorized under No. 06.2.1 and thus could be used as a raw material by food processors. PCF was produced by a small entrepreneur (PT. Infiad Indonesia), located in Cigombong village, Bogor Regency, West Java Province. Dehydrated cassava chips as raw material were supplied by a farmers' association in Sukabumi Regency, West Java Province, located approximately 80 km south of Bogor. Farmers who supply cassava implement good agricultural practices (GAP). GAP implementation was important because the PCF processor required a consistent and high-quality raw material supply. GAP implementation on cassava has already been reported [23]. The dehydrated cassava chips were used as raw materials. The production of PCF on a commercial scale has been made possible through research in new cassava processing innovations, including the designs of machinery and partnerships between the government and small enterprises. In the case of PCF production, the Indonesian government invested in machinery that consisted of a pin mill, mixer machine, extruder, dryer, and pulverizer. The equipment was installed in accordance with the Good Manufacturing Practice (GMP) standard. The general steps of PCF production were described in Patent No.IDP000084586, published in Indonesia [24]. Table 1 summarizes the principal processing machinery for PCF production. It was reported that approximately 5 tons of PCF were produced in 2021, which was about 25% of the full capacity.

Table 1. General overview of PCF production

Step	Description	Equipment
Preparation	Dried cassava was selected as the raw material. The size of the cassava chip was reduced to a small size or milled into coarse flour.	Pinmill
Moisture Adjustment	Water was added to the flour to achieve a moisture content of 25%.	Mixer
Extrusion	The hydrated flour was subjected to heat and pressure. The screw in the extruder forces the material through a heated barrel at 60 °C to 90 °C, with screw speed at 45 Hz, causing the starch granules to gelatinize partially.	Twin screw extruder
Cooling	The material exits the extruder, and it is then rapidly cooled to stabilize the gelatinized structure. This cooling process was achieved using air.	Cooling Conveyor
Drying	The extrudate needs to be dried further to reduce its moisture content to a desired level (less than 12%), in order to prevent microbial growth and prolong its shelf life.	Drying oven
Grinding	The dried extrudate was ground into a fine powder	Pulverizer
Packaging & Storage	The pregelatinized flour was tested for quality control. It was then packaged into a plastic bag for storage and distribution.	Packaging machine

At the early stage of production, the PCF was delivered to the end user in the Bogor area. It was further processed by the food industry for use in making wafers and artisanal bakery shops [6, 13]. In this study, PCF was delivered to the end user of Roti Boss artisan bakery in Malang, East Java. With excellent transportation facilities, especially on Java Island, this technology has facilitated mass production and enabled PCF applications to be more intensive. Figure 1 shows the location of cassava farmers, PCF producers, and the PCF end user in this study. The technology for PCF production has provided opportunities for smallholder farmers to experiment with new ways of accessing more profitable markets. Cassava machinery and flour processing can be adopted by development agencies, NGOs, and research centers to enhance household food security, reduce food and raw material imports, and expand market options for smallholder farmers. Figure 3 presents the diagram of the PCF supply chain from farmer to end user.

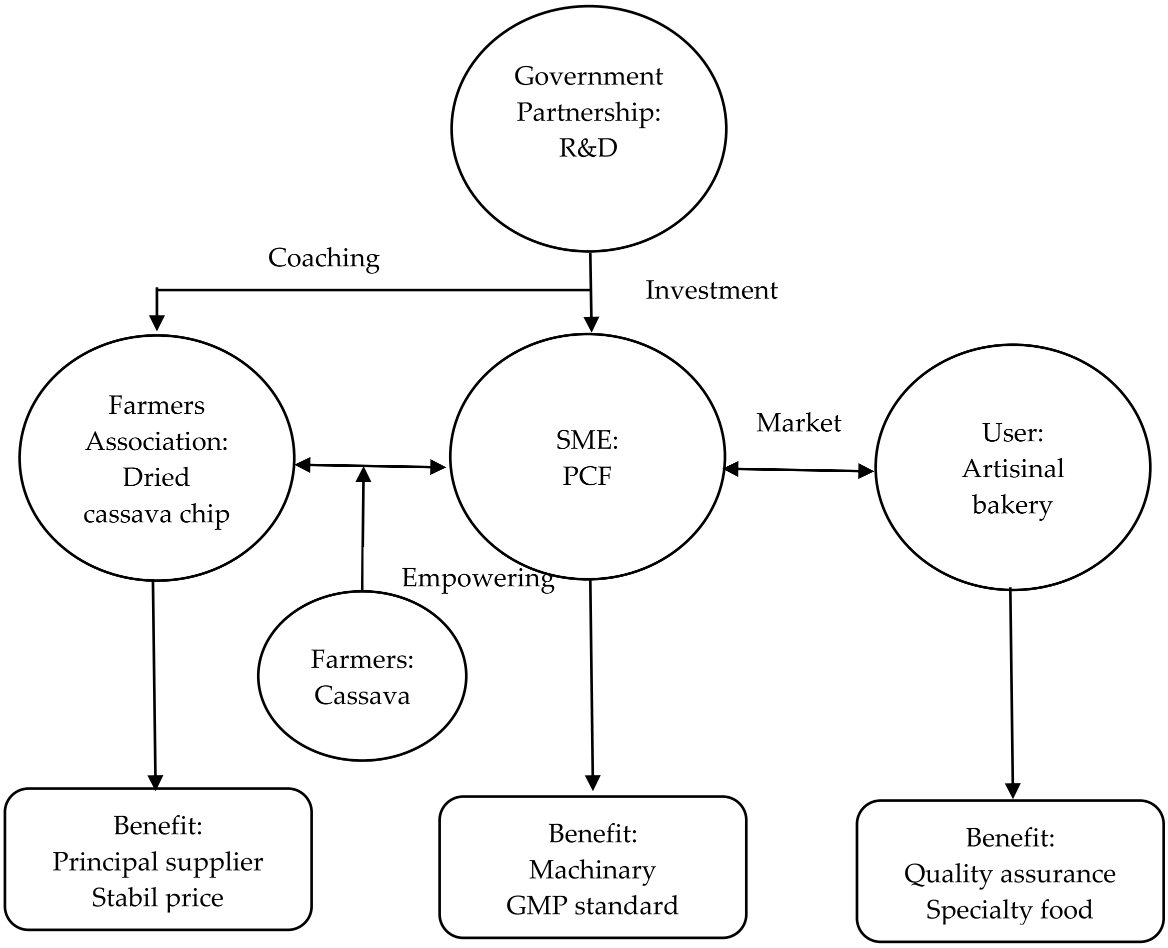

Figure 3. Diagram of cassava supply from farmers to the PCF processor and user

Table 2 shows the general characteristics of PCF produced by the small entrepreneurs at Cigombong. Low moisture content in PCF contributes to a longer shelf life. Extrusion technology has proven to be versatile in generating materials with distinct characteristics, particularly in the food production industry. Extrusion was also applicable for tuber flour refining [25]. At Cigombong, extrusion was conducted using a twin-screw extruder (local brand) with an initial temperature of 60 °C, a final temperature of 90 °C, a screw rotation speed of 44.7 Hz, and a cutter speed of 16 Hz.

Table 2. Characteristics of PCF

No	Characteristic	Value
1	Moisture (%)	9.74
2	Protein (%)	2.34
3	Fat (%)	0.28
4	HCN (ppm)	< 40
5	Microbiological contaminant or Total Plate Count (CFU)	1.2×10^4
6	Sensory properties:	White creamy color, tasteless, odorless

The application of the extrusion process for cassava flour resulted in a partially pre-cooked starch structure. The starch granules of native flour exhibit a characteristic of maltese cross pattern due to their crystalline structure, while those of PCF had a loss of birefringence. The extrusion process disrupted the crystalline structure; therefore, fragmented granules and irregular shapes were observed. Figure 4 presents the photomicrograph of starch granules in PCF.

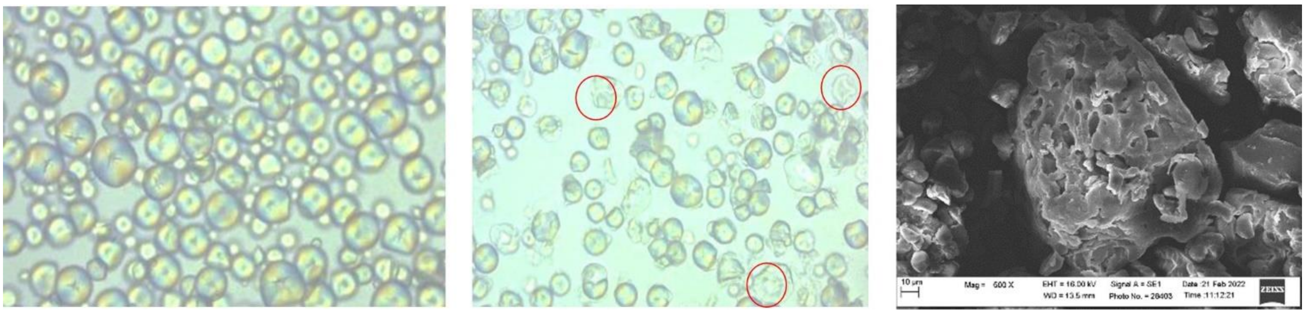

Figure 4. Starch granula (a) in native cassava flour under polarized light microscope, (b) PCF under polarized light microscope, (c) in PCF under scanning electron microscope.

The particle size, or granularity, is considered a key parameter for determining the quality of the flour after milling. The PCF was shown to have fine-sized particles (Figure 5). At least 95% of the flour passed through a 100-mesh sieve, and more than 90% passed through a 200-mesh sieve. This was comparable to the characteristics of wheat flour, where at least 98% of the flour passes through a 212-μm sieve [26]. The mesh number refers to the U.S. Standard Sieve Mesh number, which represents the number of openings per linear inch (2.54 cm) of the mesh. The mesh numbers 80, 100, 200, and 300 corresponded to particle sizes of approximately 177 μm, 149 μm, 74 μm, and 48 μm, respectively. The distribution of the flour's particle size would significantly affect the final product performance in terms of content uniformity, dissolution, thermal properties, and stability. The particle size distribution also affected the physical properties of the food powder, including bulk density, compressibility, and flowability [27,28]. It was reported that finer flours increased water-holding capacity and solubility [29]. Therefore, the PCF will have opportunities to fulfil the food ingredient market's requirements with its functional properties. It was stated that the specific functional properties of heat-processed pregelatinized cassava flours could facilitate their incorporation into various product formulations, such as baked goods and gluten-free functional foods. This could enhance the utilization of local starch sources and potentially reduce costs by substituting imported ingredients [30].

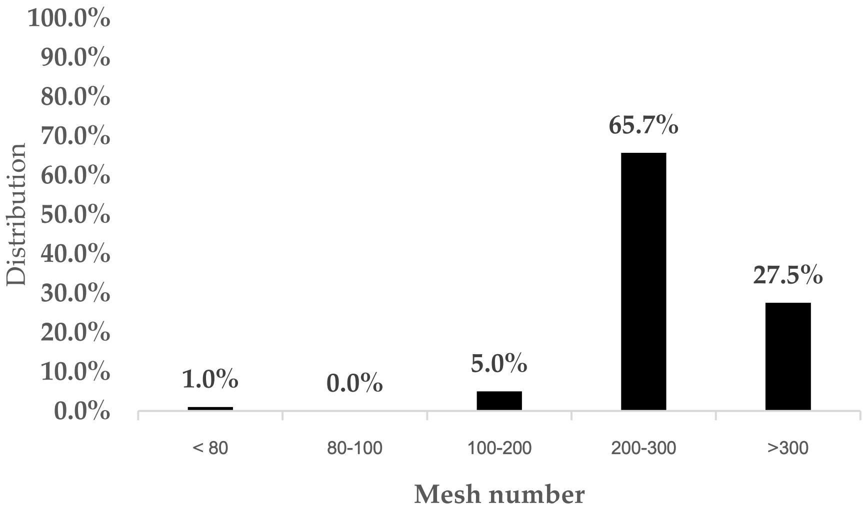

Figure 5. Particle size distribution of PCF

Pasting properties were important for controlling viscosity behavior during the processing and storage of several food systems. The PCF exhibited lower hot viscosity and higher cold viscosity than the non-PCF, due to the starch granules being pregelatinized (Figure 6). A significant decrease in the pasting profile of extruded cassava flour was previously reported [12,31]. It reflects a higher degree of gelatinization, coupled with starch degradation, due to the net effect of heat, moisture, and echanical energy applied during the extrusion process [31].

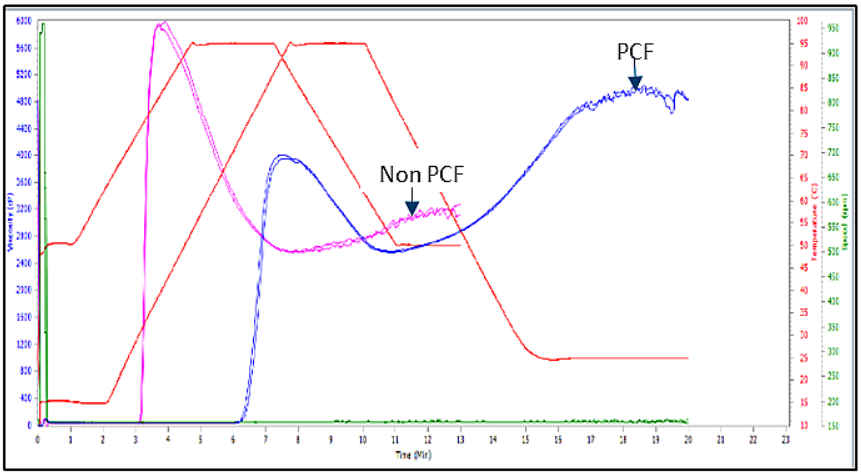

Figure 6. Pasting the profile of PCF and non-PCF

The food industry should benefit from pregelatinized cassava flour. Migration toward the application of this type of flour will encourage farmers to diversify their production. Not only will cassava use increase, but also the use of other roots and tuber crops, gluten-free cereals, and edible palms. It also provides an opportunity to revitalize the cassava flour market at a time when cassava consumption is continuously decreasing due to the adoption of Western lifestyle foods and the neglect of traditional recipes.

3.2 PCF-Based Dough Characteristics and Consumers' Acceptability of PCF-pizza

In recent years, frozen dough has gained widespread adoption in the bakery industry. The development of frozen dough has brought numerous benefits to companies, including convenient storage and transportation, as well as an extended shelf life. Frozen dough was a cost-efficient choice as bakeries can employ fewer skilled in-store bakers since base bread dough is already prepared and ready to use. It also allows bakeries to be more responsive to consumer needs, avoiding occurrences of running out of stock or over-stocking, which leads to wastage. Moreover, frozen dough helps create new market opportunities. Bakers can expand their distribution area and product range to introduce new bread products consistently. Expanding a product range is made easier by the flexibility of frozen dough, as the same frozen base dough can be customized to suit different consumer preferences in terms of shape, size, fillings, and toppings. In this study, frozen dough was preliminarily developed, and the results are presented in Table 3. The viability of yeast cells declined after 14 days and 28 days of frozen storage. However, a survival rate of more than 90% was observed in yeast. Under frozen conditions, yeast cells were susceptible to dying because of the rapid formation of ice crystals in the environment. Without the proper cryoprotectant, the yeast cell membrane can rupture, rendering biological functionality unfeasible after the thawing process [32]. Our study indicated that the yeast cells were well protected during the frozen storage of the dough. It was speculated that the freezing tolerance of yeast cells was closely associated with the presence of xanthan gum. Xanthan gum affects the water absorption properties of the food matrix and thus limits the freezing water content. This occurs due to the connection of free water; in this way, the migration of water through the intracellular medium decreases, which reduces the formation of ice crystals and promotes a decrease in the freezing point [21,33].

Table 3. Quality attribute of frozen dough during storage for 0, 14, and 28 days storage

Attribute	0 Day	14 Days	28 Days
Viability (CFU/g)	$1.1 \times 10^8 + 2.83^a$	$9.2 \times 10^6 + 7.07^b$	$6.1 \times 10^6 + 18.38^b$
Volume (cm^3)	$15.05 + 1.26^a$	$7.06 + 0.11^b$	$5.82 + 0.55^c$

Volume was commonly used to indicate consumer preferences for bakery products. The volume of frozen dough baked samples decreased as the storage time prolonged. The volume of bread was strongly related to the gas production of yeast cells and the retention capacity of the gluten-like network provided by xanthan gum. This finding aligns with the study reported by [21]. Crumb refers to the inner part of a bakery product. It should be open and airy, with uniform distribution of pores or holes. This characteristic could be achieved through proper fermentation, kneading, and baking. Figure 7 shows the appearance of the sectional structure of the baked product derived from PCF-based dough. It was found that the pore size was not uniform. The pore appearance did not differ significantly among the samples. Frozen storage produced many ice crystals, which mechanically disrupted the structural integrity of starch, causing the double helix structure of starch to break and rearrange [21]. Based on the volume and crumb properties, frozen dough stored for 14 days was still suitable for producing PCF-pizza.

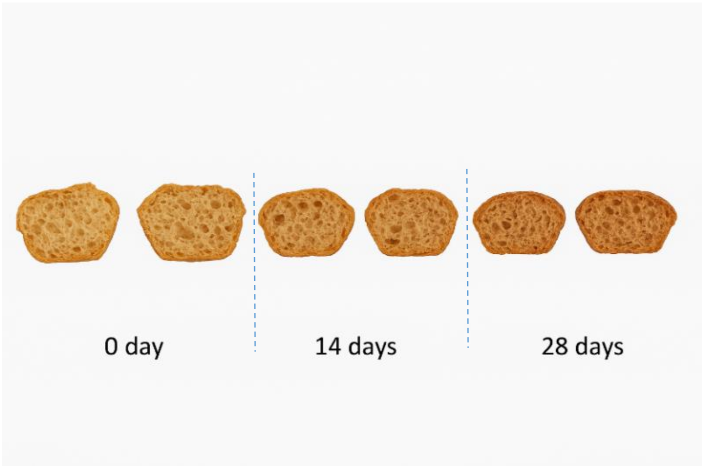

Figure 7. Pore/crumb of baked products derived from dough after frozen storage

This study was carried out through contact with artisan bakers who have experience in making artisan bakery products, including pizza, in Malang Regency, East Java. The baker used wheat flour to make pizza, and she had no experience making pizza with non-wheat flour. Most artisan bakers lacked the experience to handle frozen dough. It is worth noting that the fusion dish of PCF-pizza was categorized as a gluten-free bakery. The baking conditions were assessed thanks to the experience of the artisan bakers. The formulation involved adjusting the composition of the ingredients to meet not only the technological requirements of the pizza but also the nutritional and organoleptic needs of the consumer. The mixture of PCF flour and all ingredients, including sugar, water, and commercial yeast, was well-kneaded in a standing mixer to homogenize the dough. The dough was then incubated for 2 hours before being shaped. The shaping of the dough was manually carried out using a pan (diameter Ø 10 cm) filled with 80 g of dough. The shaped dough was partially baked in the baking oven at 150°C for 10 minutes. They were then placed on a table at room temperature for additional topping. The dough was further baked at 150 °C for 10 minutes. Dough preparation and baking of the PCF-pizza were carried out successively in a short time. It was noticed that PCF-pizza has a similar appearance to regular pizza (Figure 8).

Figure 8. PCF-Pizza (left) half-baked and (right) fully baked

The characteristics of 69 respondents participating in this study are presented in Table 4. The participant number meets international ISO recommendations of (30–100). A larger panel provides more accurate and consumer-representative sensory results. It was noted that of the total 69 respondents, 78% were female, and 22% were male. Most of the respondents were > 20 < 50 years old. Based on their employment status, about 46% of the respondents were entrepreneurs, 27.5% were public servants, and the remaining 26% were students.

Table 4. Characteristics of respondents

Description	N	%
Gender		
•Female	54	78.3%
•Male	15	21.7%
Age		
•< 20-year-old	8	11.6%
•> 20 - < 30-year-old	27	39.1%
•> 30 - < 40	19	27.5%
•> 40 - < 50	12	17.4%
•> 50	3	4.3%
Employment status		
•Entrepreneurs	32	46.4%
•Public servants	19	27.5%
•Student	18	26.1%
Having experience in gluten-free bakery consumption		
•No	40	58.0%
•Yes	28	40.6%
Consider the importance of gluten-free products		
•No	8	11.6%
•Neutral	14	20.3%
•Yes	47	68.1%

The respondents' preferences for PCF-pizza are summarized in Figures 9, 10, and 11. About 40.6% of respondents have experience in gluten-free bakery consumption. However, most of the respondents (68.1%) considered the importance of gluten-free products. In general, the fusion dish of PCF-pizza was well accepted by respondents. Sensory attributes such as taste, texture, and color were preferred by 42.0%, 34.8%, and 36.2% of respondents, respectively. In addition, most respondents (63.8%) stated that the maximum price was IDR 30000 – 35000 for a medium-sized PCF-pizza (Ø 22 cm). These results suggest that PCF-pizza could be a viable option in the potential market of Malang Regency. It also agreed with the previous study [16]. Therefore, it was recommended that efforts be made to ensure market availability.

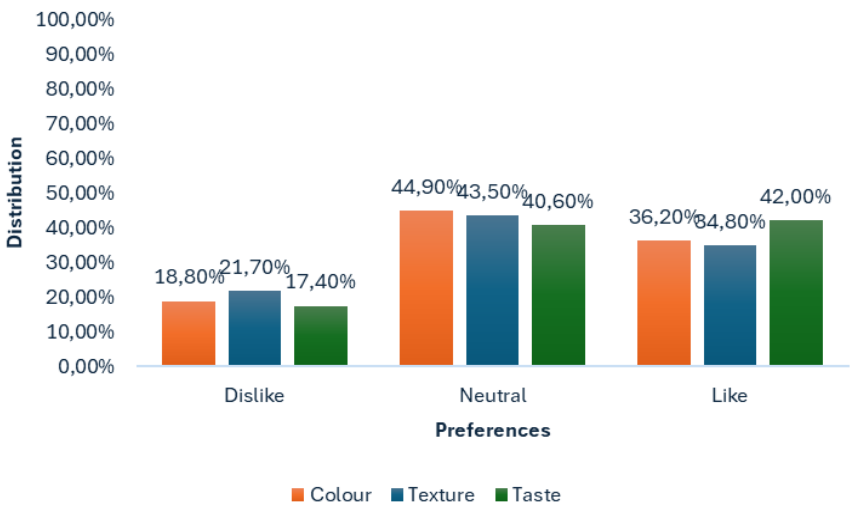

Figure 9. Consumers preferences on color, texture, and taste of PCF-Pizza

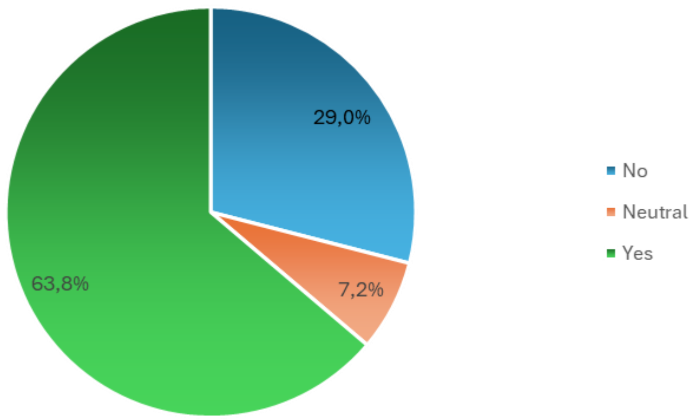

Figure 10. Consumers Willingness to Pay for PCF-Pizza

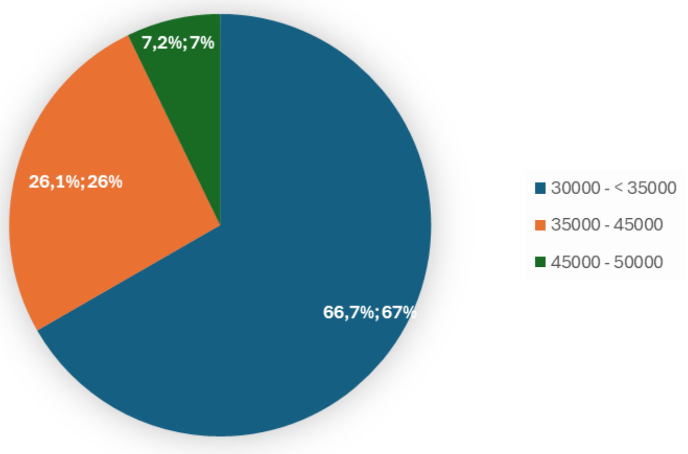

Figure 11. Consumers preference for price (IDR) of PCF-Pizza

The originality of this study lies in its combined focus on smallholder-produced PCF, frozen dough technology, and consumer acceptance of PCF-pizza. To our knowledge, no prior work has systematically linked cassava flour innovation with frozen dough applications and artisan-level product development. By bridging traditional cassava utilization with contemporary food trends, the study provides novel insights into the functional properties of PCF and its role in enhancing the competitiveness of local agro-industrial products.

4. Conclusions

PCF was considered a new cassava processing innovation, achieved by combining extrusion cooking with milling using a pulverizer. This process ensures that the PCF has a unique characteristic, including the special structure and fine texture of the pre-cooked starch. Overall, the findings provide valuable insights into the PCF's contribution to the development of the acceptable fusion dish, PCF-pizza, especially in Malang, East Java. It was found that frozen dough stored for 14 days was still suitable for producing PCF-pizza. PCF-pizza's potential market was available in the Malang Regency, as approximately 63% of the respondents accepted the color, texture, and taste of PCF-pizza.

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