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STUDY ON PROCESSING BANANA POWDER CONTAINING RESISTANT STARCH FOR FOOD APPLICATIONS FROM GREEN CAVENDISH BANANA *(Musa Acuminata)*

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ABSTRACT

The study investigated the processing of green "Cavendish banana" into green banana flour for food applications. Green banana, often discarded during cultivation, possess a high proportion of resistant starch. Resistant starch in green bananas offers numerous health benefits and is highly suitable for food production. However, unripe bananas are highly perishable after harvest and have an astringent taste, making them difficult to utilize in food products. This study revealed that bananas harvested at 83 days of age, is the most suitable for processing powder. Treating green bananas with 0.5% ascorbic acid effectively inhibited the browning process of the resulting flour. Heat treatment of bananas for 10 minutes significantly reduced the astringency of the flour, with tannin content decreasing to 3.24 mg TAE/g. The heat-treated banana flour exhibited a resistant starch content exceeding 15% (dry basics) and was subsequently dried at 70 °C to a moisture content of approximately 5%. The dried banana flour product contained 12.83% (dry basic) resistant starch and demonstrated a solubility exceeding 10%. The flour also exhibited favorable sensory attributes, aligning with consumer preferences.

1. INTRODUCTION

Cavendish bananas (*Musa acuminata Colla AAA Group,* cv. '*Cavendish*'), belonging to the Musaceae family, are a versatile crop cultivated for various purposes, including food, fibers and medicinea. Bananas are one of the most popular fruits globally, ranking fourth in importance after rice, wheat, and maize. They contain significant amounts of micronutrients such as vitamin B, vitamin C, potassium, and calcium.

Green bananas are particularly rich in starch, notably resistant starch (RS) (Cano et al., 1997; Gutierrez et al., 2008). Starch is a crucial dietary component for humans, categorized into two types: readily digestible starch (hydrolyzed by amylases) and resistant starch (RS), which resists amylase digestion. Green banana flour has been reported to contain a high amount of total dietary fiber (over 50% dry matter) and RS (close to 50% of the remaining dry matter). This significant RS content has attracted considerable attention due to its potential health benefits (Langkild et al., 2002; Fasolin et al., 2007). Upon reaching the colon, RS is fermented by gut microbiota, producing beneficial metabolites. These include short-chain fatty acids like butyrate and propionate, which promote gut health. RS also exhibits prebiotic effects, stimulating the growth of beneficial gut bacteria and contributing to laxation (Topping et al., 2001). The caloric value of RS has been estimated at 2 kcal/g (Liversey, 1994). Based on this lower energy content, RS has been proposed as a dietary component for weight management (Tapell, 2004). Additionally, it may help reduce colonic pH, prevent the degradation of the protective mucus layer in the colon, and lower the risk of colorectal cancer.

The RS in bananas was characterized by a tightly packed granular structure with high dehydration capacity. This compact structure hinders hydrolysis by amylases. Consequently, this type of starch is not digested in the stomach or the upper part of the small intestine, with fermentation occurring primarily in the distal small intestine and colon.

During banana cultivation, small banana hands, undersized fruits, and deformed fruits are typically removed to optimize nutrient allocation to the remaining fruits. On average, approximately 20% of green bananas are discarded regularly, amounting to 20-30 kg/ha per day. This represents a substantial and continuous source of raw material in banana plantations. However, these green bananas currently lack effective utilization strategies and are often used as fertilizer or animal feed, resulting in low economic value.

The inherent astringency of green banana pulps limits their direct consumption. Therefore, this study focuses on developing a process for producing banana flour from green Cavendish bananas. The objective is to propose a solution for processing banana powder with good quality and introduce a cost-effective source of RS with numerous health benefits. This approach aims to investigate the physicochemical properties and factors affecting green banana powder to explore its potential as a functional carbohydrate source for human health.

2. MATERIALS AND METHODS

2.1 Main material

Green Cavendish bananas were harvested from Xanh Viet farm located in Tan Tien commune, Thoai Son district, An Giang province, Vietnam. Bananas were harvested at a uniform maturity stage, between 77 and 85 days after flowering and transported to the lab within 3 hours. Following the transporting, the bananas were stored at a cool temperature of 20 °C for one day before processing and analysis.

2.2 Chemicals

Analytical chemicals were produced by Merk, USA. Resistant starch assay kit was made by Megazyme Ireland.

2.3 Methods

Preparation of Green Banana Flour: Green bananas were peeled, retaining the inner white peel layer, and sliced to a thickness of 2 mm. The slices then processed and dried to 5% of moisture contents. The dried slices were subsequently milled and sieved through a 63 µm mesh screen. The resulting green banana flour was stored in sealed PA (polyamide) bags at 2-8 °C until further analysis.

The moisture content was determined by measuring the weight loss after drying, as described in AOAC 925.10. Briefly, exactly 5 g of sample was placed in a weighed container and dried in an oven at 105 ^{0}C then cooled to room temperature in a desiccator. The dried samples were weighed and dried until constant weight. Total drying time was about 60 hours.

Total sugar content was determined by acid dinitro-salicylic (DNS): Diluting 5 mg sample in 100 ml volumetric flask. 0.5 ml of diluted sample was taken into 25 ml of a volumetric flask then added 0.5 ml HCL 3M. Boiling the 25 ml flask in water for 15 minutes then cooled down to room temperature. Adding 0.5 ml

NaOH 3M to neutralize the solution. Exactly 3 ml of DNS was added the neutralized solution and then boiled in water for 10 minutes. Water was added up to 25 ml, the solution then was measured the absorbance at 540 nm. The absorbance was used to determine the total sugar content based on a standard curve.

Tanin content was determined by Folin-Denis method (Laitonjam, 2013), exactly 0.5 mg sample and 0.5 distilled water were added into a test tube, then 0.5 ml Folin-Denis and 2 ml of Na_2CO_3 20% were added, vortex the tube and heated it in boiled water for 1 minutes then cooled down to room temperature, measure the absorbance at 700 nm. The tannin content was calculated based on a standard curve.

Resistant starch was determined by following the protocol of the resistant starch assay Kit from Megazyme method (AOAC Method 2002.02. AACC Method 32-40.01. CODEX Type II Method). Accurately weigh 100 mg ± 5 mg of the test sample into a capped test tube. Add 4.0 mL of α-amylase and amyloglucosidase solution to the tube 4 Closing the cap and vortexed then incubated the tube at 37 ^{o}C for 16 hrs in the water bath. Then 4..0 ml etanol (95 %) was added and vortexed, the solution then was centrifuged at 1,500 *g* for 10 minutes. Discard the solvent and dilute pellets in 2 ml of IMS 50 %. 6 ml of IMS 50 % was added then centrifuged at 1,500 g for 10 minutes. This step was repeated twice then discarded the solution. The residue is resistant starch. The residue then dried at 105 ^{0}C to determine the dry matter and percentage of RS was calculated following the equation RS (% CBK) = W/M x 100 where W weight of RS (dry basis) and M weight of sample.

Starch solubility: A 1g sample of the powder was dissolved in 20 ml of distilled water. The solution was then transferred to a centrifuge tube and centrifuged at 6,000 rpm for 10 minutes. The sedimented fraction was collected and dried at 105 °C until the moisture content matched that of the original powder. The percentage of the sample that dissolved in water was defined as the powder's solubility

Starch solubility (% dry basis) = ((mck-m)*100)/mck where mck is weight of dry mater of sample (g) and m is weight of dry matter after votex and drying at 105 ^{0}C

Colorimeter: L, a and b values of green banana powder were determined using Minolta Spectro colorimeter CR-400, Japan.

3. RESULTS AND DISCUSSION

3.1 Influence of harvest time on green banana qualities

During the ripping time, bananas undergo a series of physical, biochemical, and chemical changes that can contribute to quality of the banana powder. Understanding these changes is crucial for developing effective time to harvest the banana to improve quality of the powder.

One significant factor influencing post-harvest quality is the maturity stage at harvest.

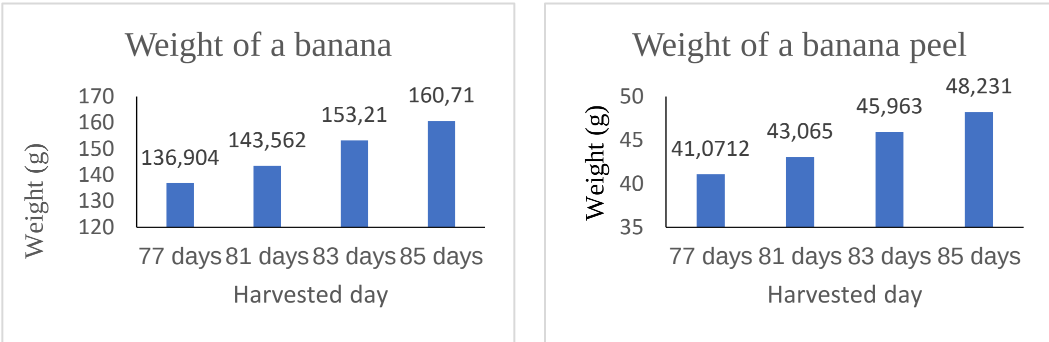

Figure 1: Weight changes of green bananas during the cultivation

Harvesting at different stages results in variations in fruit weight, size, and pulp development. Determining the optimal harvest time is essential for maximizing fruit quality and market value.

Figure 1 illustrates the gradual increase in banana weight over different days of maturity. At the 77-day harvest point, the weight of banana and peel weights were 136.904 g and 41.07 g, respectively, lower than those at 85 days (160.71 g and 48.23 g, respectively). This observation suggests ongoing metabolic activity and growth in the bananas.

While on the plant, bananas continuously engage in metabolic processes, accumulating organic matter such as vitamins, minerals, and starch, leading to a gradual increase in weight. Upon reaching peak accumulation, the fruits exhibit a turgid appearance due to water uptake, marking the initiation of the ripening process (Do Dang Giap, 2018).

For bananas at 85 and 83 days of maturity, the weight increase slows down, reaching 160.71 g and 153.21 g, respectively. This deceleration indicates the commencement of the maturation plateau, where growth subsides and the fruit prepares for ripening. Harvesting at the onset of ripening yields a softer fruit structure, making it susceptible to be bruising and damage, thereby diminishing its market value and causing economic losses for producers.

Table 1: Color parameters of the center of a banana

Day of cultivation	Color parameter (*)		
	L	a	b
77	$77.03^{b} \pm 1.87$	$-15.87^{a} \pm 0.47$	$25.62^{c} \pm 1.43$
81	$76.94^{a} \pm 2.49$	$-14.09^{b} \pm 0.26$	$26.22^{a} \pm 1.50$
83	$78.59^{b} \pm 2.14$	$-14.45^{b} \pm 0.97$	$27.26^{b} \pm 1.12$
85	$80.27^{c} \pm 1.24$	$-13.32^{c} \pm 0.34$	$30.98^{d} \pm 1.37$
F	9.71	18.43	53.58
P	0.0000	0.0000	0.0000

Note: (*) Values represent the mean of three replicates. Means followed by the same letter (a, b, c...) within a column are not significantly different at the 5% level by Least Significant Difference (LSD) test.

Table 1 demonstrates the color changes in banana pulp at different maturity stages. Fruit color reflects the ripening process, with a distinct shift indicating the conversion of starch to sugar. Bananas at 77 days of age exhibit a lower lightness value (L = 77.03) compared to those at 85 days of age (L = 80.27), indicating a trend towards brighter coloration with increasing maturity. Concurrently, the b value, representing yellowness, peaks at 85 days of age. This increase in b value signifies the progression towards a yellow hue, suggesting the onset of ripening and softening of the fruit, making it less suitable for harvest and long-distance transportation.

Moisture contents in bananas also were analyzed and they vary across different harvest dates, displaying an increasing trend. Bananas harvested at 77 days of age have a moisture content of 68.95%, lower than those harvested at 81. 83. and 85 days, which exhibit moisture contents of 70.96%, 77.07%, and 72.68%, respectively. This increase in moisture content reflects the conversion of starch to sugar and the generation of water as a byproduct. However, a slight decrease in moisture content is observed at 85 days of age, from 77.07% to 72.68%, indicating the onset of dehydration. This dehydration is undesirable for harvesting as it can lead to yield reduction.

Considering the combined factors of weight gain, color change, and moisture loss, harvesting green bananas at 83 days after fruit set appears to be optimal. This harvest time ensures high yield while maintaining fruit firmness and suitability for transportation, as the bananas have not yet reached the advanced stages of ripening.

3.2 Effects of banana pre-treatments on powder quality

3.2.1 Ascorbic Acid (AA - Vitamin C) Treatment

Browning in fruits, whether induced by mechanical damage or physiological processes during post-harvest storage, is a major contributor to quality deterioration. This browning results from the enzymatic oxidation of phenolic compounds, primarily catalyzed by polyphenol oxidase (PPO), in the presence of oxygen. The resulting quinones are highly reactive, readily interacting with other compounds such as amino acids and proteins, leading to the formation of dark pigments (Richard-Forget et al., 1992).

Research by Kavrayan and Aydemir (2001) demonstrated the superior efficacy of ascorbic acid in mitigating browning reactions compared to citric acid or NaCl immersion treatments. Consequently, this study selected ascorbic acid as the additive to investigate its potential in preventing browning during the peeling of raw bananas.

Table 2: Effects of vitamin C concentrations on color attributes of green banana pulps

Vitamin C concentration (%)	Color values			
	L	a	b	WI
0.00	85.84±0.59^{c}	-11.45±0.11^{a}	8.51±0.09^{a}	79.90±0.28^{c}
0.25	87.44±0.57^{b}	-11.84±0.62^{b}	8.64±0.47^{a}	80.68±0.29^{b}
0.50	90.26±0.44^{a}	-12.27±0.15^{c}	8.71 ±0.37^{a}	82.07±0.32^{a}
0.75	90.66±0.26^{a}	-12.45±0.05^{c}	8.50±0.18^{a}	82.27±0.16^{a}

F	257.14	12.78	1.03	63.61
P	0.0000	0.0000	0.3933	0.0000

Note:(*) Values represent the mean of three replicates. Means followed by the same letter (a, b, c...) within a column are not significantly different at the 5% level by Least Significant Difference (LSD) test, WI: the overall color

Table 2 demonstrates the impact of varying ascorbic acid concentrations on the L* value (lightness) of green banana flour. Ascorbic acid treatment significantly improved the L* value, indicating enhanced product brightness. Samples treated with ascorbic acid were noticeably whiter than untreated samples or those treated with low, ineffective concentrations. However, at concentrations of 0.5% and 0.75%, the L* and whiteness index (WI) values differed significantly from the other two samples.

Ascorbic acid is a potent antioxidant and anti-browning agent that effectively inhibits enzymatic browning without causing damage to plant tissues (Pongsakul et al., 2006). Increasing ascorbic acid concentrations generally result in a whiter product, but this effect plateaus beyond a certain concentration. In this study, a concentration of 0.50% ascorbic acid yielded a high degree of whiteness, comparable to that achieved with 0.75%.

Treatment with 0%, 0.25%, 0.5%, and 0.75% ascorbic acid did not significantly affect the yellowness (b*) values at the 5% significance level. The overall color, represented by the WI, reflects the degree of discoloration in the semi-finished flour after ascorbic acid treatment (Nguimbou et al., 2013). Among the samples treated with ascorbic acid, the WI values varied with different concentrations. The 0.25% and untreated samples showed significant differences compared to the 0.5% and 0.75% treated samples. The highest WI value was observed at 0.75% ascorbic acid, but this was not statistically different from the 0.5% concentration at the 5% significance level. Therefore, to optimize cost-effectiveness, a concentration of 0.5% ascorbic acid is recommended for treating the semi-finished banana flour.

3.2.2 Effects of heating green bananas on powder properties

Prior to starch extraction, green bananas undergo heat treatment to inactivate browning enzymes, which can negatively impact the color and quality of the final product. This heating process also gelatinizes the remaining starch in the green bananas, enhancing the sensory properties of the resulting flour and improving its palatability in food applications. Additionally, heat treatment can reduce the astringency associated with green bananas

Table 3: Effects of heating time on banana pulp color

Heating time (mins)	Color values (*)		
	L	a	b
5	87.28±1.34^{b}	-15.92±0.05^{c}	16.42±0.36^{b}
10	88.45±0.42^{a}	-15.59±0.07^{b}	16.78±0.20^{a}
15	87.13±0.78^{b}	-15.12±0.02^{a}	15.86±0.36^{c}
F	6.65	656.66	24.05

P	0.0041	0.0000	0.0000

Note:(*) Values represent the mean of three replicates. Means followed by the same letter (a, b, c...) within a column are not significantly different at the 5% level by Least Significant Difference (LSD) test

Heat treatment plays a crucial role in stabilizing the color of the raw material and the final banana starch product. Insufficient heating time (5 minutes) results in incomplete gelatinization of the banana starch, leading to uneven color distribution. The product exhibits a lighter exterior but a darker core due to the incomplete inactivation of enzymes responsible for browning. Conversely, prolonged heat treatment can lead to the degradation of color compounds and the formation of undesirable Maillard reaction products. This reaction, occurring between sugars and amino acids, causes a darkening of the material.

Furthermore, the L-value, indicating lightness, decreased in samples subjected to 15 minutes of heat treatment, showing no significant difference ($p>0.05$) compared to those heated for 5 minutes. Therefore, a heating time of 10 minutes was determined to be optimal for preserving the desired color characteristics and effectively inhibiting enzymatic browning. This optimized heat treatment ensures the production of banana starch with desirable color attributes while preventing undesirable color changes during storage.

Table 4: Effects of heating time on solubility and tannin concentration of green banana

Heating time (mins)	**Solubility (% dry basic)**	**Tannin (mg TAE/g)**
5	11.33±1.02^{b}	3.80±0.14^{a}
10	12.60±1.08^{a}	3.24±0.11^{b}
15	9.56±1.30^{c}	2.25±0.80^{c}
F	32.55	374.55
P	0.0000	0.0000

Note:(*) Values represent the mean of three replicates. Means followed by the same letter (a, b, c...) within a column are not significantly different at the 5% level by Least Significant Difference (LSD) test.

Table 4 presents the solubility and tannin content of the studied samples. The solubility increased with heating time from 5 to 10 minutes and subsequently decreased. The 10-minute sample exhibited the highest solubility (12.60%). Heating induced starch gelatinization, leading to a gradual increase in the solubility index. However, prolonged heating caused excessive swelling and rupture of starch granules, resulting in leaching of solids into the cooking water and a consequent decrease in solubility, as observed in the 15-minute sample.

Tannins, naturally occurring polyphenolic compounds, are susceptible to hydrolysis at high temperatures. Therefore, extended heating durations can lead to tannin degradation and a reduction in their content. As shown in Table 4, the tannin content varied significantly ($p < 0.05$) across the three heating times, with the highest content observed at 5 minutes (3.80 mg TAE/g dry matter) and the lowest at 15 minutes.

While a 5-minute heating time yielded the highest tannin content, excessive tannins can impart astringency to the product. Therefore, a

10-minute heating time was deemed optimal, balancing nutrient retention, minimizing losses, and preserving product color. This duration effectively gelatinizes the starch while mitigating tannin degradation and maintaining desirable sensory attributes.

5 mins 10 mins 15 mins

Figure 2: Green banana starch granule at different heating time under microscope

Heat treatment at high temperatures disrupts hydrogen bonds between starch molecules, affecting the micellar structure and leading to hydration (Tako and Hizukuri, 1999). This increased molecular mobility enhances water diffusion into the starch granules, causing swelling and an increase in granule size and volume, as observed in the sample heated for 5 minutes.

Extending the heating time to 10 minutes resulted in a 50% reduction in the number of gelatinized starch granules. Larger granules, with a greater surface area exposed to heat, were preferentially disrupted due to the breakage of hydrogen bonds. Intense hydration caused some starch molecules to detach from the micellar network and diffuse into the surrounding water, leading to starch solubilization (Hoang Kim Anh et al., 2005; Dam Sao Mai et al., 2012). This observation is supported by the results depicted in Figure 2.

At 15 minutes of heat treatment, the granular structure of the starch was no longer discernible. Amylose and amylopectin molecules were released from the granules and dissolved into the aqueous medium. Based on the findings in Figure 2. a heating time of 10 minutes appears to be optimal, balancing the extent of gelatinization and starch solubility.

Table 5: Effects of heating time on resistant starch and total sugar content of green bananas

Heating time (Mins)	Resistant starch (% dry matter)	Total sugar (% dry matter)
5	16.02±1.17^{a}	5.61±0.38^{b}
10	15.95±2.36^{a}	6.48±0.57^{a}
15	9.48±1.18^{b}	5.92±0.29^{b}
F	45.83	9.38
P	0.0000	0.0010

Note:(*) Values represent the mean of three replicates. Means followed by the same letter (a, b, c...) within a column are not significantly different at the 5% level by Least Significant Difference (LSD) test .

The results presented in Table 5 demonstrate that the resistant starch (RS) content in green banana flour is influenced by heat treatment duration. The lowest RS content (9.48%) was observed at 15 minutes of heating, followed by 10 minutes (15.95%). The highest RS content was found at 5 minutes (16.02%).

According to the National Research Council (2005), resistant starch is a form of starch that escapes digestion in the small intestine. It passes intact through the small intestine and undergoes fermentation in the large intestine, producing short-chain fatty acids (SCFAs). These SCFAs serve as an energy source for colon cells, conferring benefits to the digestive system and gut microbiota. These findings indicate that green bananas contain a high level of RS, and a significant portion of this RS persists even after heat treatment.

Data presented in Table 5 also reveal that the total sugar content in the flour samples is relatively low, and is affected by heat treatment. A heating time of 5 minutes appears insufficient to hydrolyse starch into sugars. Extending the heating time to 10 minutes leads to the hydrolysis of some readily digestible starch, resulting in increased glucose levels. However, further increasing the heating time to 15 minutes causes a decrease in total sugar content. This reduction is likely attributed to the soluble nature of sugars, which tend to leach into the surrounding liquid during the heating process.

Heating for 10 minutes resulted in the highest total sugar content (6.48%), showing a statistically significant difference ($p < 0.05$) compared to heating for 5 minutes and 15 minutes. This suggests an optimal heating time for maximizing sugar content while preserving RS in green banana flour.

Influence of drying temperature on the quality of green banana flour

Following heat treatment, green bananas were sliced and dried at various temperatures until a moisture content of 5% was achieved. Subsequently, the dried slices were finely ground, and the quality parameters of the resulting flour were analyzed as presented in Table 6.

Table 6: Effect of drying temperature on quality of green banana powder

Drying temp (^{0}C)	Ratio pass through size 63 µm (%)	Solubility (% DM)	Total sugar (% DM)	RS (% DM)	Tannin (mgTAE/g DM)
60	86.10±0.20^a	13.26±1.15^a	6.19±0.29^a	13.27±1.61^a	1.66±0.07^a
70	86.33±0.60^a	12.20±2.07^a	6.07±0.42^a	12.83±1.36^a	1.59±0.06^{ab}
80	78.63±0.25^b	9.64±2.35^b	4.73±0.44^b	8.40±0.83^b	1.49±0.07^c
90	76.50±0.26^b	8.67±2.87^b	4.58±0.44^b	6.19±0.62^c	1.52±0.02^{bc}
F	574.85	1.99	68.81	68.91	8.45
P	0.0000	0.1365	0.0000	0.0000	0.0003

Note:(*) Values represent the mean of three replicates. Means followed by the same letter (a, b, c...) within a column are not significantly different at the 5% level by Least Significant Difference (LSD) test.

The samples analyzed were subjected to starch gelatinization prior to drying. However, drying at different temperatures still influenced the physicochemical properties of the final product.

Results presented in Table 6 indicate that the lowest percentage of flour passing through the sieve was observed at 90 °C. This can be attributed to the rapid initial moisture diffusion at higher drying temperatures, which subsequently forms a hard surface layer. This layer impedes further moisture removal from the inner layers, affecting the grinding process and resulting in non-uniform particle size. The highest percentage of flour passing through the sieve was achieved at 70 °C (86.33%).

Solubility was also affected by drying temperature. As shown in Table 6. higher drying temperatures resulted in decreased solubility. This is likely due to the pre-gelatinized state of the starch, which hinders internal diffusion of water molecules. The dried material becomes hard and brittle, limiting its ability to dissolve. The highest solubility was observed at 60 °C (13.26%), while the lowest was at 90 °C (8.67%). However, there was no significant difference in solubility between 60 °C and 70 °C at the 5% significance level.

Furthermore, Table 6 demonstrates the influence of temperature on total sugar content, RS content, and tannin content. Notably, RS content continued to decrease with higher drying temperatures, suggesting that high temperatures may further hydrolyze resistant starch into more digestible components. A drying temperature of 70 °C appears to be optimal, as it minimizes RS loss (12.20%) and requires the shortest drying time (approximately 15 hours).

4. CONCLUSION

The study has successfully developed a process for producing green banana flour from unripe Cavendish bananas, a byproduct often discarded in banana plantations. The optimal harvest time for green bananas is 83 days after fruit set, balancing yield and fruit quality. Treatment with 0.5% ascorbic acid effectively inhibits browning in the banana flour. Heat treatment for 10 minutes significantly reduces astringency and improves the flour's sensory properties. Drying the flour at 70 °C preserves resistant starch content and minimizes drying time. The resulting green banana flour boasts a high resistant starch content (12.83%) and good solubility (above 10%), making it a promising ingredient for functional food applications. This process not only adds value to a previously underutilized resource but also offers potential health benefits to consumers and promotes sustainable agricultural practices. Further research could explore the application of this green banana flour in various food products and investigate its potential impact on human health through clinical trials.

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