PHYSICAL AND CHEMICAL PROPERTIES OF DIFFERENT VARIETIES OF TAIWANESE BANANAS AND THEIR APPLICATION IN BANANA FLAT-RICE NOODLES

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ABSTRACT

Three varieties of ripe and unripe bananas as well as indica rice (taichung sen no. 17) were analyzed for the production of flat-Rice Noodles. The ripe bananas contained the lowest amylose, total starch, and resistant starch contents (rsc). The L-Value, hardness, and rsc of the flat-rice noodles with unripe bananas were higher than the values of those prepared using ripe bananas; the opposite trend was observed for a and b values and cooking loss. The solubility and swelling power of the flat-rice noodles using ripe bananas were significantly higher than those of the noodles prepared using unripe bananas.

INTRODUCTION

Bananas (\textit{Musa spp.}) are extremely popular fruits\cite{1,2,3,4} that are consumed worldwide owing to their texture, flavor, high nutritional value,\cite{5} and low cost. This fruit is rich in phenolic compounds and flavonoids and exhibits antioxidant properties,\cite{2} because of which the regular consumption of bananas is considered to be beneficial to human health. The most popular Taiwanese banana varieties are Pei Chiao (PC), Formosana (FS), and Tai-Chiao No. 5 (TC5). These are typically eaten fresh\cite{2} or processed into various products, including banana powder, dried fruit, banana chips, bread, and juice.\cite{2,4} However, these processes do not completely afford the desired results because of different banana characteristics as well as the limited understanding of their processing applications. Moreover, significant wastage of bananas occurs because of overproduction and inadequate processing and preservation technologies. Therefore, an in-depth understanding of banana characteristics and development of new industrial applications can reduce the generation of banana waste.

Rice is an important grain and staple food worldwide.\cite{6} It is the primary source of energy for more than 50% of the world population, particularly in Asian countries.\cite{7} Starch is the main component of rice,\cite{6} and the investigation of its properties and structure is important. Among the indica rice varieties, Taichung Sen No. 17 (TCS 17) has the highest amylose content and is cultivated only in Taiwan.\cite{8} The amylose content of rice is key to determining its functional properties. It is generally speculated that gelatinization occurs more easily in rice with a high amylose content,\cite{9} allowing the formation of retrograded starch (RS III).

The health benefits of resistant starch are well-known and similar to those of dietary fiber. Therefore, it has generated considerable interest in the food processing industry because of its ability to reduce the risk of colon cancer, rectal cancer, coronary heart disease, diabetes, and other diseases.\cite{10} Unripe bananas are rich in RS II,\cite{11} and owing to their low digestibility, substantial

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research efforts have been directed toward investigating their use as a raw material for food processing. During the ripening process, starch is converted into sucrose, glucose, and fructose via enzymolysis.\textsuperscript{[10,12]} Although numerous studies have reported the content and quality of banana starch, the quality characteristics and functionality of Taiwanese bananas remain unclear. Therefore, the application of Taiwanese bananas in functional foods is limited and research into the quality and functionality of TCS 17 and Taiwanese bananas is necessary. In this study, TCS 17 as well as ripe and unripe Taiwanese bananas of three different varieties (PC, FS, and TC5) are studied to analyze their total starch, amylose, and resistant starch contents (RSC). These bananas were then used to prepare flat-rice noodles, and the characteristics of these noodles, including color, hardness, cooking loss rate, RSC, solubility, and swelling power, were analyzed.

**MATERIALS AND METHODS**

**Materials**

Kernels of TCS 17 (grown in Taiwan) were harvested in 2020. Commercially ripe and unripe bananas of three different varieties (PC, FS, and TC5) were purchased from a local market (Pingtung, Taiwan). All chemicals and reagents used in this study were of analytical grade.

**Preparation of ripe and unripe banana flours**

Whole flour was prepared using ripe and unripe bananas according to a method reported in the literature with some modifications.\textsuperscript{[3]} Bananas were cleaned and brushed, and their ends were removed. The fruit was cut into 0.5 cm slices and immediately rinsed with citric acid solution (0.3% w/v). The slices were dried in a constant-temperature oven (DKN 612; Yamoto Company, Tokyo, Japan) at 50°C for 12 h, ground using a laboratory grinder (RT-N08; Rong Tsong Solutions, Taichung, Taiwan), and passed through a 50-mesh sieve (270 μm; Retsch, Haan, Germany). Flour samples were stored at 7°C in sealed plastic containers until analysis.

**Amylose content**

The amylose contents of the ripe and unripe bananas were determined using a previously published method with slight modifications.\textsuperscript{[11]} The banana sample (90 mg), 1 mL of 95% ethanol, and 9 mL of 1 N NaOH were mixed and incubated at 30°C for 24 h. The volume was adjusted to 100 mL by adding distilled water. Next, 1 mL of 1 N acetic acid and 2 mL of iodine solution (0.2% I\textsubscript{2} in 2% KI) were added to a 5 mL aliquot of this adjusted solution. The volume was adjusted to 100 mL by adding distilled water and mixing for 20 min. The absorbance was measured at 620 nm using a spectrophotometer (U-1500; Hitachi, Japan). The amylose content was calculated from a standard curve prepared using potato amylose (A-0512; Sigma-Aldrich, St. Louis, MO, USA) and waxy corn starch (S-9679, Sigma-Aldrich, St. Louis, MO, USA). The analyses were performed in triplicate.

**Total starch content**

The total starch contents of the ripe and unripe bananas were determined using a YSI 7100 Biochemistry Analyzer (YSI Incorporated, Yellow Springs, OH, USA) according to a previously published method with some modifications.\textsuperscript{[11]} This method was based on an immobilized enzyme biosensor that measured the glucose levels after hydrolysis. A 0.5 g sample of banana powder was weighed and transferred to a 100 mL volumetric flask, and 25 mL of distilled water was added. Next, 2 N NaOH was added to the first flask and incubated in a boiling water bath (100°C), followed by the addition of 2 N HCl. The flask was allowed to cool to <50°C to facilitate chemical solubilization before the total starch content was determined. Acetate buffer (1 N) and amylglucosidase solution were added
to both flasks and incubated at 40°C for 70 min to determine the quantity of gelatinized starch. After incubation, 5 mL of 25% trichloroacetic acid was immediately added to each flask to prevent hydrolysis.

**Resistance Starch Content**

The RSC was determined by following a previously described method.[11] Banana powder samples (0.4 g, dry basis) were weighed in centrifuge tubes with 20 mL of phosphate buffer (pH 6.0 [55.6 mM]), and 0.16 g of α-amylase (A-3176, Sigma-Aldrich, St. Louis, MO, USA) was added to each tube. The mixture was incubated at 37°C for 16 h. The sample was adjusted to a pH of 4.5 using phosphoric acid solution (2 mL/100 mL) and 0.4 mL of amylglucosidase (A-7095, Sigma-Aldrich, St. Louis, MO, USA) was added, followed by the incubation of the solution at 60°C for 30 min. The sample was centrifuged at 4,000 × g for 15 min in a high-speed microcentrifuge (CF15R; Hitachi, Koki, Ltd., Tokyo, Japan), and the resulting residue was resuspended in 20 mL of phosphate buffer (pH 7.5 [0.08 M]) and 0.4 mL of protease (P-2143, Sigma-Aldrich, St. Louis, MO, USA). The resuspended sample was incubated at 42°C for 4 h, centrifuged at 6,000 × g for 15 min, dried to a constant weight at 60°C in a constant-temperature oven (DKN 612, Yamato Company, Tokyo, Japan), and weighed to determine the RSC. The analyses were performed in triplicate. RSC was calculated using the following equation:

\[
\text{RSC(g/100g, dry basis)} = \left(\frac{\text{Resistant starch weight}}{\text{Sample weight}}\right) \times 100
\]

where RSC, resistant starch weight, and sample weight are expressed in grams.

**Steamed banana flat-rice noodles**

The procedure used to prepare banana flat-rice noodles was based on a method proposed in the literature with slight modifications.[11] The TCS 17 rice sample was removed from the refrigerator maintained at 7°C and placed in a stainless-steel container at room temperature for 2 h. Next, 200 g of TCS 17 was weighed in a stainless-steel basin, and 200 g of distilled water was added to facilitate soaking at room temperature for 2 h. A grinder (Fe-05, Yung Soon Lih Food Machine Co., Ltd. Taichung, Taiwan) was used to grind TCS 17 for 5 min. The ground material was then poured into a stainless-steel basin, which was heated using a thermostatic water bath (BH-230D; Yihdder Company, New Taipei City, Taiwan) maintained at 85°C for 18 min to stimulate gelatinization. Thereafter, the ground material was removed and placed in a refrigerator at 4°C for 2 h. Subsequently, 200 g of water was added, and the mixture was thoroughly stirred to form a rice paste. The powders of ripe and unripe bananas of different varieties were individually added to the paste and mixed well (Table 1). The individual mixtures were then poured into a 60 × 3 × 1 cm³ rectangular stainless steel tray and placed into a steamer (Ks-610 U, Quickly Food Machinery Co., Ltd. Taoyuan, Taiwan) for 5 min. After cooling to room temperature, the product was cut into 30 × 1 × 0.2 cm³ strips, which afforded the banana flat-rice noodle product that was subsequently analyzed in this study.

**Color characteristics**

The colors of the ripe and unripe banana flat-rice noodles were analyzed using a Color Quest XE Measuring System (Hunter Associates Laboratory, Reston, USA). The analyses were performed in triplicate.

**Cooking loss**

To determine the cooking loss, 2 g (X) of each sample and 20 mL of distilled water were weighed. Next, distilled water was placed into a crucible with a constant weight (W) and boiled using a heating plate
Table 1. Experimental specifications for steamed banana flat-rice noodles.

| Sample | Rice pulp [g] | Water [g] | Unripe banana powder [g] | Ripe banana powder [g] | Salt [g] |
|--------|---------------|-----------|--------------------------|------------------------|---------|
| Blank  | 100           | 200       |                          |                        | 2       |
| UPC    | 95            | 200       | 5                        |                        | 2       |
| UFS    | 95            | 200       | 5                        |                        | 2       |
| UTC5   | 95            | 200       | 5                        |                        | 2       |
| RPC    | 95            | 200       |                          |                        | 2       |
| RFS    | 95            | 200       | 5                        |                        | 2       |
| RTC5   | 95            | 200       | 5                        |                        | 2       |

UPC, Unripe Pei Chiao; UFS, Unripe Formosana; UTC5, Unripe Tai-Chiao No. 5; RPC, Ripe Pei Chiao; RFS, Ripe Formosana; RTC5, Ripe Tai-Chiao No. 5

(HP-303D, NewLab Macro Fortunate Company, Taipei, Taiwan). The weighed sample was then added to boiling distilled water and heated for 5 min before removing it from the heating plate. The remaining liquid was then placed in an oven (DKN 612, Constant Temperature Oven, Yamoto Company, Tokyo, Japan) maintained at 105°C and baked to a constant weight (W1). Cooking loss was then calculated using the following formula: cooking loss = ((W1 − W)/X) × 100. Three measurements were performed for each sample set.

**Hardness**

Hardness was measured using an EZ Test-500 N texture analyzer (TAXTZ-5, Shimadzu Co., Kyoto, Japan), following a previously published protocol with some modifications.\(^1\) Hardness measurements were performed by penetration using a cylindrical plunger (10 mm diameter, depression speed = 30 mm/min) and 500 N load cell. The sample was a 3 × 3 × 3 cube. The samples were compressed twice to 50% of their original height, and hardness was determined based on two compression cycles. The analyses were performed in triplicate.

**Solubility and swelling power**

The solubility and swelling power of the ripe and unripe bananas were determined according to a previously described method with some modifications.\(^1\) A 0.6 g sample of banana powder (dry basis) was mixed with distilled water in a 50 mL graduated centrifuge tube and diluted to a total volume of 40 mL. The slurry was heated at 50, 60, 70, 80, and 90°C for 30 min. The tube was removed, wiped dry on the outside, and cooled to 30°C. It was then centrifuged at 6,000 × g for 20 min in a high-speed microcentrifuge (CF15R; Hitachi, Koki, Ltd., Tokyo, Japan) and the resulting supernatant was decanted into a pre-weighed crucible. Solubility was determined using a constant-temperature oven (DKN 612, Yamoto Company, Japan) maintained at 105°C, and the sedimented paste was weighed. The swelling power and solubility were calculated using Equations 2 and 3, respectively:

\[
Swelling power (\text{g g}^{-1}) = \frac{\text{Weight of sediments}}{(\text{Sample weigh} - \text{Weight of soluble})} \tag{2}
\]

swelling power is in g g\(^{-1}\) and the weights of the sediment, sample, and solution are in grams.

\[
\text{Solubility (}\%\) = \left(\frac{\text{Weight of solution}}{\text{Weight of sample}}\right) \times 100 \tag{3}
\]
Statistical analysis

The calculations were performed using Microsoft Office Excel 2010 (Microsoft Corporation, Redmond, WA, USA). The characteristics and RSC data were analyzed considering the variance using the Statistical Analysis System software (SAS Institute, Cary, NC, USA). Differences between the mean values were determined using Duncan’s multiple range test, with significance defined as \( p < .05 \).

RESULTS AND DISCUSSION

Amylose, total starch, and RSC of TCS17 and bananas

The amylose and total starch contents of TCS17 were 28.66 g/100 g and 77.99 g/100 g, respectively (Table 2). The high amylose content of indica rice has been reported in previous studies. Wang et al. reported that the amylose contents of different varieties of rice were 18.1–31.6 g/100 g.\(^6\) Lai reported an amylose content of 28.8 g/100 g for TCS17,\(^13\) which was comparable to the value obtained in this study (Table 2). The total starch content data were consistent with those reported by Wu et al.,\(^7\) who found that the total starch content of rice was approximately 75 g/100 g; this was comparable to the results obtained by Park et al. (76.06–81.66 g/100 g).\(^14\) Tsuiki et al. reported an RSC of 15–35 g/100 g for rice,\(^15\) which was comparable to the result obtained in this study (31.76 g/100 g) (Table 2).

The data for the amylose content, total starch content, and RSC of different banana varieties (PC, FS, and TC5) are shown in Table 2. The values for the amylose content were in the range of 14.46–32.17 g/100 g, which were comparable to the results obtained by Olatunde et al. (13.87–42.07 g/100 g).\(^16\) The total starch content values of different varieties of ripe and unripe bananas used in this study 23.16–79.05 g/100 g. Ravi and Mustaffa determined the amylose contents and total starch content of nine varieties of unripe bananas and obtained values of 24.41–36.87 g/100 g and 80.53–86.76 g/100 g, respectively,\(^17\) which were comparable to the results obtained in this study. The results of previous literature reports indicate that unripe bananas have a higher total starch content in comparison to ripe bananas.\(^18\) In addition, starch can be converted into sucrose, glucose, and fructose via enzymolysis during the ripening process,\(^10,12\) which results in a decrease in the total starch content. The amylose and total starch contents of ripe bananas (PC, FS, and TC5) were all significantly lower than those of unripe bananas \((p < .05)\) (Table 2).

The RSC values for the ripe and unripe bananas of different varieties were 15.63–42.33 g/100 g (Table 2). Febriyatna et al. reported that the RSCs of the ripe and unripe bananas were 39.76–40.01 g/100 g,\(^19\) which were comparable to the results obtained herein. Banana starch is resistant to α-amylase- and glucoamylase-based hydrolysis\(^11\) and is referred to as RS II.\(^20\) Starch is the main component of bananas; it is converted into soluble solids during the ripening process, resulting in an

| Experimental variable | Amylose content [g/100 g] | Total starch content [g/100 g] | Resistant starch content [g/100 g] |
|-----------------------|---------------------------|-------------------------------|----------------------------------|
| TSC 17                | 28.66 c                   | 77.99 b                       | 31.76 c                          |
| UPC                   | 32.17 a                   | 79.05 a                       | 42.33 a                          |
| RPC                   | 19.30 p                   | 30.70 c                       | 19.40 d                          |
| UFS                   | 30.78 b                   | 78.39 b                       | 34.00 d                          |
| RFS                   | 15.56 f                   | 26.03 d                       | 17.03 e                          |
| UTC5                  | 29.07 c                   | 78.05 b                       | 32.00 d                          |
| RTCS                  | 14.46 f                   | 23.16 e                       | 15.63 d                          |

Superscript letters (a–f) denote significant differences \((p < 0.05)\).

TCS 17, Taichung Sen 17; UPC, Unripe Pei Chiao; RPC, Ripe Pei Chiao; UFS, Unripe Formosana; RFS, Ripe Formosana; UTC5, Unripe Tai-Chiao No. 5; RTCS, Ripe Tai-Chiao No. 5.
increase in the sugar content and decrease in RSC.\textsuperscript{[12]} Accordingly, the RSCs of the ripe bananas used in this study were significantly lower than those of unripe bananas (\( p < .05 \)) (Table 2).

\textbf{Color of banana flat-rice noodles}

The L values of banana flat-rice noodles prepared using ripe and unripe bananas of different varieties were in the range of 41.78–47.86 (Table 3). The L values of various test groups were lower than those of the control group (50.14). Tiboonbun et al. prepared rice noodles using unripe banana flour,\textsuperscript{[21]} which showed an L value of 47.82, comparable to that obtained in this study. In addition, the L values of the ripe-banana-containing flat-rice noodles (RPC, RFS, and RTC5) were all significantly lower than those of the unripe-banana-containing flat-rice noodles (UPC, UFS, and UTC5) (\( p < .05 \)), because ripe bananas are rich in pigments such as carotenoids,\textsuperscript{[2]} which result in relatively low L values.

The a and b values were 0.02–1.01 and 1.29–3.99, respectively (Table 3). The a and b values for UPC, UFS, and UTC5 were 0.02, 0.42, and 0.58 and 1.29, 2.90, and 2.70, respectively. The corresponding a and b values for the flat-rice noodles prepared using ripe bananas (RPC, RFS, and RTC5) were 0.77, 1.01, and 0.79, and 2.86, 3.96, and 3.99, respectively. The a and b values for different test groups (PC, FS, and TC5) were significantly higher than those of the control group (−1.03 for a, −2.68 for b; \( p < .05 \)). Tiboonbun et al. reported that the a and b values for rice noodles increased significantly with the addition of banana flour owing to the effects of polyphenol oxidase on the phenolic compounds in banana.\textsuperscript{[21]} Accordingly, the a and b values of flat-rice noodles prepared using ripe bananas of different varieties were considerably higher than those of the unripe-banana-containing flat-rice noodles (\( p < .05 \); Table 3).

\textbf{Hardness of banana flat-rice noodles}

The hardness of banana flat-rice noodles prepared using ripe and unripe bananas of different varieties was 1.34–2.85 kgf/mm\(^2\) (Table 4). The hardness of RPC (1.34 kgf/mm\(^2\)), RFS (1.50 kgf/mm\(^2\)), and RTC5 (1.46 kgf/mm\(^2\)) in different test groups did not vary significantly from that in the control group (1.44 kgf/mm\(^2\); \( p > .05 \)); however, the hardness of UPC (1.74 kgf/mm\(^2\)), UFS (2.85 kgf/mm\(^2\)), and UTC5 (2.59 kgf/mm\(^2\)) was considerably higher than that of the control group (\( p < .05 \)). Among the different varieties of bananas, the addition of UFS afforded the highest hardness (2.85 kgf/mm\(^2\)), whereas the addition of RPC yielded the lowest (1.34 kgf/mm\(^2\)). Chou et al. reported that an increase in hardness due to the addition of unripe bananas may be because of the retrogradation of the large quantity of starch in unripe bananas when these are cooled after heating.\textsuperscript{[11]} The hardness of the unripe-banana-containing flat-rice noodles was significantly higher than that of the ripe-banana-containing flat-rice noodles (\( p < .05 \)).

\begin{table}[h]
\centering
\begin{tabular}{lccc}
\hline
Experimental variable & L\(^*\) & a\(^*\) & b\(^*\) \\
\hline
Blank & 50.14\(^a\) & −1.03 \(^c\) & −2.68\(^d\) \\
UPC & 47.86\(^b\) & 0.02\(^b\) & 1.29\(^c\) \\
RPC & 43.43\(^d\) & 0.77\(^b\) & 2.86\(^b\) \\
UFS & 47.33\(^b\) & 0.42\(^b\) & 2.90\(^b\) \\
RFS & 42.43\(^ab\) & 1.01\(^a\) & 3.96\(^a\) \\
UTC5 & 44.89\(^c\) & 0.58\(^b\) & 2.70\(^b\) \\
RTC5 & 41.78\(^a\) & 0.79\(^b\) & 3.99\(^a\) \\
\hline
\end{tabular}
\caption{Color analysis data of banana flat-rice noodles containing different varieties of ripe and unripe bananas.}
\end{table}

Superscript letters in the same row indicate significant differences (\( p < 0.05 \)). UPC, Unripe Pei Chiao; RPC, Ripe Pei Chiao; UFS, Unripe Formosana; RFS, Ripe Formosana; UTC5, Unripe Tai-Chiao No. 5; RTC5, Ripe Tai-Chiao No. 5.
Table 4. Hardness, cooking loss, and resistant starch content of banana flat-rice noodles containing different varieties of ripe and unripe bananas.

| Experimental variable | Hardness [kgf/mm²] | Cooking loss [%] | RSC [g/100 g] |
|------------------------|--------------------|------------------|---------------|
| Blank                  | 1.44<sup>d</sup>   | 1.14<sup>bc</sup> | 10.50<sup>c</sup> |
| UPC                    | 1.79<sup>c</sup>   | 1.46<sup>bc</sup> | 12.83<sup>a</sup> |
| RPC                    | 1.34<sup>d</sup>   | 1.91<sup>a</sup>  | 11.67<sup>b</sup> |
| UFS                    | 2.85<sup>a</sup>   | 1.45<sup>ab</sup> | 12.22<sup>a</sup> |
| RFS                    | 1.50<sup>d</sup>   | 1.94<sup>a</sup>  | 11.46<sup>b</sup> |
| UTC5                   | 2.59<sup>b</sup>   | 1.56<sup>ab</sup> | 12.51<sup>a</sup> |
| RTC5                   | 1.46<sup>d</sup>   | 1.96<sup>a</sup>  | 11.33<sup>b</sup> |

Different superscript letters in the same row denote significant differences (p < 0.05). UPC, Unripe Pei Chiao; RPC, Ripe Pei Chiao; UFS, Unripe Formosana; RFS, Ripe Formosana; UTC5, Unripe Tai-Chiao No. 5; RTC5, Ripe Tai-Chiao No. 5; RSC, Resistant Starch Content.

Cooking loss of the banana flat-rice noodles

The cooking losses of banana flat-rice noodles prepared using ripe and unripe bananas of different varieties varied from 1.45% to 1.96% (Table 4). The cooking losses of the banana flat-rice noodles containing RPC (1.91%), RFS (1.94%), and RTC5 (1.96%), as well as UPC (1.46%), UFS (1.45%), and UTC5 (1.56%) were significantly higher than that of the control group (1.14%; p < .05). Wandee et al. prepared noodles containing banana powder and reported a cooking loss of 1.5–2.7%, which was comparable to that obtained in this study. Among the different varieties of bananas, the addition of RTC5 yielded the highest cooking loss (1.96%), whereas the addition of UFS afforded the lowest (1.45%). Pragati et al. suggested that the water-absorption capacity of unripe bananas was higher than that of the ripe bananas; hence, unripe bananas showed a lower cooking loss. Accordingly, in this study, the cooking loss of ripe-banana-containing flat-rice noodles was significantly higher than that of unripe-banana-containing flat-rice noodles (p < .05; Table 4).

RSC of the banana flat-rice noodles

The RSCs for the flat-rice noodles prepared using different varieties of ripe and unripe bananas varied from 11.33 to 12.83 g/100 g (Table 4). Chou and Li used different varieties of sweet potato in varying proportions to prepare a savory rice pudding; the product had an RSC of 10.00–12.01 g/100 g, which was consistent with the results of this study. The RSCs of RPC (11.67 g/100 g), RFS (11.46 g/100 g), and RTC5 (11.33 g/100 g), as well as UPC (12.83 g/100 g), UFS (12.22 g/100 g), and UTC5 (12.51 g/100 g) were substantially higher than that of the control group (10.50 g/100 g) (p < .05). Among the different varieties, UPC afforded the highest RSC (12.83 g/100 g), whereas RTC5 yielded the lowest (11.33 g/100 g).

Wang et al. reported that the RSC of unripe bananas was 21.9 g/100 g after boiling, which was slightly higher than the results obtained herein, presumably because they did not use the same raw materials (i.e., rice). Tiboobun et al. reported that the RSC of the rice noodles prepared using unripe banana flour increased. Mohammed Zafar et al. added banana flour to rice papads to increase their RSCs. An increase in the sugar content of the banana starch during ripening was due to the conversion of soluble solids to sugar, which decreased the RSC. In this study, the RSCs of the ripe-banana-containing flat-rice noodles of different varieties were significantly lower than those of the unripe-banana-containing flat-rice noodles (p < .05; Table 4).

Solubility and swelling power of the banana flat-rice noodles

The solubilities of flat-rice noodles prepared using ripe and unripe bananas were 4.44–19.16% at a temperature of 50–90°C (Table 5), and the solubility gradually increased with an increase in temperature. Thiranusornkij et al. prepared bread using Thai black rice, and found that the
solubility increased significantly (1.57–11.9%; p < 0.05) upon an increase in temperature (55–95°C), which was consistent with the trend identified in this study. Herein, the solubilities of flat-rice noodles prepared with ripe and unripe bananas gradually increased with an increase in temperature within the 50–90°C range, which could be due to changes in the size and shape of the starch granules produced by the gradual increase in the fusion, swelling, deformation, and erosional processes. Consequently, in this study, the solubilities of the ripe-banana-containing flat-rice noodles were significantly higher than those of the unripe-banana-containing flat-rice noodles (p > 0.05) for different varieties of bananas (Table 5).

Wang et al. showed that the solubilities of unripe bananas were <10% in the temperature range of 55–95°C,[24] which were comparable to the solubility data obtained for the unripe-banana-containing flat-rice noodles prepared in this study. In addition, Ng et al. reported that the solubility of ripe bananas at 55–95°C was approximately 15%,[27] indicating that their solubility was higher than that of the unripe bananas.

The swelling power of flat-rice noodles prepared using ripe and unripe bananas of different varieties varied from 9.49 to 13.98 gg⁻¹ in the temperature range of 50–90°C (Table 6). Wang et al. reported a swelling power of 2.00–27.00 gg⁻¹ for unripe bananas at 55–95°C.[24] Furthermore, Thiranusornkij et al. prepared bread with a swelling power of 4.38–19.00 gg⁻¹ using Thai black rice,[26] which was consistent with the data obtained in this study. de Barros Mesquita et al. also determined the swelling powers of different banana varieties and obtained values (13.20–15.19 gg⁻¹) that were comparable to the values obtained in this study.[26]

The swelling power was related to the degree of starch dispersion at high temperatures.[24] After heat treatment at 50–80°C, the swelling power of the different varieties of the flat-rice noodles containing ripe and unripe bananas increased significantly from 9.49 to 13.98 gg⁻¹ (p < 0.05) (Table 6) because the increased interaction between the perfect crystalline structure and amylose chains restricted the hydration of the

| Table 5. Solubility [%] data for banana flat-rice noodles containing different varieties of ripe and unripe bananas. |
|-----------------------------------------------|
| **Experimental variable** | **Temperature [°C]** |
| | 50 | 60 | 70 | 80 | 90 |
| Blank | 4.44⁶⁴ | 4.99⁶⁴ | 9.11⁶⁴ | 14.13⁶⁴ | 19.16⁶⁴ |
| UPC | 5.55⁶⁴�⁰ | 6.44⁶⁴♭ | 9.54⁶⁴♭ | 14.44⁶⁴♭ | 17.78⁶⁴♭ |
| RPC | 8.88⁶⁴♭ | 9.55⁶⁴♭ | 11.99⁶⁴♭ | 15.89⁶⁴♭ | 18.33⁶⁴♭ |
| UFS | 4.99⁶⁴♭ | 5.55⁶⁴♭ | 9.44⁶⁴♭ | 11.80⁶⁴♭ | 14.44⁶⁴♭ |
| RFS | 7.89⁶⁴♭ | 10.00⁶⁴ | 11.38⁶⁴ | 12.03⁶⁴ | 15.99⁶⁴♭ |
| UTC5 | 5.00⁶⁴♭ | 6.11⁶⁴♭ | 8.89⁶⁴ | 12.22⁶⁴♭ | 15.56⁶⁴♭ |
| RTC5 | 5.89⁶⁴♭ | 7.22⁶⁴♭ | 10.11⁶⁴ | 15.99⁶⁴♭ | 16.11⁶⁴♭ |

Values in the same row or column denoted with different superscript uppercase letters are significantly different (p < 0.05).

UPC, Unripe Pei Chiao; RPC, Ripe Pei Chiao; UFS, Unripe Formosana; RFS, Ripe Formosana; UTC5, Unripe Tai-Chiao No. 5; RTC5, Ripe Tai-Chiao No. 5.

| Table 6. Swelling power [gg⁻¹] of banana flat-rice noodles containing different varieties of ripe and unripe bananas. |
|-----------------------------------------------|
| **Experimental variable** | **Temperature [°C]** |
| | 50 | 60 | 70 | 80 | 90 |
| Blank | 10.39⁶⁴♭ | 10.24⁶⁴♭ | 11.87⁶⁴♭ | 13.72⁶⁴♭ | 11.54⁶⁴♭ |
| UPC | 9.49⁶⁴♭ | 10.45⁶⁴♭ | 11.34⁶⁴♭ | 11.91⁶⁴♭ | 10.45⁶⁴♭ |
| RPC | 10.02⁶⁴♭ | 11.27⁶⁴♭ | 12.19⁶⁴♭ | 12.99⁶⁴♭ | 10.71⁶⁴♭ |
| UFS | 9.87⁶⁴♭ | 10.31⁶⁴♭ | 10.83⁶⁴♭ | 11.74⁶⁴♭ | 10.28⁶⁴♭ |
| RFS | 10.02⁶⁴♭ | 11.65⁶⁴♭ | 12.16⁶⁴♭ | 12.74⁶⁴♭ | 11.86⁶⁴♭ |
| UTC5 | 9.54⁶⁴♭ | 10.99⁶⁴♭ | 11.33⁶⁴♭ | 12.89⁶⁴♭ | 10.88⁶⁴♭ |
| RTC5 | 10.54⁶⁴♭ | 11.56⁶⁴♭ | 13.06⁶⁴ | 13.98⁶⁴♭ | 11.75⁶⁴♭ |

Values in the same row or column denoted with different superscript uppercase letters are significantly different (p < 0.05).

UPC, Unripe Pei Chiao; RPC, Ripe Pei Chiao; UFS, Unripe Formosana; RFS, Ripe Formosana; UTC5, Unripe Tai-Chiao No. 5; RTC5, Ripe Tai-Chiao No. 5.
amorphous starch region.\textsuperscript{[24]} When the temperature exceeded 80°C, the swelling power of the starch granules gradually increased.\textsuperscript{[29]} In this study, at a temperature of 90°C, the swelling power significantly decreased from 13.98 to 10.28 g·g\textsuperscript{-1} (p < .05; Table 6). This could be due to the destruction of the granular structure and leaching of the granule compounds.\textsuperscript{[29]} which caused the gradual hydration of the starch granules and breakage of the hydrogen bonds. The crystalline region is transformed into an amorphous region, and the water absorption and swelling of the granules continue,\textsuperscript{[30]} which swells and collapses starch granules and decreases the swelling power. In this study, the swelling power of ripe-banana-containing flat-rice noodles was significantly higher than that of unripe-banana-containing noodles (p > .05) for different varieties of bananas (Table 6).

Huang et al.\textsuperscript{[31]} measured the swelling powers of different varieties of unripe bananas to be <11.0 g·g\textsuperscript{-1}, which were comparable to the swelling powers obtained for the unripe-banana-containing flat-rice noodles in this study. Reddy et al. reported the swelling power of ripe banana flour to be <15.0 g·g\textsuperscript{-1} when the heating temperature was 50–90°C, indicating that the swelling power of ripe bananas was higher than that of unripe bananas.\textsuperscript{[32]}

Conclusion

In this study, the quality characteristics and RSCs of TCS17 and three varieties of ripe and unripe bananas were investigated. These were used to prepare banana flat-rice noodles for further analysis. The amylose contents, total starch content, and RSCs of unripe bananas were significantly higher than those of TCS17. The lowest values were obtained for the ripe bananas (p < .05). Among the prepared banana flat-rice noodles, the L values of the noodles containing ripe and unripe bananas were significantly lower than those of the control group (TCS17; p < .05). RPC, RFS, and RTC5 showed significantly higher a and b values and cooking loss rates compared to the unripe bananas (p < .05). Moreover, RTC5 exhibited the best results in all cases, except for a value. However, the opposite trend was observed for hardness. A higher RSC content was found in noodles prepared using unripe bananas compared to ripe-banana-containing noodles; both ripe and unripe bananas showed higher RSCs than that of the control (p < .05), with the highest value obtained for UPC and the lowest for RTC5. In terms of solubility and swelling power at 50–90°C, RPC, RFS, and RTC5 showed higher values than UPC, UFS, and UTC5 (p < .05). Furthermore, the solubility significantly increased with an increase in temperature (p < .05), and the highest swelling power was observed at 80°C. The results of this study show that different varieties of ripe and unripe Taiwanese bananas can be useful ingredients for (1) the development of various rice-based food products, (2) increasing the quality and functionality of rice-based food products, and (3) effectively addressing the imbalance between the production and sales of bananas and rice.

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References

[1] Zhang, W.; Bi, J.; Yan, X.; Wang, H.; Zhu, C.; Wang, J.; Wan, J. In Vitro Measurement of Resistant Starch of Cooked Milled Rice and Physico-chemical Characteristics Affecting Its Formation. Food Chem. 2007, 105(2), 462–468. DOI: 10.1016/j.foodchem.2007.04.002.
[2] Singh, B.; Singh, J. P.; Kaur, A.; Singh, N. Bioactive Compounds in Banana and Their Associate Health Benefits - A Review. Food Chem. 2016, 206, 1–11. DOI: 10.1016/j.foodchem.2016.03.033.
[3] Bakar, S. K. S. A.; Ahmad, N. F.; Chemical, J. F. Functional Properties of Local Banana Peel Flour. J. Food Nutr. Res. 2018, 6, 492–496. DOI: 10.12691/jfnr-6-8-1.
[27] Ng, K. F.; Abbas, F. M. A.; Tan, T. C.; Azhar, M. E.; Physicochemical, P. Gel Textural Properties of Wheat-ripe Cavendish Banana Composite Flours. *Int. Food Res. J.* 2014, 21, 655–662.

[28] de Barros Mesquita, C.; Leonela, M.; Francoa, C. M. L.; Leonela, S.; Garcia, E.; dos Santos, L.; T. P. R. Characterization of Banana Starches Obtained from Cultivars Grown in Brazil. *Int. J. Biol. Macromol.* 2016, 89, 632–639. DOI: [10.1016/j.ijbiomac.2016.05.040](https://doi.org/10.1016/j.ijbiomac.2016.05.040).

[29] Fontes, S. D. M.; Cavalcanti, M. T.; Candeia, R. A.; Almeida, E. L. Characterization and Study of Functional Properties of Banana Starch Green Variety of Mysore (Musa AAB-Mysore). *Food Sci. Technol. (Campinas)*. 2017, 37(2), 224–231. DOI: [10.1590/1678-457x.18916](https://doi.org/10.1590/1678-457x.18916).

[30] Harijono Estiasih, T.; Saputri, D. S.; Kusnadi, J. Effect of Blanching on Properties of Water Yam (*Dioscorea Alata*) Flour. *Adv. J. Food Sci. Technol.* 2013 (5), 1342–1350. DOI: [10.19026/ajfst.5.3108](https://doi.org/10.19026/ajfst.5.3108).

[31] Huang, S.; Martinez, M.; Bohrer, B. M.; Compositional, T. Functional Attributes of Commercial Flours from Tropical Fruits (Breadfruit and Banana). *Foods*. 2019, 8(11), 586. DOI: [10.3390/foods8110586](https://doi.org/10.3390/foods8110586).

[32] Reddy, C. K.; Haripriya, S.; Suriya, M. Effect of Acetylation on Morphology, Pasting and Functional Properties of Starch from Banana (*Musa AAB*). *Indian J. Sci. Res. Technol.*. 2014, 2, 31–36.