Journal of Food and Nutrition Research, 2018, Vol. 6, No. 11, 682-688
Available online at http://pubs.sciepub.com/jfnr/6/11/1

DOI:10.12691/jfnr-6-11-1

Effect of Different Yam Varieties and Addition on Resistant Starch Type III Formation and Physical Properties of Steamed Rice Bowl Cake

Mingchang Li, Chin Fu Chou*

Department of Food Science and Nutrition, Meiho University, Pingtung 91202, Taiwan
*Corresponding author: x00011064@meiho.edu.tw

Received October 11, 2018; Revised November 14, 2018; Accepted November 28, 2018

Abstract This research aimed to evaluate the effect of different varieties and proportion of yam on the resistant starch type III content (RSC) and physical properties of steamed rice bowl cake. According to the research results, RSC (9.2-11.7%) was significantly increased ($p < 0.05$) along with increasing the yam proportion in some experiment variables, where Taichung Sen 17 (TCS 17), Da shan line 2 (10, 20 and 30%), and Heng chun (10%) had the lowest RSC (9.2%). The 20 and 30% proportion showed the highest RSC (11.7%) in Tainung 5. Furthermore, significant differences ($p < 0.05$) were found in some experiment variables of texture profile analysis. Results indicated that the proportion of yam was positively related to hardness, cohesiveness and adhesiveness. Besides, color analysis results of steamed rice bowl cake with different varieties and proportion of yam were significantly different ($p < 0.05$). The control (TCS 17) was significantly lighter (L*=67.99) than Tainung 5 (L*=54.50, 52.67 and 51.20), and similar to Da shan line 2 (L*=69.37, 68.54 and 68.49) and Heng chun (L*=72.82, 69.97 and 71.39). Significant higher ($p < 0.05$) a* and b* values were observed in steamed rice bowl cake of Da shan line 2 (a*=-1.07, -0.73 and -0.60), Tainung 5 (a*=6.93, 8.59 and 9.03), Heng chun (a*=-1.63, -1.34 and -1.41) and Da shan line 2 (b*=2.41, 3.42 and 4.49), Heng chun (b*=0.45, 0.82 and 1.00), respectively. The significant differences ($p < 0.05$) were observed in some experiment variables of solubility and swelling power.

Keywords: *Taichung Sen 17, rice, yam, steamed rice bowl cake, resistant starch*

Cite This Article: Mingchang Li, and Chin Fu Chou, “Effect of Different Yam Varieties and Addition on Resistant Starch Type III Formation and Physical Properties of Steamed Rice Bowl Cake.” *Journal of Food and Nutrition Research*, vol. 6, no. 11 (2018): 682-688. doi: 10.12691/jfnr-6-11-1.

1. Introduction

Rice is the most important staple food crop for a large part of the world's human population, especially in Taiwan, and it plays an important energy source in people’s diets [1]. Furthermore, starch is the major component of rice [2,3], and its functional and structural properties are important.

Starch is the major source of dietary carbohydrates and is the most abundant storage polysaccharide in plants [4]. It is present in high amounts in cereal, root and tuber [4,5]. The most important sources of starch are corn, potato, wheat, tapioca, rice and yam. Starch is a polymer of glucose linked together by α-D-(1-4) and/or α-D-(1-6) glycosidic bonds [4]. It consists different two D-glucan polymers, one is amylose, which is a primarily linear structure, and the other is amylopectin, which is a branched structure [6,7]. It is also used for different textures of food [8]. Especially, amylose content of rice is a major factor affecting the textural, functional and physicochemical properties for food, and can be related to its rheological and swelling properties [2,7].

Resistant starch (RS) is defined as the sum of starch and products of starch degradation not absorbed in the small intestine of healthy individuals [9,10,11]. Higher RS in food can reduce the blood glucose level after a meal, which is useful in diabetes and obesity controlling [12,13]. Especially, resistant starch type III (RS III, retrograded starch) is particularly interesting since its functional and thermal stable properties during food processing [8]. The higher amylose content of *Indica* rice is easy to retrograde, and further form RS III [1,7].

Taichung Sen 17 (TCS 17) is the variety of rice that is with the highest amylose conten, this may have a positive effect on RS □ formation [1,7]. TCS 17 is only planted in Taiwan, and it benefits the RS □ producing [14]. Besides, RS III formation is associated with retrograded amylose [6]. The texture of rice-made food is known to easily become hard, which makes the taste worse over the time. This is because of the retrogradation resulted in RS III increasing through recrystallization of amylose. Therefore, TCS 17 has been lost the popularity due to its low acceptability in taste and mouth feel.

Steamed rice bowl cake is one of the traditional dishes in Taiwan, and the texture of steamed rice bowl cake is soft and stretchy. Traditionally, *Indica* rice has been used for making steamed rice bowl cake because it can provide a favorable texture and appearance. However, instead of *Indica* rice, other starch crops such as yam have never been utilized for making steamed rice bowl cake.

Yam (Family *Dioscoraeceae*) is a high economic value food crop, and an important source of energy [15,16] in people's diets. Starch is the major component of yam and provides large proportion of daily caloric intake. Since yam tubers contain about 70–82% starch [17,18], the cooking, processing characteristics and storage quality of yam-containing products, and perhaps the physiological effectiveness of the bioactive ingredients involved will be greatly dependent on starch properties of yam [19]. According above mentions, starch properties of yam affect the physicochemical, functional, and textural characteristics for yam-containing products [20]. The yam is also rich in carbohydrate, dietary fibers, vitamin B-complex, and is an important source of the β-carotene, mineral, such as manganese. Oluwanmukomi and Akinsoka [21] further reported higher amounts of phosphorus in yam (0.022%) [17,21]. Particularly, the yam has a higher amylose content when compared to potato, rice and cassava [17], and it benefits the RS III producing [14]. The yam is becoming increasingly popular for various products manufacturing such as steaming, boiling, roasting, and frying [20]. That is to say, the yam is becoming widely accepted in the daily diet as a cheap source of carbohydrate [18] and yam is becoming an alternative of rice.

Steamed rice bowl cake is the one of Taiwanese traditional rice-made food, but as the impact of instant food, the consumption of rice is decreasing gradually. Therefore, promoting Taiwanese traditional rice-made food is becoming an important task. As a matter of fact, the yam has been used as a food crop. Moreover, the yam is not only cheaper but also can be processed into higher quality products. Different varieties of yam differ in many of their characteristics, ranging from the physicochemical, fuuctional, textural properties and mouth feel. However, nowadays, the main application of yam has so far less utilized for industry in Taiwan. Besides, research regarding the combination of both yam and rice for the development of Taiwanese traditional rice-made food is so far limited.

Nowadays, natural and health food without chemical processing is the major demand for consumers. Overall, in order to improve the quality and functional demands of steamed rice bowl cake and to broaden the utility of rice. The objectives of this research were to evaluate the effect of different varieties (Da shan line 2, Tainung 5 and Heng chun) and proportion (0, 10, 20, 30%) of yam on the RSC, texture, color, solubility and swelling power of steamed rice bowl cake, and finally to evaluate the optimal conditions for the production of steamed rice bowl cake with high RSC.

2. Materials and Methods

2.1. Materials

Indica rice kernal, Taichung Sen 17 (TCS 17, grown in Taiwan) had been harvested in 2017. The total starch and amylose content of TCS 17 was analyzed by the method described by Chou and Li [7]. The total starch and amylose content of TCS 17 had been determined as 77.99 and 28.66%, respectively.

Three varieties of yam harvested in Taiwan namely yellow flesh color (Da shan line 2), purple flesh color (Tainung 5) and white flesh color (Heng chun) were purchased from a local market (Pingtung, Taiwan). The freshly harvested material of rice and yam were collected and stored at 7°C for further processing. All used chemicals and reagents were in analytical grade.

2.2. Production of Mashed Yam

Three varieties of yam (Da shan line 2, Tainung 5 and Heng chun) were allowed 2 h to equilibrate at room temperature. Then, these yam were manually cleaned by hand followed with clean water to remove soils. The cleaned yam were cut into 1 cm3 volume and steamed by a steamer (Model No KS-980, Quickly Food Machinery Co., Ltd., Taoyuan, Taiwan) for 30 min. The mashed yam were then allowed 2h to equilibrate at the room temperature and used for further processes.

2.3. Steamed Rice Bowl Cake Preparation

First, the TCS 17 rice kernal and mashed yam were then allowed 2 h to equilibrate at the room temperature before the preparation. Second, 100 g TCS 17 rice kernel were soaked in 350 mL distilled water for 30 min. Each group of TCS 17 rice kernel and mashed yam was weighed according to Table 1 and steamed by a steamer (Model No KS-980, Quickly Food Machinery Co., Ltd., Taoyuan, Taiwan) for 40 min.

Table 1. Formulas of Each Group

	Proportion of recipe			
	TSC17	Da shan line 2	Tainung 5	Heng chun
Control	100	0	0	0
1	90	10	0	0
2	80	20	0	0
3	70	30	0	0
4	90	0	10	0
5	80	0	20	0
6	70	0	30	0
7	90	0	0	10
8	80	0	0	20
9	70	0	0	30

TCS 17=Taichung Sen 17.

2.4. Resistant Starch Type Ⅲ Content (RSC) Analysis

A method previously described by Chou and Li [7] for the RSC analysis was used in this research. 0.4 g sample powders (dry basis) were weighed in a centrifuge tube, 20 mL pH 6.0 phosphate buffer (55.6 mM) and 0.16 g α-amylase (Sigma A-3176, Steinheim, Germany) were added and incubated at 37°C for 16 h. The sample was adjusted to pH 4.5 using phosphoric acid solution (2 mL/100 mL), 0.4 mL amyloglucosidase (Sigma A-7095, Steinheim, Germany) was added and incubated at 60°C for 30 min. After incubation, the sample was centrifuged at 4000 ×g for 15 min by a high-speed micro centrifuge (CF15R, Hitachi, Koki, Ltd., Tokyo, Japan), the residue was resuspended in 20 mL pH 7.5 phosphate buffer (0.08 M), 0.4 mL protease (Sigma P-2143, Steinheim, Germany) was added and incubated at 42°C for 4h. Finally, the sample was centrifuged at 6000×g for 15 min, dried to constant weight at 60°C by a constant-temperature oven and weighed for the RS weight. The analysis was carried out in triplicate.

The RSC was calculated by the following equation:

$$RSC\left(\%, drybasis\right) = \left(Resistantstarchweight / Sampleweight\right) \times 100\%. \quad (1)$$

2.5. Texture Profile Analysis (TPA)

The textural properties of the steamed rice bowl cake were analyzed using the EZ Test-500N texture analyzer (TAXTZ-5, Shimadzu Co., Kyoto, Japan) attached to a cylindrical plunger (10 mm diameter, depression speed = 30 mm/min) and a 500 N load cell, by performing texture profile analysis (TPA). The freshly prepared samples were prepared by cutting the steamed rice bowl cake to cube shaped samples (2 cm^3 volume). The samples were compressed twice to 50% of the original height, texture profile analyses were determined by two compression cycles. Texture profile parameters measured include hardness, cohesiveness, adhesiveness, gumminess, springiness and chewiness. The analysis was performed with triplicates.

2.6. Color Determination

Colors of steamed rice bowl cake were measured using Hunter Lab Color Measuring System (Color Quest XE, Hunter Associates Laboratory, Reston, USA). The analysis was performed with triplicate.

2.7. Solubility and Swelling Power

The solubility and swelling power of the steamed rice bowl cake determine was carried out by a modification of the previous method [19]. 0.6 g of sample powders (dry basis) was dissolved with distilled water to a total volume of 40 mL using a 50 mL graduated centrifuge tube. The suspension was stirred since it might cause fragmentation of the starch granules. The slurry in the tube was heated at 65℃ for 30 min. This tube was then removed, wiped dry on the outside and cooled to room temperature. It was then centrifuged at 6000 ×g for 20 min by a high-speed micro centrifuge (CF15R, Hitachi, Koki, Ltd., Tokyo, Japan). The supernatant was decanted into a pre-weighed moisture can. The solubility was determined by a constant-temperature oven at 105°C and the residue weighted. The sedimented paste was weighed and swelling power as well as percent solubility calculated using equations (2) and (3), respectively.

$$Swelling\ power = \frac{Weight\ of\ sediment}{Sample\ weight - Weight\ of\ soluble} \quad (2)$$

$$Soluble\left(\%\right) = \frac{Weight\ of\ soluble}{Weight\ of\ sample} \times 100\%. \quad (3)$$

2.8. Statistical Analysis

The data obtained were first calculated using Microsoft Office Excel 2010 (Microsoft Corporation, Redmond, WA). Analysis of variance (ANOVA) for the effect of varieties (Da shan line 2, Tainung 5 and Heng chun) and proportion (10, 20 and 30%) on the resistant starch content and physical characteristics of steamed rice bowl cake was accomplished using the Statistical Analysis System (SAS, USA). The differences among mean values were processed by Duncan's Multiple Range Test, and significance was defined at $p < 0.05$.

3. Results and Discussion

3.1. Resistant Starch Type III Content (RSC) of Steamed Rice Bowl Cake

Table 2 shows the effects of different varieties of yam (Da shan line 2, Tainung 5 and Heng chun) and proportion (10, 20 and 30%) on the RSC of steamed rice bowl cake. The measured RSC of steamed rice bowl cake ranged between 9.2 and 11.7%, which agreed with previously reported values of 10.00-12.01% [7]. This may be explained that the starch relapses to a structure during gelatinization that could be highly resistant to amylase hydrolysis which is referred to as RS III [22]. The amylose content, processing and storage conditions may affect the gelatinization and retrogradation, further affecting the RS III formation [23].

Most starchy food, such as cereals, beans and tuber root are necessary processed by heating with or without water addition before consumption [20]. The temperature of steaming method is about 100°C, and gelatinization temperatures of yam starch is reported ranging between 65°C and 75°C [24], caused physical modifications or rupture of starch granular structure due to gelatinization after hydration and then dissolved [20], and these fragments can combine with other molecules creating a new compounds resistant to amylase hydrolysis [5]. Previous research reported that steam cooking at atmospheric pressure formed higher RSC than steam cooked at higher pressure [7,22]. In addition, recrystallization during retrogradation could be formed by the association between amylose and amylopectin through the cooling of steamed rice bowl cake preparation [10,20], resulting in similar RSC between different varieties of yam. Furthermore, processing raw materials in most food destroys RS I and RS II, but it can produce RS III (retrograded amylose) [25]. RS III is produced by gelatinization, which is a disruption of granular structure by heating starch, and then retrogradation during cooling.

Compared with different varieties and proportion of yam, the control (TCS 17), Da shan line 2 (10, 20 and 30%), and Heng chun (10%) have the lowest RSC (9.2%). Previous research [28] reported that various factors such as milling degree, heating treatment, moisture content during processing, and other components in food (proteins or lipids) are known to influence the formation of RS III in processed foods. In addition, the higher RSC in processing food may attribute to the encapsulation of starch molecule by protein matrix, further forms new compounds in food [26], and the interaction between amylose and amylopectin [27], increase the realignment of starch chains, leading to it less susceptible to amylase hydrolysis and also limit the action of amylolytic enzymes on substrate, further influencing RS III formation.

It was observed in Table 2 that the 20 and 30% proportion showed the highest RSC (11.7 and 11.7%) in Tainung 5. Higher RSC could be observed in this research when compared with previous researches [28], and this may be attributed to the higher amylose content of TCS 17 and yam [29]. Especially, yam has higher amylose content when comparing to potato, rice and cassava [17]. Previours research further reported the yam with 21.69-31.56% amylose content [16], which amylose retrogrades quickly during the first few hours of cooling after gelatinization during steamed rice bowl cake preparation [5].

Furthermore, various factors are known to affect the RS III formation in processed foods. TCS 17 has higher amylose content than *Japonica* rice. The high degree of amylose polymerization, formation of amylolytic enzyme-resistant double helices stabilized by hydrogen bonds [30], and about 30-60% moisture content during steamed rice bowl cake preparation may be attributed to the main reasons. It is known that water acts as a plasticizer for retrogradation of amylose, and this can be maximized in about 30-60% moisture content [31].

Table 2. The Resistant Starch Type III Analysis Result of Steamed Rice Bowl Cake With Different Proportion of Yam

Experiment variable		Resistant starch (%)
Control		9.2^{b}
Da shan line 2	10%	9.2^{b}
	20%	9.2^{b}
	30%	9.2^{b}
Tainung 5	10%	10.8^{a}
	20%	11.7^{a}
	30%	11.7^{a}
Heng chun	10%	9.2^{b}
	20%	10.0^{a}
	30%	10.0^{a}

Different superscript letters indicate significant differences ($p < 0.05$).

3.2. Texture Profile Analysis (TPA) of Steamed Rice Bowl Cake

Texture is one of the major factors which influence food acceptability and mouth feel, especially for rice-made food. The texture profile analysis of steamed rice bowl cake based on different varieties of yam (Da shan line 2, Tainung 5 and Heng chun) and proportion (10, 20 and 30%) was shown in Table 3. Significant differences ($p < 0.05$) were found in all experiment variables. Compared with different varieties and proportion of yam, the 30% proportion of Tainung 5 showed the highest hardness and cohesiveness. This result indicates that the higher proportion of the yam, the better acceptability and mouth feel of the steamed rice bowl cake.

The texture properties of rice starch gel depend upon structure of starch granule and other components. This may be explained by higher crude fiber content of Tainung 5 which absorbs more water. This result was also observed by Chou and Li [7], who observed that steamed rice bowl cake containing sweet potato and rice flour displayed higher hardness and cohesiveness.

Previous research [32] reported the hardness of a starch gel increased linearly with retrogradation rate during storage, and it is highly correlated with the starch content of gel, maximum rate of retrogradation was observed at a 50–55% solid content [32], similar to the steamed rice bowl cake in this study, the amylose retrogradation rate might continuously and quickly increase.

When the starch granule is heated up to the gelatinization temperature in excess water, heat and moisture transfer phenomena occur. In addition, rigidity of starch gel is highly correlated with retrogradation of starch granules after gelatinization, syneresis and crystallisation of amylopectin [33]. Though the starch molecules in starch-rich food is enhanced during retrogradation leading to an increase in the hardness of steamed rice bowl cake [34].

Therefore, presence of soluble carbohydrates from the combination of both yam and rice with relatively high amylose content materials could enhance retrogradation of starch gel formation that would gave rise to harder gels. Puncha-arnon and Uttapap [35] further indicated that the formation of starch gel mainly depends on hold water in the network within the swollen starch granules. Amylose leaks out of the swollen starch granules also plays an important role, but it becomes significant when the swollen starch granules disrupt [7].

Hardness, cohesiveness, adhesiveness, gumminess, springiness and chewiness of all steamed rice bowl cake were in the range of 231.5-307.4 gf, 425.5-501.9, -149.6-(-118.1) gf.sec, 148.5-160.5 gf, 0.9-1.1 and 1.1-1.3 gf, respectively. These observation are agreement with the previously reported by Chou and Li [7]. This indicates that the steamed rice bowl cake with different varieties and proportion (10, 20 and 30%) of yam (Da shan line 2, Tainung 5 and Heng chun) are with good acceptability. From these results, we concluded that the 30% proportion in Tainung 5 was the most suitable for making the steamed rice bowl cake.

Table 3. The Texture Profile Analysis (TPA) Result of Steamed Rice Bowl Cake With Different Yam Proportions

Experiment variable		Hardness (gf)	Cohesiveness	Adhesiveness (gf.sec)	Gumminess (gf)	Springness	Chewiness (gf)
Control		286.3^{c}	481.8^{c}	-127.7^{d}	149.8^{g}	1.1^{g}	1.3^{a}
Da shan line 2	10%	234.6^{i}	425.5^{i}	-149.6^{f}	160.5^{a}	0.9^{b}	1.1^{b}
	20%	247.7^{h}	452.9^{f}	-136.6^{f}	158.5^{b}	0.9^{b}	1.1^{b}
	30%	279.1^{e}	475.9^{e}	-129.6^{e}	155.3^{b}	0.9^{b}	1.3^{b}
Tainung 5	10%	267.4^{f}	446.1^{g}	-136.9^{f}	158.5^{d}	1.0^{a}	1.3^{a}
	20%	258.0^{g}	481.8^{c}	-125.3^{c}	153.3^{e}	1.0^{a}	1.3^{a}
	30%	307.4^{a}	501.9^{a}	-119.2^{b}	148.5^{f}	1.1^{a}	1.3^{a}
Heng chun	10%	231.5^{j}	434.9^{h}	-138.8^{g}	157.4^{c}	1.1^{a}	1.2^{a}
	20%	282.4^{d}	477.9^{d}	-129.5^{a}	155.2^{d}	1.1^{a}	1.3^{a}
	30%	305.4^{b}	495.5^{b}	-118.1^{a}	152.9^{e}	1.1^{a}	1.3^{a}

Different superscript letters indicate significant differences ($p < 0.05$).

3.3. Color Evaluation of Steamed Rice Bowl Cake

The results of color evaluation presented in Table 4 showed that color characteristics of steamed rice bowl cake with different varieties (Da shan line 2, Tainung 5 and Heng chun) and proportion (10, 20 and 30%) of yam were significantly different ($p < 0.05$). The measured L* value of steamed rice bowl cake ranged between 51.20 and 72.82. Compared with different varieties and proportions of yam, the control (TCS 17) was significantly lighter (L* = 67.99) than Tainung 5 (L*=54.50, 52.67 and 51.20). This research revealed that L* value increased with increasing yam (Da shan line 2 and Heng chun) proportion, which may be attributed to the deep color of the yam. Previous research indicated some varieties of yam were rich in different colored pigments, such as β-carotene, a precursor of Vitamin A, are responsible for different colors in yam [21].

The chromaticity coordinate a* measures red when positive and green when negative, while b* measures yellow when positive and blue when negative. Starch, which is colourless, the deep red and yellow color of yam were confirmed by their higher a* and b* values. This may be possibly explained by the fact that Da shan line 2, Tainung 5 and Heng chun were the varieties of yellow, purple and white, respectively. The higher a* and b* values indicated yellow-orange color in steamed rice bowl cake with different varieties of yam (Da shan line 2, Tainung 5 and Heng chun) may due to the presence of polyphenols, carotene, and other compounds [36].

Moreover, it has been reported that β-carotene is the precursor of Vitamin A [21], serves as an important nutrient in food as it has functional properties due to their antioxidative activity.

Table 4. The Hunter Lab Values of Steamed Rice Bowl Cake With Different Yam Proportions

Experiment variable		L*	a*	b*
	Control	67.99^{e}	-2.25^{g}	0.45^{d}
Da shan line 2	10%	69.37^{c}	-1.07^{e}	2.41^{c}
	20%	68.54^{d}	-0.73^{d}	3.42^{b}
	30%	68.49^{d}	-0.60^{d}	4.49^{a}
Tainung 5	10%	54.50^{f}	6.93^{c}	-6.94^{g}
	20%	52.67^{g}	8.59^{b}	-7.51^{f}
	30%	51.20^{h}	9.03^{a}	-6.29^{e}
Heng chun	10%	72.82^{a}	-1.63^{f}	0.45^{d}
	20%	69.97^{b}	-1.34^{e}	0.82^{d}
	30%	71.39^{a}	-1.41^{e}	1.00^{d}

3.4. Solubility and Swelling Power Evaluation of Steamed Rice Bowl Cake

The solubility is the percentage of starch solubilized in water during gelatinization. The solubility of steamed rice bowl cake with different varieties (Da shan line 2, Tainung 5 and Heng chun) and proportion (10, 20 and 30%) of yam is between 4.4 and 10.0% at 65℃ (Table 5). These observation are agreement with the previously reported by Alex and Georges [37]. Compared with different varieties and proportions of yam, the control (TCS 17) was significantly higher (10.0%) than Da shan line 2 (8.3, 8.3%), Tainung 5 (4.4, 6.6 and 5.0%) and Heng chun (6.7, 8.3 and 8.3). This research revealed that solubility decreased with addition of yam, which may be attributed to the difference of yam varieties [19,37].

Starch is insoluble in water at ambient temperature, however if increasing the temperature, starch granules could be swollen up to a certain degree [20]. Therefore, swelling power and solubility is the evidence of the interaction between starch chains within the amorphous and crystalline domains, and also provide an evidence of association bonding within the granules of yam starch [19]. Swelling power reflecting the hydration capacity of the water-insoluble starch fraction [37]. The swelling power of steamed rice bowl cake with different varieties (Da shan line 2, Tainung 5 and Heng chun) and proportion (10, 20 and 30%) of yam is between 6.9 and 11.4 g/g at 65°C (Table 5). These observation are agreement with the previously research [19], who reported that the higher swelling power have the lowest associative forces. These may be attributed to the difference of yam varieties [19,37]. Therefore, the heating treatment slightly affected starch granule size. As the temperature higher than 50°C, there was a progressive increase in swelling power of yam [20]. In this research, the starch granules gelatinization during steaming about 100°C, starch granule hydrate progressively, hydrogen bonds are ruptured resulting in crystalline regions being converted into amorphous regions and granules continue to imbibe water and swell [16,20], caused starch granules swelled and collapse [16]. It was observed in Table 5 that Da shan line 2 showed the higher swelling power (11.4, 8.5 and 8.6 g/g) than Tainung 5 (8.3, 7.6 and 6.9 g/g), but similar to the results of Heng chun (9.2, 9.1 and 8.1 g/g). These results are agreement with the observations in swelling power of purple yam, which may be attributed to its higher amylose content [20].

In this research, the greater extent of starch granule swelling was because of the lower protein and lipid content. Sanful and Engmann [36] reported the swelling power of starch gel decreased linearly with protein and lipid content during retrogradation. Especially, the retrogradation rate is highly correlated with the starch content of gel. In a starch gel, maximum rate of retrogradation was observed at a 50–55% solid content [20], similar to the steamed rice bowl cake in this research.

Other components in starch gel, including protein, lipid, and non-starch polysaccharide, would also facilitate or impede the network formation within the swollen starch granules (Chou and Li 2018).

Table 5. The Solubility and Swelling Power of Steamed Rice Bowl Cake With Different Yam Proportions

Experiment variable		Solubility (%)	Swelling power (g/g)
Control		10.0^{a}	8.7^{dc}
Da shan line 2	10%	8.3^{b}	11.4^{a}
	20%	8.3^{b}	8.5^{de}
	30%	10.0^{a}	8.6^{de}
Tainung 5	10%	4.4^{e}	8.3^{de}
	20%	6.6^{c}	7.6^{g}
	30%	5.0^{d}	6.9^{h}
Heng chun	10%	6.7^{c}	9.2^{b}
	20%	8.3^{b}	9.2^{bc}
	30%	8.3^{b}	8.1^{f}

4. Conclusion

Results of this research revealed the effects of different varieties (Da shan line 2, Tainung 5 and Heng chun) and proportion (10, 20 and 30%) of yam on the RSC, texture, color, solubility and swelling power of steamed rice bowl cake. According to the results, the texture profile analysis and color evaluation were significantly affected by different varieties and proportion of yam. The effects of different varieties and proportion of yam on RSC of steamed rice bowl cake showed that control (TCS 17), Da shan line 2 (10, 20 and 30%), and Heng chun (10%) had the lowest RSC. Some similar RSC among different varieties of yam (Tainung 5 and Heng chun) was observed. The above results suggest that firms should consider this method to further develop the Taiwanese traditional rice-made food combination of both yam and rice. Moreover, significant differences (p < 0.05) were found in all experiment variables of texture profile analysis. Compared with other experiment variables, the hardness, cohesiveness and adhesiveness of steamed rice bowl cake were positively related to the proportion of yam. The 30% proportion in Tainung 5 is the most suitable for making the steamed rice bowl cake.

Furthermore, the L*, a* and b* value of steamed rice bowl cake were significantly affected by the different flesh color of yam varieties and proportion. Higher a* and b* values indicate that yellow-orange color in steamed rice bowl can be attributed to different varieties of yam. The solubility and swelling power were significantly affected by the addition of yam. Thus, this suggests that the food industry should consider the application of yam in order to further develop rice-made food. In summary, results of this research has revealed that the yam is not only a potentially useful but also a natural material for high RSC in the manufacturing of rice-made food with better acceptability in texture and color characteristics.

Acknowledgments

We thank the Meiho University in Pingtung supporting excellent equipments and technology. All of the authors participated in this study, and read and approved the final manuscript.

References

[1] Chou, C.F., Yen, T.F., and Li, C.T., "Effects of different cooking methods and particle size on resistant starch content and degree of gelatinization of a high amylose rice cultivar in Taiwan," *Journal of Food, Agriculture and Environment*, 12 (2). 6-10. 2014.

[2] Wang, L., Xie, B., Shi, J., Xue, S., Deng, Q., Wei, Y., and Tian, B., "Physicochemical properties and structure of starches from Chinese rice cultivars," *Food Hydrocolloids*, 24(2). 208-216. 2010.

[3] Shih, F., King, J., Daigle, K., An, H. J., and Ali, R., "Physicochemical properties of rice starch modified by hydrothermal treatments," *Cereal Chem*, 84(5). 527-531. 2007.

[4] Reddy, D. K., and Bhotmange, M.G., "Viscosity of starch: A comparative study of Indian rice *(Oryza Sativa L.)* varieties," *International Review of Applied Engineering Research*, 4(5). 397-402. 2014.

[5] Amani, N. G. G., Kamenan, A., Rolland-Sabaté, A., and Colonna, P., "Stability of yam starch gels during processing," African *Journal of Biotechnology*, 4 (1). 94-101. 2005.

[6] Shamai, K., Bianco-Peled, H., and Shimoni, E., "Polymorphism of resistant starch type III," *Carbohydrate Polymers*, 54. 363-369. 2003.

[7] Chou, C., and Li, M., "A research of effect of three sweet potato varieties and addition on resistant starch content and physical characteristics of steamed rice bowl cake," *Journal of Food and Nutrition Research*, 6(8). 551-556. 2018.

[8] Shamai, K., Bianco-Peled, H., and Shimoni, E., "Polymorphism of resistant starch type III," *Carbohydrate Polymers*, 54. 363-369. 2003.

[9] Goni, I., Garcia-Diz, L., Manas, E., and Saura-Calixto, F., "Analysis of resistant starch: A method for foods and food products," *Food Chemistry*, 56(4). 445-449. 1996.

[10] Mun, S., and Shin, M., "Mild hydrolysis of resistant starch from maize," *Food Chemistry*, 96(1). 115-121. 2006.

[11] [Zhang, W., Bi, J., Yan, X., Wang, H., Zhu, C., Wang, J., and Wan, J., "In vitro measurement of resistant starch of cooked milled rice and physico-chemical characteristics affecting its formation," *Food Chemistry*, 105(2). 462-468. 2007.

[12] Alderson, A. K., and Guraya, H. S., "Effects of microwave heat moisture treatment on properties of waxy and non-waxy rice starches," *Food Chemistry*, 97(2). 318-323. 2006.

[13] Walter, M., Silva, P., and Denardin, C., "Rice and resistant starch: Different content depending on chosen methodology," *Journal of Food Composition and Analysis*, 18(4). 279-285. 2005.

[14] Namratha, J., Asna, U., and Prasad, N., "Effects of storage on resistant starch content of processed ready-to-eat foods," *Food Chemistry*, 79(3). 395-400. 2002.

[15] Akissoe, N., Mestres, C., Handschin, S., Gibert, O., Hounhouigan, J., and Nago, M., "Microstructure and physico-chemical bases of textural quality of yam products," *LWT - Food Science and Technology*, 44. 321-329. 2011.

[16] Harijono, Estiasih, T., Saputri, D. S. and Kusnadi, J., "Effect of blanching on properties of water yam (Dioscorea alata) Flour," *Advance Journal of Food Science and Technology*, 5(10). 1342-1350. 2013.

[17] Reis, R. C., Côrrea, P. C., Devilla, I. A., Santos, E. S., Ascheri, D. P. R., Servulo, A. C. O., and Souza, A. B. M., "Drying of yam starch (*Discorea ssp*.) and glycerol filmogenic solutions at different temperatures," *LWT - Food Science and Technology*, 50. 651-656. 2013.

[18] Kanita, T., "Comparasion in some characteristics of yam tubers starch (*Dioscoreaceae spp.*) from Thailand," *International Journal of Environment and Rural Development*, 1(2). 102-106. 2010.

[19] Nii Amoo, A. R., Dufie, W. F., and Ibok, O. "Physicochemical and pasting properties of starch extracted from four yam varieties," *Journal of Food and Nutrition Sciences*, 2(6). 262-269. 2014.

[20] Rosida, R., Harijono, Estiasih, T. and Sriwahyuni, E., "Functional and pasting characteristics of modified water yam flour (*Diocorea alata*)," *International Food Research Journal*, 24(5). 1880-1888. 2017.

[21] Oluwamukomi, M. O., and Akinsola, O. O., "Thermal and physicochemical properties of some starchy foods: yam (*Dioscorea rotundata*), cocoyam (*Xanthosoma sagittifolium*) and plantain (*Musa paradisiaca*)," *Food Science and Technology*, 3(1). 9-17. 2015.

[22] Abioye, V. F., Adeyemi, I. A., Akinwande, B. A., Kulakow, P., and Maziya-Dixon, B., "Effect of steam cooking and storage time on the formation of resistant starch and functional properties of cassava starch," *Cogent Food and Agriculture*, 3, 1-11. 2017.

[23] Garcia-Alonso A., Jimenez-Escrig A., Martin-Carron N., Bravo L., and Sauro-Calixto F., "Assessment of some parameters involved in the gelatinization and retrogradation of starch," *Food Chemistry*, 66(2). 181-187. 1999.

[24] Alexis, S. D., and Georges,A. N., "Technical sheet of some wild yam (*Dioscorea*) species starch functional properties," *Journal Of Pharmacy*, 3(6). 66-72. 2013.

[25] Puncha-arnon, S., and Uttapap, D., "Rice starch vs. rice flour: Differences in their properties when modified by heat–moisture treatment," *Carbohydrate polymers*, 91(1). 85-91. 2013.

[26] Kumari, M., Urooj, A., and Prasad, N., "Effect of storage on resistant starch and amylose content of cereal-pulse based ready-to-eat commercial products," *Food Chemistry*, 102(4). 1425-1430. 2006.

[27] Wu, Y., Chen, Z., Li, X., and Wang, Z., "Retrogradation properties of high amylose rice flour and rice starch by physical modification," *LWT-Food Science and Technology*, 43(3). 492-497. 2010.

[28] Sagum, R., and Arcot, J., "Effect of domestic processing methods on the starch, non-starch polysaccharides and in vitro starch and protein digestibility of three varieties of rice with varying levels of amylose," *Food Chemistry*, 70(1). 107-111. 2000.

[29] Jha, A. K., and Bhattacharya, A., "Preparation and in vito evaluation of sweet potato starch blended sodium alginate microbeads," *Advances in Natural and Applied Sciences*, 2(3). 122-129. 2008.

[30] Abdel-Aal, E.M., and Rabalski, I., "Effect of baking on nutritional properties of starch in organic spelt whole grain products," *Food Chemistry*, 111. 150-156. 2008.

[31] Lin, J., Wang, S., and Chang, Y., "Effects of molecular size on gelatinization thermal properties before and after annealing of rice starch with different amylose contents," *Food Hydrocolloids*, 22(1). 156-163. 2008.

[32] Lee, S.Y., Woo, K.S., Lim, J.K., Kim, H.I., and Lim, S.T., "Effect of processing variables on texture of sweet potato starch noodles prepared in a nonfreezing process," *Cereal chemistry*, 82(4). 475-478. 2005.

[33] Ng, K.R., Abbas, R.M.A., Tan, T.C., and Azhar, M.E., "Physicochemical, pasting and gel textural properties of wheat-ripe Cavendish banana composite flours," *International Food Research Journal*, 21(2). 655-662. 2014.

[34] Charoenrein, S., and Preechathammawong, N., "Effect of waxy rice flour and cassava starch on freeze–thaw stability of rice starch gels," *Carbohydrate Polymers*, 90. 1032-1037. 2012.

[35] Puncha-arnon, S., and Uttapap, D., "Rice starch vs. rice flour: Differences in their properties when modified by heat–moisture treatment," *Carbohydrate polymers*, 91(1). 85-91. 2013.

[36] Sanful, R. E., and Engmann, F. N., "Physico-Chemical and pasting characteristics of flour and starch from aerial yam," *American Journal of Food Science and Nutrition*, 3(1). 1-7. 2016.

[37] Alexis, S. D., and Georges, A. N., "Swelling and solubility of some wild yam species starch granules," *Focusing on Modern Food Industry*, 2 (3). 118-122. 2013.