JST: Engineering and Technology for Sustainable Development
Volume 34, Issue 4, October 2024, 024-032

Effect of Blanching Conditions on Color, Antinutrient, Paste and Gel Properties of Taro Flour

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Abstract

The objective of this study was to increase our understanding taro flour quality characteristics and their sensitivity to the effects of thermal processing. To investigate this, the variability of color values, antinutrient (calcium oxalate), paste and gel properties of dried taro flour was evaluated by blanching taro root slices at different temperatures (80, 90, and 100°C) and durations (1, 2, and 3 minutes). Blanching temperature improved the color values and reduced calcium oxalate more than the blanching duration. About 50-75% of the variability of Rapid Viscosity Analyser (RVA) pasting properties and hardness of flour gels kept at 4 °C for 24 h was contributed by blanching temperatures. Flour gel consistency had a higher variance (65%) from blanching time, although blanching temperature also contributed significantly to variability. Raising the blanching temperature boosted the consistency and hardness of taro flour gel, but lowered its viscosity and pasting temperature. Meanwhile, extending the blanching duration heightens taro flour viscosity and gel consistency but diminished gel hardness. Viscosities were negatively correlated with gel consistency but positively with hardness. Understanding the extent of the specific blanching process affecting functional properties of taro flour is useful for food technologists to apply in foods and other applications.

Keywords: Blanching, gel consistency, gel hardness, pasting properties, taro flour.

1. Introduction

Taro (*Colocasia esculenta* (L.) Schott), known as elephant ear, is a familiar agricultural product for many and is widely grown in Vietnam. Taro is rich in nutrients, containing antioxidants such as phenolic compounds, carotenoids, and ascorbic acid, as well as being rich in starch, fiber, and minerals [1]. It has been reported that taro contains approximately 3 to 19% mucilage and 70 to 80% starch depending on extraction method [1]. It can be used in various dishes and beverages. Particularly, taro contains a significant amount of resistant starch, which is beneficial for health, such as reducing blood sugar, diabetes, and obesity [2]. Taro has been employed in the treatment of asthma, skin and neurological disorders, internal hemorrhaging, pneumonia, and hypertension. Moreover, taro demonstrates protective properties against cancer and cancer-related risk factors, such as carcinogens and biological agents. It also helps mitigate various pathophysiological conditions like inflammation and oxidative stress, while managing metabolic dysfunctions and enhancing the immune system. As a potential alternative staple with a lower glycemic index (GI) than potatoes, taro consumption might reduce or prevent several diseases, including certain types of cancers [1]. Additionally, taro is a gluten-free food that is high in calories, and low in fat and protein content. Additionally, mucilage has a wide range of therapeutic properties, has become well known, and is widely used due to its ability to prevent oxidation, and the ability to scavenge different free radicals. Even at low concentrations, mucilage exhibits excellent viscosity, water-holding capacity, oil-holding capacity, and antimicrobial activity [1]. These remarkable functional properties make mucilage a promising ingredient for potential applications as a fat replacer, gel former, thickener, and emulsifier [1]. Fresh taro is exported to many countries worldwide or used as a raw material for processing various products like chips and ice cream. However, fresh taro flesh is highly perishable in storage and becomes excessively viscous when mixed due to mucilage content.

Enhancing the value of taro through processing methods to diversify products and extend shelf life while reducing post-harvest losses is essential [3]. One of the best preservation methods is processing taro into dried flour or starch. Taro flour has lighter weight, longer shelf life and requires less transportation charges [4]. Flour is convenient for blending in industrial production into various foods, cosmetics, textiles, pharmaceuticals, and many other applications.

ISSN 2734-9381
https://doi.org/10.51316/jst.177.etsd.2024.34.4.4
Received: Jun 14, 2024; revised: Aug 17, 2024;
accepted: Aug 30, 2024.

Taro flour possesses special properties such as elasticity, stickiness, thickening, and film-forming ability. However, taro contains calcium oxalate, which causes itching [5]. Some alkaline and acid chemicals are used to reduce the amount of calcium oxalate [6]. Additionally, during the flour processing, the polyphenol oxidase enzyme causes browning of the flour [4]. Sodium metabisulfite is often used to inhibit browning reactions [7]. However, the use of chemicals may not be safe for consumers' health and the environment. Therefore, the blanching process can reduce the calcium oxalate content [8] and inactivate many enzymes including polyphenoloxidase [9], but heat treatment may affect the physicochemical properties (paste and gelation) of the plantain (green banana) flour [10]. Therefore, this study evaluates the impacts of blanching conditions of taro slices on the flour properties of paste (viscosity) and gel (consistency and hardness).

2. Materials and Methods

2.1. Materials

Taro was grown at Lap Vo farm, Dong Thap province, Vietnam. Taro roots were harvested at the period after growing 5 months. Taro roots were packed into perforated PVC bags before cardboard boxes. They were transported to the Institute of Food and Biotechnology of Can Tho University, Vietnam within 2 hours. Taro roots were washed and kept in the refrigerator (12 ºC) for experiments within 2 days.

2.2. Flour Preparation

Taro roots had weight of 700 g to 800 g and diameter from 9.0 cm to 12 cm. They were peeled and sliced with thickness of 2-3 mm. The taro slices were blanched in the hot water at different temperatures (80, 90, and 100 ºC) and times (1, 2, and 3 minutes). The blanched slices were dried at 60 ºC until the moisture of 8%. After grinding, flour was sifted through the sieve with a diameter of 0.105 mm. The flour samples were kept in glass jars with tin lids.

2.3. Calcium Oxalate Analysis

Calcium oxalate (CO) was determined according to Rozali *et al.* (2021) [11] with modification. A total of 1 g of tuber taro or taro flour was suspended in 95 ml of distilled water and 5 mL of 6 M HCl was added. The suspension was heated at 100 ºC for 1 hour, followed by cooling. Then, 125 ml of water was added and filtered using the filter paper. A total of 62.5 mL of filtrate was diluted to 150 mL and boiled. Then, titrated the solution with 0.1 N $KMnO_4$ solution until it turned pink which lasted for 30 seconds. The total calcium oxalate content is calculated by the following equation:

$$CO\left(\frac{\text{mg\%}}{DW}\right) = \frac{V \text{ x } 0{,}00225 \text{ x } 2.4 \text{ x } 100}{m \text{ x } 5 \text{ x } (100-W)} \text{x } 10^5 \quad (1)$$

where: *CO*, calcium oxalate (mg% in dried weight); *V*, volume (mL) of KMO_4; m, weight of sample (g); *W*, water content (%); *DW*, dried weight.

2.4. Color Values of Taro Flour

The color attributes of the flours were measured with a Colour meter (WR-10QC, China) based on $L*$, $a*$, and $b*$ values. A glass cell containing the powdered flour was placed above the light source and covered with a white plate, and $L*$, $a*$, and $b*$ values were recorded. The Whiteness index (*WI*) was calculated according to Nguimbou et al. (2021) [12] as follows:

$$WI = 100 - \sqrt{(100 - L^*)^2 + b^{*2} + a^{*2}} \quad (2)$$

where L^*, a^*, and b^* were the color attributes.

2.5. Flour Pasting Properties

Pasting properties of flour were analysed using a Rapid Visco Analyser (RVA)-4500 (PerkinElmer Inc., Australia) according to Standard Method 1 (STD1) provided with the instrument. Flour (2.5 g, 8.0% moisture) was weighed into a test canister and with 22.5 mL of distilled water. The mixture was agitated manually 10 times with the plastic paddle in the canister before inserting the canister into the instrument. According to STD1, the flour suspension was stirred at 960 rpm 10 seconds before the shear input was decreased and held constant at 160 rpm during the subsequent heating and cooling cycle. The suspension was heated from 30 to 95 °C for 7.0 min, and held at 95 °C for 7.0 min before cooling to 30 °C for 7.0 minutes. Pasting viscosities were calculated using the Thermocline software provided with the instrument (modified from Sirira *et al*., (2005) [11].

2.6. Gel Hardness

After RVA testing, the canister containing flour paste was covered with paraffin film and kept at 4 ºC for 24 h. Gel texture was determined using a TA-XT2 Texture Analyser. The gel (with a dimension of 27 mm in height and 30 mm in diameter) was compressed at the speed of 2 mm/s with a strain 25% by an acrylic cylindrical probe having 35 mm diameter. The peak was termed the gel hardness (modified from Sirirat *et al*., (2005) [13])

2.7. Gel Consistency

Flour (100 mg) from all samples was weighed in duplicate into 13 mm x 100 mm tubes and 200 mL of ethyl alcohol (95%), containing 0.025% thymol blue, was added to each tube as well as 2 mL 1N KOH. Tubes were mixed using a Vortex Genie mixer (Scientific Industries, Inc., NY, USA), and then placed in a vigorously boiling water bath for 8 minutes. The tubes were then removed from the water bath, held at room temperature for 5 minutes, and then cooled in an ice water bath for 15 minutes. Following this, tubes were laid horizontally on a light box on top of graphing paper. After 1 hour, the distance that the gel migrated in the tube was measured [14].

2.8. Statistical Analysis

All analyses were performed on at least duplicate samples, and statistical analyses were performed using Statgraphic 19 Centurion. Mean square values from Analysis of Variance (ANOVA) were used to assess contributions to variation of flour properties due to blanching conditions. The components of variance were expressed as a percentage of total sums of squares for the effects of the blanching temperature and time on properties of flour. Fisher t-tests between pairs of variables

3. Results and Discussion

Some chemical compositions of the flour from fresh taro were protein of 6.71%, lipid of 0.71%, starch of 73.78%, and mucilage of 2.96%, and calcium oxalate of 610.23 mg% in dry weight.

The data were aggregated according to blanching and time to evaluate the effects of these factors separately on calcium oxalate, color values, RVA (Rapid viscosity Analysis) paste viscosities, gel hardness, and gel consistency of the taro four. The full data set was used to examine the significance and magnitude of the contributions of blanching temperatures and time, and their interactions, to the variance of these properties as in Table 1.

3.1. Calcium Oxalate

As shown in Table 1, calcium oxalate (CO) contents were significantly influenced by blanching temperature and time. As shown in Fig. 1, the blanching temperature accounted 87.08% to the variance of calcium oxalate while the duration contributed 9.06% to the variance.

A significant reduction of CO in the taro flour was noted from 290.61 down to 189.84 mg% when the data were grouped according to blanching temperature as in Table 2.

Table 1. Mean square value from ANOVA for flour color, calcium oxalate, paste and gel properties of taro root slices blanched at different temperatures and time

	CO	*L**	*WI*	*PV*	*BD*	*TV*	*SB*	*FV*	*PT*	*GC.*	*HD*
Temp (A)	$2x10^4$ ***	1,3***	20.8***	$2x10^6$**	$6x10^6$**	$1x10^6$***	$4x10^6$***	$9x10^5$**	$3x10^3$***	7x10*	$2x10^{-2}$***
Time (B)	$2x10^3$ **	0.6***	1.1**	$8x10^5$*	$2x10^5$*	$2x10^6$***	$8x10^4$	$1x10^4$*	$3x10^2$**	$2x10^2$**	$7x10^{-3}$**
AxB	$1x10^2$	2.8***	3.1***	$2x10^4$	$6x10^4$	$1x10^5$**	$5x10^5$*	$5x10^4$*	$3x10^2$**	4.9	$4x10^{-4}$
Residual	$1x10^2$	0,1	0.1	$2x10^4$	$2x10^5$	$8x10^3$	$9x10^{\hat{e}}$	$1x10^2$	6.4	1x10	$2x10^{-4}$

*The values designated with *, **, and *** indicate significant difference at $p < 0.05$, 0.01, and 0.001, respectively. Abbreviations: Temp, temperature; CO, calcium oxalate; WI, whiteness index; PV, peak viscosity; TV, trough viscosity; BD, breakdown; FV, final viscosity; SB, setback; PT, pasting temperature; GC, gel consistency; HD, gel hardness*

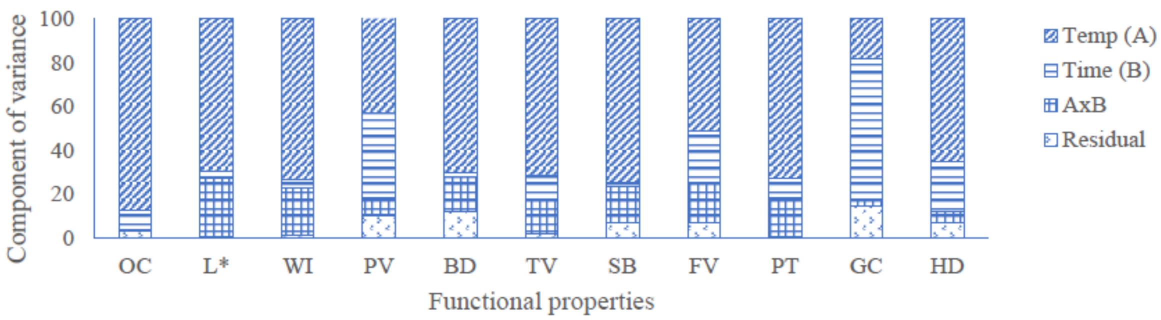

Fig. 1. Components of variance for color, calcium oxalate, paste and gel properties of flour taro blanched at different temperatures and time

Abbreviations: CO, calcium oxalate; WI, whiteness index; PV, peak viscosity; TV, trough viscosity; BD, breakdown; FV, final viscosity; SB, setback; PT, pasting temperature; GC, gel consistency; HD, gel hardness

Table 2. Paste and gel viscosities of flour from taro blanched at different temperatures and times

Properties	Temperatures	Blanching time (min)			Average
		1	2	3	
CO	80 °C	303.24 ± 6.54*	292.21 ± 16.31	276.40 ± 8.98	290.61 ± 13.49[a]
	90 °C	279.98 ± 14.32	269.54 ± 1.71	254.70 ± 8.67	268.07 ±12.70[b]
	100 °C	215.17 ± 16.04	189.30 ± 9.59	165.04 ± 8.17	189.84 ± 25.07[c]
	Average	266.13 ± 45.63[a]	250.35 ± 54.07[b]	232.05 ± 29.03[c]	
L*	80 °C	84.25 ± 0.07	85.70 ± 0.05	86.08 ± 0.02	85.35 ± 0.87[c]
	90 °C	87.32 ± 0.16	88.29 ± 0.02	89.31 ± 0.25	88.30 ± 0.90[a]
	100 °C	87.28 ± 0.33	85.60 ± 0.21	85.34 ± 0.10	86.08 ± 0.96[b]
	Average	86.28 ± 1.59[c]	86.53 ± 1.36[b]	86.91 ± 1.89[a]	
WI	80 °C	81.69 ± 0.52	82.62 ± 0.47	84.01 ± 0.04	82.77 ± 1.09[c]
	90 °C	85.26 ± 0.07	86.01 ± 0.28	87.46 ± 0.12	86.24 ± 1.01[a]
	100 °C	84.31 ± 0.09	83.37 ± 0.12	82.32 ± 0.26	83.33 ± 0.90[b]
	Average	83.75 ± 1.67[b]	84.00 ± 1.61[b]	84.60 ± 2.35[a]	
PV	80 °C	2012.01±105.42	3556.00±11.31	3221.00±14.14	3129.67±178.58[A]
	90 °C	2614.10±19.79	2743.50±183.14	2261.50±80.16	2539.50±93.29[B]
	100 °C	2073.51±41.72	3195.00±184.67	2821.00±95.77	2696.50±171.02[AB]
	Average	2233.67±85.20[b]	3164.83±128.20[a]	2767.51±75.97[ab]	
BD	80 °C	2552.01±106.66	3381.50±51.62	3086.00±9.90	3006.50±420.43[A]
	90 °C	1675.52±105.36	790.00±8.49	972.00±46.67	1145.83±467.64[B]
	100 °C	1045.02±100.41	2126.50±88.91	1783.00±808.93	1651.50±552.61[B]
	Average	1757.53±75.84[a]	2099.33±129.96[a]	1947.00±106.50[a]	
TV	80 °C	60.03±4.24	174.50±62.93	135.00±4.24	123.17±58.16[B]
	90 °C	274.00±5.66	1185.50±174.66	1150.50±78.49	870.00±516.45[A]
	100 °C	1028.50±58.69	1068.50±65.76	1038.00±142.84	1045.00±20.90[A]
	Average	454.17±508.77[b]	809.50±553.03[a]	774.50±556.67[a]	
SB	80 °C	2642.50±823.78	2931.00±60.81	3405.00±107.48	2992.83±384.99[A]
	90 °C	2579.50±7.78	1512.00±123.04	1460.00±124.45	1850.50±631.87[B]
	100 °C	1244.50±198.70	1326.50±24.75	1296.00±267.29	1289.00±41.45[C]
	Average	1916.17±789.58[a]	1896.33±877.72[a]	1817.67±1173.16[a]	
FV	80 °C	2702.50±819.54	3105.50±2.12	3540.00±111.72	3116.00±418.85[A]
	90 °C	2853.50±13.44	2697.50±51.62	2610.50±202.94	2720.50±123.12[AB]
	100 °C	2273.00±257.39	2395.00±90.51	2334.00±410.12	2334.00±61.00[B]
	Average	2609.67±301.18[a]	2732.67±356.55[a]	2828.17±631.78[a]	
PT	80 °C	86.60±0.35	85.33±0.39	85.63±0.11	85.85±0.67[A]
	90 °C	84.8±0.04	74.70±3.11	42.48±3.14	67.38±22.17[AB]
	100 °C	44.45±2.19	40.93±0.11	43.73±5,76	43.03±1.86[C]
	Average	72.01±23.88[a]	66.98±23.18[ab]	57.28±24.56[b]	
GC	80 °C	41.00±0.41	46.75±7.42	52.50±0.71	46.75±5.75[B]
	90 °C	43.50±0.71	50.03±0.04	56.00±6.36	49.84±6.25[AB]
	100 °C	47.50±0.51	51.00±3.54	62.25±1.06	53.58±7.71[A]
	Average	44.00±3.28[c]	49.26±2.23[b]	56.92±4.94[a]	
HD	80 °C	0.22±0.01	0.20±0.02	0,18±0.01	0.20±0.02[B]
	90 °C	0.34±0.01	0.31±0.04	0.26±0.02	0.30±0.04[A]
	100 °C	0.26±0.02	0.18±0.02	0.18±0.03	0.20±0.05[B]
	Average	0.27±0.06[a]	0.23±0.07[b]	0.23±0.04[b]	

The average data are aggregated over the respective temperature or time. Different letters in the same column (A, B or C) or row (a, b or c) indicate significant difference at $p < 0.05$. Abbreviations and units: Abbreviations: CO, calcium oxalate; WI, whiteness index; PV, peak viscosity; TV, trough viscosity; BD, breakdown; FV, final viscosity; SB, setback; PT, pasting temperature; GC, gel consistency; HD, gel hardness; viscosities in cP, gel consistency in mm; and gel hardness in N/cm^2

Calcium oxalaye could be decreased from 52 to 68% with the temperature from 80 to 100 ºC. It was found that CO of the taro flour decreased from 266.13 down to 232.05 mg% when the data were grouped according to blanching time. The reduction of calcium oxalate was from 56 to 62% according to the blanching duration from 1 to 3 minutes. This was corroborated by studies done by [8] that the blanching (boiling and steaming) reduced from 21 to 56% of the oxalate content of taro flour significantly as a result of leaching (i.e., dissolution) of the soluble oxalates into the boiling and steaming water.

3.2. Color Values

As shown in Table 1, the color values (L^* and *WI*) of taro flour were significantly affected by blanching temperature and duration. As shown in Fig. 1, the blanching temperature accounted for a substantial portion of the variance in L^* and *WI*, contributing 69.62% and 73.44%, respectively. In contrast, blanching duration contributed 2.9% and 4.01%, respectively, to the variance. The interaction between blanching temperature and duration also had a notable impact, explaining 26.83% and 21.36% of the variance in L^* and *WI*, respectively.

A significant increase in L^* and *WI* values was observed, from 86.2 to 86.9 and from 83.7 to 84.6, respectively, when the data were grouped according to blanching time from 1 to 3 minutes (Table 2). The highest L^* and *WI* values, 88.3 and 86.2 respectively, were achieved at a blanching temperature of 90 °C. The color values of the taro flour were improved as a result of the inactivation of polyphenol oxidase [9].

3.3. Pasting Properties

The pasting properties of taro flour samples varied between the same blanching time (1 minute) with different temperatures as shown in Fig. 2; and between the same blanching temperarure (80 ºC) with different times, as shown in Fig. 3

These pasting properties were shown by the representative RVA profiles. Peak, holding (i.e. hot paste or trough), and final viscosities were all influenced significantly by blanching temperature and time, and interactions between these factors, as shown in Table 1.

As shown in Fig. 1, the blanching temperature accounted for a substantial part of the variation with 48% in peak viscosit, with 71% in holding viscosity with 74% in break viscosity (difference between peak and holding viscosities), with 51% in final viscosity, with 75% in set-back viscosity (difference between final and holding viscosities), and with 73% in pasting temperature.

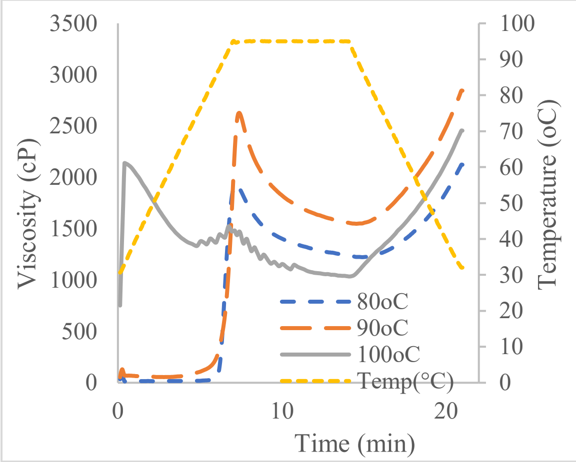

Fig. 2. RVA profiles of flour from taro blanched for 1 minute at different temperatures

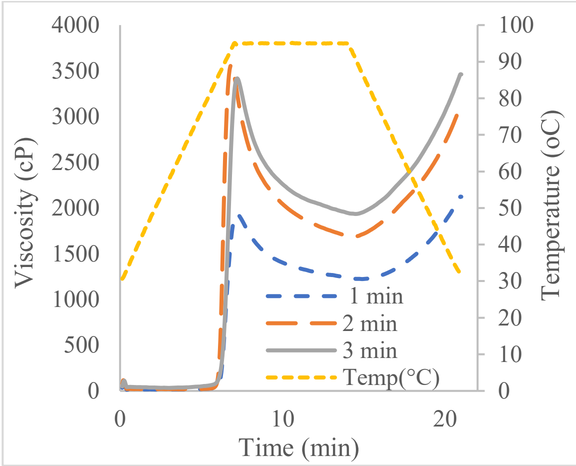

Fig. 3. RVA profiles of flour from taro blanched at 80ºC with different times.

Blanching time significantly contributed to the variability in the peak viscosity, and final viscosity for 38% and 15%, respectively.

As shown in Fig. 1, interaction between blanching temperature, and time accounted for 20%, 15%, 16% and 27% of total variance in break viscosity, trough viscosity, setback viscosity, and final viscosity, respectively. The pasting temperature varied significantly due to the blanching temperature accounting for 73% of the total variance.

Significant differences were noted when the data were grouped according to blanching temperature and time with the values for peak, trough, and final viscosities ranging between 2233 and 3130 cP, 123 and 1045 cP, and 2334 and 3116 cP, respectively, as shown in Table 2.

The blanching temperatures from 80 to 100 ºC, the peak and final viscosities significantly decreased. The dried flour from taro blanched at 80 ºC had the highest average values for peak (3130 cP) and final viscosities (3116 cP), whereas the lowest values were for flour from taro blanched at 90 ºC, shown as in Table 2.

Blanching at higher temperatures resulted in a significant increase in trough viscosity (TV) from 123 to 1043 cP. The increase in viscosity with elevating temperature could be due to the removal of water from the amylose solution released by the granules as they swelled [15].

However, according to [16], blanching reduced paste viscosity due to lower swelling power and pre-gelatinization of starch in sweet potato flour. Additionally, It suggested that pre-gelatinized starch followed by re-gelatinization led to a decrease in paste viscosity

The pasting temperature was decreasing from 86 to 41ºC when taro blanched from 80 to 100 ºC. It could be explained that starch in the taro flour had been already gelatinized at a high temperature, resulting the starch was more easily pasted again.

Blanching time significantly impacted the taro's pasting properties. Increasing the time from 1 to 3 minutes led to a change in peak viscosity (2233 to 3164 cP), breakdown viscosity (1757 to 2099 cP), and trough viscosity (454 to 809 cP). The highest values of peak, breakdown and trough viscosities were obtained at the blanching duration of 2 minutes. The setback viscosity showed a slight decrease from 1916 to 1818 cP despite the increase in others. However, final viscosities increased from 2609 to 2828 cP following the blanching time from 1 to 3 minutes. Additionally, the pasting temperature decreased from 70 to 62 ºC, as shown in Table 2.

In the previous report of [16], the peak viscosity (1946 cP), trough viscosity (1744 cP), breakdown viscosity (200 cP), final viscosity (1231 cP), and setback viscosity (487 cP) were the lower viscosities but the pasting temperature (93.6 ºC) was conversely higher in taro. Pasting temperature refers to the temperature at which starch granules start to swell and break, so the lower pasting temperatures here suggest the taro starch started gelatinization at a lower temperature resulting from the partial gelatinized starch. This observation was similar with the previous report from [17]. The viscosity difference might result from different taro varieties or the impact of blanching as precooking of starch. The viscosity of flour has been reported to be affected by the contents of starch, amylose, minerals; and starch granular sizes and the extent of starch damage during flour processing [18]. The presence of dietary fiber could reduce starch viscosity by restricting the entry of water molecules into the starch granules [19].

3.4. Gel Consistency

Gel consistency refers to the firmness, elasticity, and overall physical behavior of a gel. It's a measure of how well a gel holds its shape and resists flow. Table 1 shows that the blanching temperature and time significantly affected gel consistency. The blacnhing time was the main factor influencing the gel consistency, accounting for 65% of the total variance, as shown in Fig. 1. Temperature had a minor effect (28%) on gel consistency. Gel consistency increased from blanching conditions with high temperature and long time, as shown in Table 2. Within the same blanching time, enhancing the blanching temperature from 80 °C to 100 °C resulted in an increase in the gel consistency of taro flour from 46.75 mm to 53.58 mm. The highest gel strength (62.25 mm) was achieved at 100°C. At a constant temperature, prolonging the blanching time from 1 minute to 3 minutes led to an increase in the swelling power of taro flour from 44 mm to 56.92 mm, as shown in Table 2. The highest gel strength (62.25 mm) was obtained at 3 minutes. Overall, the gel consistency of taro flour ranged from 41.00 mm to 62.25 mm during blanching (medium to soft gel).

Blanching can lower the thickness of pastes (viscosity) because it affects the starch. This was observed in studies [16] that the starch granules either swell less or cook partially (pre-gelatinize) during blanching, leading to lower viscosity and a thinner paste. Blanching typically weakens gels formed by starches. This could lead to a softer gel.

3.5. Gel Hardness

Gel hardness (gel strength) was measured on the RVA paste after it was kept at 4 °C for 24 h. As shown in Table 1, blanching temperature and time, all sharply contributed to the variability of flour gel strength, which significantly varied between blanching temperature and time. Temperature accounted for 68% of the total variation in gel strength, whereas time contributed only about 19%, as shown in Fig. 1. The large standard deviations of the averaged values were consistent with many factors contributing to the variability of flour gel strength, including the additional effects of starch retrogradation.

Gel hardness is a crucial property that determines the texture of starch-based products such as yam, pastries, and noodles [20]. Gel hardness obtained the strongest value (30 N/cm^2) at 90 ºC, as shown in Table 2. However, gel strength relatively decreased from 0.27 to 0.23 (N/cm^2) when taro slices were blanched from 1 to 3 minutes, as shown in Table 2. Blanching partially cooks or gelatinizes the starch granules [21], which can then start to re-crystallize (retrogradation). This re-crystallization weakens the gel network formed by the starch molecules (amylose and amylopectin) and softens gel strength.

Suriya *et al*. (2006) [4] observed that freeze-dried or direct solar-dried blanched flour had higher gel hardness compared to their raw counterparts (freeze-dried or direct solar-dried, respectively). Interestingly, freeze-dried blanched flour exhibited weaker gel strength than direct solar-dried raw flour.

3.6. Correlations between Viscosity and Gel Properties from the Taro Flour with Blanching Condition

Pearson correlation coefficients to test for relationships between viscosities and gel properties are shown in Table 3.

Several of the significant correlations observed between viscosities, gel consistency, and gel hardness within the complete dataset were expected, as these properties were evidently interconnected, shown as in Table 3. For instance, peak viscosity had a strong and positive correlation (r = 0.88; p < 0.001) with breakdown viscosity. Pasting temperature showed a strong negative correlation with trough viscosity (r = -0.84, p < 0.001), but was positively correlated with breakdown viscosity (r = 0.50, p < 0.05) and setback (r = 0.84, p < 0.001). This suggests that taro flours retrograde more easily, leading to the formation of viscous gels. Additionally, final viscosity demonstrated a highly significant positive correlation with setback (r = 0.88, p < 0.001).

Similarly, it was reported in the chickenpea flour [21] that pasting temperature was negatively correlated with peak viscosity (r = -0.744, p < 0.005), trough viscosity (r = -0.806, p < 0.005), final viscosity (r = -0.823, p < 0.005) and setback (r = -0.485, p < 0.05). Final viscosity showed a highly significant positive correlation with setback (r = 0.656, p < 0.005).

In addition, the gel consistency had significantly positive relationships with holding viscosity (r = 0.57, p < 0.05), but inverse correlation with pasting temperature (r = -0.60, p < 0.01,). This indicated that the taro flour gel had a lower consistency and a higher viscosity value.

Flour gel hardness were negatively correlated with peak viscosity (r = -0.67, p < 0.01) and breakdown viscosity (r = -0.67, p < 0.01) , but positively with trough viscosity (r = 0.62, p < 0.01), and final viscosity (r = 0.48, p < 0.05).

When flour pastes were cooled, a process of gel formation took place due to intermolecular association, protein denaturation, and amylose aggregation [22]. During cooling, the final paste exhibited an increase in viscosity due to gel formation. Consequently, gels with higher final viscosities also had higher hardness values.

Table 3. Correlations between blanching conditions with viscosity, gel consistency, and texture of taro flour

	Temp	Time	PV	BD	TV	SB	FV	PT	GC
PV	-0.26	0.31							
BD	-0.59**	0.08	0.88***						
TV	0.80***	0.28	-0,30	-0.73***					
SB	-0.85***	-0.05	0.47*	0.79***	-0.90***				
FV	-0.72***	0.20	0.54*	0.69**	-0.59*	0.88***			
PT	-0.85***	-0.29	0.10	0.50*	-0.84***	0.84***	0.64**		
GC	0.42	0.80***	0.14	-0.19	0.57*	-0.40	-0.14	-0,.60**	
HD	0.03	-0.47*	-0.67**	-0.55*	0.13	-0.12	-0.08	0.20	-0.34

*Pearson correlation coefficients indicate significance at level alpha <0.05. For 18 samples, the minimum r significance at p ¼ 0.05 is 0.45. The values designated with *, **, and *** indicate significant correlations at p < 0.05, 0.01, and 0.001, respectively. Correlations significant at p < 0.001 are indicated in bold. Abbreviations: PV, peak viscosity; TV, trough viscosity; BD, breakdown; FV, final viscosity; SB, setback; PT, pasting temperature; GC, gel consistency; HD, gel hardness; viscosities in cP, gel consistency in mm; and gel hardness in N/cm^2.*

4. Conclusion

The relative contributions of blanching temperature and time factors to the variability of taro flour functional properties have been evaluated using taro root slices exposed to thermal processing. While the results obtained are characteristic of the varieties selected for this study and the specific combination of thermal processing factors, the results nevertheless showed that blanching conditions could significantly affect the functional properties of flour that are important in foods and other applications. About 50 - 75% of the variability of RVA pasting properties and hardness of flour gels kept at 4 °C for 24 h was contributed by blanching temperatures. Flour gel consistency had a higher variance (65%) from blanching time, although blanching temperature also contributed significantly to variability. Increasing the blanching temperature enhances taro flour gel consistency and gel hardness but decreases gel viscosity and pasting temperature. If the blanching time was prolonged, taro flour viscosity and gel consistency relatively increased, but gel hardness decreased. Viscosities had an inverse relationship with gel consistency but a positive correlation with hardness. Our study shows that blanching over 90 ºC for 2 minutes, the taro flour obtained the highest color values of $L*$ and whiteness index, while calcium oxalate content was reduced about 72%. The highest gel hardness was obtained from flour of taro blanching at 90 ºC.

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