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Effect of Pre-Gelatinization Conditions on the Total Oxalate Content and Techno-Functional Properties of Taro (*Colocasia esculenta*) Flour

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Abstract

Like most roots and tubers, taro (*Colocasia esculenta*) corms have a short shelf-life due to the high moisture content, which aggravates their post-harvest losses. They also contain high amounts of calcium oxalates, limiting their use in food applications. To help add value and diversify the use of taro corms as well as curb food losses, various strategies have been proposed, such processing of the corms into flour. This study aimed at evaluating the total oxalate content and techno-functional properties of taro flour as affected by the pre-gelatinization conditions (*i.e.*, method and time). Pre-gelatinized taro flour was prepared by subjecting peeled and cleaned taro corms to roasting (190˚C), boiling (100˚C), and steaming (100˚C) for 10 min, 20 min and 30 min, respectively, for each method, followed by drying at 55˚C and milling. Generally, all the properties of flour were significantly affected by the pre-gelatinization conditions ($P < 0.05$). The total oxalate content of the pre-gelatinized taro flour ranged from 33.26 to 76.90 mg/100g. Pre-gelatinization by boiling significantly reduced the oxalate content (56.7%), while roasting resulted in the least reduction (36.2%). The flour colour *i.e.* L^*, hue, and chroma ranged from 38.47˚ - 70.30˚, 42.64˚ - 69.43˚, and 7.78˚ - 10.58˚, respectively. Roasting resulted in flour with the largest L^* (70.30˚) and hue angle (69.43˚). Boiling also resulted in flour with the highest bulk density (BD) (0.86 g/cm^3) and the lowest water solubility index (WSI) (9.39%). Steamed flour had the highest water absorption index (WAI) (3.81 g/g), water holding capacity (WHC) (4.59 g/g), and swelling capacity (SC) (4.86 g/g). This study shows that pre-gelatinization (*i.e.* by boiling, steaming or roasting) significantly affects the total oxalate content and techno-functional properties of taro flour, which in turn influences its use in other food applications thus increasing the utilization and production of taro simultaneously.

Keywords

Taro Flour, Pre-Gelatinization, Techno-Functional, Oxalates

1. Introduction

Under the threat of food insecurity, root and tuber crops play a vital role in enhancing food security. Low and medium-income countries such as those in sub-Saharan Africa (SSA) highly rely on them as staple foods for their nutrition and cash income [1]. Roots and tubers account for 20% of dietary calories consumed in SSA countries [2]. Several varieties and species are produced and consumed, including cassava, potatoes, sweet potatoes, and taro. They come in second in importance after cereals as carbohydrate sources [3]. This is also backed up by data on their annual global production *i.e.* approximately 836 million tonnes, with the main producers being Asia at 43%, followed by Africa at 33%) [3].

Taro (*Colocasia esculenta* Linn.) is a herbaceous perennial root crop used as a staple food in tropical and subtropical countries [4]. According to FAO/UN report in 2018, the world production of taro is about 10.3 million tonnes, with Africa producing 9.5 million tonnes representing 92.2%. Rwanda and Burundi are the leading producers in the East African (EA) region at 2.1% and 1.1%, respectively [5]. In Kenya, small-scale farmers produce taro in the western, Nyanza, rift valley and central province regions [6]. Regrettably, little attention has been given to this underutilized crop in Kenya and hence, no statistical data has been documented for taro production in Kenya since 2017 by FAO.

The corms obtained from taro have great potential to provide an economical source of dietary energy in the form of carbohydrates as they contain 70% - 80% (DM basis) starch. The starch is 98.8% digestible; this makes it ideal for people and children with digestive difficulties [7]. The corms also contain a significant amount of dietary fiber, vitamins such as A, C, E, B_6, folate and minerals such as magnesium, iron, zinc, phosphorous, potassium, manganese, and copper as trace elements [8]. However, apart from the high perishability of taro corms due to their high moisture content, their consumption and utilization have also been limited by the presence of anti-nutritional and acridity factors such as high amount of calcium oxalate crystals, which cause sharp irritation and burning in the mouth and throat [9]. In order to combat post-harvest losses and improve the production, utilization and consumption of taro, production of pre-gelatinized taro flour which could be applied for use in several food products such as thickeners, bakery products, noodles production and infant food formulations have been envisaged.

Pre-gelatinization is a thermal processing technique that physically modifies the starch structure [10]. It involves applying heat sufficient to bring about starch gelatinization, followed by drying and grinding [11]. Pre-gelatinization significantly affects the physicochemical and functional properties of flour by disrupting the starch granular structure [12]; as such, pre-gelatinized flour can absorb water and increase viscosity immediately even with cold water [13]. The pre-gelatinized flour also has increased swelling power, solubility, water-holding capacity, and gelatinization temperature and starch paste stability. With the enhanced properties, the resulting flour is of good quality and can be used to develop novel food products [14]. This study aimed to investigate the effect of pre-gelatinization conditions on the total oxalate content and techno-functional properties of taro flour.

2. Materials and Methods

2.1. Materials

Freshly harvested dasheen-type of taro corms (*Colocasia esculenta* var *esculenta*) were obtained from Embu County (**Figure 1**), Kenya and processed at the Food Pilot Plant at the Department of Dairy and Food Science and Technology, Egerton University.

Figure 1. Taro corms (*Colocasia esculenta* var *esculenta*).

2.2. Preparation of Pre-Gelatinized Taro Flour

Taro corm were cleaned, peeled, steeped in portable water and sliced to about 5 mm thickness using a kitchen slicer on a disinfected working top. Pre-gelatinized taro flour was prepared using the method described by Sun, Li [15] with modifications; roasting (at 130˚C, for 10 min, 20 min, and 30 min), boiling (95˚C, for 10 min, 20 min, and 30 min), and steaming (at 100˚C, for 10 min, 20 min, and 30 min) methods, dried at 55˚C for 10 h and milled. The flours were screened through an 80 µ mesh sieve, and then stored in airlock plastic containers before using (see **Figure 2**). Raw taro flour was used as a control.

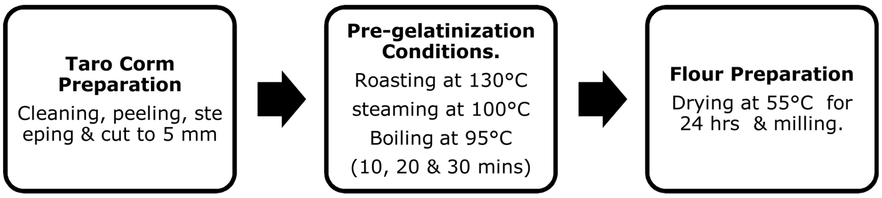

Figure 2. Flow-chart for preparation of pre-gelatinized taro flour.

2.3. Determination of Total Oxalate Content of Pre-Gelatinized Taro Flour

Analysis of the total oxalate content was done by HPLC method [16] with modifications suggested by [17]. Briefly, 0.5 g fresh weight of sample was homogenized in 4 ml of 0.5N HCl. The homogenate was heated at 80˚C for 10 min with intermittent shaking. To the homogenate, distilled water was added up to a volume of 25 ml, then 3 ml of the solution was withdrawn and centrifuged at 12000 ×g for 10 min. Supernatant (1 ml) was passed through a microfilter (0.45 µ) before HPLC analysis. Standards were prepared at varying concentrations for quantification (see **Figure 3**). HPLC analysis was done using Shimadzu UV-VIS detector, Hypsil C_{18} column (5 µ M, 4.6 mm × 250 mm) HPLC grade water (550) was used as the static phase and the mobile phase was a solution 0.02 M H_2SO_4. The flow rate was 0.6 ml·min^{-1}, the pressure of 62 kg F and the detection wavelength of 221 nm.

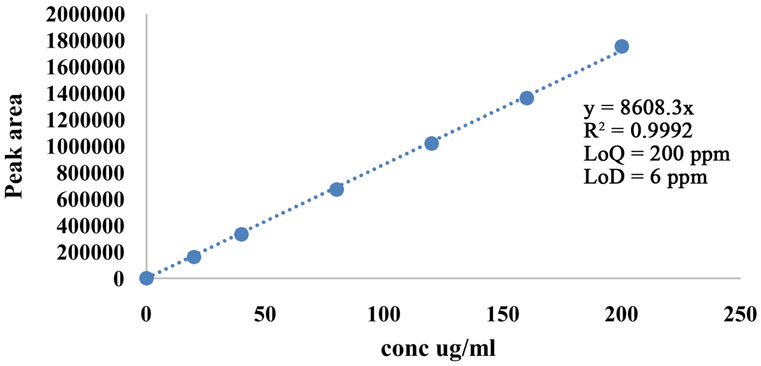

Figure 3. Standard curve for used for determining total oxalate content in pre-gelatinized taro flour.

2.4. Determination of Techno-Functional Properties of Pre-Gelatinized Taro Flour

1) *Colour Determination*: Color measurements of flour samples were carried out using a Hunter colorimeter Model D 25 optical Sensor (Hunter Associates Laboratory Inc., Reston, VA., USA) based on L* (*lightness*/*darkness*, 100 = *white*, 0 = *black*), a* (redness/greenness, +, red; −, green) and b* (yellowness/blueness, +, yellow; −, blue) values as described [18] Hue angle (arctan [b^*/a^*] and Chrome (saturation index) ($[a^2 + b^2]^{1/2}$) was calculated described by [19].

2) *Bulk density* (*BD*) was determined as described by [20]. Taro flour (50 g) was measured in a graduated measuring cylinder (100 ml), and the volume was recorded. The bottom of the cylinder was gently tapped on a laboratory bench several times until there was no further diminution of the sample level and the final volume recorded. The BD was calculated as the weight of sample per unit volume of sample (g/cm).

3) *Water holding capacity* (*WHC*) was determined according to the method described by [21] with slight modification. Distilled water (10 ml) was mixed

with 1 g of sample in a pre-weighed centrifuge tube, vortexed, and left to stand at room temperature for 24 h. After which, centrifugation at 688 × g for 15 min was done, then the supernatant was decanted and the residue was weighed, dried at 80˚C and reweighed. The WHC was expressed as grams of water per gram of dry flour sample, as shown in the Equation (1) below.

$$\text{WHC}\left(\text{g/g}\right)=\frac{\text{Weight of wet residue}-\text{Weight of dry residue}}{\text{Weight of dry residue}} \tag{1}$$

4) *Oil holding capacity* (*OHC*) was determined as per the method described by [22] with a slight modification. Samples (1 g) were mixed with 10 ml of corn oil in pre-weighed centrifuge tubes. The contents were vortexed for 1 min and left to stand at room temperature (25˚C) for 24 h. Afterwhich, the tubes were centrifuged for 15 min at 688 ×g. The separated oil was then removed with a pipette, and the tubes were inverted for 24 hrs to drain the oil before reweighing. The OHC was expressed as grams of oil bound per gram of the sample on a dry basis.

5) *Water absorption index* (*WAI*) *and Water solubility index* (*WSI*) was determined as described by [23]. Ground sample (1 g) was, put into pre-weighed centrifuge tubes, and 10 ml of distilled water was then added. The tubes were vortexed and left to stand at room temperature (25˚C) for 24 h. The tubes were then shaken and centrifuged at 688 ×g for 15 min. The supernatant portion was decanted into pre-weighed Petri-dish and dried at 105˚C for 12 h. The weight of the remaining gel in the tube was taken as the WAI (Equation (2)). WSI was calculated as shown in Equation (3).

$$\text{WAI}\left(\text{g/g}\right)=\frac{\text{Weight of wet residue}-\text{Weight of dried residue}}{\text{Weight of the sample}} \tag{2}$$

$$\text{WSI}\left(\text{g/g}\right)=\frac{\text{Weight of dissoved solids in the supernatant}}{\text{Weight of dry sample}\times 100} \tag{3}$$

6) *Swelling capacity* (SC) was determined according to the method described by [24] with a slight modification. Samples (1 g) were weighed and placed in a graduated cylinder and the initial volume recorded. Distilled water (10 ml) at room temperature (25˚C) was added to the flour samples and mixed. It was tapped gently to eliminate air and let to stand for 24 h, and the final volume was noted. SC was calculated as shown in Equation (4) below.

$$\text{SC}=\frac{\text{final volume wet residue}}{\text{initial volume dry sample}} \tag{4}$$

2.5. Statistical Analysis

Data obtained was analyzed using the PROC GLM procedure of the Statistical Analysis System (SAS Institute Inc., 2006) software Version 9.1. The statistical evaluation employed a completely randomized design (CRD) in a 3 × 3 factorial arrangement. Test of significance was done by performing an analysis of variance

(ANOVA) at 5% significance level. The means separation was done using Tukey's Honestly Significant Difference (HSD) method. The results are expressed as mean ± standard deviation from three replication measurements.

3. Results and Discussion

3.1. Effect of Pre-Gelatinization Method on the Total Oxalate Content of Taro Flour

The results for total oxalates is shown in **Table 1** and illustrated in **Figure 4**. Raw taro had a total oxalate content of 76.90 mg. Pre-gelatinization by boiling for 10 min, 20 min, and 30 min reduced the oxalate content by 23.1%, 51.1% and

Table 1. Effect of pre-gelatinization on the total oxalate content of taro flour.

METHOD	TIME (mins)	OXALATES (mg/100g)
Raw (control)	0	76.90^{a} ± 0.79
Boiling	10	47.76^{cd} ± 3.26
	20	37.59^{de} ± 1.44
	30	33.26^{e} ± 1.64
Steaming	10	53.64^{b} ± 1.06
	20	49.21^{bc} ± 5.30
	30	44.54^{cd} ± 1.86
Roasting	10	53.62^{b} ± 4.31
	20	50.39^{bc} ± 0.98
	30	49.07^{bc} ± 0.99

Key: Values are mean ± standard deviations. The superscript letters along the column are mean separation showing significant difference at P < 0.05; columns with the same letter are not significantly different.

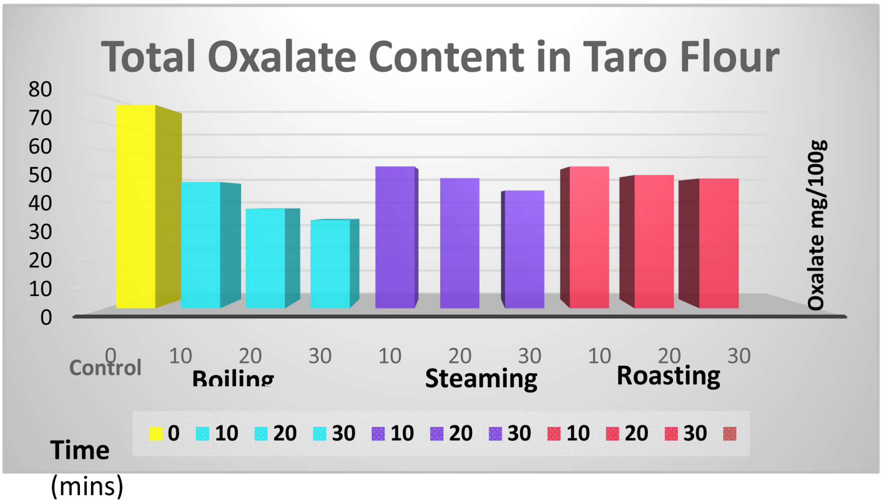

Figure 4. Graph showing total oxalate content total oxalate content in pre-gelatinized taro flour.

56.7%, respectively. Steaming for 10 min, 20 in and 30 min reduced the oxalate content by 30.3%, 36.0%, and 42.08%, respectively. Roasting for 10 min, 20 min and 30 min reduced the oxalate content by 30.3%, 34.5% and 36.2%, respectively. Generally, pre-gelatinization by boiling method resulted in a significant reduction of the oxalate content, while pre-gelatinization by roasting resulted in the least reduction. The mean values trend also shows that all the pre-gelatinization methods decreased oxalate concentration on a dry matter basis and even further with prolonged time.

Dietary oxalates that occur due to the presence of calcium oxalate are detrimental to health as they are associated with aggravation of kidney stones and malabsorption of calcium when foods containing high amounts of oxalate are consumed [25]. For this reason, they need to be eliminated or reduced to acceptable levels since the oxalate restriction, which is defined as the dietary oxalate limit, is no more than 40 - 50 mg [26]. Oxalates can be reduced through processing methods such as soaking, fermentation and heating.

Heat thermally decomposes oxalates and can be done by either boiling, steaming, or baking/roasting. Also, in the presence of heat, the ascorbic acid (vitamin C) present in taro corms can be oxidized to form diketogulonic acid, which is unstable and breaks down to oxalate [27]. Boiling and steaming (wet heating) reduced the oxalate content of taro flour significantly when compared to roasting (dry heating) as a result of leaching (*i.e.*, dissolution) of the soluble oxalates into the boiling and steaming water. This is corroborated by studies done by [28] and [29] on the effect of cooking on oxalate concentration in three cultivars of New Zealand-grown oca tubers (*Oxalis tuberosa*) and selected Thai vegetables, respectively. Also, according to a report by [30], the kinetics of oxalate reduction follows a unimolecular or first-order reaction.Thus, it isinfluenced by temperature and time, so the mean values of oxalate concentration decreased significantly with time across the different methods.

3.2. Effect of Pre-Gelatinization Method on the Functional Properties of Taro Flour

3.2.1. Effect of Pre-Gelatinization Method on Colour

Table 2 represents the colour characteristics of pre-gelatinized taro flour. The results showed that the lightness (L^*) index of taro flour ranged from 38.47 to 70.30 which was significant at ($p < 0.05$). Pre-gelatinization by roasting resulted in flour with a light L^* value of 70.30 ± 0.95, whereas the control had an L^* value of 38.47 ± 0.35. Hue (H°) is the colour that the human eye can perceive, and it's critical for perception and acceptability of a product. Hue ranged from 42.64° to 69.43° with pre-gelatinization by roasting having the largest hue angle. The chroma (C°), which indicates the degree of colour saturation/intensity, ranged from 7.78 to 10.58, with control having the least value. The L° value typically ranges from 0 - 100 with 0-being dark and 100-being the lightest [31]. The low L° value obtained for the raw taro flour (control) can be due to the high concentration of colour pigments present in the taro corms *i.e.*, anthocyanin, while

Table 2. Colour characteristics of pre-gelatinized taro flour.

METHOD	TIME (mins)	Lightness (L˚)	Hue (H˚)	Chroma (C˚)
Raw (control)	0	$38.47^{f} \pm 0.35$	$58.53^{c} \pm 1.89$	$7.78^{e} \pm 0.18$
Boiling	10	$61.17^{d} \pm 1.85$	$50.64^{de} \pm 1.23$	$10.09^{b} \pm 0.30$
	20	$58.93^{e} \pm 1.14$	$46.79^{fg} \pm 2.24$	$9.98^{bc} \pm 0.12$
	30	$58.60^{e} \pm 1.90$	$45.16^{fgh} \pm 0.64$	$9.59^{c} \pm 0.18$
Steaming	10	$63.50^{c} \pm 0.56$	$48.09^{ef} \pm 0.69$	$10.58^{a} \pm 0.10$
	20	$62.43^{cd} \pm 1.75$	$43.51^{gh} \pm 4.12$	$10.35^{ab} \pm 0.20$
	30	$61.10^{d} \pm 0.87$	$42.64^{h} \pm 082$	$7.97^{e} \pm 0.17$
Roasting	10	$59.03^{e} \pm 1.19$	$51.45^{d} \pm 1.89$	$10.32^{ab} \pm 0.44$
	20	$65.30^{b} \pm 0.17$	$63.77^{b} \pm 1.25$	$9.89^{bc} \pm 0.56$
	30	$70.30^{a} \pm 0.95$	$69.43^{a} \pm 0.83$	$8.90^{d} \pm 0.01$

Key: Values are mean ± standard deviations. The superscript letters along the column are mean separation showing significant difference at ($P < 0.05$); columns with the same letter are not significantly different.

the high value obtained (whiteness) from the pre-gelatinized taro flour can be attributed to the degradation of the anthocyanin (colour pigment) resulting in discoloration and thus the flour tending towards white. Red, yellow, and green colours are categorized and represented by H values of 0˚, 90˚, and 180˚, respectively. The large H˚ value obtained from flour prepared by pre-gelatinization by roasting can be attributed to the release of colour pigments from the reaction of heat and carbohydrates present in the taro flour such as caramelization [32]. These results are in tandem with the observations made by [33] in their study where they noted that as degree of cooking increased, so did browning of taro flour due to the reaction of free sugars as a result of starch hydrolysis.

3.2.2. Effect of Pre-Gelatinization Method on BD, WAI, WHC, WSI, SC and OHC

Table 3 below shows the results obtained from the analysis of the effect of pre-gelatinization conditions on other techno-functional properties of taro flour. There was a significant difference in the BD, WAI, WHC, and SC. Compared to the native flour *i.e.*, raw taro flour, there was a significant increase in the functional properties of the flours. Pre-gelatinization for 10 min, 20 min and 30 mins respectively increased the BD values by 10.26%, 8.97%, and 8.97% for boiling, 6.41%, 6.41% and 2.56% for steaming and 3.85%, 2.56% and 2.56% for roasting. The WAI value increased respectively by 107.2%, 84.43% and 80.84% for boiling, 128.1%, 105.9% and 85.63% for steaming, 73.65%, 54.49% and 43.71% for roasting. The WHC increased by 130.1%, 105.8% and 105.8% for boiling, 165.3%, 136.9% and 116.8% for steaming and 112.7%, 108.1% and 82.08% for roasting respectively. The WSI increased by 132.4%, 147.5% and 152.7% for boiling, 196.3%, 224.5% and 352.7% for steaming and 225.4%, 300.3% and 376.2% for

Table 3. Other techno-functional properties of pre-gelatinized taro flour.

METHOD	TIME (mins)	BD g/cm^3	WAI g/g	WHC	WSI %	SC g/g	OHC
Raw Taro (control)	0	0.78^e ± 0.01	1.67^h ± 0.01	1.73^g ± 0.06	4.04^h ± 0.01	1.02^g ± 0.05	0.50^a ± 0.14
Boiling	10	0.86^a ± 0.00	3.46^b ± 0.01	3.98^c ± 0.00	9.39^g ± 0.01	3.88^c ± 0.08	0.53^a ± 0.05
	20	0.85^a ± 0.00	3.08^c ± 0.01	3.56^e ± 0.03	10.00^{fg} ± 0.06	3.34^d ± 0.01	0.46^a ± 0.03
	30	0.85^{ab} ± 0.0	3.02^d ± 0.01	3.57^e ± 0.01	10.21^f ± 0.2	3.20^e ± 0.00	0.41^a ± 0.00
Steaming	10	0.83^{bc} ± 0.01	3.81^a ± 0.01	4.59^a ± 0.04	11.97^e ± 0.42	4.86^a ± 0.07	0.46^a ± 0.00
	20	0.83^c ± 0.00	3.44^b ± 0.02	4.10^b ± 0.01	13.11^d ± 0.37	4.29^b ± 0.01	0.52^a ± 0.02
	30	0.80^d ± 0.00	3.01^d ± 0.02	3.75^d ± 0.05	18.29^b ± 0.19	3.88^c ± 0.01	0.51^a ± 0.02
Roasting	10	0.81^d ± 0.01	2.90^e ± 0.03	3.68^{de} ± 0.08	13.15^d ± 0.37	3.95^c ± 0.02	0.47^a ± 0.03
	20	0.80^{de} ± 0.01	2.58^f ± 0.03	3.60^e ± 0.02	16.17^c ± 0.15	3.15^e ± 0.04	0.49^a ± 0.04
	30	0.80^{de} ± 0.00	2.40^g ± 0.01	3.15^f ± 0.02	19.24^a ± 0.39	2.15^f ± 0.01	0.50^a ± 0.02

Key: MC—moisture content; BD—bulk density; AP—apparent porosity; FC—foaming capacity; WAI—water absorption index; WHC—water holding capacity; SC—swelling capacity; OHC—oil holding capacity; Values are mean ± standard deviations. Superscript letters along the column are mean separation showing significant difference at $P < 0.05$; columns with the same letter are not significantly different.

roasting respectively. An increment of 280.4%, 227.5% and 213.7% for boiling, 376.5%, 320.6% and 280.4% for steaming and 287.3%, 208.82% and 110.78% for pre-gelatinization by roasting was observed for the SC. The BD, WAI, WHC, and SC generally decreased while WSI increased with prolonged pre-gelatinization time among the different methods. There was no significant difference in the OHC among the flour pre-gelatinized using different methods and time at ($P < 0.05$).

Also known as the packing density, bulk density (BD) measures the heaviness of the flour. It is a vital parameter in determining how the flour should be handled, *i.e.*, suitability of application in particular food formulations, packing, storage, and transportation. It reflects the load the sample can carry if allowed to rest directly on one another. In the present study, BD ranged from 0.76 to 0.86 for the different treatments. The results showed a significant difference at ($P < 0.05$) these values are close to those observed by [34] for partially pre-gelatinized starch from cassava (0.80 g/ml) and higher than those observed in pre-gelatinized sweet potato flour (0.5 g/ml) by [35]. High BD is desirable as it offers an excellent packaging advantage as large quantities may be packed within a constant volume. The high BD also suggests their suitability to function as a thickener in food products as it helps to reduce paste thickness which is an essential factor in convalescent and child feeding. At the same time, low BD is helpful in formulating infant and weaning foods [22]. Higher bulk density is desirable for greater ease of dispensability of flours [36].

The general increase in WAI, WHC, WSI and SC of the pre-gelatinized taro flours when compared to the raw taro flour can be attributed to the fact that during pre-gelatinization there is the destruction of starch granules, reduction in the degree of crystallinity, and degradation of starch molecules as confirmed in a study done by [37] to determine the effect of pre-gelatinization by twin drum drier on physicochemical properties of wheat starch. Upon heating, the starch granules are susceptible to loosening with a limited chance of re-association as their semi-crystalline structure is broken. This phenomenon causes the substantive change in the starch structure by disrupting starch molecules' hydrogen bonding and exposing the side chains [38]. When water is added to the flour, the water molecule is associated with hydrogen bonding to the hydroxyl groups exposed on the amylose and amylopectin molecules, hence increasing WHC. Also, according to [39] [40] and [41] the increased WHC can be attributed to the high carbohydrate content of taro flour as well as the non-starch components such as mucilage and fiber which contribute to high water absorption capacity of taro flour. The interaction of water molecules and the hydroxyl groups also causes expansion and increases the size of the starch granules hence, increasing SC as it depends on the hydrogen bonding [38] [42]. Because of the change to the structure of the starch granules there is increased fragmentation of amylase and amylopectin and as such they are leached [43] and consequently increased WSI. The water is also able to penetrate into the starch matrix and thus increase WAI. [38] and [44] also noted a similar trend in their studies on the morphological, physicochemical, and pasting properties of modified water chestnut (*Trapabispinosa*) starch and the effects of particle size and gelatinization of Job's tears powder on the instant properties respectively. WAI may have also been enhanced by mucilage present in taro corm flour [40].

However, the general decreasing trend of WAI, WHC and SC across the different pre-gelatinization methods with time can be attributed to the fact that with prolonged pre-gelatinization time, the starch can become completely gelatinized and this interferes with the hydrogen bonding, decrease in the hydrophilic groups of the molecules of starch and complete starch fragmentation with loss of birefringence, and this consequently affects the WHC and WAI negatively [11] [42]. The SC may have decreased due to the dentation of the starch granules [38].

3.3. Correlation Coefficients of Other Techno-Functional Properties of Pre-Gelatinized Taro Flour

Correlation coefficients of the techno-functional properties of taro flour pre-gelatinized using different methods and time are shown in **Table 4**. Bulk density strongly significantly affected positively WAI (r = 0.75), WHC (r = 0.59), and SC (r = 0.56). Water Absorption Index significantly affected positively WHC (r = 0.95) and SC (r = 0.95). Water holding capacity significantly affected positively the WSI (r = 0.54) and SC (r = 0.96). The water solubility index significantly affected positively the SC (r = 0.55).

Table 4. Correlation coefficients of techno-functional properties of pregelatinized taro flour.

	BD	WAI	WHC	WSI	SC	OHC
BD	1	0.75***	0.59***	−0.17^{ns}	0.56**	−0.23^{ns}
WAI		1	0.95***	0.30^{ns}	0.95***	−0.08^{ns}
WHC			1	0.54**	0.96***	−0.08^{ns}
WSI				1	0.55**	0.03^{ns}
SC					1	−0.05^{ns}
OHC						1

Key: MC—moisture content; BD—bulk density; AP—apparent porosity; FC—foaming capacity; WAI—water absorption index; WHC—water holding capacity; SC—swelling capacity; OHC—oil holding capacity; ns—not significant at $P < 0.05$; ***significant at $P < 0.001$; **significant at $P < 0.01$ and *significant at $P < 0.05$.

WAI, WHC, WSI and SC have positively correlated due to the fact the upon hydration with water, the pre-gelatinized starch granules which have their structure rearranged, the water can penetrate the starch matrix, and the exposed hydroxyl end is associated with water molecule through hydrogen bonding this result in swelling and increase in size and may burst to release the amylase which solubilizes in the water [45]. WAI indicates the flour's ability to absorb water within its matrix and swell for desirable consistency in food systems. This improves consistency and yield, giving body to the developed food product [46]. It represents the ability of a product to associate with water under conditions where water is limited [47]. WSI indicates the level of starch degradation [46].

4. Conclusion

The different pre-gelatinization conditions significantly affect the total oxalate content and techno-functional properties of taro flour compared to the native flour. Boiling is seen tosignificantly reduce the total oxalate content; Steaming is observed to result in flour with the highest water holding capacity, water absorption index, and swelling capacity; Roasting affects the colour characteristics of taro flour as it seen to produce flour with the largest Lightness and Hue index. Owing to these properties, the suitability of pre-gelatinized taro flour can be determined for application in various food products such as thickening agent, formulation of complementary and bakery food products, and increase its utilization and production simultaneously.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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