



Physicochemical properties of *gari* prepared from frozen cassava roots

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ABSTRACT

Gari is a fermented cassava products widely consumed in many parts of Africa including Nigeria. Cassava has a low shelf-life due to physiological and microbiological changes that occur after harvest. In this study, the physicochemical properties of *gari* produced from frozen cassava roots were investigated. Cassava roots were stored for a period of 0, 7, 14, 21 and 28 days. With the exception of *gari* yield (31.3–34.5%), freezing generally influenced the physicochemical properties of *gari* obtained from the cassava roots. Functional properties, including bulk densities and swelling power, decreased as the days of freezing increased. With the exception of pasting temperature (approx. 64 °C) and time to peak (approx. 7 min), other pasting properties were significantly affected by freezing. Cassava roots may be frozen for 28 days without significant changes in the sensory properties. Freezing may serve as a promising alternative for extending the shelf life of cassava root and the resulting roots may be used in the production of *gari* with satisfactory functionality and sensory attributes.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most important food crops grown in the tropical regions of the world, including Nigeria (Idowu & Akindele, 1994). The bulk of cassava produced in Nigeria is processed into various forms for consumption rather than for industrial use (Idowu & Akindele, 1994). Cassava can be processed into various traditionally fermented products such as *fufu*, *elubo* and *gari*. These products are traditional foods that are consumed largely across various cultural divides. Among these products, *gari* appears to enjoy wider consumption possibly due to its relatively longer shelf life compared to other food products from cassava as well as its ease of preparation (Omueti, Amusan, Fayemi, & Asiiye, 1993). *Gari* is creamy-white, partially gelatinized, roasted free-flowing granular flour made from fermented cassava roots (Sanni, Adebawale, Awoyale, & Fetuga, 2008). During the production of *gari*, cassava roots are peeled, washed and grated to produce a mash. The mash is bagged using a porous sack and then allowed to ferment for 3–5 days. Thereafter, the fermented mash is placed in an adjustable press machine for 1–3 h to remove excess starchy water. The mash is then sieved and roasted (garify). *Gari* represent a major food source for many people in other parts of Africa and in Latin America (Ukhun & Nkwocha, 1989). However, the cassava root used in the preparation of *gari* and other fermented food products have a very short shelf-life of about 3 days. The root deteriorate rapidly after

harvest and this deterioration result from physiological and microbiological processes (Cooke, Rickard, & Thompson, 1988; Rickard, 1981). According to these authors, the initial loss of acceptability is due to physiological deterioration. Microbiological or secondary deterioration usually occurs only after physiological deterioration has begun (Cooke et al., 1988; Rickard, 1981). These physiological and microbiological processes, if not controlled, can affect the quality of the resulting products. Rapid post-harvest physiological deterioration of cassava roots is reportedly due essentially to wound responses including increased activity of some enzymes such as phenylalanine ammonia lyase, peroxidase and polyphenol oxidase (Rickard, 1985). Other physiological changes include the formation of leucoanthocyanidins, catechins, scopoletin and condensed tannins, and often the formation of a wound periderm (Rickard, 1985).

Several traditional and modern methods of storing the cassava roots have been developed to control the deterioration of cassava roots. For instance, Cooke et al. (1988) reported that subsistence farmers leave cassava roots in the ground until needed, or if storage is required after harvest, re-bury the roots in a trench. Modern methods include refrigeration, waxing, chemical treatment, controlled atmosphere and deep-freezing (Cooke et al., 1988; Karim, Fasasi, & Oyeyinka, 2009; Rickard, 1981; Uchekukwu-Agua, Caleb, Manley, & Opara, 2015a; Uchekukwu-Agua, Caleb, & Opara, 2015b). Although these techniques are quite expensive and requires high technology and expertise, the

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quality of the stored tubers have been found to be superior to those stored using traditional methods (Cooke et al., 1988; Rickard, 1981).

So far, studies on the quality of *gari* have focused on cassava root stored using traditional methods. Traditional methods such as storage of cassava root in polythene bags, jute bags, trench and plastic storage boxes containing saw dust and the quality of the resulting *gari* from the stored roots have been reported (Karim et al., 2009). These authors reported that *gari* of good quality can be prepared from cassava roots stored for 7 days using plastic storage boxes and trench containing wet sawdust (Karim et al., 2009). Storage of cassava roots for a period of 0–4 days at ambient temperature (25–30 °C) was found to significantly reduce the cyanide contents of *gari* (Idowu & Akindele, 1994). Furthermore, the yield of *gari* reportedly reduced by approximately 50% at the end of the 4th day of storage (Idowu & Akindele, 1994).

There are evidences that deep-freezing leads to a considerable textural loss of foods but can retain quality of resulting products (Fellows, 2000). Currently, there is no report on the quality of products such as *gari* from refrigerated or deep frozen cassava roots. No doubt, freezing and refrigeration can considerably extend the quality of cassava roots than traditional methods of storage (Fadeyibi, 2012; Uchechukwu-Agua et al., 2015b). However, it is important to establish the quality of the resulting products from cassava roots stored at low temperature. Hence, in this study, the physicochemical properties of *gari* produced from cassava roots frozen for a period of 4 weeks was investigated. The novelty of this research stems from the fact that, there are no reports on the quality of frozen cassava roots.

2. Materials and methods

2.1. Materials

Fresh matured cassava roots (variety TMS 326) were harvested from the University of Ilorin, Agricultural Research Farm. All chemicals used were laboratory-grade. The cassava roots were transferred into the Food Processing Laboratory, Department of Home Economics and Food Science, University of Ilorin, Nigeria for further processing.

2.2. Storage of cassava roots and preparation of *gari*

Cassava roots were washed in distilled water, drained and weighed. The washed samples, 10 kg, each were packaged in polythene bags and placed in a home chest freezer operating at a temperature of $-18\text{ }^{\circ}\text{C} \pm 2$. The roots were stored for a period 7, 14, 21 and 28 days. Cassava roots immediately processed after harvest served as the control.

Gari was prepared from either fresh or frozen cassava roots as reported previously with slight modifications (Idowu & Akindele, 1994). Briefly, cassava roots were peeled, washed and grated using a grating machine powered by Lister Diesel engine (5-1 6HP 650RPM, UK). The grated pulp was packed into a jute bag and pressed to remove water. The pulp was fermented for 5 days, sifted to remove coarse fibre and roasted at about 80 °C to obtain *gari*. *Gari* yield was determined as the ratio of the weight of the *gari* per unit weight of peeled cassava.

2.3. Analyses

2.3.1. Objective colour measurement

The CIE tristimulus L, a, and b parameters of *gari* were measured using a chroma meter (ColourFlex-Diffuse). The chroma meter operates on the CIE L, a and b colour schemes, L (lightness) axis – 0 is black, 100 is white, a (red-green) axis-positive values are red; negative values are green and 0 is neutral, b (yellow-blue) axis-positive values are yellow; negative values are blue and 0 is neutral. The instrument was standardized and the samples were placed in the sample holder. Colour measurement was replicated three times.

2.3.2. Particle size distribution

The particle size of the *gari* samples was determined based on the method reported by Oduro, Ellis, Dziedzoave, and Nimako-Yeboah (2000) with few modifications. Briefly, Fifty (50) grams of *gari* was sieved through a set of graded Tyler sieves of aperture sizes 5.00, 4.00, 3.0, 1.80, 1.40 and 1.00 mm using a Retsch Vibro shaker (Model 65056, W. Germany) set at frequency of 50 Hz for 10 min. Fractions retained on each sieve were then weighed and used to calculate the particle size distribution of the samples.

2.3.3. Swelling capacity

Swelling capacity was determined by filling *gari* samples into a 50 mL glass measuring cylinder. Distilled water was added at room temperature to give a total volume of 50 mL. The top of the cylinder was tightly covered and the contents mixed by inverting the cylinder. After 2 min the cylinder was inverted again. The cylinder was then left to stand for additional 3 min and the final volume occupied by the *gari* was recorded. Swelling capacity was determined by dividing the volume of *gari* in water by the initial volume of *gari* (Oduro et al., 2000).

2.3.4. Bulk densities

Loose and packed bulk densities of *gari* samples were determined using the method described by (Falade & Oyeyinka, 2015). Briefly, a measuring cylinder (100 mL) was filled with the sample to mark (100 mL), and the content weighed. Packed bulk density was also obtained by following the same procedure, but with additional tapping for 50 times prior to weighing. Bulk density was calculated as the ratio of the bulk weight and the volume of the container (g/mL).

2.3.5. Chemical composition

Moisture contents were determined using AOAC (2000) methods, pH was determined using a pH meter, while cyanide contents were determined by the method of (Kemdirim, Chukwu, & Achinewhu, 1995).

2.3.6. Pasting properties of *gari*

The pasting properties of the *gari* were examined using a Rapid Visco-Analyzer (Newport Scientific Australia) as previously reported (Oyeyinka, Singh, & Amonsou, 2016). Briefly, samples (2.8 g) were weighed into the test canister containing 25 mL of distilled water. The mixture was agitated by mixing manually before inserting the canister into the instrument. The sample was stirred at 960 rpm for 10 s before the shear input was decreased and held constant at 160 rpm during the subsequent heating and cooling cycles.

2.3.7. Sensory properties

Sensory evaluation of *gari* was carried out as using a multiple comparison test. Fifty (50) panellists, selected from student of the Department of Home Economics and Food Science, University of Ilorin, Nigeria were used for the evaluation. The selected students were those who consume *gari* regularly. Prior to the sensory analysis, they were screened with respect to their interest and ability to differentiate food sensory properties. The samples were evaluated for aroma, appearance, sourness, and overall acceptability using a 9-point hedonic scale where 1 and 9 represent dislike extremely and like extremely, respectively.

2.4. Statistical analysis

All analyses were performed in triplicate. Data were analysed using analysis of variance (ANOVA) and means were compared using the Fisher Least Significant Difference (LSD) test ($p < 0.05$).

Table 1
Yield and chemical composition of *gari* from frozen cassava root.

Freezing period (Days)	Yield (%)	pH	Cyanide (mg/Kg)	Moisture (%)
0	34.5 ^a ± 0.10	3.76 ^{ab} ± 0.01	6.41 ^a ± 0.08	9.77 ^b ± 0.01
7	34.0 ^a ± 0.12	3.65 ^c ± 0.04	6.15 ^a ± 0.02	10.74 ^b ± 0.02
14	32.5 ^b ± 0.02	3.73 ^{bc} ± 0.04	4.29 ^b ± 0.17	11.13 ^a ± 0.02
21	31.3 ^b ± 0.01	3.84 ^a ± 0.05	4.46 ^b ± 0.01	9.84 ^b ± 0.02
28	31.5 ^b ± 0.01	3.42 ^d ± 0.01	4.48 ^b ± 0.32	11.26 ^a ± 0.02

Mean ± SD. Mean with different superscript along the column are significantly different ($p < 0.05$).

3. Results and discussion

3.1. *Gari* yield

Gari yield (approx. 35%) from freshly harvested cassava root was slightly higher than those from the frozen cassava roots (31.5–34%) (Table 1). *Gari* yield decreased slightly with increase in the freezing period. Previous researchers similarly observed that the *gari* yield from cassava roots stored at ambient temperatures decreased with increasing storage period (Akingbala, Oyewole, Uzo-Peters, Karim, & Baccus-Taylor, 2005; Idowu & Akindele, 1994). The *gari* yield in this study is in the range of values (10–34%) reported in the literature (Achinewhu, Barber, & Ijeoma, 1998; Akingbala et al., 2005; Karim et al., 2009). Akingbala et al. (2005) reported *gari* yield of 10.0–29.9% for cassava stored in polythene bags and a yield of 17.4–29.9% for cassava stored in the trench for 0–21 days. However, higher yields of *gari* up to 67.1% from cassava roots stored at ambient temperature (25–30 °C) for 0–4 days were reported by other authors (Idowu & Akindele, 1994).

3.2. Colour and physical appearance

Objective colour measurement of the *gari* samples showed that Lightness (L), greenness (negative a), and yellowness (positive b) values of the control sample were slightly higher than *gari* prepared from frozen cassava roots (Table 2). The difference in the colour of the samples was not very significant. The slight insignificant difference observed in the colour of the *gari* samples obviously resulted from the fact that freezing prevented or slowed down the physiological changes in the cassava roots during storage. Physiological changes is characterised mainly by discolouration of the cassava roots (Karim et al., 2009). Thus, freezing seemed to have reduced the rate of discoloration which otherwise would have altered the colour of the roots and eventually lead to significant changes in the colour of the *gari* samples. Colour and appearance, among other factors are important attributes that determine the quality of *gari*. The *gari* from frozen cassava roots had similar appearance, which was only slightly different from the control *gari* sample (Fig. 1). Thus, freezing seem not to significantly ($p < 0.05$) affect the colour and appearance of the *gari* samples.

Table 2
Colour and mean particle size distribution of *gari* from frozen cassava root.

Freezing period (Days)	Colour parameters			Sieve size ^a						
	L	a	b	1 mm	1.4 mm	1.8 mm	3 mm	4 mm	5 mm	Fine particle
0	68.68 ^a ± 1.97	−2.69 ^a ± 0.19	26.60 ^a ± 0.78	1.37 ^e	15.98 ^c	33.29 ^b	40.26 ^a	7.71 ^d	1.15 ^e	0.21 ^f
7	63.91 ^b ± 4.32	−2.71 ^a ± 0.37	25.72 ^{ab} ± 1.23	1.29 ^f	11.17 ^d	25.24 ^b	42.26 ^a	14.36 ^c	4.27 ^e	1.39 ^f
14	68.00 ^a ± 3.14	−3.05 ^a ± 0.37	25.28 ^b ± 0.87	5.41 ^e	18.60 ^c	24.54 ^b	35.51 ^a	11.17 ^d	3.55 ^{ef}	1.21 ^f
21	65.71 ^{ab} ± 1.49	−3.51 ^b ± 0.38	26.60 ^a ± 0.50	2.40 ^d	13.55 ^c	27.34 ^b	40.76 ^a	12.31 ^c	3.01 ^d	0.62 ^e
28	66.05 ^{ab} ± 3.81	−3.69 ^b ± 0.13	26.47 ^a ± 1.15	1.47 ^e	13.97 ^c	32.74 ^b	41.39 ^a	8.69 ^d	1.41 ^e	0.33 ^f

Mean ± SD. Mean with different superscript along the column are significantly different ($p < 0.05$).

^a Average values are reported in percentage (%).

3.3. Particles size distribution

The particle size of *gari* varied significantly ($p < 0.05$) among the samples, but did not follow any particular trend with increasing length of freezing period (Table 2). Variation in particle size distribution of *gari* samples is suggested to result from differences in the grating procedure, roasting process and the extent of fermentation of the cassava mash (Oduro et al., 2000). However, in this study, it is unlikely that any of the above mentioned factors accounted for the variation in particle size. This seems plausible since the samples were subjected to the same grating procedure, roasting process and period of fermentation. The most probable reason for the variation in particle size among the *gari* samples is the extent of starch damage caused by freezing. According to Akingbala et al. (2005), the greater the degree of starch damage, the smaller the dextrinized particle. In this study, *gari* obtained from freshly processed cassava root, which served as the control had much lower amounts (0.21%) of fine particles compared with the *gari* (0.33–1.31%) from frozen cassava roots (Table 2). This could be due to lower amount of starch damage in fresh cassava roots compared with the frozen roots. Beside other factors such as appearance that dictates the quality of *gari*, particle size seems to be one of the most important. Consumers will most likely have higher preference for fine particles (Akingbala et al., 2005).

3.4. Functional properties

The functional properties of *gari* obtained from frozen cassava roots that were determined are bulk densities (loose and packed) and swelling power (Fig. 2). Expectedly, packed bulk density (PBD) of the samples were higher than the loose bulk density (LBD). Both LBD and PBD significantly ($p < 0.05$) decreased with increasing freezing period. Bulk density is associated with the particle size and measures the compactness of particles (Perez, 1997). The decrease in the bulk densities of the samples with increasing days of freezing could be associated with the reduced particles size of the *gari* samples (Table 2). This is advantageous as samples with reduced bulk densities will allow the use of more economical packaging materials (Falade & Oyeyinka, 2015).

The swelling index of the *gari* samples followed the same trend as the bulk densities, with the swelling index values (2.05–4.40) reducing as the days of freezing increased (Fig. 2). At the end of the 28 days freezing period, there was approximately 53% reduction in swelling index of the *gari* samples. Previous studies similarly reported significant reduction in the swelling index of *gari* samples with increase in storage period (Akingbala et al., 2005). Swelling index represent the ability of *gari* samples to imbibe water and swell at room temperature. It is highly important as it indicates the degree of gelatinization of the *gari* sample and a high swelling capacity is very desirable for good quality *gari*. Several factors may influence the swelling index of food samples. For instance, high degree of starch damage predisposes food to a lower swelling capacity (Akingbala et al., 2005). Thus, it is hypothesized that the freezing conditions, could have resulted in high starch damage



Fig. 1. Physical appearance of *gari* produced from frozen cassava roots. D: Days of frozen storage.

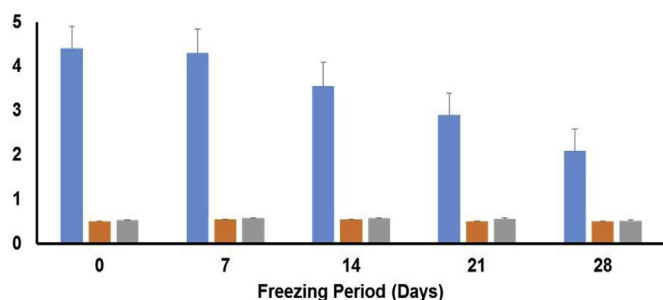


Fig. 2. Functional properties of *gari* produced from frozen cassava roots. Error bars indicate standard deviation (N = 2).

resulting in greater reduction in granule size (Table 2) and swelling ability (Fig. 2). This seems plausible since slow freezing rate, usually encountered using typical home freezers generates large ice crystals that results in greater tissue damage. The swelling index of the *gari* samples in this study is within the range (1.6–3.6) reported in the literature (Akingbala et al., 2005; Oduro et al., 2000).

3.5. Chemical composition

The chemical composition of the *gari* samples is presented in Table 1. Moisture contents (9.77–11.26%) of the *gari* samples showed slight variation which was not very significant ($P < 0.05$) (Table 1). These values are in agreement with the literature (Akingbala et al., 2005; Idowu & Akindele, 1994). Ukpabi and Ndimele (1990), reported that *gari* samples with moisture content in the range of 13 and 16% could store for between 2 and 7 months.

The pH of *gari* samples ranged between 3.42 and 3.84 for *gari* obtained from cassava roots frozen for 28 days and *gari* from freshly processed cassava roots respectively (Table 1). Freezing appears to

affect the pH of the samples. The pH of the *gari* samples increased with increase in the freezing period, though, there was a decline at the 4th week of storage. The reason for the observed trend in pH of the *gari* samples remains unclear. However, it is possible that enzymes responsible for the fermentation process have been immobilized or inactivated during freezing. After thawing and subsequent grating prior to fermentation, enzyme activity may have been affected. This may explain the increase in pH of the *gari* samples produced from frozen cassava roots. The decrease in their activity may reduce the amount of lactic acid produced during fermentation and hence a lower acidity in the products.

Cyanide levels (6.41 mg/kg) in the *gari* from freshly processed cassava roots were significantly ($p < 0.05$) higher than samples (4.29–6.15 mg/kg) obtained from frozen roots (Table 1). The cyanide contents of the *gari* samples is within the value (10 mg/kg) considered safe by Food and Agriculture Organization/World Health (FAO/WHO, 1991). The reduction in cyanide levels, especially in *gari* samples from frozen cassava may be due to the processing conditions the cassava roots in this study have been subjected to. Cassava contains cyanogenic glucosides that are toxic for humans and can lead to serious health disorders, when consumed in quantities exceeding the recommended safe levels (Montagnac, Davis, & Tanumihardjo, 2009). For example, consumption of about 50–100 mg/kg cyanide has been associated with acute poisoning and has been reported to be lethal to adults (Halström & Møller, 1945). Consuming small amounts of cyanide for a long term may result in severe health problems such as glucose intolerance (Ernesto et al., 2002) and tropical neuropathy (Osuntokun, 1980). Several factors including cassava variety, processing conditions such as fermentation period may influence the cyanide contents of *gari*. The bitter variety is particularly high in cyanide content exceeding levels considered safe for consumption. Hence, efforts are made to ensure that the period of fermentation is long enough to ensure detoxification of cyanide.

Table 3
Pasting properties of *gari* from frozen cassava root.

Parameter	Freezing period (Days)				
	0	7	14	21	28
PV (RVU)	148.50 ^a ± 1.53	95.08 ^c ± 4.47	74.21 ^d ± 0.76	96.79 ^c ± 1.12	116.25 ^b ± 3.29
TV RVU	134.38 ^a ± 0.29	84.42 ^d ± 2.47	61.50 ^e ± 0.11	90.08 ^c ± 1.65	114.42 ^b ± 0.47
BDV RVU	15.63 ^a ± 0.29	11.66 ^c ± 0.58	12.71 ^d ± 0.88	8.70 ^e ± 0.53	8.33 ^b ± 0.24
SBV (RVU)	118.00 ^a ± 0.58	63.79 ^{cd} ± 0.76	67.40 ^c ± 0.72	78.83 ^b ± 1.29	62.33 ^d ± 1.06
FV (RVU)	247.37 ^a ± 1.94	146.21 ^c ± 0.41	128.71 ^d ± 0.88	167.92 ^c ± 1.76	177.25 ^b ± 0.12
PT (°C)	65.55 ^a ± 0.35	65.53 ^a ± 0.14	65.25 ^a ± 0.21	65.65 ^a ± 0.35	65.25 ^a ± 0.78
Peak time (min)	7.00 ^a ± 0.00	7.00 ^a ± 0.00	7.00 ^a ± 0.00	6.96 ^a ± 0.05	6.60 ^a ± 0.09

Mean ± SD. Mean with the same superscript along a row are not significantly different ($p < 0.05$). PV: Peak viscosity; TV: Trough viscosity; BDV: Breakdown viscosity; SBV: Setback viscosity; FV: Final viscosity; PT: Pasting temperature.

Table 4
Mean sensory scores of *gari* from frozen cassava root.

Freezing period (Days)	Appearance	Sourness	Aroma	Particle size	Overall acceptability	Total score
0	5.41 ^b ± 2.18	6.37 ^a ± 1.07	6.33 ^a ± 1.24	5.26 ^a ± 1.70	6.37 ^a ± 1.39	29.44 ^a ± 6.38
7	6.15 ^{ab} ± 1.35	6.07 ^a ± 1.51	6.33 ^a ± 1.24	5.59 ^b ± 1.50	6.41 ^a ± 1.21	30.74 ^a ± 4.84
14	6.22 ^{ab} ± 1.50	6.00 ^a ± 1.30	5.74 ^a ± 1.19	5.59 ^a ± 1.55	6.22 ^a ± 1.21	29.78 ^a ± 4.37
21	6.15 ^{ab} ± 1.23	5.89 ^a ± 1.47	5.81 ^a ± 1.46	5.33 ^a ± 1.88	6.15 ^a ± 1.02	29.33 ^a ± 4.37
28	6.56 ^b ± 1.39	6.11 ^a ± 1.57	6.22 ^a ± 1.36	5.70 ^a ± 1.63	6.26 ^a ± 1.27	30.96 ^a ± 5.26

Mean ± SD. Mean with different superscript along the column are significantly different ($p < 0.05$).

3.6. Pasting properties

With the exception of the pasting temperature (approx. 64 °C) and time to peak (approx. 7 min), which was very similar across the samples, freezing had significant ($p < 0.05$) impact on other pasting properties of the *gari* (Table 3). In general, there was a significant reduction in the pasting properties of the *gari* samples after freezing. Peak viscosities of the samples ranged between 74.21 and 134.28 RVU (Table 3). The control sample had higher peak viscosity than *gari* from the frozen cassava roots. Peak viscosity is the ability of starch to swell freely before their physical breakdown and measures the maximum viscosity developed during or soon after heating (Adebowale, Sanni, & Awonrin, 2005). High peak viscosity is associated with high starch content. Thus, the reduction in peak viscosity of the *gari* samples following freezing suggest possible disintegration of the intact starch granules by the ice-crystals formed during freezing. The breakdown in the starch granule integrity possibly reduced the ability of the samples to hold water during cooking, which resulted in low swelling index (Fig. 1). Breakdown viscosities, which measures the susceptibility of the starch granules to disintegrate during heating varied between 8.33 and 15.63 RVU (Table 3). *Gari* from frozen cassava tubers displayed lower breakdown viscosities compared to the control sample, suggesting that freezing enhanced the ability of the samples to withstand thermal process.

Gari samples showed a significant ($p < 0.05$) decrease in setback viscosity after freezing. Approximately 47% reduction in setback viscosity was observed in *gari* samples obtained from cassava roots frozen for 28 days. Setback relates to the tendency of starch to retrograde during storage. Retrogradation describes the process in which a heated starch paste cools, and the exuded amylose molecules re-associate and unite the swollen starch grains in an ordered structure that results in viscosity increase (Lai, Lu, & Lii, 2000). The viscosity of the *gari* samples after cooling as measured by the final viscosity, showed that, the control sample had higher viscosity than the samples from frozen cassava roots. The viscosity of cooked *gari* paste is very important in various applications. For instance, it could be used to determine how sticky the paste would be during consumption (Sanni et al., 2008). *Eba* is a stiff paste made by dissolving *gari* in hot water. Thus, with the same quantity of *gari* and water, *eba* with varying degree of viscosity can be produced using *gari* from cassava roots frozen for varying periods.

3.7. Sensory properties

Mean sensory scores of *gari* samples prepared from frozen cassava roots is presented in Table 4. Although there were slight variation in the sensory properties of the *gari* samples, freezing appeared not to significantly ($p < 0.05$) affect the sensory properties of the *gari*. Appearance and sourness of *gari* are important parameters that determine the quality of *gari*. Consumers relish the sour taste and creamy appearance of fermented *gari*, though the preference for sour *gari* may vary depending on the processing method used in a locality. In the current study, the control sample, i.e. *gari* obtained from unfrozen cassava root had slightly lower appearance rating than the *gari* obtained from frozen cassava root. This is in agreement with the objective colour measurement (Table 3). However, the sourness and aroma of *gari* from frozen cassava root were slightly higher than the control samples. Aroma and sourness are controlled by the drop in pH due to the production of lactic and formic acids by *Corynebacterium* spp. The increased acidity promotes the growth of *Geotrichum* spp. that detoxifies the cassava by releasing gaseous hydrogen cyanide by hydrolysis of the cyanogenic glycosides present in the cassava. Aldehydes and esters produced by *Geotrichum* spp. give the characteristic aroma and taste to the product.

4. Conclusions

Freezing of cassava roots did not substantially influence the sensory properties of *gari* obtained from the frozen roots. However, the pasting, functional and chemical properties seem to be affected by freezing period. Cassava roots can be kept frozen for 28 days without substantial changes in the eating quality of the resulting *gari*. Although freezing appear expensive in developing nations of the world, the application of freezing in extending the shelf-life of cassava roots offers a great solution to huge losses caused by rodents, physiological and microbiological damages. *Gari* with varying degree of stickiness can be produced using frozen cassava roots. Future studies may also investigate the starch functionality of the frozen roots to determine their potentials in food and non-food applications.

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