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Influence of Fermentation on Carotenoids and the Sensory Appeal of a Solid-State Fermented Biofortified Cassava Product

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ABSTRACT
The introduction of biofortified cassava (BC) varieties was aimed at addressing vitamin A deficiency identified in sub-Saharan African countries. However, the challenges lie in preserving the carotenoids during the processing of BC roots due to the susceptibility of carotenoids to degradation. This study focused on investigating the impact of fermentation conditions on the retention of carotenoids and the sensory appeal of its *gari* and its cooked dough, *eba*, using Hedonic and just-about-right (JAR) scales. The solid-state fermented samples consistently retained high levels of trans isomer of beta carotene after 48 h in samples subjected to daylight conditions as well as those in a dark environment. Additionally, a negative correlation was observed between the percentage retention of total beta carotene and the yellowness of the fermented samples. The fermentation time had a significant ($p<0.05$) effect on the sensory attributes on the hedonic scale. The colour, aroma, moldability, and texture of *eba,* were significantly ($p<0.05$) affected by the light exposure during fermentation. The texture and overall acceptability were significantly ($p<0.05$) influenced by the fermentation time when assessed using the JAR scale. In conclusion, carotenogenesis was achieved during the solid-state fermentation of biofortified cassava, and the most bioactive isomer of beta-carotene was optimally retained.

Keywords: Carotenogenesis,total carotenoid, β-carotene, *garri, eba.*

1.0 Introduction

Cassava ((*Manihot esculenta* Crantz) is a significant global crop, and in Nigeria, it serves as a staple food for over 100 million people daily (Onyemauwa, 2010). Nigeria is the leading producer of cassava globally, with its production increasing from 42.5 million tons in 2010 to 61 million tons in 2020 (World Food and Agriculture, 2021). Small-scale farmers predominantly cultivate cassava due to its resilience in long-term drought and poor soil conditions compared to other staple crops (Esuma *et al.,* 2016). In African countries, 50% of the cassava produce is consumed as processed food, 38% in fresh or cooked form, and 12% is used for animal feed (Ceballos *et al.,* 2017). While white cassava, commonly available, can meet most of the body's daily energy requirements, it lacks sufficient protein, essential micronutrients, and vitamin A (Montagnac *et al.,* 2009). Vitamin A deficiency is a significant public health concern, followed by

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iron, zinc, and iodine deficiencies (Owens *et al.,* 2014). Vitamin A deficiency increases susceptibility to infections, particularly in women and children, and can lead to illnesses and vision impairments, potentially causing partial or complete blindness (Saltzman *et al.,* 2013). It has been reported that two-thirds of dietary vitamin A worldwide and over 80% in the developing world come from carotenoids in vegetables (Ceballos *et al.,* 2017)

Ongoing efforts are being made to enhance the nutritional value of cassava through biofortification, resulting in increased carotenoid content (Udoh *et al*., 2022). Carotenoids are important for their conversion to vitamin A when consumed, and biofortified varieties are gaining acceptance and may help address vitamin A deficiency in sub-Saharan Africa (Udoh *et al.,* 2022). However, retaining carotenoids during the processing of biofortified cassava roots into commonly consumed products remains a challenge due to their susceptibility to degradation caused by processing (Maziya-Dixon *et al*., 2015).

Interestingly, carotenoid-producing genes have been found in lactic acid bacteria isolated from fermentation processes (Garrido-Fernández *et al.,* 2010; Turpin *et al.,* 2016; Antognoni *et. al.,* 2019), while the manipulation of illumination has encouraged β-carotene synthesis by carotenoid-producing fungi (Bhosale *et al.* 2002). Fermentation, a key process in cassava conversion to shelf-stable products, involves the activities of microorganisms and can result in higher product yields and improved quality (Londoño-Hernandez *et al.* 2020). Successful adoption of biofortified cassava in combating vitamin A deficiency in sub-Saharan Africa requires careful consideration of post-harvest processing methods to optimise carotenoid retention. Since carotenoid retention is greatly influenced by the processing methods and variety used (Eyinla *et al.,* 2019), the study examined the impact of fermentation conditions on carotenoid retention and sensory acceptability of solid-state fermented biofortified cassava product.

2.0 Materials and Methods

2.1 Materials

TMS-IBA-070593, a biofortified cassava variety, was used in this study. It was obtained from the International Institute of Tropical Agriculture (IITA) in Ibadan. Chemical reagents of analytical grade were used.

2.2. Methods

2.2.1 Sample preparation/analysis

TMS-IBA-070593 mature roots (aged 11-12 months) were harvested from the International Institute of Tropical Agriculture (IITA) research farm in Ibadan, Nigeria. *Gari* was prepared according to the procedures outlined by Eyinla *et al.* (2019). A hundred and ten kilogrammes of freshly harvested roots were divided into 11 parts of 10 kg each. Using a stainless-steel knife, each part was manually peeled simultaneously and thoroughly cleaned with potable water. The washed roots were immediately grated using an electricity-driven engine and packed in polypropylene woven sacks and labeled A to J. Five of the sacks were white and the other five were black. The five white-colored sacks were closed and left under shade, whereas, the five-colored sacks were closed and kept in a dark room for spontaneous fermentation. The eleventh sample was treated as a control sample after zero hours of fermentation. Unfermented control samples were immediately taken to the laboratory.

Every 24 h, a sack of samples was withdrawn from each of the A-E and F-J sections. The withdrawn sack was dewatered by pressing in a locally fabricated hydraulic press, and 1 kg of the pressed mash was wrapped in aluminum foil, kept in a Ziplock bag, and taken to the laboratory immediately for analysis under cold chain in locally source polystyrene foam boxes. The remaining pressed samples were garrified at temperatures ≤ 80°C. Temperature was measured using a Benetech digital infrared thermometer. The procedure was repeated for all samples withdrawn every 24 h for 5 days of fermentation. The colour profile analysis

was performed immediately on the samples. Wet-fermented samples for carotenoid analysis were stored in thermocool freezer at – 6°C prior to analysis.

2.2.2 Carotenoid identification and quantification

The carotenoid profile of freshly harvested root and fermented cassava mash was analyzed using high performance liquid chromatography (HPLC) procedures reported by Rodriguez-Amaya and Kimura (2004) in HarvestPlus handbook for carotenoid analysis. True retention of total carotenoid and total beta carotene were calculated using methods described by Maziya-dixon *et al.,* 2015.

2.2.3 Colour

Colour characterisation of the samples was done according to Carvalho *et al.* (2022).

2.2.4 Sensory evaluation

Sensory evaluation of *gari* and its cooked dough, *eba*, was conducted using a "hedonic scale", employing modified methods from Lasekan *et al.* (2016), while the "just-about-right" scale was conducted with methods described by Bechoff *et al.* (2018). Sensory parameters assessed included the color, aroma, sourness, sweetness, and texture of *gari*, as well as the color, aroma, moldability, and texture of *eba.*

3.0. Results and Discussion

3.1. Carotenoid retention

Fermentation has been widely utilised in the processing of cassava into various African staple foods (Ogbo *et al.,* 2006). An initial decrease in the total carotenoid (TC) content of the fermented mash was observed in the first 24 h of fermentation under both daylight and dark conditions. The retention rates were 41.59% and 69.73% respectively, compared to the initial content of 82.87%. This can be attributed to the spontaneous degradation of carotenoids caused by exposure to environmental factors during pre-fermentation unit operations. The decreased total carotenoid (TC) under daylight conditions may be attributed to TC degradation caused by exposure to daylight and other environmental factors, as compared to the dark condition (Figure 1).

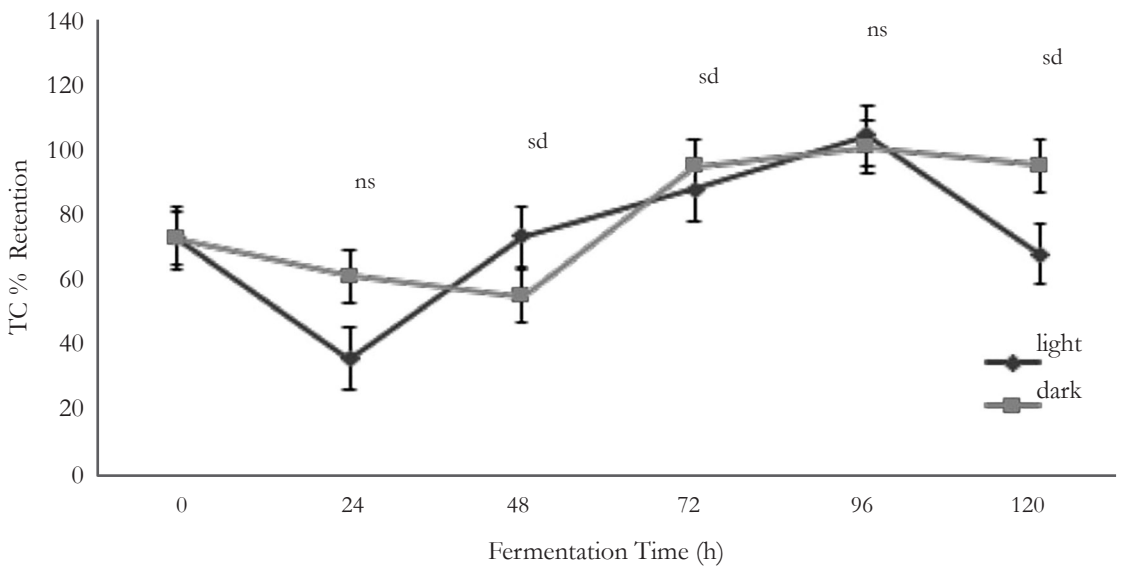


Fig. 1: Changes in total carotenoid (TC) during a 120 h fermentation of grated cassava mash under light and dark conditions

In this study, only β-carotene was detected as the PVA carotenoid. This contrasts with the findings of Ceballos *et al.* (2017), who reported the presence of β-Cryptoxanthin, α-carotene, and lutein in biofortified cassava roots. However, Yeum and Russell (2002) reported that ß-carotene is the major PVA found in cassava, while some non-PVA carotenoids are also found in the parenchyma of cassava root.

An initial decrease in the total ß-carotene (TBC) was observed during the first 24 h of fermentation. Carotenoid retention decreased during the initial 24 h of fermentation. This can be attributed to the spontaneous degradation of carotenoids due to exposure to environmental factors during pre-fermentation unit operations. The reduced total β-carotene (TBC) in the day light condition could be attributed to the degradation of TBC due to photodegradation and other environmental factors, as compared to the degradation of TBC in the dark room environment (see Figure 2).

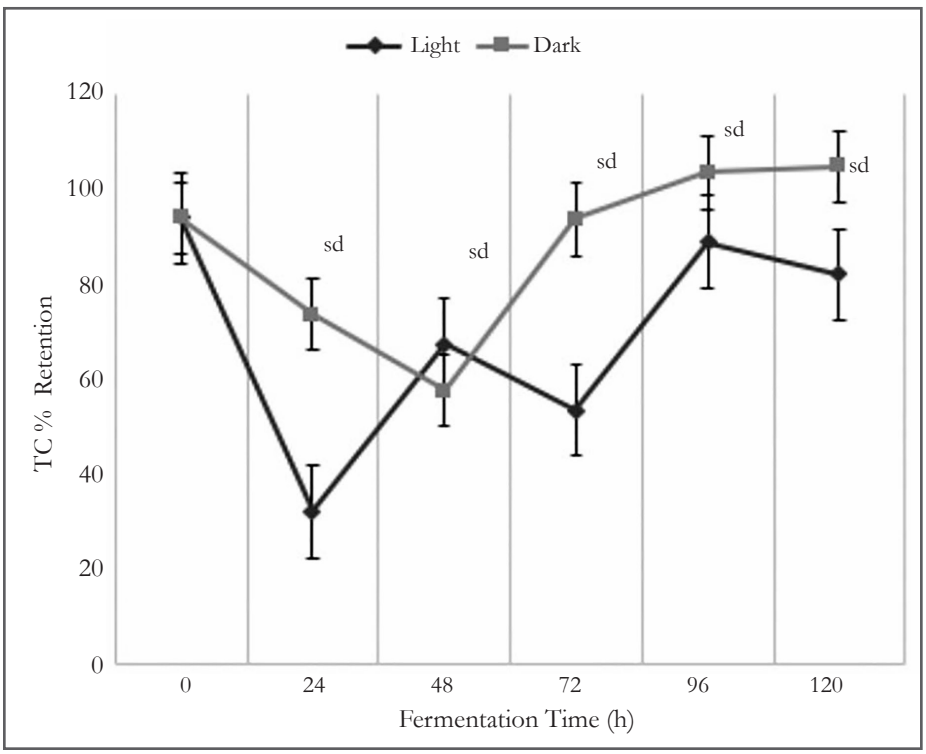


Fig. 2: Variations in total beta carotene (TBC) during a 120 h fermentation in light and dark conditions

Collard and Levi (1959), as well as Collard (1963), reported that *Corynebacterium manihot* dissolves starch within the first 48 hours of fermentation, and organic acids such as lactic and acetic acid are released (Oyewole and Odunfa, 1988). In this study, at the 48th hour of fermentation, the total beta-carotene (TBC) of the DE further reduced to 57.3%, while that of the LE slightly increased to 67.06%. The filtrate from the fermenting mash was relatively retained in the dark room experimental condition compared to the daylight experimental condition. The degradation could have been caused by the dissolution of the dark room where some of the retained TBC were dissolved in the leached fluid containing organic acid due to the hydrophobic nature of carotenoids (Sliwka *et al.,* 2009). The

carotenoid retention in the LE rose after the 24th hour of fermentation and exhibited on undulating pattern as the fermentation extended, despite being exposed to daylight, because of uncontrollable environmental factors. The mash in the dark room experienced a gradual increase in the TBC as the fermentation time increased, with optimum retention values of 106.4% and 104.7% respectively (Figure 2). Similar findings were reported by Eyinla *et al.* (2019), who observed a 41.93% retention after one day and a 30.33% retention after three days of solid-state fermentation of the TMS 0597 cassava variety. It is also consistent with the report of Osagie *et al.* (2019) that *gari* made from fermented yellow cassava has a relatively higher level of beta carotene compared to *gari* made from unfermented cassava mash, depending on the duration of the fermentation process. In comparison to products made from fresh cassava roots, Bokanga (2001) found that various fermented cassava products contained higher levels of riboflavin. This further suggests that some vitamins may be synthesized during fermentation. During the fermentation of cassava, the grated cassava mash is exposed to light, oxygen, and microorganisms, which break down the cassava substrate to produce organic acids. The increase in total beta carotenoids (TBC) count is due to the activity of microorganisms, as light and oxygen can degrade carotenoids. Factors such as light, pH, and temperature of the medium can influence the production of carotenoids by bacteria and fungi (Ramirez *et al.,* 2001; Burja *et al.,* 2006; Santos *et al.,* 2016).

The transformation from trans to cis form was monitored during fermentation. The control sample had 83.49%, 91.74%, and 102.38% of 9-cis, 13-cis, and trans isomers of carotenoids, respectively. The fermented samples consistently retained high levels of trans isomer, with varying retention values, during the fermentation period. Carotenoids are naturally present in the trans isomer in food but can be isomerized to the cis-isomer (9-cis and 13-cis) during processing or exposure to UV light and heat. In this study, the trans isomer was predominantly retained which is consistent with previous findings (Bechoff *et al.,* 2018; Thakkar *et al.,* 2009; Kimura *et al.,* 2007). Both light exposure and fermentation duration significantly ($p<0.05$) influenced the trans-cis isomerization of carotenoids. At the 48th hour of fermentation, the trans isomer was optimally retained, with a percentage retention of 85.5% and 70.4% in the daylight condition and darkroom environment, respectively. By 120 hours of fermentation, the retention percentage of the trans isomer increased to 98.7% in the daylight condition and 126.0% in the dark room environment (Figure 3).

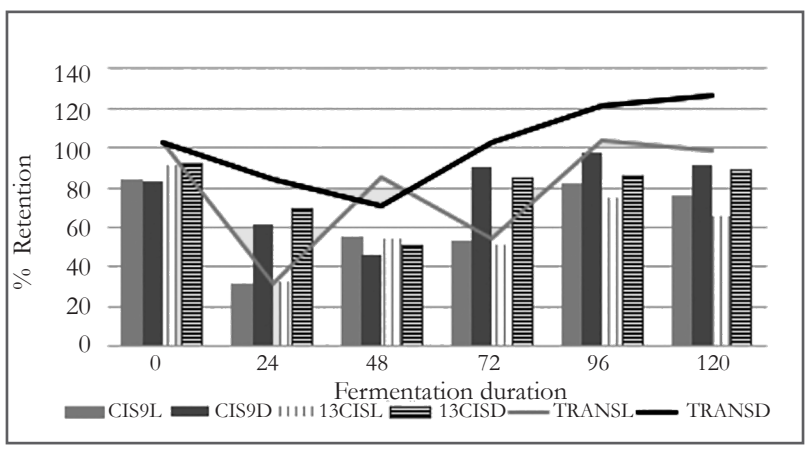


Fig. 3: The trans-cis isomerization process during a 120-hour PVA cassava fermentation.

Cis-isomers' conversion is considered a disadvantage of processing, as they have about half the provitamin A activity of trans-ß carotene. The levels of 9-cis and 13-cis isomers in cassava mash reached their lowest points after 24 hours of fermentation in daylight and 48 hours in the darkroom environment. Total carotenoids (TC) and total ß carotene (TBC) synthesis began at 48 hours in the dark room and at 24 hours in the daylight condition. This suggests that carotenoid isomerization from trans to cis form is minimal during fermentation, and the fermenting organisms do not promote this isomerization. At the end of fermentation, the bioactive trans-isomer, was more abundant than the cis isomer. The trans-cis isomerization depends on the duration and intensity of carotene exposure to processing conditions and a variety of differences. Predicting trans-cis isomerization during cassava processing is challenging due to the interaction between variety and processing.

3.2. Colour parameters

The colour parameters (lightness, redness, and yellowness) of the cassava mash were monitored under different fermentation conditions. Lightness (L*) and yellowness (b*) were significantly affected by light exposure during fermentation (Table 1). There is a negative correlation between TBC, and the yellowness of the samples (supplementary Table 1). Although, the yellow hue of biofortified cassava variety is due to the existence of β-carotene, the depth of the yellow color may not always signify a greater β-carotene concentration. The visible yellow pigment might be generated by fermenting organisms like *Corynebacterium variable*, which is recognized for producing yellow pigmentation during cultivation (Collard 1960). The yellow color of the mash showed a significant negative correlation with TBC, and day light exposure.

Table 1: Effect of lightning and fermentation duration on colour parameters of fermented cassava

	Lightness (l*)	Redness/Greenness (a*)	Yellowness/Blueness(b*)
Daylight			
Light	96.34±0.17	0.16±0.08	58.44±0.26
Dark	97.94±0.17	0.03±0.08	59.68±0.26
LSD	0.52	0.25	0.79
P<0.05	<0.001	0.263	0.005
Fermentation duration			
0	92.78^{a} ±0.30	0.09^{b} ±0.14	55.30^{a}±0.44
24	98.03^{bc}±0.30	-0.60^{a}±0.14	63.14^{d}±0.44
48	97.86^{b}±0.30	0.01^{b}±0.14	62.17^{d}±0.44
72	97.57^{b}±0.30	0.43^{b} ±0.14	57.36^{b} ±0.44
96	97.72^{b}±0.30	0.35^{b} ±0.14	57.44^{b} ±0.44
120	98.86^{c}±0.30	0.30^{b} ±0.14	58.96^{c} ±0.44

Figures with the same alphabets across each column are not significantly ($p<0.05$) different from each other, while figures with different alphabets across each column are significantly ($p<0.05$) different from each other.

3.3. Sensory evaluation

Sensory evaluation is a scientific approach used to assess and interpret human responses to products based on their sensory perceptions. The hedonic scale gauges a respondent's preference or aversion to a sensory attribute, while the just-about-right (JAR) scale measures the ideal level of a sensory attribute in a product considering its intensity and acceptability. The hedonic scale is widely used due to its ruler-like and equally spaced properties. The JAR scale is a bipolar measurement with opposing anchors at each end and a midpoint labelled as 'just-right' or 'just-about-right' (Booth *et al.,* 1983; Shepherd *et al*., 1989; Anon 2003; Meullenet *et al.,* 2007, Rothman and Parker, 2009). This midpoint is considered the participant's ideal level (van Trijp, *et. al.,* 2007). The combination of the hedonic and JAR scales offers guidance for product reformulation or optimisation (Lu *et al.,* 2023).

The panelists involved in this study were untrained but regularly consumed biofortified cassava *gari*. This aims to eliminate the biases in the JAR scale, as identified by Rothman and Parker (2009), which result from cognitive factors that influence perception. The panelists did not find that daylight had a significant effect on the sensory qualities of *gari*, as assessed using both the hedonic scale (Table 2) and the JAR scale (Table 3). The hedonic scores for the sensory qualities ranged from "neither liking nor disliking" to "slight liking." The JAR ratings for the *gari* samples varied from "insufficient" to "just about right" for aroma, colour, sourness, taste, and texture. The aroma of *gari* produced from the 120 h fermented mash was perceived as "just about right." The aroma detected in this sample can be attributed to the accumulation of organic acids during this fermentation period, which is consistent with the characteristic of "*Ijebu gari",* highly prized by southwestern Nigerians. The panelists mostly rated the aroma of *gari* samples as 'neither liked nor disliked' on the hedonic scale, except for the *gari* samples from 48 h of fermented mash, which were assessed as 'slightly liked'.

The panelists found that the *gari* samples from 72 h fermented mash had a "just about right" colour, although this sample was also rated as "slightly liked" on the hedonic scale. Other samples of *gari* were found to have a "lightly yellow" colour, which was not preferred by the panelists according to the JAR scale. The panelists were indifferent toward them on the hedonic scale. This is in-line with the findings of Shepherd *et al.* (1985) and Vickers (1988), who suggested that JAR and hedonic ratings may not predict the same optimal ingredient levels. The Chroma meter was also able to measure the level of yellowness in the *gari*, with optimal levels found in samples prepared from 42-h and 72 h fermented mash (Table 1).

Both JAR scaling and ideal scaling implicitly assume that a participant has an "ideal" level for a specific attribute, which may not be valid if the individual is truly indifferent to changes in that attribute (Li *et al.,* 2014). The fermentation duration had a significant ($p<0.05$) effect on the sensory attributes measured using the hedonic scale. However, the aroma and texture were not significantly ($p<0.05$) affected by fermentation duration when the JAR scale was used to measure the intensity and acceptability. The observed difference can support the findings of Moskowitz (2001) and van Trijp *et al.* (2007) that JAR scaling can be a challenging task for inexperienced consumers. This is because JAR ratings involve at least three decisions: perceiving attribute intensity, determining the location of the participants' ideal point, and comparing the difference between perceived intensity and the ideal point.

Table 2: Effect of lightning and fermentation duration on sensory acceptability of *gari* using the hedonic scale

	Colour	Aroma	OA	Sourness	Taste	Texture
Daylight						
Light	4.01±0.10	3.86±0.07	3.87±0.07	3.76± 0.08	3.90±0.07	3.78± 0.07
Dark	3.96±0.10	3.75±0.07	4.02±0.07	3.59± 0.08	3.88±0.07	3.71± 0.07
p<0.05	0.61	0.23	0.11	0.12	0.81	0.57
LSD	0.19	0.19	0.19	0.22	0.21	0.21
Fermentation duration						
0	3.76±0.17^{a}	3.61±0.12^{a}	3.98±0.12^{ab}	3.23± 0.14^{a}	3.66±0.13^{a}	3.58±0.12^{a}
24	4.01±0.17^{abc}	3.86±0.12^{ab}	3.88±0.12^{ab}	3.56± 0.14^{ab}	3.96±0.13^{ab}	4.06±0.12^{b}
48	4.35±0.17^{c}	4.03±0.12^{b}	4.06±0.12^{ab}	3.93± 0.14^{b}	4.09±0.13^{b}	4.03±0.12^{b}
72	4.20±0.17^{bc}	3.90±0.12^{ab}	4.16±0.12^{b}	3.80± 0.14^{b}	4.04±0.13^{ab}	3.81±0.12^{ab}
96	3.86±0.17^{ab}	3.70±0.12^{ab}	3.88±0.12^{ab}	3.85± 0.14^{b}	3.65±0.13^{a}	3.51±0.12^{a}
120	3.74±0.17^{a}	3.72±0.12^{ab}	3.70±0.12^{a}	3.68± 0.14^{b}	3.93±0.13^{ab}	3.49±0.12^{a}

Figures with the same alphabets across each column are not significantly ($p<0.05$) different from each other, while figures with different alphabets across each column are significantly ($p<0.05$) different from each other.

Table 3: Effect of lightning and fermentation duration on sensory acceptability of *gari* using the JAR scale

	Aroma	Colour	Sourness	Taste	Texture
Daylight					
Light	1.83±0.04	1.77±0.05	1.75±0.04	1.95±0.05	1.73±0.05
Dark	1.99±0.04	1.80±0.05	1.90±0.04	2.15±0.05	1.86±0.05
p<0.05	0.005	0.65	0.02	0.002	0.08
LSD	0.11	0.13	0.12	0.13	0.15
Fermentation duration					
0	1.76±0.07^{a}	1.36±0.08^{a}	1.66±0.07^{a}	1.95±0.08^{a}	1.84±0.09^{bc}
24	1.95±0.07^{ab}	1.55±0.08^{a}	1.68±0.07^{a}	2.06±0.08^{a}	1.56±0.09^{a}
48	1.86±0.07^{ab}	1.79±0.08^{b}	1.93±0.07^{b}	2.14±0.08^{a}	1.75±0.09^{abc}
72	1.98±0.07^{ab}	2.15±0.08^{c}	1.94±0.07^{b}	2.18±0.08^{a}	1.71±0.09^{ab}
96	1.88±0.07^{ab}	1.90±0.08^{b}	1.80±0.07^{ab}	1.95±0.08^{a}	2.00±0.09^{c}
120	2.01±0.07^{b}	1.93±0.08^{bc}	1.93±0.07^{b}	2.05±0.08^{a}	1.90±0.09^{bc}

Figures with the same alphabets across each column are not significantly ($p<0.05$) different from each other, while figures with different alphabets across each column are significantly ($p<0.05$) different from each other.

Sensory scores on the *eba* samples reflect that daylight exposure did not have a significant ($p<0.05$) effect on the aroma, color, moldability, and texture of the *eba* samples, as assessed by the hedonic and JAR scales. The panelists were somewhat indifferent about the sensory attributes assessed, including aroma, colour, moldability, mouthfeel, overall acceptability, and texture of the *eba* samples using the hedonic scale . The aroma and texture of *eba* prepared from 120 h fermented mash were only rated as "just-about-right", while other samples were assessed as having a "too-weak" aroma and a "too-soft" texture, respectively, according to the panelists' preferences. The moldability and colour of this sample after 120 h were also rated as "just-about-right." The panelists observed that the fermentation duration significantly ($p<0.05$) impacted the color, moldability, and texture of the *eba* samples, as assessed using the JAR scale. This can be related to the absorption of starch during the fermentation process and the gelatinization of the starch during *eba* preparation. The texture and overall acceptability were significantly ($p<0.05$) influenced by the fermentation duration when assessed using the hedonic scale. This can be related to the absorption of starch during the fermentation process and the gelatinization of the starch during *eba* preparation. The texture and overall acceptability were significantly ($p<0.05$) affected by the fermentation duration as evaluated using the hedonic scale.

Table 4: Effect of lightning and fermentation duration on sensory acceptability of *eba* using the JAR scale

	Aroma	Colour	Mouldability	Texture
DayLight				
Light	1.92±0.03	1.76±0.04	1.96±0.03	1.83±0.03
Dark	1.93±0.03	1.83±0.04	2.04±0.03	1.86±0.03
p<0.05	0.88	0.26	0.127	0.59
LSD	0.11	0.11	0.1	0.05
Fermentation duration				
0	1.76 ± 0.06^{a}	1.25 ± 0.07^{a}	1.65 ± 0.06^{a}	1.55 ± 0.06^{a}
24	1.88 ± 0.06^{ab}	1.65 ± 0.07^{b}	1.98 ± 0.06^{b}	1.83 ± 0.06^{b}
48	1.93 ± 0.06^{ab}	1.78 ± 0.07^{b}	2.25 ± 0.06^{c}	1.95 ± 0.06^{b}
72	1.99 ± 0.06^{b}	2.04 ± 0.07^{cd}	1.98 ± 0.06^{b}	1.84 ± 0.06^{b}
96	1.93 ± 0.06^{ab}	1.84 ± 0.07^{bc}	2.01 ± 0.06^{b}	1.90 ± 0.06^{b}
120	2.05 ± 0.06^{b}	2.23 ± 0.07^{d}	2.13 ± 0.06^{bc}	2.00 ± 0.06^{b}

Figures with the same alphabets across each column are not significantly ($p<0.05$) different from each other, while figures with different alphabets across each column are significantly ($p<0.05$) different from each other.

Table 5: Effect of lightning and fermentation duration on sensory acceptability of *eba* using the hedonic scale

	Aroma	Colour	Moldability	Texture	Mouthfeel	OA
Daylight						
Light	3.43±0.08	3.68±0.07	3.71±0.07	3.67±0.07	3.42±0.07	3.84±0.07
Dark	3.58±0.08	3.67±0.07	3.80±0.07	3.65±0.07	3.54±0.07	3.76±0.07
P<0.05	0.17	0.16	0.36	0.87	0.29	0.32
LSD	0.22	0.21	0.2	0.19	0.37	0.19
Fermentation Duration						
0	3.48±0.14^{a}	3.59±0.12^{a}	3.39±0.12^{a}	2.73±0.12^{a}	3.08±0.13^{a}	3.45±0.11^{a}
24	3.28±0.14^{a}	3.95±0.12^{a}	3.79±0.12^{b}	3.73±0.12^{b}	3.55±0.13^{b}	3.95±0.11^{c}
48	3.60±0.14^{a}	3.79±0.12^{a}	3.75±0.12^{b}	3.90±0.12^{b}	3.63±0.13^{b}	4.11±0.11^{c}
72	3.50±0.14^{a}	3.61±0.12^{a}	3.86±0.12^{b}	3.90±0.12^{b}	3.73±0.13^{b}	3.83±0.11^{bc}
96	3.50±0.14^{a}	3.55±0.12^{a}	3.84±0.12^{b}	3.95±0.12^{b}	3.43±0.13^{ab}	3.93±0.11^{c}
120	3.66±0.14^{a}	3.55±0.12^{a}	3.92±0.12^{b}	3.75±0.12^{b}	3.48±0.13^{b}	3.58±0.11^{ab}

Figures with same alphabets across each column are not significantly ($p<0.05$) different from each other, Figures with different alphabets across each column are significantly ($p<0.05$) different from each other .OA= Overall acceptability

4.0 Conclusion

In conclusion, carotenoids were synthesized (carotenogenesis) during the solid-state fermentation of biofortified cassava roots. The synthesized trans isomer of beta-carotene was maximally retained for 120 h in the dark environment and 96 h in the light environment. *Gari* and *eba* made from the 120 h fermented cassava had the most preferred sensory attributes on the hedonic and just-about-right scales.

Declaration of conflicting interest

There is no conflict of interest regarding this manuscript.

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References

Antognoni, F., Mandrioli, R., Potente, G., Saa, D.L.T., and Gianotti, A. (2019). Changes in carotenoids, phenolic acids and antioxidant capacity in bread wheat doughs fermented with different lactic acid bacteria strains. *Food Chemistry*, 292(1): 211-216.

AOAC, I. (1990). AOAC: Official Methods of Analysis (Volume 1). K. Helriched.. Association of Official Analytical Chemists. Inc., Arlington.

Bechoff, A., Tomlins, K.I., Chijioke, U., Ilona, P., Westby, A., and Boy, E. (2018). Physical losses could partially explain modest carotenoid retention in dried food products from biofortified cassava. *PLoS One*, 13(3): e0194402

Bhosale, P., and Gadre, R.V. (2002). Manipulation of temperature and illumination conditions for enhanced beta-carotene production by mutant 32 of Rhodotorula glutinis. *Letters in Applied Microbiology,* 34(5): 349-353.

Bokanga, M. (2001). Compendium on post-harvest operations. *International Institute of Tropical Agriculture, Ibadan, Nigeria*, 32.

Burja, A.M., Radianingtyas, H., Windust, A. and Barrow, C.J. (2006). Isolation and characterization of polyunsaturated fatty acid producing Thraustochytrium sp.: screening of strains and optimization of omega-3 production. *Applied Microbiology and Biotechnology,* 72(6):1161-1169.

Ceballos, H, Davrieux, F. and Talsma, E.F., *et al.* Carotenoids in Cassava Roots. Carotenoids. Epub ahead of print 14 June 2017. DOI: 10.5772/INTECHOPEN.68279

Ceballos, H., Davrieux, F., Talsma, E.F., Belalcazar, J., Chavarriaga, P. and Andersson, M.S. (2017). Carotenoids in cassava roots. In *Carotenoids,* InTech, pp. 189-221.

Collard, P. (1963). A species of Corynebacterium isolated from fermenting cassava roots. *Journal of Applied Bacteriology*, 26(2), 115-116.

Collard, P. and Levi, S. (1959). A two-stage fermentation of cassava. *Nature*, 183(4661), 620-621.

de Carvalho, R.R.B., Marmolejo Cortes, D.F., Bandeira e Sousa, M., de Oliveira, L.A. and de Oliveira, E.J. (2022). Image-based phenotyping of cassava roots for diversity studies and carotenoids prediction. *PloS One*, 17(1): e0263326.

Dixon, B., Awoyale, W., and Dixon, A. (2015). Effect of processing on the retention of total carotenoid, iron and zinc contents of yellow fleshed cassava roots.

Esuma, W., Herselman, L. and Labuschagne, M.T. *et al.* (2016). Genome-wide association mapping of provitamin A carotenoid content in cassava. Euphytica. Epub ahead of print 9 September 2016. DOI: 10.1007/s10681-016-1772-5

Eyinla, T.E., Maziya-Dixon, B., Alamu, O.E. and Sanusi, R.A. (2019). Retention of pro-vitamin A content in products from new biofortified cassava varieties. *Foods*, 8(5): 177.

Gambaro, A. and McSweeney, M.B. (2020). Probiotic and prebiotics in foods: Challenges, innovations and advances, Chapter 8. *Advances in Food and Nutrition Research*, 94: 295-337.

Garrido-Fernández, J., Maldonado-Barragán, A., Caballeros-Guerrero, B., Hornero-Méndez, D., and Ruiz-Barba, J. L. (2010). Carotenoid production in *Lactobacillus Plantarum*. *International Journal of Food Microbiology*, 140(1): 34-39.

Kimura, M., Kobori, C.N., Rodriguez-Amaya, D.B. and Nestel, P. (2007). Screening and HPLC methods for carotenoids in sweet potato, cassava and maize for plant breeding trials. *Food Chemistry*, 100(4): 1734-46.

Lu, Q., Ding, W., Guo, X., Xiao, T. and Wang, X. (2023). Drivers of consumer preference derived from active volatiles for cooked eriocheir sinensis. *Animals*, 13(3): 541.

Maziya-Dixon, B., Awoyale, W., Dixon, A.G.O. Effect of processing on the retention of total carotenoid, iron and zinc contents of yellow-fleshed cassava roots. *Journal of Food and Nutrition Research,* 3(38): 483-488.

Montagnac, J.A., Davis, C.R. and Tanumihardjo, S.A. (2009). Nutritional Value of Cassava for Use as a Staple Food and Recent Advances for Improvement. *Comprehensive Reviews in Food Science and Food Safety,* 8(3): 181-194.

Moskowitz, H.R. (2001). Sensory directionals for pizza: A deeper analysis. *Journal of Sensory Studies*, 16(6): 583-600.

Ogbo, F.C. (2006). Assessment of some locally developed technologies for shortening the retting time of cassava. *African Journal of Biotechnology,* 5(9): 775-777.

Onyemauwa, C.S. (2010). Analysis of household consumption of cassava products in Ohaozara, Ebonyi State, Southeast Nigeria. *Research*, 2:1-6.

Osagie, V.E., Onimawo, I.A. and Alamu, O.E. (2017). Residual β-carotene and cyanide levels in gari produced from unfermented yellow cassava (Manihot esculenta Crantz) using local processing method. *Journal of Scientific Research and Reports*, 16(2): 1-5.

Owens, B.F., Gore, M.A. and Magallanes-Lundback, M. (2014). A foundation for provitamin a biofortification of maize: Genome-wide association and genomic prediction models of carotenoid levels. *Genetics*, 198:1699-1716.

Oyewole, O.B. and Odunfa, S.A. (1988). Microbiological studies on cassava fermentation for '*lafun*' production. *Food Microbiology*, 5(3): 125-133.

Ramirez, J.M., Andreu, J.M. and Fujihara, T. (2001). Cultural and sex differences in aggression: A comparison between Japanese and Spanish students using two different inventories. *Aggressive Behavior: Official Journal of the International Society for Research on Aggression*, 27(4): 313-322.

Rodriguez-Amaya and Kimura. (2004). HarvestPlus handbook for carotenoid analysis. HarvestPlus technical monographs 2. Washington, DC and Cali: International Food Policy Research (IFPRI) and International Center for Tropical Agriculture (CIAT).

Rothman, L. and Parker, M.J. (2009). Just-about-right (JAR) scales: Design, usage, benefits, and risks: American Society for Testing and Materials. *West Conshohocken, PA: ASTM International.*

Saltzman, A., Birol, E. and Bouis, H.E. (2013). Biofortification: Progress toward a more nourishing future. *Global Food Security,* 2:9-17.

Santos, R.C., Diogo, R.A., Fontana, J.D. and Bonfim, T.M.B (2016). Carotenoid production by halophilic archaea under different culture conditions. *Current Microbiology,* 72(5): 641-651.

Shepherd, R., Smith, K., and Farleigh, C.A. (1989). The relationship between intensity, hedonic and relative-to-ideal ratings. *Food Quality and Preference,* 1: 75-80.

Shittu, T.A., Alimi, B.A., Wahab, B., Sanni, L.O. and Abass, A.B. (2016). Cassava flour and starch: Processing technology and utilization. *Tropical Roots and Tubers,* 415-450.

Sliwka, H.R., Partali, V. and Lockwood, S.F. (2009). Hydrophilic carotenoids: Carotenoid aggregates. Carotenoids: Physical, chemical, and biological functions and properties; *Landrum, JT, Ed*, 31-58.

Thakkar, S.K., Huo, T., Maziya-Dixon, B. and Failla, M.L. (2009). Impact of style of processing on retention and bioaccessibility of ß-carotene in cassava (Manihot esculanta, Crantz). *Journal of Agricultural and Food Chemistry,* 57(4):1344-8.

Turpin, W., Renaud, C., Avallone, S., Hammoumi, A., Guyot, J.P. and Humblot, C. (2016). PCR of crtNM combined with analytical biochemistry: an efficient way to identify carotenoid producing lactic acid bacteria. *Systematic and Applied Microbiology*, 39(2) 115-121.

Udoh, L.I., Agogbua, J.U., Keyagha, E.R. and Nkanga, I.I. (2022). Carotenoids in cassava (Manihot esculenta Crantz). In carotenoids-new perspectives and application, IntechOpen.

van Trijp, H.C.M., Punter, P.H., Mickartz, F. and Kruithof, L. (2007). The quest for the ideal product: Comparing different methods and approaches. *Food Quality and Preference*, 18(5): 729-740.

Vickers, Z., Holton, E., and Wang, J. (1998). Effect of yogurt sweetness on sensory specific satiety. *Journal of Sensory Studies*, 13(4): 377-388.

World Food and Agriculture – Statistical Yearbook 2021. World Food Agric – Stat Yearb 2021. Epub ahead of print 28 October 2021. DOI: 10.4060/CB4477EN

Yeum, K.J. and Russell, R.M. (2002). Carotenoid bioavailability and bioconversion. *Annual Review of Nutrition*, 22(1): 483-504.

Supplementary Table 1: Correlation of fermentation duration, lightning, colour parameters and carotenoid variables

	FT	Light	TBC	CIS13	CIS9	TRANS	Lightness	Redness	Yellowness
FT	1								
Day Light	0.00	1							
TBC	0.33	0.41*	1						
CIS13	0.08	0.43*	0.95**	1					
CIS9	0.36	0.38	0.97**	0.93**	1				
TRANS	0.39	0.40	0.98**	0.90**	0.91**	1			
Lightness	0.61**	0.34	0.01	-0.19	-0.01	0.10	1		
Redness	0.47*	-0.15	0.28	0.20	0.33	0.27	-0.15	1	
Yellowness	-0.05	0.20	-0.43*	-0.50*	-0.52**	-0.33	0.51*	-0.40	1

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