Received: 24 May 2019 | Revised: 26 September 2019 | Accepted: 18 October 2019

DOI: 10.1111/jfpe.13322

ORIGINAL ARTICLE

Journal of Food Process Engineering

WILEY

β-Carotene-fortified *gari*: Processing variables effect on nutritional and sensory qualities

Ernest E. Abano[1] | Enoch T. Quayson[2] | Martin Bosompem[3] | Margaret Quarm[4]

[1]Department of Agricultural Engineering, School of Agriculture, College of Agricultural and Natural Sciences (CANS), University of Cape Coast, Cape Coast, Ghana

[2]Department of Biochemistry, School of Biological Science, CANS, University of Cape Coast, Cape Coast, Ghana

[3]Department Agricultural Economics and Extension, School of Agriculture, CANS, University of Cape Coast, Cape Coast, Ghana

[4]Department of Agriculture, Komenda Edina Eguafo Abirim Municipal Assembly, Elmina, Ghana

Correspondence

Ernest E. Abano, Department of Agricultural Engineering, School of Agriculture, College of Agricultural and Natural Sciences (CANS), University of Cape Coast, Cape Coast, Ghana.

Email: eabano@ucc.edu.gh

Abstract

Different proportions of orange-fleshed sweet potatoes (OFSP) were used to substitute cassava mash and fermented spontaneously to produce composite *gari*—a gritty-crispy ready-to-eat food product. Both the amount of OFSP and the fermentation duration (FD) caused significant increases in the β-carotene content of the composite *gari*. OFSP addition reduced the luminance while roasting made the composite *gari* yellower when compared with the cake used. Addition of OFSP negatively affected the swelling capacity of the *gari* although not significant. The taste, texture, flavor, and the overall preferences for the composite *gari* decreased due to the addition of the OFSP but FD improved them. The sample with 10% OFSP and FD of 1.81 days was found to produce the optimal *gari*. One portion of the optimal *gari* would contribute to 34.75, 23.2, 23.2, 27, 17, and 16% of vitamin A requirements among children, adolescent, adult males, adult females, pregnant women, and lactating mothers, respectively. The study demonstrated that partial substitution of cassava with OFSP for *gari* production would have the potential to fight the high prevalence rate of vitamin A deficiency among less developed regions of Africa.

Practical applications

Gari is a major staple for Ghanaians and people in the West African subregion due to its affordability and swelling capacity. It is mainly eaten raw with water, sugar, groundnut, and milk as *gari-soakings* or with hot water to prepare gelatinized food called *gari-kai* in Ghana or "eba" among Nigerians. However, *gari* is limited in β-carotene, a precursor of vitamin A. Orange-fleshed sweet potato (OFSP) is known to contain a large amount of β-carotene, a vitamin A precursor. There is severe clinical vitamin A deficiency (VAD) prevalence among Ghanaians and many African countries. Therefore, addition of OFSP to *gari* would have the potential to fight the high prevalence rate of VAD among less developed regions of Africa.

1 | INTRODUCTION

Vitamin A deficiency (VAD) is the leading cause of preventable blindness and contributes to severity of infections, child mortality, maternal mortality, and poor pregnancy outcomes. VAD is a serious public health problem in Ghana. The prevalence of VAD in Ghana is estimated at 76% (USAID, 2016; World-Vision, 2014), which is close to double that of Africa's average of 41.9% (USAID, 2016). Food and Agriculture Organization (FAO) and World Health Organization (WHO) statistics on food systems for better nutrition show that Ghana is the third worst country in the world with severe VAD problems after Sao Tome and Principe (95.6%) and Kenya (84.4%), which occupy the first and second positions, respectively (FAO/WHO, 2005). VAD prevalence is the highest among children under 5 years of age and among women of childbearing age. VAD prevalence among under 5 years of age and women of childbearing age in Ghana has

 © 2019 Wiley Periodicals, Inc.

worsened from an estimated amount of 20% in 2004 to its current rate of 35.6% (Glover-amengor et al., 2016). The main cause of VAD is low dietary intake of foods rich in vitamin A or its precursors. This is a main problem among the poor since their diets tend to be of limited diversity and low in food of animal parts with high vitamin A content such as the liver. Infections also contribute to VAD. Promotion of food-based diets rich in vitamin A is considered the most sustainable approach to addressing VAD (Low et al., 2007), with supplementation considered a short-term strategy and fortification as medium term. Golden rice (*Oryza sativa*), carrot (*Daucus carota* subsp. *sativus*), and orange-fleshed sweet potato (OFSP; *Ipomea batatas*) are among the best sources of β-carotene with about 85% of the carotenoids in them capable of being converted to vitamin A after consumption (FAO/WHO, 2005). However, golden rice is not grown in Ghana while carrot on the other hand is expensive. In addition, although biofortified cassava and red palm oil (RPO) could be used in *gari* production to enhance color and pro-vitamin A carotenoids, *gari* produced from RPO is reported to show high β-carotene stability than that from biofortified cassava stored under ambient conditions (Bechoff et al., 2015) but has the disadvantage of generating peroxides, especially at the high roasting temperature (Alyas, Abdulah, & Idris, 2006), and unpleasant smell during storage, which are harmful to the human body. Compared to cassava, sweet potato is reported to have high β-carotene stability (Nascimento, Fernandes, Mauro, & Kimura, 2007).

This leaves OFSP as the viable option to meet the vitamin A needs of Ghanaian citizens (Low et al., 2007). Increased consumption of OFSP products therefore has the potential to contribute to improved vitamin A status among Ghanaians. Incorporation of OFSP into food systems as a strategy to improved nutrition has been suggested (Laurie, Faber, & Claasen, 2018). OFSP (*I. batatas*) composite bread as a significant source of dietary vitamin A is documented (Awuni, Alhassan, & Amagloh, 2018). The potential of OFSP to improve the vitamin A status in young children has been confirmed in both efficacy and effectiveness studies (Hotz et al., 2012; Tumwegamire et al., 2004; van Jaarsveld et al., 2005). OFSP is produced in large quantities in the Central and Eastern Regions of Ghana. However, there are unsold OFSP roots by farmers who produce them especially during bumper harvest because consumers complain of its undesirable soft texture after wet cooking, rendering wet-cooked OFSP unappealing, so the produce is underutilized and its cultivation is not encouraged. Farmers livelihood are seriously affected due to the unsold commodities. In addition, there is unsatisfied demand by farmers and processors to possess adequate knowledge and skills to process OFSP into secondary and tertiary products or develop it into OFSP-containing products. It is against this background the study adopted a strategy to incorporate it into existing and well-known staple, *gari*, which conventionally lacks the nutrients inherent in OFSP, particularly, pro-vitamin A carotenoids. *Gari* is a ready-to-eat grit produced from roasted fermented cassava mash, and it is a major staple for Ghanaians and people in the West African subregion due to its affordability and swelling capacity (SC). It is mainly eaten raw with cold water, sugar, groundnut, and milk as *gari-soakings* or with hot water to prepare gelatinized food called "*gari-kai*" in Ghana or "eba" among Nigerians. During *gari* processing, the cassava mash is typically fermented for up to 4 days prior to roasting depending on the cassava variety and taste preferences by the particular community. The fermentation process and roasting affect the taste, flavor, and color of the *gari*. Some *gari* processors in Ghana add the artificial egg yellow food color powder made of sodium chloride, tartrazine E-102, and allura red E-129 to change the natural white *gari* to enhance its attractiveness. Fermentation of the cassava mash is a two-phase regime. In the first phase, the starch in the mash is broken down to sugars by *Corynebacterium* and metabolizes into organic acids. The organic acids break down the cyanogenic glucosides in the cassava and release hydrogen cynanide (HCN). The second phase initiates the growth of *Geotrichum candida* to produce mold leading to release of aldehydes and esters from the sugars, which characterize the typical *gari* flavor. It is against this background that the project seeks to develop OFSP-*gari* to investigate how its proportionate amount and fermentation duration (FD) affects the nutritional, functional, and sensory quality of OFSP-*gari*. In addition, the study optimized the OFSP amount and FD and assessed the contribution of the optimal and validated composite *gari* to the recommended dietary allowance (RDA) of vitamin A among children, adolescents, adult males, and adult females, as well as pregnant and nursing mothers.

2 | MATERIALS AND METHODS

2.1 | Sample preparation

Mature and wholesome *Afisiafi* cassava variety purposely developed for *gari* production and OFSP roots were harvested fresh from certified farms by the Department of Food and Agriculture of the Ministry of Food and Agriculture, Ghana, at Jukwa and Dahyia communities, respectively, in the Cape Coast Metropolitan Assembly and immediately brought to the *gari* processing center for processing. The cassava roots were peeled and washed while the OFSP roots were thoroughly washed without peeling. After washing, the samples were allowed to drain to remove excess water. A total weight of 20 kg each mixed according to the design proportions (Table 1) was grated into smooth mash. The mash was packed into polypropylene bags, tied, screw-pressed to dewater, and fermented spontaneously without the addition of a starter culture.

2.2 | Experimental design

A two-factor, three-level factorial response surface method was used for the study (Table 1). This design was chosen due to its robustness for optimization studies involving many responses and at least two factors. The effect of different proportions of OFSP ranging from 10 to 30% was chosen based on similar studies for composite bread (Nzamwita, Gyebi, & Minnaar, 2017) and composite *gari* cost implications (Awuni et al., 2018). The FD from 1 to 3 days was selected based on the traditional duration of fermentation in Ghana. This combination yielded 11 experimental runs with two center points using the Minitab 17 software with each run duplicated. The control sample

TABLE 1 Result of two-factor, three-level RSM for the OFSP–cassava composite gari

X1 (%)	*X2* (d)	BC (μg/ml)	*L**	*a**	*b**	SC	Appearance	Taste	Texture	Flavor	OA
10	3	27.85	84.669	5.56	36.17	2.86	5.5	6.1	6.1	5.8	6.5
20	1	11.63	80.032	6.35	36.19	3.36	4.2	5.2	4.1	4.3	4.5
10	1	6.06	83.898	3.58	40.45	3.96	6.2	6.2	6.2	6.5	6.8
20	3	32.32	81.041	6.49	38.06	2.78	4.6	5.6	4.5	4.5	4.9
30	2	27.78	76.382	8.84	43.11	3.40	4.6	5.5	4.3	4.3	4.5
20	2	18.35	79.36	7.66	40.24	3.10	5.4	5.7	5.3	5.0	5.5
30	3	35.36	77.982	8.52	40.00	2.87	3.9	4.9	4.7	4.5	4.7
20	2	23.78	79.36	7.63	40.23	2.96	5.7	5.9	5.1	5.4	5.6
20	2	27.78	83.471	7.66	40.20	2.89	5.2	5.7	5.5	5.6	5.7
10	2	16.07	75.807	5.31	42.96	3.16	7.2	6.5	5.9	5.7	6.6
30	1	13.04	88.938	9.25	41.92	3.42	3.8	4.1	5.0	4.8	4.2
Contr	1	5.27	88.938	−0.62	21.92	4.78	8.0	7.2	7.2	7.2	8.0
Contr	2	5.58	88.657	0.50	20.39	4.48	7.8	7.0	6.7	6.9	7.4
Contr	3	4.97	89.277	0.26	16.85	4.63	7.6	7.1	6.2	6.5	7.0

was without the addition of OFSP. The effect of the two factors on the β-carotene content, luminescence, and color of *gari* (brightness, *L** redness, *a**, and yellowness, *b**); SC; and sensory attributes including appearance, color, flavor, taste (sourness), texture, and overall acceptability was investigated and used for the optimization studies.

2.3 | Roasting of OFSP composite *gari*

After the simultaneous screw-pressing and spontaneous fermentation of the mash, the resulting cake was pulverized and screened through 1.2-mm screens. The screened dough was roasted in stainless steel pans at a temperature of 100 ± 5°C for 20.14 ± 1.5 min until the moisture content reached 5.0 ± 1.4% (dry basis) ensuring that the product is very crispy. These conditions were chosen based on preliminary trials conducted. Temperatures during roasting allow for gelatinization and drying to take place, and subsequently impacts on the crispiness and grittiness of the composite *gari* were monitored using an infrared thermometer. After roasting, the product was poured into a clean dry bowl and allowed to cool for 30 min to bring the product temperature to about 40°C. The cooled OFSP–cassava composite *gari* was sifted through 0.6-mm screens to ensure uniformity and finer particles size of the final food product and packaged in 500-ml airtight plastic bottles and kept in a freezer at −10°C for further analysis.

2.4 | Determination of β-carotene

The β-carotene of the fresh mash and roasted *gari* was determined following the method reported by Sadaf et al. (2013) with slight modification. One gram each of the fresh mash or roasted *gari* was weighed and transferred into a volumetric flask to which 10 ml of absolute ethanol was added and left for about 20 min with periodic shaking. The extraction of the carotenoids in the roasted samples was aided by using a mortar and pestle. The extraction with ethanol was repeated thrice ensuring that most of the pigment was removed from the test sample. The resulting solution was filtered using 0.45-μm filter paper. Exactly 15 ml of petroleum ether (40–60°C) was added to the filtrate, shaken gently, and left to stand for 20 min resulting in a two-layered solution. The top layer with the β-carotene was pipetted for the absorbance reading at a wavelength of 450 nm against a blank of petroleum ether. The concentration of β-carotene was calculated (Equation 1 from the average of duplicate readings:

$$\text{Total carotenoids}\,(\mu\text{g/ml}) = \frac{\text{ABS} \times \text{V}(\text{ml}) \times 10{,}000}{2592 * W(\text{g})}, \tag{1}$$

where ABS is the absorbance, *V* (ml) is the volume of solvent used for the extraction, *W* (g) is the weight/volume of sample initially taken, and 2,592 is the extinction coefficient of β-carotene in petroleum ether.

2.5 | Color measurements

The color of the product was measured in Hunter's parameters with a real-time automatic color difference meter (Ocean Optics, 77,501, 400 μV. The machine was calibrated by placing the source of the measuring light flux (D65°) against the surface of the white calibration plates supplied by the manufacturer. After standardization, color spectrum for each of the sample was determined. The data were processed through an Ocean Optics' SpectraSuite data processor to extract the color parameters from which the *L**, *a**, *b**, and hue angles values were selected. The color brightness coordinates, *L**, measure the brightness value of the *gari* and range from black (0) to white (100). The chromaticity coordinates, *a**, measures the redness when positive (+60) and greenness when negative (−60), and the chromaticity coordinate, *b**, measures yellow when positive and blue when negative.

2.6 | Swelling capacity

SC was determined according to the method reported by Iwuoha (2004). An amount of 3 g of each sample was transferred into clean, dry, and graduated (50 ml) cylinders. The sample was gently leveled and its volume (V_1) was noted prior to addition of 30 ml distilled water. The cylinder was swirled and allowed to stand for 1 hr while the change in volume (swelling) was recorded after 15 min (V_2). The swelling power of each composite cassava–OFSP *gari* sample was calculated as a multiple of the original volume using Equation (2):

$$SC = \frac{V_2 - V_1}{V_1}. \quad (2)$$

2.7 | Sensory analysis

A sensory panel was formed from among the staff and students of the University of Cape Coast, Ghana. The criteria for selection of the panelists were that (a) they were available and willing to participate in the sensory analysis tests, (b) they were regular consumers of *gari*, (c) they were of sound health, no allergies, and dentures, (d) they were not color blind and could taste sweet, bitter, and umami tastes, and (e) could identify roasted *gari* flavors. A consumer test consisting of 50 people (both males and females) was selected. The panelists were semitrained to recognize and score different quality attributes of the composite OFSP–cassava *gari* samples including appearance, color, flavor, taste (sourness), texture (graininess), and overall acceptability. The test samples were served at room temperature conditions at 11:00 a.m. in the morning to the panelists. Prior to the sensory testing, the panelists stayed away from any food for at least an hour. The samples were served in transparent plastic cups in a well-lit sensory evaluation room maintained at a temperature of 20°C. The panelists were served water for rinsing mouth in between sample testing. The panel assessed the samples using a 9-point hedonic scale denoted as like extremely 9; like very much 8; like moderately 7; like slightly 6; neither like nor dislike 5; dislike slightly 4; dislike moderately 3; dislike very much 2; and dislike extremely 1.

2.8 | Optimization of the OFSP–cassava composite *gari* process

The optimization of the OFSP–cassava composite *gari* production was performed using the response optimizer composite desirability index (CDI) in the Minitab Statistical Software. Equation (3) suggested by Myers, Montgomery, and Anderson-Cook (2002) was used to compute CDI:

$$CDI = \left[\prod_{i=1}^{n} \mathrm{di}(Y_i)\right]^{\frac{1}{n}}, \quad (3)$$

where n^* is the number of responses and di is the desirability index for each response variable. Y_i is a multivariate optimization approach used to show the desirability of the various responses. The CDI ranges between 0 and 1 with 0 being the least desirable while 1 is the most desirable. Maximization of CDI is the aim of optimization studies. The optimization process combines goals such as maximize, minimize, or target for the factors and the responses. In this study, the goal for the OFSP amount and spontaneous FD was at any level within the design range. However, for the various responses studied, maximizing β-carotene content, brightness, yellowness, SC, and the sensory attributes was desired with the exception of the redness of the composite *gari*, which was minimized.

2.9 | Assessment of the contribution of OFSP–cassava composite *gari* to vitamin A requirements

The vitamin A content of the optimized composite *gari* was calculated as retinol activity equivalents (RAE) using an RAE conversion factor of 1 μg β-carotene equaling to 0.167 μg retinol equivalent as recommended by the FAO/WHO joint report (FAO/WHO, 2005). The contribution of the optimized *gari* to the people of different groups was determined based on a volume basis of 100 ml as one portion of the OFSP–cassava composite *gari*. The bioconversion of retinol to vitamin A activity was estimated to be 1 μg β-carotene to 0.5 μg of retinol. The groups of individuals used for the assessment of the vitamin A contribution of the OFSP–cassava composite *gari* are children, adolescents, adult males, and adult females between the respective ages of 3 and 9 years, 10 and 18 years, and 19 and 65 years as well as pregnant women and lactating mothers.

2.10 | Statistical analysis

Analysis of variance was carried out using the Minitab 17 Statistical software to determine the influence of OFSP amount and FD on the β-carotene content, color, SC, and sensory properties of the OFSP *gari* at a probability of 95%. The response surface plots for the factors and the significance of each model term for a second-order polynomial function was generated.

3 | RESULTS AND DISCUSSION

3.1 | β-Carotene in OFSP–cassava composite *gari*

β-Carotene, which is converted to vitamin A by the human body when consumed and is in high amount in OFSP, has the potential to combat the VAD in developing countries. The effect of OFSP amount and dough FD on the β-carotene content of the composite *gari* is shown in Figure 1. Expectedly, both the increases in the OFSP amount and the FD caused significant ($p < .05$) increases in the β-carotene content of the composite *gari* (Equation 3). Yet, the contribution of FD to β-carotene release in the *gari* was about 2.5 times higher than the amount of OFSP as shown by the Y_{BC} quadratic model (Equation (3)). Generally, compositing OFSP with cassava for *gari* production resulted in an increase in the amount of β-carotene in the composite *gari* (Table 1). The results agree with related studies where OFSP flour and puree were composited with wheat flour for composite bread production (Awuni et al., 2018; Nzamwita et al., 2017). Increases in β-carotene as OFSP amount is increased may primarily be due to the concentration effect of the OFSP in the cassava dough. There are a number of reasons that could account for the increase in β-carotene as fermentation time increased. Loss of solid matter as well as unaccounted moisture as fermentation time increased may be one reason (Maziya-Dixon et al., 2008). The increased extraction efficiency of carotene as a result of fermentation could be another possible reason (Rodriguez-Amaya, 1997). Indeed, the fermentation process is associated with disruption of tissues and breaking of barrier allowing for easy accessibility and extraction of supramolecular proteolipid complexes, which are the usual state of occurrence of carotenoids in tissues (De Moura et al., 2015).

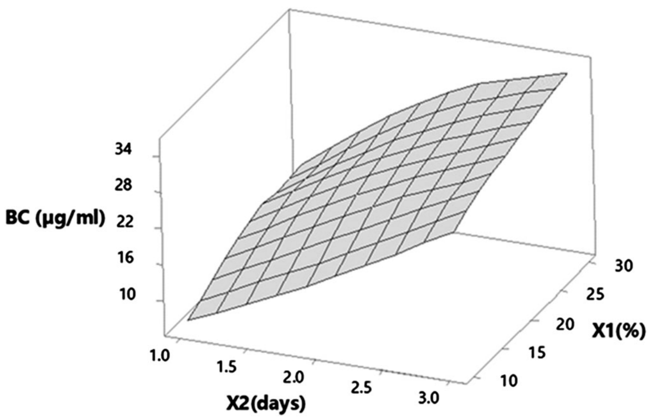

FIGURE 1 Effect of OFSP amount and dough FD on beta-carotene content in OFSP-cassava composite gari. X1 is the percentage amount of OFSP in the composite; X2 is spontaneous FD in days. FD, fermentation duration

Roasting of the *gari* affected the degradation of the β-carotene content of the fermented dough. As expected, carotenoids are susceptible to heat, and therefore, the relatively high roasting temperature conditions of the *gari* would lead to some degradation of the β-carotene. Essentially, heat application results in isomerization of all-*trans*-β-carotene to the *cis*-*trans*-β-carotene, which has a lower vitamin A activity, thus making the contribution of all-*trans*-β-carotene higher compared with the *cis*-*trans*-β-carotene as noted by Nzamwita et al. (2017). The interaction as well as the curvature effect of OFSP addition and FD was not significant model terms on the β-carotene content of the OFSP–cassava composite *gari*:

$$Y_{BC} = 23.31 + 4.36X_1 + 10.79X_2 + 0.15X_1X_2 - 1.39X_1^2 - 1.34X_2^2. \quad (3)$$

3.2 | Effect of OFSP–cassava composite on the color of *gari*

Color is one of the greatest vital quality criteria of food choice by consumers. The brightness of *gari* is an important indicator for *gari* consumers as it is a measure of its purity on the Ghanaian market. Though white *gari* is adjudged pure, yellow hue *gari* is priced higher in Ghana due to the belief that it has added nutrients from food color or red palm oil. For this reason, OFSP was chosen to simultaneously add nutrient in the form of β-carotene and color to the *gari*. Both the

TABLE 2 RSM coefficients for a quadratic model terms for the OFSP–cassava composite *gari* responses and their significance

Response	β_0	X_1	X_2	X_1X_2	$X_1{}^2$	$X_2{}^2$	R^2
BC	23.31	4.36	10.79	0.15	−1.39	−1.34	94.06
p value	<.001*	.021*	<.0001*	.932	.525	.539	
*L**	79.468	−3.6445	0.6592	0.351	0.296	0.906	99.69
p value	<.0001*	<.0001*	.001*	.029*	.098	.002*	
*a**	7.475	2.027	0.235	−0.677	−0.118	−0.771	97.31
p value	<.001*	<.0001*	.208	.019*	.657	.027*	
*b**	40.297	0.909	−0.723	0.590	2.644	−3.259	81.28
p value	<.0001*	.182	.273	.450	.033*	.015*	
SC	3.0021	−0.0483	−0.3717	0.1375	0.250	0.040	89.28
p value	<.0001*	.500	.003*	.152	.059	.714	
Appearance	5.422	−1.110	−0.047	0.185	0.441	−1.004	95.91
p value	<.0001*	<.0001*	.714	.265	.063	.003*	
Taste	5.019	−0.693	−0.003	−0.055	0.543	−0.267	71.72
p value	<.0001*	.025*	.988	.846	.17	.466	
Texture	5.832	−0.7128	0.1972	0.219	0.101	−0.559	94.75
p value	<.0001*	<.0001*	.077	.10	.495	.009*	
Flavor	5.057	−0.745	−0.137	0.090	0.363	−0.232	73.38
p value	<.0001*	.018*	.555	.748	.325	.516	
OA	5.44	−1.098	0.101	0.192	0.42	−0.433	93.44
p value	<.0001*	.001*	.499	.307	.105	.098	

*Means significant at $p < 0.05$.

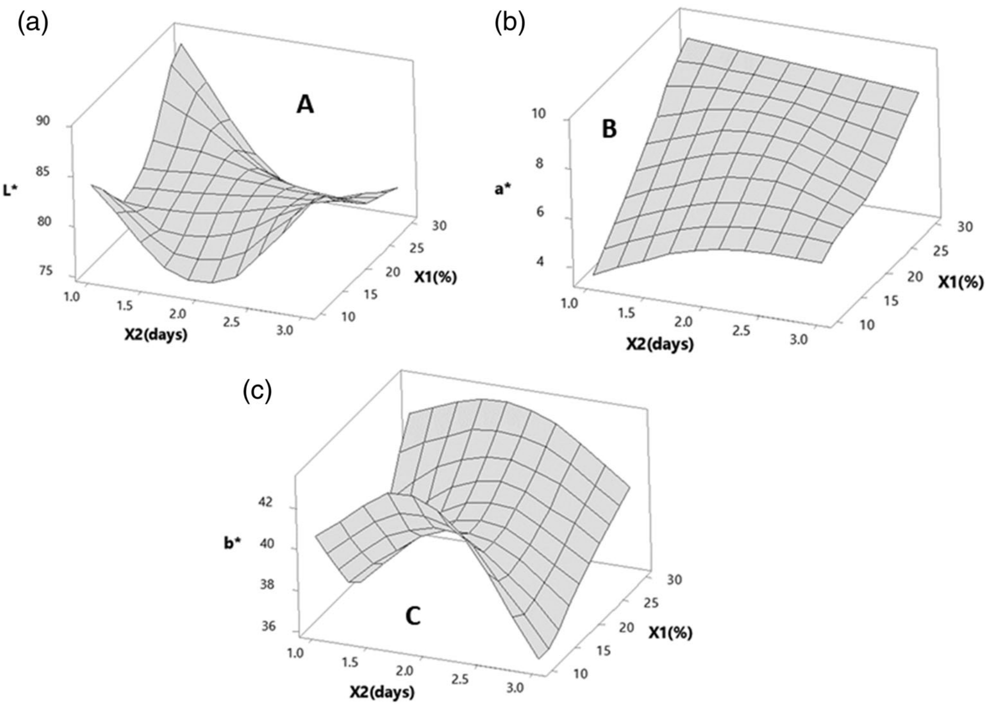

FIGURE 2 Effect of OFSP and FD on (a) brightness, (b) redness, (c) yellowness of composite gari. X1 is the percentage amount of OFSP in the composite; X2 is spontaneous FD in days. FD, fermentation duration

OFSP amount and the FD significantly affected the whiteness of the composite *gari* (Table 2). However, adding OFSP to cassava dough had a negative effect on the *gari* brightness while FD had a positive effect. The increases in the amount of OFSP decreased the brightness of the *gari* significantly with a much higher effect (5.5 times) than FD (Figure 2a; Table 2). This is expected because OFSP has an orange color and this impacted on the whiteness of cassava used for the *gari* production. The interaction between OFSP and FD as well as the curvature effect of fermentation was significant. Compared with the control samples, the brightness of all the OFSP–cassava composite *gari* decreased. This suggests that luminance of the OFSP–cassava composite *gari* diminished due to the addition of the OFSP but fermentation enhanced it. Since the brightness of the cake (data not shown) decreased after roasting, it does suggest that the high-temperature conditions used for roasting the composite cake contributed to the decreased luminance of the *gari*. This could be attributed to the high sucrose (30% of total carbohydrate in OFSP), which would undergo caramelization as was reported in a related study involving sweet potato starch in tapioca production (Akintayo et al., 2019).

The redness, $a*$, of the composite *gari* was affected significantly mainly by the addition of the OFSP and not the FD although the interaction between the amount of OFSP and FD as well as the quadratic effect of FD did affect the redness. Therefore, a lower amount of OFSP to cassava mash and fermentation for about 2 days will minimize redness of the composite *gari*. Since red *gari* is not a desirable product in Ghana, minimization of this color attributes should be desirable. It is also worthwhile mentioning that the relative contribution of OFSP amount to the redness of the *gari* was about 8.6 times that of the FD. This suggests that when OFSP is used to fortify cassava for *gari* preparation, excessive amount (>30%) should be avoided (Figure 2b). In our study, excessive amount of OFSP in the dough produced more lumps and brown pigment after roasting. Redness of the composite *gari* generally increased when compared with the control, which could also be attributed to caramelization of the high sucrose in OFSP as mentioned in the preceding section. The contribution of the Maillard reaction to redness may be very marginal as OFSP is not a rich source of protein.

The yellowness, $b*$, of the *gari* increased with increment in the amount of OFSP, while FD decreased it but both not significantly in the main regions. Both the curvature regions of the two factors used in this study affected the yellowness with the OFSP addition playing a positive role (Table 2). The amount of OFSP, however, contributed more to the yellowness of the *gari* 1.25 times that of the FD. Considering the range of hue angles of the dough used for the *gari* production (59° and 71°), it does indicate that roasting improved the hue angles of the OFSP–cassava composite *gari* samples (78° and 85°), respectively. A hue angle of 0° or 360° represents red hue, while angles of 90°, 180°, and 270° represent yellow, green, and blue hues, respectively. This suggests that the roasting of the OFSP–cassava composite dough made the *gari* yellower than the cake used to produce the *gari*. The second-order polynomial for the color parameters are displayed in Equations (4)–(6):

$$Y_{L*} = 79.468 - 3.6445X_1 + 0.6592X_2 + 0.351X_1X_2 + 0.296X_1^2 + 0.906X_2^2, \tag{4}$$

$$Y_{a*} = 7.475 + 2.027X_1 + 0.235X_2 - 0.677X_1X_2 - 0.118X_1^2 - 0.771X_2^2, \tag{5}$$

$$Y_{b*} = 40.297 + 0.909X_1 - 0.723X_2 + 0.59X_1X_2 + 2.644X_1^2 - 3.259X_2^2. \tag{6}$$

3.3 | Effect of OFSP–cassava composite on swelling capacity of *gari*

SC of *gari* is one of the quality indices influencing consumer acceptability, as it gives higher volume and a sense of satisfaction to consumers and processors alike. As a result, the swelling index of at least 300% of its original volume is preferred by consumers (Akingbala, Oyewole, Uzo-Peters, Karim, & Baccus-Taylor, 2005; Steinkraus, 1995). In this study, depending on the amount of OFSP used for the composite dough, the SC values ranged from 286 to 396% for the OFSP–cassava composite *gari* (Figure 3). These values are lower than the SC values for the *gari* made from the dough that had no OFSP (448–478%). The range of OFSP amount used from 10 to 30% for the study was not significant on the SC values (286–396%) of the composite *gari* although the effect was negative (Table 2). However, FD negatively affected the SC values of the *gari* significantly ($p < .01$). Fermentation of the OFSP composite *gari* contributed about 7.6 times to diminishing the SC of *gari* than the amount of OFSP (Figure 3). This may have happened because fermentation breaks down the carbohydrates in the OFSP–cassava dough due to the production of lactic acid. Lactic acid fermentation has been reported to result in a significant decrease in carbohydrate and fiber (Ogodo, Ugbogu, Onyeagba, & Okereke, 2017). Additionally, OFSP is a rich source of sugars including reducing sugars such as glucose and fructose and nonreducing disaccharide sucrose and reducing disaccharides maltose. Most likely, its substituting cassava dough might have decreased the starch content and other carbohydrates such as fiber content of the composite dough, in which components contribute greatly to SC of the product in which they occur. SC of *gari* in water is mainly influenced by the grit particle size, the initial moisture content, and FD, as well as the amylose and amylopectin in the *gari*. Swelling capacities of *gari* between 330 and 450% were reported when up to 20% yellow fleshed sweet potato was used to fortify bitter TS53201 cassava variety (Olayinka, Balogun, Olaide, & Wasiu, 2016). Similar SC values between 301 and 430% were reported by Ojo and Akande (2013) for cassava and sweet potato mixes up to 50% each:

$$Y_{sc} = 3.0021 - 0.0483X_1 - 0.3717X_2 + 0.1375X_1X_2 + 0.25X_1^2 + 0.040X_2^2. \quad (7)$$

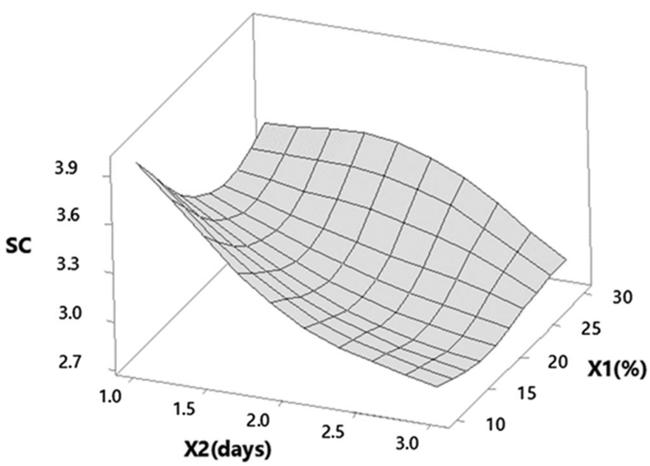

FIGURE 3 Effect of OFSP amount and FD on the swelling capacity (SC) of composite gari. X1 is the percentage amount of OFSP in the composite; X2 is spontaneous FD in days. FD, fermentation duration

3.4 | Effect of OFSP–cassava composite on the sensory properties of *gari*

The effect of the processing variables on the sensory properties when the composite *gari* samples were assessed in their dry particulate form by the panelists is shown in Figure 4. The appearance of the composite *gari* was negatively affected by the addition of OFSP significantly as indicated by the sensory results (Figure 4a) while FD affected the appearance positively but not significant. The taste, texture, flavor, and the overall acceptability were similarly affected by the fortification of cassava with OFSP while FD for all the model terms had positive effects on the taste, flavor, texture, and overall acceptability of the OFSP–cassava composite *gari*. The relative contribution of fermentation to the sensory attributes studied in this present study was higher than the OFSP addition as can be seen from the model coefficients for Equations (8)–(12). It is evident from the curvature effect that beyond 2 days of fermentation, the taste, appearance, and the texture preferences started to decline (Figure 4). This suggests that a moderate amount of OFSP in combination for about 2 days of fermentation would have the highest consumers acceptability for the OFSP–cassava composite *gari*. As fermentation proceeds beyond 2 days more lactic acid is produced, which makes the *gari* taste sour. Excessive sourness caused an unpleasant mouth feel, making a longer duration of fermentation undesirable to consumers. This observation is consistent with the report by Abass, Dziedzoave, Alenkhe, and James (2012) that *gari* should not be too acidic. Similarly, as the amount of OFSP in the composite *gari* increases the product particle size becomes coarser, which decreased the texture preference by the consumers (Figure 4b), since a smooth texture *gari* is preferred by consumers (Abass et al., 2012). Fiber from the OFSP might be contributing to the increased coarseness of the composite *gari*, especially since the tubers were not peeled before being used. High OFSP inclusion in *gari* production may therefore not be encouraged. Alhough there are obvious benefits of fermentation to *gari* production including improvement in taste, shelf life, flavor, safety, and reduction in cyanide content of bitter cassava variety, fermentation for OFSP–cassava composite *gari* should not proceed beyond 2 days if the target market is Ghana. This is not surprising because consumers in Ghana and Southeast of Nigeria prefer mild sour taste *gari* while those in the Southwest of Nigeria accept an acidic taste (Abass et al., 2012). Overall, the consumer preference and acceptability for the control *gari* was higher than the OFSP–composite *gari*. These trends depict that for OFSP to be introduced effectively into *gari* food-based systems to solve the VAD in Ghana and beyond, smaller amounts should be considered for the maximum consumer acceptability. Our results agree with studies by Olayinka et al. (2016) who reported that 10% partial substitution of *gari* with yellow fleshed sweet potato scored the highest consumer preference test over the 20% substitution.

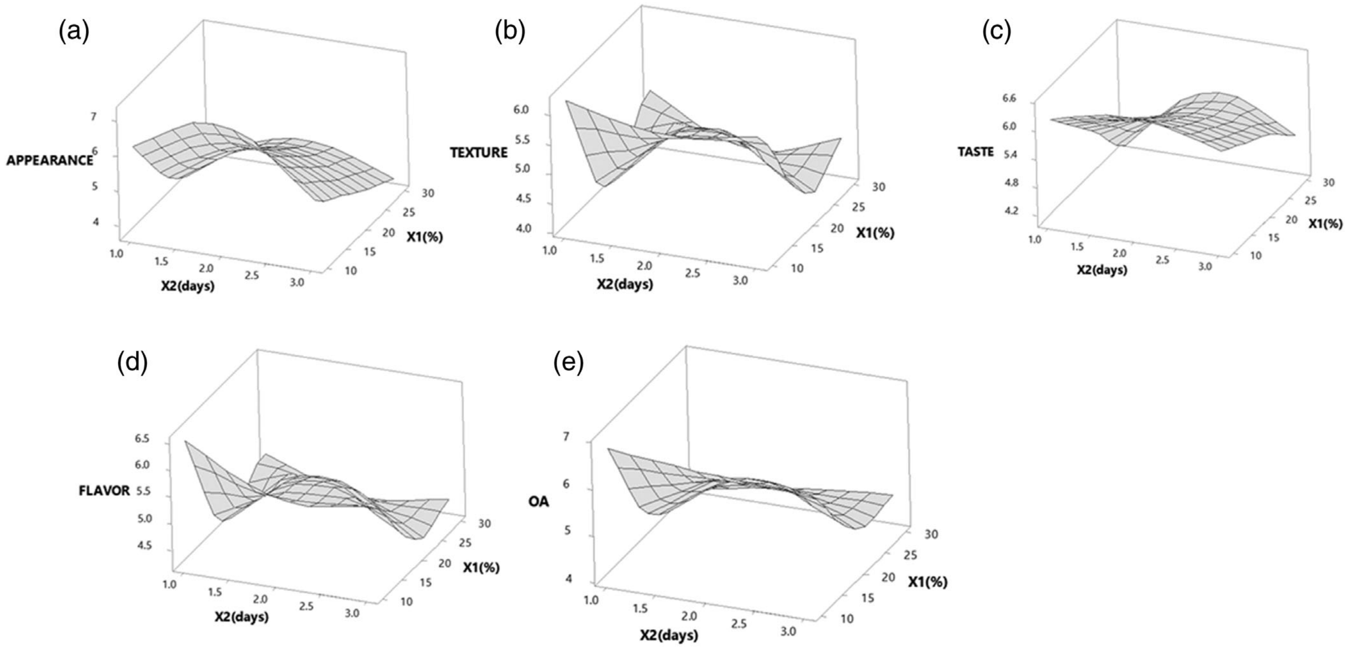

FIGURE 4 Effect of OFSP and FD on the sensory properties of the composite gari (a) appearance, (b) texture, (c) taste (d) flavor, and (e) overall acceptability. X_1 is the percentage amount of OFSP in the composite; X_2 is spontaneous FD in days. FD, fermentation duration

Intense education is, however, required for consumers to understand the benefits of higher amounts of OFSP in *gari* to demystify the negative perceptions that *gari* should be white and nothing more. The second-order polynomial showing the main, interaction, and curvature effects of the processing variables on the sensory indices is shown in Equations (8)–(12)

$$Y_{Appearance} = 6.22 - 0.3244X_1 + 3.599X_2 + 0.0185X_1X_2 + 0.00441X_1^2 - 1.004X_2^2, \quad (8)$$

$$Y_{Texture} = 5.904 - 0.1554X_1 + 1.996X_2 + 0.0219X_1X_2 - 0.001X_1^2 - 0.559X_2^2, \quad (9)$$

$$Y_{Taste} = 7.29 - 0.275X_1 + 1.18X_2 - 0.0055X_1X_2 + 0.00543X_1^2 - 0.267X_2^2, \quad (10)$$

$$Y_{Flavor} = 7.70 - 0.238X_1 + 0.61X_2 - 0.009X_1X_2 + 0.00363X_1^2 - 0.232X_2^2, \quad (11)$$

$$Y_{OA} = 8.16 - 0.3164X_1 + 1.446X_2 + 0.0193X_1X_2 + 0.0042X_1^2 - 0.433X_2^2. \quad (12)$$

3.5 | Optimization of the OFSP–cassava composite *gari*

In the range of independent variables used for the production of the composite *gari*, the simulation with 95% confidence gave 10% OFSP and FD of 1.81 days or 43 hr as the optimized processing variables. Under these optimal conditions, the maximum predicted responses were 15.47 μg/ml β-carotene, 83.38 brightness, 42.16 yellowness, 5.13 redness, 340% SC, 6.98 score for appearance, 6.63 for texture, 6.23 for taste, 6.2 for flavor, and 6.96 for overall acceptability. The composite desirability of 0.77 was obtained for the effect of OFSP amount and FD on the *gari* quality and its sensory attributes. The desirability of each of the response parameters determined in this present study is shown in Figure 5. The taste, texture, and appearance of the composite *gari* gave the highest desirability index following the optimization prediction model while the β-carotene recorded the least desirability. These predictions are good because taste, texture, and appearance are most important attributes of processed *gari* in the Ghanaian market. Consumers easily perceive texture and appearance when buying *gari*. Aggregators and consumers most often than not taste *gari* prior to buying. Similarly, *gari* grittiness, grit uniformity, and brightness of the color are considered more important to processors and consumers than the type of color (Abass et al., 2012). These attributes motivate consumers to purchase *gari* to enable them derive the needed intrinsic nutritional benefits. Verification of the optimized conditions gave 16.72 μg/ml β-carotene, 85.16 brightness, 40.2 yellowness, 4.93 redness, 350% SC, 6.75 score for appearance, 7.0 for taste, 7.35 for texture, 7.0 for flavor, and 7.2 for overall acceptability. These experimental values are closer to the predicted responses, indicating the goodness of fit of the model.

3.6 | Contribution of OFSP–cassava composite *gari* to vitamin A requirements

The contribution of *gari* to the RDA of vitamin A largely depended on the amount of OFSP in the composite *gari* (Table 1). The physiological

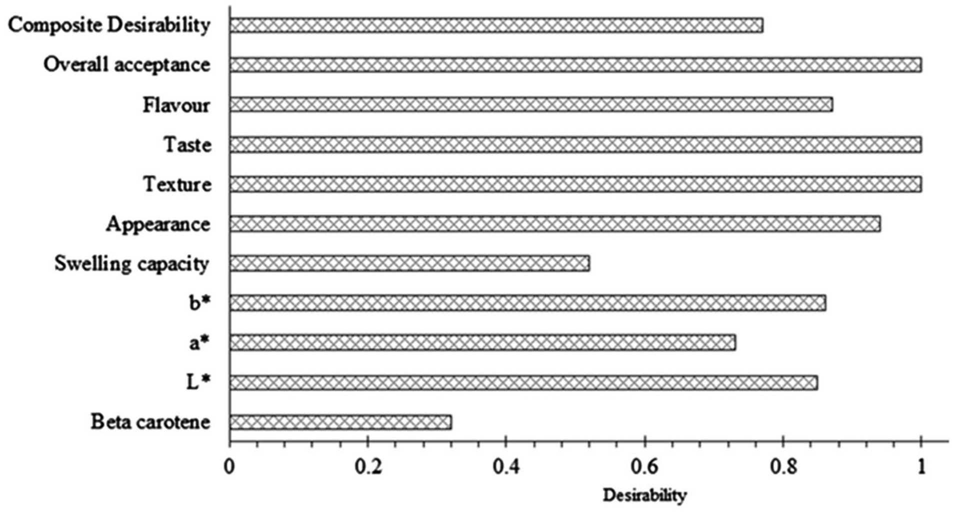

FIGURE 5 Desirability of the composite OFSP–cassava gari for the various responses studied

requirements of each group of individuals similarly vary with the vitamin A needs. From the verified optimized β-carotene content of 16.72 μg/ml for the 10% OFSP composite *gari*, the retinol equivalent (RE) was calculated to be 139 μg/100 ml or 139 μg/62 g RE (average bulk density of the OFSP–cassava composite *gari* was determined to be 0.619 ± 0.011 g/cm^3) or 695 IU. This value is by far higher than the control *gari* (46.5 μg/100 ml). Given that the RDA values for children, adolescents, adult males, and adult females are 400, 600, 600, and 500 μg, respectively, one portion of the composite *gari* can contribute to 34, 23.2, 23.2, and 27.8% of retinol among children, adolescent, adult males, and adult females, respectively. On the other hand, unfortified *gari* would provide 11, 7, 7, and 9% of retinol among the same group of individuals, respectively. Regarding pregnant and lactating mothers, one portion of the optimized OFSP–cassava composite *gari* would supply 17 and 16% while the *gari* without OFSP would provide 5.8 and 5.4% of the recommended daily requirements for pregnant women and lactating mothers, respectively. These contributions to retinol RDA of these groups suggest that additional amounts of retinol are required to meet the daily requirements. This is because the optimized composite *gari* would meet less than 50% of the RDA of vitamin A for these groups of individuals. The contribution of total β-carotene of OFSP–wheat composite bread containing 10% OFSP flour was found to be 115.6 μg/100 g, which would contribute 29% of the RDA among children between the ages of 3 and 10 years (Nzamwita et al., 2017). As the OFSP amount was increased to 20 and 30% in the bread, the respective vitamin A contribution increased to 61 and 89%. This in an indication that the OFSP amount could be increased in *gari* but that would mean that consumers would have to pay more for the same quantity of composite *gari* since OFSP is priced higher of 0.52 USD/kg than cassava (0.13 USD/kg) in Ghana. In addition, since increasing the level of OFSP negatively affected the appearance and consumer acceptability of the final product, some education would have to be undertaken, about the health benefits the higher amount of OFSP in the composite *gari*, in spite of the appearance that could provide to addressing the VAD problems.

4 | CONCLUSIONS

Addition of 10% OFSP to 90% cassava mash and fermented for 1.81 days or 43 hours prior to roasting *gari* causes an improvement in the β-carotene content of the OFSP–cassava composite *gari*, which can hypothetically be used to reduce 34% of the VAD in children between the ages of 3 and 10 years. Pregnant women and nursing mothers, on the other hand, may need more OFSP *gari* (>100 ml) or of *gari* containing higher amount OFSP to meet their vitamin A requirements. To improve the overall acceptability, texture, and cost implications of the OFSP–cassava composite *gari* as well as the ease of roasting by processors more than 30% of the OFSP in the composite *gari* should be avoided.

ACKNOWLEDGMENT

The authors are grateful to the Directorate of Research, Innovation, and Consultancies, DRIC of the University of Cape Coast for providing the financial support toward the study (Grant Number: RSG/GRP/CANS/2018/103).

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

ORCID

Ernest E. Abano https://orcid.org/0000-0001-8466-7811
Martin Bosompem https://orcid.org/0000-0001-6633-2399

REFERENCES

Abass, A. B., Dziedzoave, N. T., Alenkhe, B. E., & James, B. D. (2012). *Quality management manual for the production of gari*. Croydon, UK: IITA.

Akingbala, J. O., Oyewole, O. B., Uzo-Peters, P. I., Karim, R. O., & Baccus-Taylor, G. S. H. (2005). Evaluating stored cassava quality in gari production. *Journal of Food, Agriculture and Environment*, *3*(1), 75–80.

Akintayo, O. A., Obadu, J. M., Karim, O. R., Balogun, M. A., Kolawole, F. L., & Oyeyinka, S. A. (2019). Effect of replacement of cassava starch with sweet potato starch on the functional, pasting and sensory properties of tapioca grits. *LWT*, *111*, 513–519.

Alyas, S. A., Abdulah, A., & Idris, N. A. (2006). Changes of betacarotene content during heating of red palm olein. *Journal of Oil Palm Research*, 99–102.

Awuni, V., Alhassan, W. M., & Amagloh, F. K. (2018). Orange fleshed sweet potato (*Ipomoea batatas*) composite bread as a significant source of dietary vitamin A. *Food Science and Nutrition*, *6*, 174–179.

Bechoff, A., Chijioke, U., Tomlins, K. I., Govinden, P., Ilona, P., Westby, A., & Boy, E. (2015). Carotenoid stability during storage of yellow gari made from biofortified cassava or with palm oil. *Journal of Food Composition and Analysis*, *44*, 36–44.

De Moura, F. F., Miloff, A., & Boy, E. (2015). Retention of provitamin a carotenoids in staple crops targeted for biofortification in Africa: cassava, maize and sweet potato. *Critical Reviews in Food Science and Nutrition*, *55*(9), 1246–1269.

FAO/WHO. (2005). *Vitamin and mineral requirements in human nutrition* (2nd ed.). Geneva: World Health Organisation.

Glover-amengor, M., Agbemafle, I., Hagan, L. L., Mboom, F. P.,., Gamor, G., Larbi, A., & Hoeschle-Zeledon, I. (2016). Nutritional status of children 0–59 months in selected intervention communities in northern Ghana from the Africa RISING project in 2012. *Archives of Public Health*, *74*, 1–12.

Hotz, C., Loechl, C., de Brauw, A., Eozenou, P., Gilligan, D., Moursi, M., … Meenakshi, J. V. (2012). A large-scale intervention to introduce orange sweet potato in rural Mozambique increases vitamin A intakes among children and women. *British Journal of Nutrition*, *108*, 163–176.

Iwuoha, C. I. (2004). Comparative evaluation of physico chemical qualities of flours from steam processed yamtubers. *Journal of Food Chemistry*, *85*, 541–551.

Laurie, S. M., Faber, M., & Claasen, N. (2018). Incorporating orange-fleshed sweet potato into the food system as a strategy for improved nutrition: The context of South Africa. *Food Research International*, *104*, 77–85.

Low, J., Arimond, M., Osman, N., Cunguara, B., Zano, F., & Tschirley, D. (2007). A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *Journal of Nutrition*, *137*(5), 1320–1327.

Maziya-Dixo, B., Dixon, A.G.O., & Ssemakula, G. (2008). Changes in total carotenoid content at different stages of traditional processing of yellow fleshed cassava geno types. *International Journal of Food Science & Technology*, *44*(12), 2350–2357.

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2002). *Response surface methodology: Process and product optimization using designed experiments. Response surface methodology: Process and product optimization using de*. New York: John Wiley & Sons.

Nascimento, P., Fernandes, N. S., Mauro, M. A., & Kimura, M. (2007). Beta-carotene stability during drying and storage of cassava and sweet potato. In *II International Symposium on Human Health Effects of Fruits and Vegetables: FAVHEALTH 2007* (Vol. 841, pp. 363–366). Houston, TX: Acta Horticulturae.

Nzamwita, M., Gyebi, K., & Minnaar, A. (2017). Stability of beta-carotene during baking of orange-fleshed sweet potato-wheat composite bread and estimated contribution to vitamin a requirements. *Food Chemistry*, *228*, 85–90.

Ogodo, A. C., Ugbogu, O. C., Onyeagba, R. A., & Okereke, H. C. (2017). Effect of lactic acid bacteria consortium fermentation on the proximate composition and in-vitro starch/protein digestibility of maize (*Zea mays*) flour. *American Journal of Microbiology and Biotechnology*, *4*(4), 35–43.

Ojo, A., & Akande, E. A. (2013). Quality evaluation of gari produced from cassava and sweet potato mixes. *African Journal of Biotechnology*, *12* (31), 4920–4924.

Olayinka, R. K., Balogun, M. A., Olaide, A. A., & Wasiu, A. (2016). Physical, chemical and sensory properties of cassava (*Manihot esculenta*)-sweet potato (*Ipomoea batatas*) gari. *Ukrainian Journal of Food Science*, *4*(2), 276–289.

Rodriguez-Amaya, D. B. (1997). *Carotenoid and food preparation: the retention of provitamin Acarotenoid in prepared, processed, and stored foods*. Campinas, Brazil: Universidade Estadual de Campinas.

Sadaf, J., Masud, T., Sammi, S., Tariq, S., Sohail, A., Butt, S. J., … Ali, S. (2013). Comparative study for the extraction of beta-carotene in different vegetables. *Pakistan Journal of Nutrition*, *12*, 983–989.

Steinkraus, K. (1995). *Handbook of indigenous fermented foods, revised and expanded edition* (2nd ed.). NY: CRC Press.

Tumwegamire, S., Tumwegamire, S., Kapinga, R., Zhang, D., Crissman, C., & Agili, S. (2004). Opportunities for promoting orange-fleshed sweetpotato as a mechanism for combat vitamin-A deficiency in sub-Saharan Africa. *African Crop Science Journal*, *12*(3), 241–252.

USAID. (2016). *Nutrition strategy counter vitamin A deficiency in Ghana*. Accra: The Borgen Project.

van Jaarsveld, P. J., Faber, M., Tanumihardjo, S. A., Nestel, P., Lombard, C. J., & Spinnler Benadé, A. J. (2005). Beta-carotene-rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified relative-dose-response test. *American Journal of Clinical Nutrition*, *81*, 1080–1087.

World-Vision. (2014). *System approach to improve and sustain food security in West Africa (SATISFY)*. Accra: GhanaWeb.

How to cite this article: Abano EE, Quayson ET, Bosompem M, Quarm M. β-Carotene-fortified *gari*: Processing variables effect on nutritional and sensory qualities. *J Food Process Eng*. 2020;43:e13322. https://doi.org/10.1111/jfpe.13322