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OPTIMIZATION OF FRYING CONDITIONS AND QUALITY ATTRIBUTES OF FRIED CRISPS FROM YELLOW-FLESHED SWEETPOTATO

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Abstract
Quality of snack foods is an important consideration to consumers and industry. Primary food quality considerations of concern to consumers in particular include, chemical composition and nutritional value, as well as sensory properties. Varietal differences among sweetpotato roots and frying method have been reported to determine optimum frying temperature and time, as well as quality of sweetpotato (SP) snacks. Central composite design of response surface methodology was used to generate experimental runs to study the effect of frying temperature (140-160 °C) and time (3-6 min) combinations on quality attributes of sweetpotato crisps from yellow-fleshed SP variety. The response variables were chemical composition, colour and sensory attributes of the crisps. The optimum frying conditions were generated from the data using the numerical optimization tool of the experimental design software. Sensory attributes and consumer acceptability of the optimized crisps were evaluated. Frying temperature and time combinations had varying effects on each of the quality attributes of the crisps, with only oil content being significantly affected at p<0.5. The optimum frying temperature and time was 160 °C/6.0 min and at these conditions, the quality attributes of the crisps were moisture content 2.86%, oil content 23.10%, total carotenoids content 2066.01 µg/100 g, yellowness (b) 29.54 and crispiness (7.42).*

Keywords: *Yellow-fleshed sweetpotato, frying, optimization, snack, food quality*

Introduction

Snack foods are small portion of foods consumed by children and adults usually in between main meals. Although, within the scientific community, there is no consensus on the definition of snacks or snack foods, snacking is a global dietary habit. Production and consumption of snack and snack foods, has nutritional, health and commercial implications for stakeholders such as consumers, industry and government (Hess, et al, 2016; Potter et al., 2018). Irrespective of the stakeholder, quality of the snack food is an important consideration. Chemical composition and nutritional value, as well as sensory properties, are among the primary food quality considerations of concern to consumers in particular (Cardello, 1995; Molnar, 1995; Fellows, 2017). These quality attributes are usually determined by the processing methods used in the preparation of the snacks.

Several processing methods have also been employed in the production of snack foods; they include frying, baking and extrusion among others (Oke et al., 2018; Alam et al., 2015; Lusas and Rooney, 2001). Snacks from sweetpotato is currently attracting research attention because of their nutritional potentials among other factors (Mu et al., 2019). Sweetpotato (*Ipomoea batatas* L.) is a root crop and an important food source in many regions across the world. It is a high-yielding crop which produces even under marginal conditions (Truong et al, 2018). Nigeria is one of the leading producers of sweet potato in the world with a production of 4,029,909 tonnes from an area harvested of 1,712,363 ha (FAOSTAT, 2018). Sweet potato roots vary in flesh colour with shades of white, cream, yellow, orange and purple (Truong *et al.,* 2018). In Nigeria, a total of three orange-fleshed sweet potato varieties have been officially released between 2013 and 2018 (Okello *et al.*, 2019). However, the yellow-fleshed variety remains the most readily available in the market and most popular among consumers. Nutritionally, sweet potato serves as a major energy source due to its high carbohydrate content and is rich in many health-promoting bioactive constituents (Wang et al., 2016; Mu and Singh, 2019).

Methods most commonly used for production of sweet potato snack foods include drying, frying, roasting, baking, extrusion and other processes, and these snacks include chips, fries, crisps, biscuits, cakes, doughnuts and extruded products (Mu et al., 2019; Truong et al., 2018). However, in Nigeria methods commonly used are limited to boiling, roasting and frying, with the fried chunky chips being the most commonly sold (Onumah *et al.,*2012). Commercial production of fried sweetpotato crisps in Nigeria is still limited, whereas in some parts of the world especially United States, China and Japan, this product is widely available (Truong et al., 2018). This is in spite of the production advantage that Nigeria has. In addition, crisps possess desirable sensory attributes and extended shelf stability, relative to the chunky chips; these attributes could be exploited for commercial advantage.

Frying is a unit operation used to alter the eating quality of foods by heating it to a high temperature in oil. Fried foods have a characteristic golden colour, crisp texture, distinctive mouth feel and characteristic fried flavours and aroma (Fellows, 2017). Several factors influence the quality attributes of fried foods; in particular, foods fried at optimum temperature and time has good product quality such as golden brown colour, properly cooked and crispy (Oke et al., 2018).

Optimization of frying process have been applied to snacks from blends of wheat flour and brewers' spent cassava flour (Omidiran, 2016), plantain chips ('Ipekere') (Adeyanju et al., 2016a), fish snack (Joshy et al, 2020), and maize-based snack ('kokoro') (Idowu and Aworh, 2017). Several studies on fried sweet potato have been reported on the effect of pre-frying treatment (Fetuga et al., 2013), frying temperature and time (Fetuga et al., 2014a), variety and frying conditions (Olatunde *et al.,* 2016), packaging material and storage (Fetuga et al., 2014b), and composition and sensory quality of sweet potato crisps (Fetuga *et al.*, 2013; 2014a and b; 2016). However, it has been reported that varietal differences and frying method are determining factors in optimizing frying temperature and time, as well as quality of the product (Nasir et al., 2019; Giri et al., 2019; Timalsina *et al.,* 2019; Abd Rahman et al., 2016). The influence of differences in variety of sweet potato and frying temperature and time combination was also emphasized by Truong *et al.* (2018). There is scarcity of information on the optimum frying conditions for yellow-fleshed sweet potato variety.. Information from the present study has implications for industrial processing and quality control of optimized product. Therefore, the effect of frying temperature and time combinations on chemical composition of crisps from yellow-fleshed SP variety was investigated and optimum frying conditions determined. Sensory attributes and consumer acceptability of the optimized crisps were evaluated.

Materials and Methods

A popularly cultivated, local yellow-fleshed variety of sweet potato roots (Ex-Igbariam) (Afuape, 2014) was obtained from a farmer in Ijebu-jesa, Osun State. Refined, bleached, deodourized palm olein oil (Devon King's, Nigeria) was purchased from Kuto market in Abeokuta, Ogun State. Sweet potato roots were washed, peeled using stainless steel knives and sliced (1-2 mm). The slices were fried in a deep-fat fryer (Bush glass fryer FCO 300- UK), at various combinations of temperature and time based on the experimental design stated below.

Experimental Design

Central Composite Design (CCD) of Response Surface Methodology (RSM) was adopted with two independent variables; frying temperature (140-160 °C) and time (3-6 min), each studied at five levels (-1.414, -1, 0, 1, 1.414).

Analysis of Quality Attributes of Sweet Potato Crisps

Moisture content was determined by hot air oven method and oil content by extraction with petroleum ether (AOAC, 2005).

Total carotenoids was determined by extraction with methanol: tetrahydrofuran followed by spectrophotometric measurement at an absorbance of 450 nm (Rodriguez-Amaya & Kimura, 2004).

Colour was measured with a colour meter (Konica Minolta CR- 400/410- Japan) and expressed as L*(lightness), a*(redness), b*(yellowness) values, where L* ranged from -100 (darkness) to +100 (lightness), a* from –a* (greenness) to +a* (redness) and b* from –b* (blueness) to +b* (yellowness).

Sensory attributes of texture and colour were evaluated using quantitative descriptive analysis (QDA). Ten trained panellists used a 10-cm continuous non-structured scale line to measure the intensity of each attribute. The left end (0-cm) and right end (10-cm) measured lowest and highest intensity respectively (Greene & Bovell-Benjamin, 2004).

Modelling, Statistical Analysis and Optimization

The Design Expert statistical package, version 6.0.8 (Mathsoft Inc., Seattle, WA, USA) was employed to run a regression analysis by fitting a second order quadratic equation to the data to obtain response models. Analysis of variance using F-ratio at $p<0.05$ was used to assess statistical significance of the regression models. The models were interpreted from the response surface plots generated. The optimization toolbox of the statistical software was used to determine the optimum frying conditions. Numerical optimization was performed by setting minimum or maximum levels, as appropriate, for selected response variables, based on quality expectations for the crisps.

Sensory Evaluation of Optimized Sweet Potato Crisps

The optimized frying temperature and time generated was used to prepare sweet potato crisps. Sensory attributes (crispiness, oiliness and yellow colour) of optimized crisps were described using QDA as described earlier. A fifty in-house consumer panel comprising undergraduate students of Federal University of Agriculture, Abeokuta, Nigeria evaluated the crisps for acceptability. The degree of likeness for each attribute (colour, sweetness, crispiness, oiliness and overall acceptability) was scored by each panelist on a 9-point hedonic scale ranging from 9-'like extremely' to 1-'dislike extremely' (Greene & Bovell-Benjamin, 2004).

Results and Discussion

Effect of Frying Conditions on Quality of Sweet Potato Crisps

The effect of frying temperature (FTp) and frying time (FTm) on quality attributes (chemical composition, colour attributes and sensory properties) of crisps from yellow-fleshed sweet potato is presented in Table 1. The combination of FTp and FTm did not have a significant ($p>0.05$) ($R^2 = 0.26\text{-}0.73$) effect on any of the attributes except oil content ($p<0.01$) ($R^2 = 0.93$) of the sweetpotato crisps. The effect of FTp and FTm is also expressed by regression models for the quality attributes of the crisps as presented in equations (1) - (8), while Table 2 shows the analysis of variance and coefficients for the prediction models.

$$MC = 5.56 - 2.79A - 1.82B + 1.46A^2 + 0.03B^2 + 0.42AB \quad \text{ns} \quad (1)$$
$$OC = 23.70 + 0.86A + 0.14B + 1.62A^2 - 0.13B^2 - 3.09AB \quad \text{s} \quad (2)$$
$$TC = 1402.27 - 96.10A + 112.02B + 176.99A^2 + 372.41B^2 + 98.42AB \quad \text{ns} \quad (3)$$
$$L^* = 54.71 + 0.71A + 1.91B - 0.064A^2 - 0.52B^2 + 5.03AB \quad \text{ns} \quad (4)$$
$$a^* = 0.46 + 1.06A - 0.89B + 0.22A^2 - 1.45B^2 - 2.73AB \quad \text{ns} \quad (5)$$
$$b^* = 26.78 + 1.20A + 0.91B + 0.18A^2 - 1.92B^2 + 2.38AB \quad \text{ns} \quad (6)$$
$$Cr = 9.20 + 0.82A + 0.097B + 0.42A^2 - 1.82B^2 - 1.29AB \quad \text{ns} \quad (7)$$
$$Ye = 9.00 - 0.099A + 0.039B - 0.37A2 - 0.068B2 + 0.59AB \quad \text{ns} \quad (8)$$

s-significant, ns-not significant

The non-significance of most of the models may imply that other factors beyond the combination of FTp and FTm played more dominant roles in the trends observed for the attributes affected. Generally, frying process involves a combination of several factors which act synergistically to influence each of the quality attributes of a product (Oke et al., 2018; Fellows, 2017). A study by Omidiran *et al.* (2018) indicated that the combination of FTp and FTm did not have a significant effect on all the nine attributes investigated; although, the authors considered a third factor in their optimization.

Table 1. Effect of frying temperature and time on quality attributes of crisps from yellow-fleshed sweetpotato

Run	Temp. (°C)	Time (min)	MC (%)	OC (%)	TC (µg/100 g)	L*	a*	b*	Crispiness	Yellow colour
1	136	4.5	16.33	26.75	1877.67	53.65	-0.04	27.02	9.29	8.80
2	140	3.0	8.77	19.94	2427.67	54.72	-2.96	23.94	4.17	7.91
3	140	6.0	4.47	27.15	1850.67	50.08	-1.16	20.13	9.38	8.54
4	150	2.4	9.97	24.04	1284.33	55.40	-3.11	23.38	6.75	9.59
5	150	4.5	5.27	23.96	1346.00	53.44	0.07	27.14	9.25	8.86
6	150	4.5	5.30	23.95	1321.67	54.27	1.66	26.58	8.86	8.92
7	150	4.5	5.57	23.21	1254.00	53.68	-0.84	26.89	9.39	9.31
8	150	4.5	5.87	23.77	1500.33	58.35	-0.58	26.34	8.90	9.04
9	150	4.5	5.80	23.63	1589.33	53.81	1.97	26.95	9.58	8.89
10	150	6.6	4.57	23.35	2455.67	58.53	-3.01	27.21	3.58	9.24
11	160	3.0	5.53	28.93	2410.00	41.49	6.31	20.50	9.55	6.33
12	160	6.0	2.90	23.79	2226.67	56.98	-2.79	26.20	9.60	9.30
13	164	4.5	3.93	27.61	1080.67	62.12	0.57	31.97	9.99	8.82
Mean			6.48	24.62	1740.36	54.35	-0.30	25.71	8.33	8.73
SD			2.45	0.80	492.29	4.65	1.79	2.63	1.52	0.82
CV			37.86	3.24	28.29	8.55	-595.02	10.25	18.21	32.73

MC- moisture content, OC- oil content, TC- total carotenoids, L*- lightness, a* -redness, b* -yellowness
SD-standard deviation, CV-coefficient of variation

Table 2: Analysis of variance for the models for crisps from yellow-fleshed sweetpotato

Responses	Sources of variation	DF	Sum of Squares	Mean Square	F-Value	R^2
MC	Regression	5	104.71	20.94	3.48	0.7129
	Residual	7	42.16	6.02		
	Total	12	146.88			
OC	Regression	5	63.12	12.62	19.88	0.9342**
	Residual	7	4.45	0.64		
	Total	12	67.57			
TC	Regression	5	1.295E+006	2.589E+005	1.07	0.4328
	Residual	7	1.696E+006	2.423E+005		
	Total	12	2.991E+006			
L*	Regression	5	136.38	27.28	1.26	0.4741
	Residual	7	151.30	21.61		
	Total	12	287.68			
a*	Regression	5	60.85	12.17	3.80	0.7308
	Residual	7	22.42	3.20		
	Total	12	83.27			
b*	Regression	5	67.79	13.56	1.95	0.5826
	Residual	7	48.57	6.94		
	Total	12	116.36			
Cr	Regression	5	38.28	7.66	3.33	0.7039
	Residual	7	16.10	2.30		
	Total	12	54.38			
Br	Regression	5	1.18	0.24	0.49	0.2601
	Residual	7	3.37	0.48		
	Total	12	4.55			
Ye	Regression	5	3.61	0.72	1.07	0.4338
	Residual	7	4.71	0.67		
	Total	12	8.32			

OFSP- orange-fleshed sweetpotato, MC- Moisture content, OC- Oil content, TC- Total carotenoids, L*- Lightness, a*- Redness, b*- Yellowness, Cr- Crispiness, Br- Brown colour, Ye- Yellow colour
**significant at P<0.01

According to Diamante *et al.* (2011), time and temperature combination during frying are the most important factors influencing the quality of fried products. On the other hand, the significant effect of FTp and FTm on oil content suggests that these factors played a dominant role in the frying process and therefore. oil content may be a quality index for sweet potato crisps for the variety under study. This further suggests that oil content may be adequately predicted from the model (Equation 2). The combination of FTp and FTm had significant effects on oil content, moisture content, texture and colour of deep-fat fried plantain chips ('Ipekere') and plantain slices ('dodo') (Adeyanju *et al.* 2016a and b) and air-fried sweet potato snack (Abd Rahman et al., 2017).

The lowest moisture content (MC) of the sweet potato crisps was 2.90% at 160 °C/6.0 min while the highest was 16.33% at 136 °C/4.5 min. The MC was within the range of 1.14-18.81% for fried snacks (Abd Rahman *et al.,* 2017; Adeyanju et al., 2016a and b; Nasir *et al.*, 2019). At constant FTp, MC decreased with increase in FTm. For instance, at FTp of 140 °C, MC decreased from 8.77% (3.0 min) to 4.47% (6.0 min), at 150 °C MC decreased from 9.97% (2.4 min) through 5.27-5.87% (4.5 min) to 4.57% (6.6 min), and at 160 °C, MC decreased from 5.53% (3.0 min) to 2.90% (6.0 min). A decrease in MC during frying was reported by Sobukola et al. (2008) and Adeyanju *et al.* (2016a). Frying mechanism basically involves mass transfer of moisture from a food (Oke et al., 2018; Fellows, 2017). Shelf stability and safety of fried products are affected by MC and lipid oxidation, while microbial growth is reduced at lower MC.

Oil content (OC) of the crisps ranged from 19.94% (140 °C/3.0 min) to 27.61% (164 °C/4.5 min). Oil content can account for up to 45-62% of the fried products (Fellows, 2017; Sulaeman *et al.,* 2001). Some negative health conditions have been associated with consumption of foods with high oil content; however, if they are not consumed excessively, fried foods may serve as a source of calorie required for energy. Moderate oil content is also required for absorption and utilization of oil-soluble vitamins such as vitamin A (Lemmens *et al.*, 2014; Mills et al., 2009). At 140 °C, OC increased with time from 19.94% (3.0 min) to 27.15% (6.0 min), while at higher temperatures there was a decrease in OC from 24.04% (2.4 min) through 23.21-23.96 (4.5 min) to

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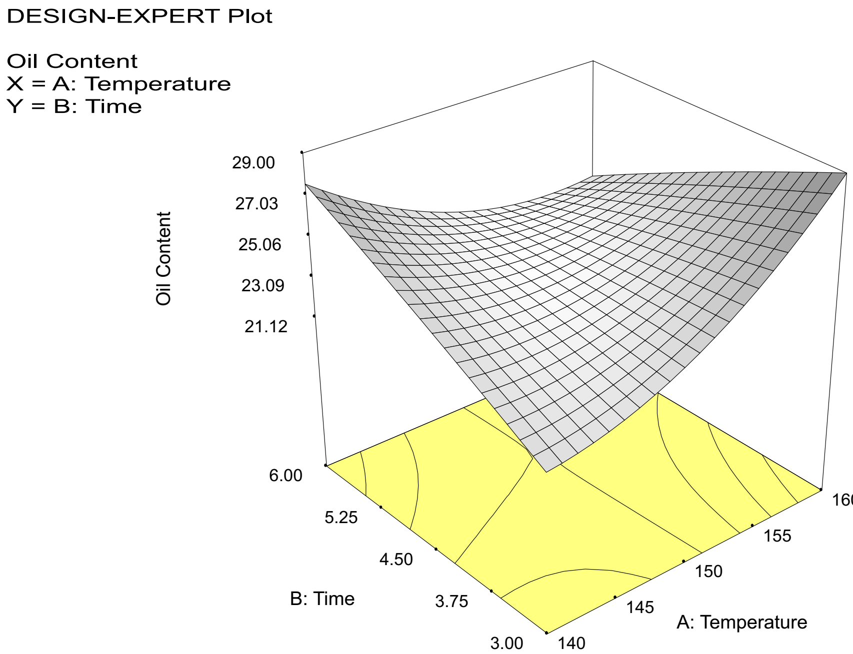

Figure 1: Effect of frying temperature and time on oil content of crisps from yellow- fleshed sweetpotato

The sweet potato crisps had a minimum total carotenoid content (TC) of 1080.67 µg/100 g at 164 °C/4.5 min and a maximum value of 2455.67 µg/100 g at 150 °C/6.6 min). Carotenoids in fruits and vegetables may manifest as yellow, orange, red or green colour depending on the structural configuration (Burri, 2011). The flesh of sweet potato roots used in the present study had a light shade of yellow colour which may be an evidence of the total carotenoid observed in the fried products. At 140 °C and 160 °C, the TC decreased with increase in frying time while at 150 °C the TC increased with time. Under the same processing and storage conditions, carotenoids differ in stability for different foods (Rodriguez -Amaya, 1997). Thus, the varying trends observed for TC of sweet potato crisps at different frying temperatures may be expected. Fried crisps from yellow-fleshed sweet potato could be promoted as snack foods to improve the vitamin A status among consumers due to the carotenoid content.

The range of colour attributes of the sweet potato crisps were, lightness L* [41.49 (160 °C/3.0 min) – 62.12 (164 °C/4.5 min)], redness a* [-0.04 (136 °C/4.5 min) – 6.31 (160 °C/3.0 min)] and yellowness b* [20.13 (140 °C/6.0 min) – 31.97 (164 °C/4.5 min)]. A similar trend of increase in value for all the colour properties with an increase in FTm was observed only at 150 °C. Varying trends in each of the colour properties were observed with increase in FTm at 140 °C and 160 °C. Instrumental colour measurements have been used for quality control where these values have been found to correlate significantly with sensory measurements (Segnini and Dejmek, 1999).

There was a general increase in crispiness of the sweet potato crisps with increase in FTp and FTm. The lowest and highest crispiness scores were 4.17 at 140 °C for 3.0 min and 9.99 at 164 °C for 4.5 min respectively. One of the main purpose of frying is the development of a characteristic crisp texture, and it is also one of the sensory texture attributes cherished by consumers of fried products (Fellows, 2017). According to Ngadi *et al.* (2008), crispness of fried foods is produced by micro structural changes including starch gelatinization and dehydration, evaporation of moisture leading to dehydration of tissue and a reduction in intracellular air, among other factors.

The sensory descriptive yellow colour of the sweet potato crisps ranged between 6.33 (160 °C/3.0 min) and 9.59 (150 °C/2.4 min). At 140 °C and 160 °C, yellow colour increased with FTm but a decreasing trend was observed at 150 °C. Golden brown colour of fried foods, formed by Maillard reactions (Sahin, 2000), is among the characteristics cherished by consumers (Fellows, 2017). However, the yellow colour of sweet potato crisps in this study may not be unconnected with the yellow colour of the raw root. The yellowness of sweetpotato crisps may contribute to sensory appeal and consumer acceptability.

Optimization

In the numerical optimization performed, the goals for the desired quality attributes of the crisps were set at minimum for moisture and oil contents, and maximum for total carotenoids (TC), crispiness and yellow colour. The optimum frying temperature and time generated (Table 3) was 160 °C for 6.0 min respectively and a desirability of 0.74.; at these conditions, the quality attributes of the crisps were moisture content (2.86%), oil content (23.10%), total carotenoids content (2066.01 µg/100 g), yellowness (b*) (29.54) and crispiness (7.42). Studies on frying of sweetpotato have reported varying optimum frying temperature and time such as 160 °C/5.35-5.40 min (Timalsina et al., 2019), 151.27 °C/4.20 min and 146.36 °C/4.20 min (Nasir et al., 2019) and 150 °C/12 min (Abd Rahman et al., 2016). The differences may be due to differences in variety/composition of sweet potato used, pre-treatment involved, and frying method used in the studies reported. The optimized sweet potato crisps were characterized (Figure 2) by crispiness (7.99), yellow colour (9.15) and oiliness (3.39). Consumer acceptability scores for the optimized sweet potato crisps (Figure 3) were colour (6.9), sweetness (7.9), crispiness (7.16), oiliness (5.34), overall acceptability (6.1).

Table 3: Optimized frying conditions and quality attributes of crisps from yellow -fleshed sweetpotato

Frying temperature (°C)	Frying time (min)	Moisture content (%)	Oil content (%)	Total carotenoids (µg/100 g)	b*	Crispiness	Desirability
160	6.0	2.86	23.10	2066.01	29.54	7.42	0.74

b* - Yelllowness

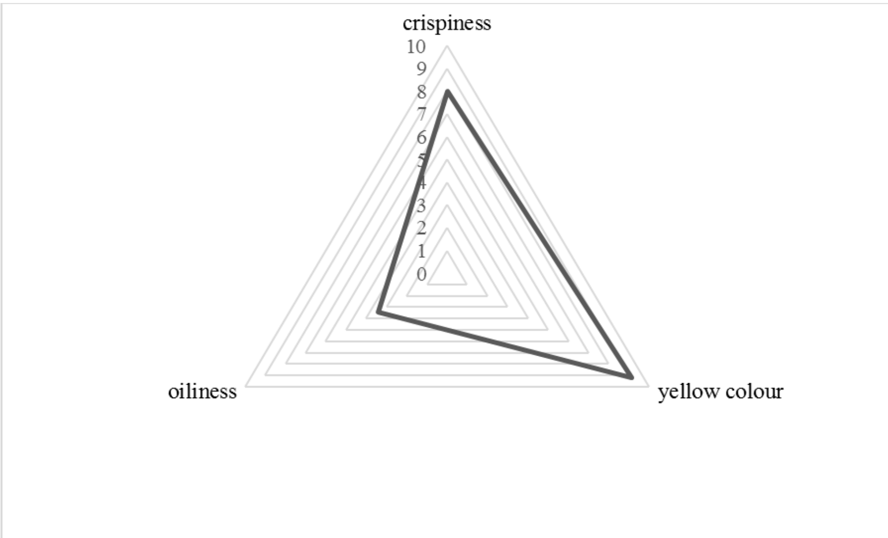

Figure 2: Descriptive sensory attributes of optimized crisps from yellow-fleshed sweetpotato

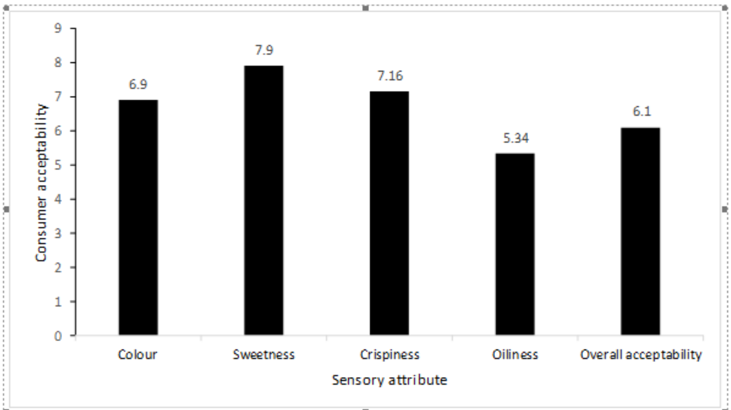

Figure 3: Consumer acceptablility of optimized crisps from yellow-fleshed sweetpotato

Conclusion

Frying temperature and time combinations had varying effects on each of the quality attributes of crisps from yellow-fleshed sweet potato. Only moisture content and crispiness showed a regular trend with an increase in frying temperature and time; the moisture content decreased while crispiness increased. Only the oil content of the crisps was significantly affected by the combination of frying temperature and time, and therefore may be a quality index of control for the sweet potato variety under study. The optimum frying temperature and time was 160 °C for 6.0 min for production of crisps from Ex-Igbariam variety of sweet potato roots. The optimum crisps were described by high sensory scores for texture and colour, and a low score for oil content. The consumer acceptability scores of the optimum crisps were high for most of the sensory attributes evaluated. As a step towards commercial production of sweet potato crisps from Ex-Igbariam variety, information from this study could be applied on a pilot scale.

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