Optimization of deep-fat frying conditions and quality attributes of orange-fleshed sweetpotato crisps by response surface methodology

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Abstract: Response surface methodology with a central composite design was applied to study the effect of frying temperature (145–164°C) and time (2.4–6.0 min) on some quality attributes of crisps from two varieties of orange-fleshed sweetpotato (OFSP) roots [Mothers’ Delight (MD) and King J (KJ)]. Response models and optimized frying conditions were generated. Frying temperature and time significantly (p < 0.01) influenced moisture content (MC) and crispiness for both varieties ($R^2 = 0.87–0.95$). Total carotenoids (TC), L*, orange and brown colours for MD variety, and a* for KJ variety, were also significantly (p < 0.05) affected but the trend varied between the varieties ($R^2 = 0.82–0.94$). MD crisps had higher TC which reduced with increase in frying conditions. Orange colour of crisps which increased for MD but decreased for KJ, with increase in frying conditions, was an important sensory quality index. At the optimum frying conditions, 151.27 °C/4.20 min for MD and 146.36 °C/4.20 min for KJ, MD crisps had lower MC (2.85%) but higher oil content (30.04%), total carotenoids (3752.33 µg/100 g), crispiness (8.84) and orange colour (8.92) than KJ. Optimized MD crisps had lower sensory oiliness and higher consumer acceptance.

ABOUT THE AUTHOR
Sururah Nasir earned an M.Sc. degree in Food Processing and Storage Technology, and this study was an output of her research. Ganiyat Olatunde was the major supervisor while Abdurazaq Adebowale and Isaac Aiyelaagbe were co-supervisors. Ganiyat Olatunde specializes in Food Quality Control and Assurance. Her research activities involved studying the relationship between raw material composition, processing conditions and quality attributes of products. Her focus is on chemical and nutritional composition, as well as sensory attributes that determine consumer acceptance. Many of her studies have been on sweetpotato, a crop globally recognized as having the potential to solve the problem of household and national food and nutritional security in Sub-Saharan Africa. She has taken part in commissioned projects including the ‘Sweetpotato for Health and Wealth in Nigeria’ project; she worked with SMEs to develop technology and establish quality requirements for baked and fried products, incorporating pro-vitamin A-rich sweetpotato varieties.

PUBLIC INTEREST STATEMENT
Optimized frying conditions generated in this study are expected to assist Small and Medium Enterprises to (i) reduce the time, costs and other resources required to produce optimum crisps with desirable quality attributes from orange-fleshed sweetpotato (OFSP) (ii) understand how chemical components and other quality factors of OFSP crisps changes with frying conditions and (ii) understand that each variety of OFSP requires different combination of frying temperature and time for optimum quality of crisps. OFSP crisps are expected to expand the range of nutritious and attractive snacks available and contribute to improved vitamin A status of consumers.

Consumption of OFSP crisps is expected to increase production of the roots and hence improved livelihoods of farmers and other stakeholders along the value chain.
**Subjects:** Agriculture & Environmental Sciences; Food Chemistry; Food Engineering  
**Keywords:** orange-fleshed sweetpotato; frying; optimization; carotenoids; food quality

1. **Introduction**

Deep-fat fried foods are globally consumed by all ages and social classes. In spite of the health concerns associated with deep-fat fried foods due to its oil content, their characteristic sensory attributes of colour, flavour and texture make them acceptable to consumers.

Deep-fat frying is a common cooking method that uses oil or fat as the heat transfer medium, in direct contact with the food at a temperature above the boiling point of water (Ananey-Obiri et al., 2018). It is a complex process, involving factors such as, temperature of the heated oil, duration of frying, method used, food weight/frying-fat volume and surface-area/volume ratios, some food characteristics and the fat source (Sabukola, Awonorin, Sanni, & Bamiro, 2008). It results in modification of the physical, chemical and sensory characteristics of food, with the products having a crisp acceptable texture, improved colour appearance, enhanced flavours and aromas (Giovanelli, Torri, Sinelli, & Buratti, 2017; Pedreschi, 2012). The main frying conditions are oil temperature and frying time, both of these influences the mechanism of mass and heat transfer, transformations and reactions in the frying process.

Optimization of the deep-fat frying process, particularly temperature and time, is important in order to produce high-quality crisps. Optimization of food involves modifying a process in order to achieve the most desirable quality at minimum resources. Response surface methodology (RSM), an optimization tool, is a collection of statistical and mathematical techniques (Bas & Boyaci, 2007). RSM has been used to optimize efficiency of ingredients (Premar, Abirami, Nandhini, & Kumar, 2018), composite flours (Shittu, Raji, & Sanni, 2007), product development and functional food preparation (Seog, Kim, & Lee, 2008). In frying processes, RSM has been applied to carrot slices (Karacabey, Ozcelik, Turan, Baltacioglu, & Kucukoner, 2017), plantain chips (Adeyanju, Olajide, & Adedeji, 2016) and coated zucchini pieces (Abtahi, Hosseini, Fadavi, Mirzaei, & Rahbari, 2016).

Sweetpotato is an important food crop in the world and an increasingly important staple in sub-Saharan Africa due to the ease of planting and health benefits (Ray & Tomlins, 2010; Truong, Avula, Pecota, & Yencho, 2018). Nigeria is a leading producer of sweetpotato in Africa with an average (1994–2017) production of 2.8 Million tonnes (FAOSTAT, 2017). In addition to carbohydrates, sweetpotatoes are rich in minerals, vitamins and other physiologically functional components including carotenoids, depending on the variety (Truong et al., 2018). Carotenoids are precursors of vitamin A (VA), which serves several biological functions, including genetic regulation, visual cycle, normal growth and development, and immune function (Burri, 2011). Vitamin A deficiency (VAD) is a serious health issue in many of the developing countries. Orange-fleshed sweetpotato (OFSP) is currently being promoted as a sustainable dietary intervention to improve the VA status of consumers, because of their natural rich source of carotenoids, especially beta-carotene, which has the highest VA activity (Burri, 2011). Carotenoid concentrations vary with sweetpotato colour; the more orange the colour, the higher the carotenoid content. The concentrations of beta-carotene also depend largely on variety of sweetpotato (Burri, 2011).

Sweetpotatoes are usually eaten without any special processing; either boiled, roasted, fried as chips, baked or in some cases, eaten raw. They are sold as deep-fried chunky chips eaten as snacks in many parts of Nigeria. Commercial processing into fried crisps is still on a very low scale. Sweetpotato crisps could be marketed as highly nutritious snack foods, particularly the orange-fleshed varieties due to its potential to combat VAD. Two OFSP varieties, [UMU SP0/1 (King J) and UMU SP0/3 (Mothers’ Delight)] were released in Nigeria (Afuape, 2013; Tumwegamire et al., 2014). Differences in chemical composition, colour and texture associated with varieties of the same type of food crop usually influence process conditions and hence product quality (Wheatley, Scott, Best, & Wiersema, 1995). In addition, OFSP cultivars are relatively new to food processors, vendors, and
consumers; therefore, it is important to establish optimum frying conditions of temperature and time required for the production of crisps with high nutritional quality and consumer-acceptable sensory properties from these varieties.

The main objective of this study was to investigate the effect of frying temperature and time on some quality attributes of crisps from two OFSP varieties, determine the optimum frying conditions, and evaluate some quality attributes of the optimized crisps.

2. Materials & methods

2.1. Materials

Two varieties of OFSP [UMU SP0/1 (King J) and UMU SP0/3 (Mothers' Delight)] were obtained from a farmer in Ijebu-jesa, Osun State. Vegetable oil (Refined, bleached, deodourized palm olein; Devon King’s brand, Nigeria) was purchased from Kuto market in Abeokuta, Ogun state.

2.2. Sample preparation

OFSP roots were washed, peeled using stainless steel knives and sliced thinly (1–2 mm thickness). The slices were fried in a deep-fat fryer (Bush Glass fryer FCO 300-UK), at various combinations of temperature and time as generated by the experimental design (2.3).

2.3. Experimental design

The design was based on the hypotheses that moisture, oil, and total carotenoid contents, as well as colour and sensory properties of the product are functionally dependent on the temperature of the oil and the frying time. Central Composite Design (CCD) of Response Surface Methodology (RSM) was adopted with two independent variables; frying temperature and time, each studied at five levels (−1.414, −1, 0, 1, 1.414).

2.4. Analysis of quality attributes of OFSP crisps

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

Total carotenoids in the crisps were determined by the method of Rodriguez-Amaya and Kimura (2004). The crisps were crushed into powder, 5 g was weighed into an extraction tube and homogenized with 50 ml of methanol:tetrahydrofuran (Me:THF) for 1 min. The solution was filtered with suction through a sintered glass funnel. Petroleum ether (PE) (40 ml) was added to the Me:THF extract in a 500 ml separatory funnel and 300 ml of distilled water was slowly added to it. The two phases separated and the aqueous (lower) phase was discarded. The sample was washed 3–4 times with 200 ml distilled water each time to remove residual Me:THF. The PE phase was collected in a 50 ml volumetric flask by making the solution pass through a small funnel containing 15 g of anhydrous sodium sulphate, the separatory funnel was also washed and the washings were passed through the funnel containing sodium sulphate. The samples were made up to volume with PE and absorbance read at 450 nm.

Colour was measured using 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 texture and colour were evaluated using quantitative descriptive analysis (QDA) by 10 trained panelists. Crispiness and colour (orange and brown) were measured using a 10-cm continuous non-structured scale; the left end (0 cm) measured lowest intensity while the right end (10 cm) measured highest intensity (Greene & Bovell-Benjamin, 2004).
2.5. Modelling, statistical analysis and optimization
Regression analysis was conducted by fitting a second-order quadratic polynomial equation to the data to obtain response equations (models) using Design Expert statistical package, version 6.0.8 (Mathsoft Inc., Seattle, WA, USA). Statistical significance of the terms in the regression models was assessed with analysis of variance (ANOVA) using F-ratio at p < 0.05. Response surface plots were generated to interpret and evaluate the models. Optimum frying conditions were determined using the optimization toolbox of the statistical software. Numerical optimization was performed by setting goals (minimum or maximum levels) for selected response variables as appropriate, based on quality expectations for the crisps. The modelling, statistical analysis and optimization procedure were conducted separately on data from each variety of OFSP.

2.6. Sensory attributes and consumer acceptability of optimized OFSP crisps
OFSP crisps were prepared using the optimized frying temperature and time generated. Sensory attributes (crispiness, oiliness and orange colour) of optimized crisps were described using QDA as in 2.4. Consumer acceptability was determined by 50 untrained in-house panelists comprising undergraduate students of Federal University of Agriculture, Abeokuta, Nigeria. Panelists scored their degree of likeness for each attribute (colour, sweetness, crispiness, oiliness and overall acceptability) on a 9-point hedonic scale ranging from 9-“like extremely” to 1-“dislike extremely” (Greene & Bovell-Benjamin, 2004).

3. Results & discussion

3.1. Model parameters for OFSP crisps
The frying conditions and responses for the two varieties of OFSP crisps are presented in Tables 1 and 2. Regression equations for the quality attributes of OFSP crisps are presented in Equations (1)-(9) for Mothers’ Delight variety (MDV), and Equations (10)-(18) for King J variety (KJV). Tables 3 and 4 show the analysis of variance and coefficients for the prediction models.

Regression equations for quality attributes of OFSP crisps from MDV:

\[
\begin{align*}
MC &= 2.21 - 3.00A - 4.49B + 1.04A^2 + 3.73B^2 + 2.55AB \quad s \\
OC &= 30.57 - 0.33A + 2.47B - 0.28A^2 + 0.24B^2 - 0.42AB \quad ns \\
TC &= 3759.65 - 1040.38A - 585.97B - 299.38A^2 + 348.41B^2 + 141.62AB \quad s \\
L_c &= 48.10 - 3.66A - 4.81B - 3.55A^2 - 0.66B^2 + 0.26AB \quad s \\
a^* &= 21.36 - 0.97A - 2.89B - 1.65A^2 - 0.68B^2 + 1.17AB \quad ns \\
b^* &= 35.67 - 4.30A - 7.58B - 3.30A^2 - 0.76B^2 + 1.60AB \quad ns \\
Cr &= 9.08 + 2.75A + 2.21B - 1.72A^2 - 2.52B^2 + 0.57AB \quad s \\
Or &= 8.80 - 2.51A - 2.45B - 2.00A^2 - 1.79B^2 - 1.83AB \quad s \\
Br &= 2.71A + 2.40B + 1.82A^2 + 1.37B^2 + 2.09AB \quad s
\end{align*}
\]

Regression equations for quality attributes of OFSP crisps from KJV:

\[
\begin{align*}
MC &= 3.83 - 1.74A - 3.37B + 0.66A^2 + 1.63B^2 + 2.02AB \quad s \\
OC &= 23.09 + 0.86A + 2.46B + 0.15A^2 - 0.19B^2 - 0.80AB \quad ns \\
TC &= 2760.80 + 42.91A - 150.52B - 202.80A^2 + 345.62B^2 + 585.00AB \quad ns
\end{align*}
\]
| Run | Temp. (ºC) | Time (min) | MC (%) | OC (%) | TC (µg/100 g) | L* | a* | b* | Crispiness | Orange colour | Brown colour |
|-----|------------|------------|--------|--------|---------------|----|----|----|------------|----------------|---------------|
| 1   | 136        | 4.5        | 5.96   | 31.66  | 4124.74       | 49.33 | 22.31 | 45.19 | 3.18       | 7.97           | 0             |
| 2   | 140        | 3.0        | 18.81  | 26.30  | 5953.96       | 49.45 | 21.06 | 37.96 | 0.03       | 7.98           | 0             |
| 3   | 140        | 6.0        | 5.25   | 32.77  | 4795.52       | 39.86 | 13.60 | 16.79 | 1.70       | 8.08           | 0             |
| 4   | 150        | 2.4        | 15.66  | 29.72  | 4925.28       | 56.22 | 26.78 | 47.80 | 0.50       | 8.80           | 0             |
| 5   | 150        | 4.5        | 2.07   | 31.43  | 3793.72       | 46.58 | 21.74 | 36.97 | 9.29       | 8.88           | 0             |
| 6   | 150        | 4.5        | 2.07   | 31.43  | 3793.72       | 46.58 | 21.74 | 36.97 | 9.29       | 8.88           | 0             |
| 7   | 150        | 4.5        | 2.07   | 31.43  | 3793.72       | 46.58 | 21.74 | 36.97 | 9.29       | 8.88           | 0             |
| 8   | 150        | 4.5        | 2.07   | 31.43  | 3793.72       | 46.58 | 21.74 | 36.97 | 9.29       | 8.88           | 0             |
| 9   | 150        | 4.5        | 2.07   | 31.43  | 3793.72       | 46.58 | 21.74 | 36.97 | 9.29       | 8.88           | 0             |
| 10  | 150        | 4.5        | 2.07   | 31.43  | 3793.72       | 46.58 | 21.74 | 36.97 | 9.29       | 8.88           | 0             |
| 11  | 160        | 3.0        | 5.11   | 25.78  | 3677.98       | 42.91 | 17.69 | 33.39 | 5.39       | 7.22           | 0             |
| 12  | 160        | 6.0        | 1.74   | 30.56  | 3086.03       | 34.36 | 14.90 | 18.61 | 9.33       | 8.38           | 0             |
| 13  | 164        | 4.5        | 1.14   | 31.73  | 1057.61       | 37.13 | 18.26 | 22.81 | 9.56       | 0              | 9.43          |

OFSP – orange-fleshed sweetpotato, MC – moisture content, OC – oil content, TC – total carotenoids, L* – lightness, a* – redness, b* – yellowness.
### Table 2. Effect of frying temperature and time on quality attributes of OFSP crisps from king J variety

| Run | Temp. (ºC) | Time (min) | MC (%) | OC (%) | TC (µg/100 g) | L* | a* | b* | Crispiness | Orange colour | Brown colour |
|-----|------------|------------|--------|--------|---------------|----|----|----|------------|---------------|--------------|
| 1   | 136        | 4.5        | 5.63   | 23.96  | 2643.67       | 49.20 | 2.38 | 32.00 | 8.90      | 7.63          | 1.07         |
| 2   | 140        | 3.0        | 3.50   | 24.28  | 2597.33       | 49.59 | 2.18 | 30.21 | 9.15      | 6.73          | 1.62         |
| 3   | 140        | 6.0        | 15.83  | 16.74  | 2526.00       | 52.99 | −2.33 | 29.59 | 5.09      | 6.10          | 0.19         |
| 4   | 150        | 2.4        | 9.43   | 21.36  | 4933.68       | 52.04 | −1.32 | 29.93 | 3.99      | 5.56          | 0.40         |
| 5   | 150        | 4.5        | 3.23   | 22.20  | 3463.00       | 53.31 | 3.15  | 33.12 | 9.23      | 6.69          | 2.14         |
| 6   | 150        | 4.5        | 3.60   | 21.00  | 2183.67       | 51.45 | 3.01  | 31.18 | 7.76      | 6.55          | 0.51         |
| 7   | 150        | 4.5        | 3.97   | 24.22  | 2667.00       | 45.92 | 6.54  | 25.31 | 9.21      | 5.43          | 3.75         |
| 8   | 150        | 4.5        | 4.00   | 25.17  | 1521.66       | 40.66 | 5.42  | 17.16 | 9.49      | 3.22          | 7.33         |
| 9   | 150        | 4.5        | 4.37   | 22.84  | 3968.69       | 46.90 | 1.22  | 25.00 | 9.37      | 7.31          | 1.65         |
| 10  | 150        | 4.5        | 2.10   | 26.85  | 2326.67       | 40.01 | 11.19 | 20.05 | 9.46      | 5.32          | 8.66         |
| 11  | 150        | 4.5        | 3.10   | 24.95  | 4095.00       | 45.72 | 10.11 | 25.75 | 8.54      | 6.03          | 7.58         |
| 12  | 150        | 6.0        | 7.37   | 20.61  | 1683.67       | 53.37 | 7.13  | 36.97 | 7.87      | 5.40          | 0.80         |
| 13  | 164        | 4.5        | 2.03   | 25.62  | 2423.00       | 48.27 | 11.54 | 31.71 | 9.29      | 1.97          | 7.88         |

OFSP – orange-fleshed sweetpotato, MC – moisture content, OC – oil content, TC – total carotenoids, L* – lightness, a* – redness, b* – yellowness.
Table 3. Analysis of variance for the models for OFSP crisps from Mother’ Delight variety

| Responses | Sources of variation | DF | Sum of squares | Mean square | F-value | R² |
|-----------|----------------------|----|----------------|-------------|---------|----|
| MC        | Regression           | 5  | 358.83         | 71.77       | 27.17   | 0.9510** |
|           | Residual             | 7  | 18.49          | 2.64        |         |     |
|           | Total                | 12 | 377.32         |             |         |     |
| TC        | Regression           | 5  | 1.317E +007    | 2.634E +006 | 6.61    | 0.8251* |
|           | Residual             | 7  | 2.792E +006    | 3.988E +005 |         |     |
|           | Total                | 12 | 1.596E +007    |             |         |     |
| L*        | Regression           | 5  | 381.06         | 76.21       | 9.14    | 0.8671** |
|           | Residual             | 7  | 58.39          | 8.34        |         |     |
|           | Total                | 12 | 439.45         |             |         |     |
| a*        | Regression           | 5  | 100.30         | 20.06       | 2.64    | 0.6536   |
|           | Residual             | 7  | 53.16          | 7.59        |         |     |
|           | Total                | 12 | 153.46         |             |         |     |
| b*        | Regression           | 5  | 693.92         | 138.78      | 1.45    | 0.5094   |
|           | Residual             | 7  | 668.25         | 95.46       |         |     |
|           | Total                | 12 | 1362.17        |             |         |     |
| Cr        | Regression           | 5  | 158.86         | 31.77       | 19.29   | 0.9323** |
|           | Residual             | 7  | 11.53          | 1.65        |         |     |
|           | Total                | 12 | 170.39         |             |         |     |
| Or        | Regression           | 5  | 156.31         | 31.26       | 22.72   | 0.9420** |
|           | Residual             | 7  | 9.63           | 1.38        |         |     |
|           | Total                | 12 | 165.94         |             |         |     |
| Br        | Regression           | 5  | 154.37         | 30.87       | 16.35   | 0.9211** |
|           | Residual             | 7  | 13.21          | 1.89        |         |     |
|           | Total                | 12 | 167.58         |             |         |     |

OFSP – orange-fleshed sweetpotato, MC – Moisture content, OC – Oil content, TC – Total carotenoids.
L* – Lightness, a* – Redness, b* – Yellowness, Cr – Crispiness, Or – Orange colour, Br – Brown colour.
*significant at P < 0.05, **significant at P < 0.01.

L* = 47.65 – 0.88A – 3.78B + 1.17A² – 0.19B² – 1.61AB  ns (13)

a* = 3.87 + 3.79A + 3.15B + 1.13A² + 0.11B² – 0.38AB  s (14)

b* = 26.35 – 0.31A – 3.07B + 3.30A² – 0.13B² – 2.96AB  ns (15)

Cr = 9.01 + 0.34A + 1.56B – 0.02A² – 1.21B² – 0.85AB  s (16)

Or = 5.84 – 1.18A + 0.12B – 0.28A² + 0.036B² + 0.00AB  ns (17)

Br = 3.08 + 2.03A + 2.49B + 0.21A² + 0.24B² + 1.34AB  ns (18)

s: significant ns: not significant

MC-moisture content, OC-oil content, TC-total carotenoids, L*-lightness, a*-redness, b*-yellowness, Cr-crispiness, Or-orange colour, Br-brown colour
3.2. Effect of frying conditions on quality attributes of OFSP crisps

3.2.1. Moisture content

Tables 1 and 2 show the effect of frying temperature (FTp) and frying time (FTm) on chemical, instrumental colour and sensory properties of sweetpotato crisps from Mothers’ Delight (MD) and King J (KJ) varieties, respectively. The moisture content (MC) of crisps ranged from 1.14% (164°C/4.5 min) to 18.81% (140°C/3 min) for MD, and from 2.03% (164°C/4.5 min) to 15.83% (140°C/6 min) for KJ. For both varieties, FTp and FTm had significant (p < 0.01) effect on MC. MC decreased as the FTp and FTm increased (Figure 1(a), 2(a)). At constant FTm, MC decreased with increase in FTp. Also, at constant FTp, MC decreased with increase in FTm. For instance, for MD, at a constant FTp of 140°C, MC decreased from 18.81% (3.0 min) to 5.25% (6.0 min), at 150°C, MC decreased from 15.66% (2.4 min) to 2.21% (6.6 min) and at 160°C, MC decreased from 5.11% (3.0 min) to 1.74% (6.0 min). However, for KJ variety, although the trend was similar at 150°C with a decrease in MC from 9.43% (2.4 min) to 2.10% (6.6 min), it was different at 140°C and 160°C; this could only be attributed to other factors beyond FTp and FTm, and

![Table 4. Analysis of variance for the models for OFSP crisps from King J variety](https://doi.org/10.1080/23311932.2019.1658977)

**OFSP** – orange-fleshed sweetpotato, **MC** – Moisture content, **OC** – Oil content, **TC** – Total carotenoids.

**L*** – Lightness, **a*** – Redness, **b*** – Yellowness, **Cr** – Crispiness, **Or** – Orange colour, **Br** – Brown colour.

*significant at P < 0.05, **significant at P < 0.01.
may be due to differences in textural compactness of the root and consequently rate of moisture flow across the tissue. The roots of KJ have a harder texture than MD variety and so may restrict moisture flow/loss. Although the MC of roots used in this study was not determined, reports indicated an average MC of 78% and 64% for MD and KJ roots, respectively (Afuape, 2013; Tumwegamire et al., 2014). Sobukola et al. (2008) and Adeyanju et al. (2016) reported a decrease in MC during frying. MC of fried products has implications for storage quality and safety; lower MC reduces the susceptibility to microbial growth and lipid oxidation.

3.2.2. Oil content

The oil content (OC) of OFSP crisps ranged from 25.07% (150°C/4.5 min) to 35.72% (150°C/6.6 min) for MDV (Table 1), and from 16.74% (140°C/6.0 min) to 26.85% (150°C/6.6 min) for KJV (Table 2). Crisps from both varieties had the highest OC at the same frying conditions (150°C/6.6 min). At longer frying times (4.5 min), increasing the FTP increased the OC while at shorter frying times (3.0 min), OC decreased. FTP and FTm had no significant (p > 0.05) effect on OC. This implies that other factors beyond FTP and FTm were responsible for the trend observed in OC. Varying trends in oil uptake of fried products have been reported and a variety of factors have been suggested. An increase in oil uptake with an increase in temperature was reported by Diaz, Totte, Giroux, Reynes, and Raoult-Wack (1996) and Adeyanju et al. (2016) for plantain chips, Sobukola et al. (2008) for yam chips, and Krokida, Orepoulou, Maroulis, & Kouris (2001) for potato chips. On the other hand, a decrease in oil uptake with increasing temperature was reported by Paz-Gamboa et al. (2015) for Taro chips, and Mayano and Pedreschi (2006) for plantain chips. In addition to frying temperature and time, Fellows (2000) highlighted a number of factors including moisture-related pre-treatments such as blanching or pre-drying that influences the amount of oil entrained in fried foods. In fried foods, oil content can account for up to 45% of the product (Fellows, 2000) or higher (58.8–62.0%) for carrot chips (Sulaeman, Giraud, Taylor, & Driskell, 2001). Although consumption of foods with high oil content has been associated with some ailments, fried foods may serve as a calorie source if it is not consumed excessively. It can also serve to absorb and increase utilization of carotenoids as precursors of vitamin A.
3.2.3. Total carotenoids

The total carotenoid content (TC) of OFSP crisps ranged from 1057.61 µg/100 g (164°C/4.5 min) to 5953.96 µg/100 g (140°C/3.0 min) for MDV (Table 2), and from 1683.67 µg/100 g (160°C/6.0 min) to 2326.67 µg/100 g (150°C/6.6 min) for KJV (Table 3). TC was significantly (p < 0.05) affected by FTp and FTm for MDV but not for KJV (p > 0.05). Carotenoids have a relationship with colour of fruits.
and vegetables, and depending on the structural configuration, may manifest as yellow through orange to red or green hue (Burri, 2011; deMan, 1999). In the current study, the fresh OFSP roots of MDV had a deep-orange flesh colour while that of KJV was light-orange colour. This trend was similar to Afuape (2013) and Tumwegamire et al. (2014), who reported that TC for OFSP roots were 10,500–14,370 µg/100 g and 700–1650 µg/100 g for MDV and KJV, respectively. The higher values for carotenoids in OFSP fried crisps relative to the values for fresh roots may be due to the loss of moisture (dry weight basis typical of fried and crispy products) which resulted in an increase in the concentration of carotenoids. The decrease in TC of OFSP crisps with increase in FTP and FTm (Figure 1(b)) was in accordance with Rodriguez-Amaya (1997) and Sulaeman et al. (2001). The stability of carotenoids differs in different foods even when the same processing and storage conditions are used. The major cause of carotenoid degradation during processing and storage is oxidation (enzymatic and nonenzymatic), while cutting of the food, longer processing time and higher processing temperatures reduces retention of carotenoids (Rodriguez-Amaya, 1997). Fried crisps from both MDV and KJV could be promoted as snack foods to improve the VA status among consumers due to their high carotenoid content, with MD being a richer source.

3.2.4. Colour

The range of colour values for crisps from MD variety (Table 1) were, lightness L* [34.36 (160°C/6.0 min)—56.22 (150°C/2.4 min)], redness a* [13.60 (140°C/6.0 min)—26.78 (150°C/2.4 min)] and yellowness b* [16.79 (140°C/6.0 min)—47.80 (150°C/2.4 min)]. The range for KJ variety (Table 2) was L* [40.01 (150°C/6.6 min)—53.37 (160°C/4.5 min)], a* [-2.33 (140°C/6.0 min)—11.54 (164°C/4.5 min)] and b* [17.16 (150°C/4.5 min)—36.97 (160°C/6.0 min)]. FTP and FTm had significant (p < 0.01) effect on L* for MD variety and on a* (p < 0.05) for KJ variety. This suggests that each of L* or a* could be a quality index for fried crisps for each variety accordingly. As the FTP and FTm increased, L* decreased for MD (Figure 1(c)) while a* increased for KJ. Decrease in L* value has been linked with non-enzymatic browning reactions that accelerates at high temperatures (Dueik, Robert, & Bouchon, 2010). According to Sulaeman et al. (2001), increasing frying temperature lowered the redness value a, which also correlated with decreased carotenoid content for carrot chips. For MD variety in the present study, L*, a*, b* and total carotenoids reduced with increase in FTP and FTm.

3.2.5. Sensory attributes

Crispiness for MDV ranged from 0.03 (140°C/3.0 min) to 9.56 (164°C/4.5 min) and from 3.99 (150°C/2.4 min) to 9.49 (150°C/4.5 min) for KJV. For both varieties, FTP and FTm had significant (p < 0.01) effect on crispiness. Crispiness increased with increase in frying temperature and time for MD (Figure 1(d)) while a variable trend was observed for KJ at different frying temperatures with increase in time (Figure 2(c)). Texture differences in raw root may be responsible for the different trends exhibited between the crisps from the two OFSP varieties. KJ roots had a harder texture and appear to exhibit higher crispiness (3.99–9.15) at lower temperatures (136°C-150°C/2.4 min). However, MDV exhibited higher crispiness (5.39–9.56) at higher temperatures (150°C/4.5 min-164°C). Crispiness is an important textural attribute that contributes to consumer acceptance of fried products (Kumar, Asha, & Prakash, 2015; Sulaeman et al., 2001); therefore, high scores for crispiness but without burnt appearance are desirable. According to Fellows (2000), texture of fried foods is produced by changes to proteins, fats and polymeric carbohydrates.

Orange and brown colours of crisps from MDV were significantly (p < 0.01) affected by FTP and FTm. Orange colour of MD crisps increased with increase in frying conditions within the range of 136°C/4.5 min (7.97) and 150°C/4.5 min (8.92) and a high score (7.22) was also observed at 160°C/3.0 min (Figures 1(d), 2(c)). Orange colour of crisps contributes to sensory appeal and therefore high scores for this attribute are desirable. The brown colour of the OFSP crisps was an indication of burnt product and therefore undesirable. There appears to be an inverse relationship between orange and brown colours of the crisps; the higher the scores for orange colour, the lower the score for brown colour. For instance, at higher frying temperature
and time combinations (150°C/6.6 min, 160°C/6.0 min, 164°C/4.5 min), MD crisps had scores of orange colour (0) and brown colour (7.63–9.43), which implies that these frying temperature and time combinations were unsuitable for sensory appeal of the crisps. Orange and brown colours of KJ crisps were not significantly (p > 0.05) affected by FTp and FTm, suggesting that these parameters will not be suitable indices for quality control of crisps from KJV.

3.3. Optimization
RSM as an optimization tool reduced the number of trials (experiments) for frying of OFSP crisps; 13 as opposed to 32, that would have been required for two variables (frying temperature and time) at five levels (2⁵). This is expected to reduce time, materials, and overall cost required to achieve optimum processing conditions and desired product quality (Bas & Boyaci, 2007). The response models (equations) generated serve to study the effect of frying temperature alone and in combination with frying time on the quality attributes of OFSP crisps. The models that were significant (p < 0.05) will help to predict specific quality attributes of the crisps accordingly. The direction in which to change the process variables to achieve desired quality of the crisps can also be determined by the models.

Numerical optimization was performed by setting the following goals for the desired quality attributes of OFSP crisps: minimum moisture and oil contents, and maximum total carotenoids (TC), crispiness and orange colour. The optimum frying conditions generated (Table 5) indicated that the same frying time (4.20 min) is required for both varieties but at a higher temperature for MD (151.27°C) than for KJ (146.36°C). The quality attributes of the crisps at these optimum conditions indicate that MDV will have a lower MC (2.85%) but higher oil content (30.04%), TC (3752.33 µg/100 g), crispiness (8.84) and orange colour (8.92) than KJ (Table 5).

3.4. Sensory attributes and consumer acceptability of optimized OFSP crisps
Sensory attributes of optimized OFSP crisps are described in Figure 3. Although crispiness of both varieties appears to be close (8.64–8.92), KJ crisps with the higher crispiness (8.92) had a higher oiliness (7.61) and lower orange colour (4.92) than MD crisps.

Consumer likeness for sweetness (7.98–8.06) and crispiness (7.12–7.16) for both OFSP crisps were similar; however, MD crisps with the higher overall acceptability (7.78) was scored lower for sweetness (7.98), crispiness (7.12) and colour (5.56) but higher for oiliness (7.08) (Figure 4). The lower oiliness described for MD (2.50) (Figure 3) may be responsible for its higher degree of likeness and overall acceptability. This may be an indication of the health consciousness of consumers against consuming oil-rich foods. Since MDV has an additional advantage of higher total carotenoids (Table 1), deep-fat fried crisps from this variety may be recommended as a snack to improve the vitamin A status of consumers. Product quality and consumer acceptance of newly developed food products or those containing new ingredients have been predicted by descriptive sensory characterization (Greene & Bovell-Benjamin, 2004; Lynch, Koppel, & Reid, 2017; Olatunde, Tomlins, Henshaw, & Idowu, 2016).

4. Conclusions
FTp and FTm influenced moisture content and crispiness but not oil content for both varieties of OFSP. Total carotenoids (TC), L*, orange and brown colours for MDV, as well as a* for KJV, were influenced by the frying conditions. Each variety exhibited varying and sometimes opposing trends in most quality attributes as a function of frying conditions. Although crisps from both varieties may be promoted as a source of vitamin A due to their TC content, MD crisps had higher values which reduced with increase in frying conditions. In addition to frying conditions, textural differences in hardness and differences in intensity of orange flesh of OFSP roots appear to be an important factor influencing some of the quality attributes of OFSP crisps. The orange colour of the crisps which increased for MD but decreased for KJ, with increase in frying conditions, was also an important sensory quality index. The optimum frying conditions and corresponding qualities for each variety were: Mothers’ Delight (151.27 °C/4.20 min) with moisture content (MC)-2.85%, oil
Table 5. Optimized frying conditions and quality attributes of OFSP crisps

| Variety         | Frying temperature (°C) | Frying time (min) | Moisture content (%) | Oil content (%) | Total carotenoids (µg/100 g) | Crispiness | Orange colour |
|-----------------|-------------------------|-------------------|----------------------|----------------|-------------------------------|------------|---------------|
| Mothers’ Delight| 151.27                  | 4.20              | 2.85                 | 30.04          | 3752.33                       | 8.84       | 8.92          |
| King J          | 146.36                  | 4.20              | 5.43                 | 22.25          | 2803.20                       | 8.47       | 6.21          |

OFSP – orange-fleshed sweet potato.
content-30.04%, TC-3752.33 µg/100 g, crispiness-8.84, orange colour-8.92 and King J (146.36 °C/4.20 min) with MC-5.43%, oil content-22.25%, TC-2803.20 µg/100 g, crispiness-8.47, orange colour-6.21. MD crisps with a lower sensory oiliness had a higher consumer acceptance.

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