Heliyon

*Received:*
6 November 2018
*Revised:*
20 February 2019
*Accepted:*
13 March 2019

Cite as:
Oluwatoyin Oladayo Onipe,
Daniso Beswa,
Victoria Adaora Jideani,
Afam Israel Obiefuna Jideani.
Development of a low-fat,
high-fibre snack: effect of bran
particle sizes and processing
conditions.
Heliyon 5 (2019) e01364.
doi: 10.1016/j.heliyon.2019.e01364

# Development of a low-fat, high-fibre snack: effect of bran particle sizes and processing conditions

**Oluwatoyin Oladayo Onipe** [a], **Daniso Beswa** [b], **Victoria Adaora Jideani** [c], **Afam Israel Obiefuna Jideani** [a,*]

[a] *Department of Food Science and Technology, School of Agriculture, University of Venda, Private Bag X5050, Thohoyandou 0950, Limpopo Province, South Africa*

[b] *Department of Life and Consumer Sciences, School of Agriculture and Life Sciences, University of South Africa, Private Bag X6, Florida 1710, Gauteng Province, South Africa*

[c] *Department of Food Science and Technology, Cape Peninsula University of Technology, Faculty of Applied Sciences, PO Box 1906, Bellville 7535, Western Cape Province, South Africa*

[*] Corresponding author.

E-mail address: Afam.Jideani@univen.ac.za (A.I.O. Jideani).

## Abstract

The influence of fine and medium wheat bran (WB) particle sizes on process and quality parameters of a cereal fried dough (*magwinya*) was investigated. *Magwinya* is a snack that resembles, but different from doughnut and it is commonly consumed in most Sub-Saharan African countries. The effect of WB, fermentation and frying time was investigated on weight, diameter, volume, colour, hardness, fat, ash, and moisture, contents of *magwinya*. Further investigation on mineral and fibre contents as well as the consumer acceptance of optimised samples was also carried out. Predictive models were generated from responses with all lack of fit values >0.1, $R^2$ values ≤0.99 and desirability function of 0.82 and 0.78 for fine and medium WB, respectively. Close agreement between experimental and predicted values for fat and ash was found. The linear, quadratic and interaction effects of process variables significantly (p < 0.05) increased ash, hardness, lightness and moisture and reduced volume and fat content of *magwinya*. incorporation of 15 g WB, dough fermentation time of

https://doi.org/10.1016/j.heliyon.2019.e01364

71.66 min (fine WB) and 76.43 min (medium WB) and 3 min frying time significantly ($p < 0.05$) reduced fat content of *magwinya* by 44.96% and 22.92%, respectively, and increased ash by 50.41% and 54.20%, respectively. Fine WB resulted in the least fat content while medium WB increased the ash and minerals.

Keywords: Food science, Food technology

## 1. Introduction

Despite the shifting consumer eating trends towards healthy diet, deep-fried snack foods still form a large portion of our daily diets. *Magwinya* – a popular snack in most sub-Saharan African countries is one of the deep-fried snacks with high affordability. From a nutritional point of view, this snack is characterised by lack of essential nutrients, vitamins, minerals, dietary fibre and high fat content (0.2 g/g, dry weight basis) (Onipe et al., 2018). Its high fat content is mainly due to evaporation of water from the dough matrix and oil uptake during frying (Mellema, 2003; Ziaiifar et al., 2008). Increased intake of foods low in micronutrients and high in fat, sugar and salt is a causal factor for overweight and obesity (Malhotra et al., 2008; Steyn et al., 2011; Temple et al., 2011).

Obesity and overweight are associated with cardiovascular disease and type 2 diabetes mellitus and other diseases (Ji et al., 2017). Among the factors that contribute to obesity in developing countries are diet change, less active lifestyle, health and nutrition (FAO, 2018). The consumer-focus in the on-going obesity epidemic is not the only problem; consumers have been conditioned to purchase what is available and affordable. In a recent survey (unpublished data), it was discovered that *magwinya* is a favourite snack amongst high school and university students because of its affordability, taste and convenience. With the increasing rate of childhood and teenage obesity, it is expedient that a nutrient-rich *magwinya* be developed. Therefore, there is a need for manufacturers to prioritise healthier and more nutritious food thereby allowing consumers make wise and healthy food choices (Otero et al., 2018). Successful research attempts to reduce oil uptake of *magwinya* include use of coarse wheat bran (WB) (Onipe et al., 2018) and psyllium husk fibre and oat bran (Kwinda et al., 2018).

In a study by Onipe et al. (2018), WB was utilised as a functional ingredient in the optimisation and development of a low-fat high fibre *magwinya*. Extensive studies and reviews have been carried out on WB for valorisation and its utilisation in food (Prückler et al., 2014; Onipe et al., 2015) highlighting its effect in bakery products (Noort et al., 2010; Yadav and Rajan, 2012; Hemdane et al., 2016; Sobota et al., 2015). The changes WB impacts on dough include increased water absorption, delayed dough development, decreased dough strength and reduced bread loaf volume


https://doi.org/10.1016/j.heliyon.2019.e01364

(Zhang and Moore, 1997; Onipe et al., 2017). Size reduction alone and coupled with enzymatic treatment (Santala et al., 2014) has been employed to combat the negative effects of coarse WB in food products. We recently used coarse bran in *magwinya* with success in oil reduction (Onipe et al., 2018). However, consumer acceptance was not satisfactory. WB flour with medium and fine particles sizes were utilised as a result. To achieve the desirable outcome, Response surface methodology (RSM) was used to optimize the formulation and processing of *magwinya* using three factors, three-level Box−Behnken experimental design combined with RSM and quadratic model to improve the effectiveness expressed in terms of ash and fat content of the product. The effects of three independent variables (WB, fermentation and frying time) and their interactions were examined. We also hypothesised that the incorporation of WB to *magwinya* and optimisation of its processing conditions will reduce oil content.

## 2. Materials and methods

### 2.1. Materials

Wheat flour and bran (Snowflake mills, South Africa), yeast, sunflower oil, salt and sugar were purchased from a local supermarket in South Africa. All chemicals (analytical grade) and reagents were purchased from Merck (Pty, Ltd South Africa).

### 2.2. Experimental design and response surface optimization

Three factors were investigated at two levels each. WB content (A), fermentation time (B) and frying time (C) were chosen as independent variables to model. The range and levels of the independent variables investigated in this study are presented below (Table 1). Response surface plots were attained using the fitted model by keeping the least effective independent variable at a constant value while changing the other two variables. The numerical optimization of the frying process was aimed at finding the levels of WB content, fermentation and frying time which could

**Table 1.** Experimental range and levels of independent variables used for Box-Benkhen experimental design.[a]

| **Variables ($X_i$)** | **Coded levels ($x_i$)** | | |
|---|---|---|---|
| | **Low (−1)** | **Centre (0)** | **High (1)** |
| Wheat bran (g) [$X_1$] | 1 | 8 | 15 |
| Fermentation time (min) [$X_2$] | 45 | 82.5 | 120 |
| Frying time (min) [$X_3$] | 1 | 2 | 3 |

[a] Transformation between the coded and the uncoded variables is given by $X_1 = 7x_1 + 8$; $X_2 = 37.5\ \mathrm{X}_2 + 82.5$; $X_3 = X_3 + 2$.


https://doi.org/10.1016/j.heliyon.2019.e01364

maximize ash content and minimize oil content. The design of the experiment and the data treatment of the Box−Behnken experimental design were performed using Design expert statistical software version 8.0.6 (Stat-ease Inc, Minneapolis MN, USA). The quadratic model for Box-Behnken design is given in Eq. (1):

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_{ii}^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{n} \beta_{ij} X_i X_j \tag{1}$$

where $X_i$ and $X_j$ are the independent variables, Y represents the dependent variable (weight, diameter, volume, hardness, L*, a*, b*, ΔE, moisture, oil or ash), $\beta_0$, $\beta_i$, $\beta_{ii}$ and $\beta_{ij}$ corresponds to the regression coefficients of the intercept, linear, quadratic and interaction terms, respectively.

## 2.3. Size reduction of wheat bran

Milling, sieving and storage of commercial WB was carried out as described by Onipe et al. (2017). The WB was milled using an ultra-centrifugal mill (Retsch ZM 200, Haan Germany). Medium and fine particle size fractions were obtained from milled bran using a vibratory sieve shaker (Fritsch Analysette 3 SPARTAN, Idar-Oberstein Germany). The WB fractions with medium and fine particle sizes were stored in airtight polyethylene bags at −20 °C until needed.

## 2.4. *Magwinya* preparation

*Magwinya* was prepared according to the method of Onipe et al. (2018). Dry ingredients: wheat flour-WB composite (100 g), sugar (15 g), salt (1 g) and yeast (1 g) were weighed and thoroughly mixed and lukewarm water (65 ml), was added. The dough was kneaded in a mixer (Russell Hobbs RHSB237, South Africa) for 10 min. The dough was fermented at 30 °C for 45−120 min (Table 1), cut into 50 g pieces, shaped into a ball and deep-fried for 1−3 min at 180 °C. Control sample (100 g wheat flour: 0 g WB) was fermented at 30 °C for 120 min and deep-fried at 3 min. Frying experiments were performed in a 3.5 L deep fryer (Russell Hobbs RDF300, South Africa) with temperature and time control. The fryer was filled with sunflower oil and heated to 180 °C (±2 °C) for 1 h prior to frying in order to stabilise the temperature. Ratio of sample to oil was maintained at 1:23 to avoid drastic temperature fluctuation. Oil was discarded after four frying batches. *Magwinya* was placed on an absorbent paper to absorb excess oil and allowed to cool down to room temperature prior to analysis.

## 2.5. Weight, diameter and volume

Weight, diameter and volume of samples were measured in triplicates as described by Onipe et al. (2018). *Magwinya* was cooled down to ambient temperature and


https://doi.org/10.1016/j.heliyon.2019.e01364

weights of three *magwinya* from the same experimental run were collected using a digital weighing balance. Rapeseed displacement method 10−05 of AACC (2000) was used for measurement of *magwinya* volume. After volume measurement, the *magwinya* were sliced with a sharp utility knife and diameter was measured using a Vernier Calliper VC04 (Walter-Stern Inc. NY, USA).

## 2.6. Hardness

Hardness of *magwinya* was measured in triplicates using a texture analyser (TA. XT Plus, Stable Micro Systems Ltd, Godalming, UK) fitted with a 5-kg load cell and P/36 cylindrical probe. Three whole *magwinya* samples from the same experimental run were subjected to return-to-start tests at 40% strain, test speed of 2 mm/s and post-test speed of 1 mm/s. Hardness was recorded as the peak positive force (g) in the force-deformation curve (Onipe et al., 2018).

## 2.7. Colour determination

A Colour flex Spectrophotometer (Hunter Associates Laboratory, Reston, Va., U.S.A) with illuminant D65 and a 10° observer was used to measure the crumb and crust colour of *magwinya* based on the CIE system (L*, a* and b*). The instrument was calibrated with a zero-calibration tile followed by white calibration plate (CX2540). Crust and crumb colour of three magwinya from the same experimental run were measured. *Magwinya* samples were placed in the sample cup, covered and scanned using the spectrophotometer. The samples were sliced for crumb measurement. Colour change (ΔE) of *magwinya* was calculated from the L*, a* and b* values using Eq. (2).

$$\Delta E = \sqrt{\left[(L - Lc)^2 + (a - ac)^2 + (b - bc)^2\right]} \tag{2}$$

where: Lc, ac and bc represent the colour values for the control sample.ΔE represents the degree of overall colour change of a sample in comparison to colour values (Lc, ac and bc) of the control sample − *magwinya* without bran (Pathare et al., 2013).

## 2.8. Moisture, oil, ash and fibre contents

Moisture, oil and ash contents were determined in triplicates using approved methods 44-15, 30-25.01 and 08-01.01 of AACC (1999), respectively; and fibre was estimated using 985.29 of AOAC (2000).

After frying, *magwinya* was cut into slices and dried in a forced air oven at 105 °C to constant mass and cooled in a desiccator. Percentage moisture content was obtained from the division moisture loss and sample weight (Eq. 3). Dried samples were


https://doi.org/10.1016/j.heliyon.2019.e01364

ground into powder using a grinder and fat content was determined by a 4-h solvent extraction using petroleum ether (40−60 °C) in an automated Soxhlet extractor. Fat content was calculated using Eq. (4). Silica crucibles were ignited, cooled in a desiccator and weighed upon attaining room temperature. Fresh samples (3 g) were weighed into the crucibles, covered and placed in a muffle furnace at 550 °C overnight. Crucibles were cooled in a desiccator, weighed and percentage ash calculated (Eq. 5).

$$\text{Moisture content}\ (\%) = \frac{\text{moisture loss}}{\text{sample weight}} \times 100 \tag{3}$$

$$\text{Fat content}\ (\%) = \frac{\text{weight of extract}}{\text{sample weight}} \times 100 \tag{4}$$

$$\text{Ash content}\ (\%) = \frac{\text{Weight of residue}}{\text{Weight of sample}} \times 100 \tag{5}$$

## 2.9. Mineral analysis

Mineral analysis was conducted using the method of Szymczycha-Madeja (2014) with slight modifications. In order to solubilise the acid-extractable elemental content of the sample, digestion was performed on a MARS microwave digester, using ultra-pure $HNO_3$, or $HNO_3$ + HCl, at elevated temperature and pressure. After a cooling period, the extractant was made up to 50 ml volume with deionised water, then analysed using either inductively coupled Plasma atomic emission spectrometer (ICP-AES) and/or inductively coupled plasma mass spectrometer (ICP-MS) for the selected analytes. Calcium and Magnesium were analysed on a Thermo ICap 6200 ICP-AES (Thermo Fisher Scientific Inc. USA). The instrument was calibrated using NIST (National Institute of Standards and Technology, Gaithersburg MD, USA) traceable standards to quantify selected elements. A NIST-traceable quality control standard of a separate supplier than the main calibration standards were analysed to verify the accuracy of the calibration before sample analysis. Where samples have undergone a digestion step, the results were corrected for the dilution factor resulting from the digestion procedure. Samples were analysed for Fe, Mn and Zn on an Agilent 7900 quadrupole ICP-MS (Thermo Fisher Scientific Inc. USA). Samples were introduced through a 0.4 ml/min micro mist nebulizer into a Peltier-cooled spray chamber at a temperature of 2 °C, with a carrier gas flow of 1.05 L/min. The elements were analysed under He-collision mode to remove polyatomic interferences.

## 2.10. Consumer acceptance

Consumer acceptability of one control and three optimized *magwinya* samples was carried out using a 9-point hedonic scale from 1 (dislike extremely) to 9 (like


https://doi.org/10.1016/j.heliyon.2019.e01364

extremely) according to Kemp et al. (2011). Qualities assessed were colour (crumb and crust), texture (hardness and chewiness), aroma, oiliness, dryness and overall acceptability. Four samples, each on a coded plate were presented to 50 untrained panellists (students of the university) simultaneously in a random order seated in individual booths to avoid interaction with one another. Water was provided to cleanse the palate in-between tests. Ethical clearance was obtained from the University Research Ethics Committee before consumer tests were conducted.

### 2.11. Microstructure

Scanning electron micrographs of dough and *magwinya* samples was determined according to the method of Kim et al. (2012) with some modifications. Imaging of the samples was accomplished using a Zeiss MERLIN Field emission scanning electron microscope (Zeiss, Oberkochen, Germany). Dough samples were freeze-dried for 24 h and fractured into 3−5 mm sections. Prior to imaging, the samples were mounted on a stub with double sided carbon tape. The samples were then coated with a thin layer of gold using an Edwards Gold Sputter Coater to make the sample surface electrically conductive. The secondary electron (SE) images (in duplicates) were captured using a Zeiss In-lens SE1 detector and show the surface structure of material. Beam conditions during surface analysis were 5 kV and approximately 250pA.

### 2.12. Statistical analysis

Design Expert software (version 8.0.6.) was used to perform regression analysis and analysis of variance of data. Significance of each independent variable was determined from P-value (at 95% confidence level). Adequacy of the models were determined using the lack of fit values and coefficient of determination ($R^2$). Responses were predicted through quadratic polynomial regression models. The 3D response surface graphs of variable-response relationship were plotted using the software. Desirability levels for variables were also generated and confirmatory experiments were subsequently performed to validate the models. Sensory data were analysed by one-way analysis of variance (ANOVA) and significant differences among mean values were assessed with Duncan's multiple range test using SPSS 23 for windows (SPSS Inc., Chicago, IL) statistical software package.

## 3. Results and discussion

### 3.1. Diameter, weight, volume and hardness of *magwinya*

#### *3.1.1. Diameter*

Diameter of *magwinya* with fine (MFB) and medium WB (MMB) ranged from 55.15 mm to 61.44 mm (Table 2) and 53.29−59.76 mm, respectively (Table 4). There were


https://doi.org/10.1016/j.heliyon.2019.e01364

https://doi.org/10.1016/j.heliyon.2019.e01364





**Table 2.** Box-Behnken design with the observed responses for some physicochemical properties of *magwinya* with fine wheat bran.

| **Independent variables** | | | **Response variables** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X_1$ **(g)** | $X_2$ **(min)** | $X_3$ **(min)** | **Dia (mm)** | **Wt (g)** | **Vol (cm$^3$)** | **$L_{crs}$** | **$a^*_{crs}$** | **$b^*_{crs}$** | **$\Delta E_{crs}$** | **$L_{crm}$** | **$a^*_{crm}$** | **$b^*_{crm}$** | **$\Delta E_{crm}$** | **MC (%)** | **OC (%)** | **Ash (%)** | **Hardness (N)** |
| Control | | | 59.59 (1.66) | 47.83 (1.17) | 103.33 (5.16) | 42.76 (4.31) | 17.50 (1.78) | 30.72 (2.63) | | 72.36 (3.13) | 2.25 (0.22) | 21.64 (1.29) | | 34.28 (2.74) | 14.00 (1.09) | 0.69 (0.06) | 11.83 (2.07) |
| 1 | 45 | 2 | 56.95 (0.99) | 49.49 (0.22) | 76.67 (15.28) | 42.95 (3.52) | 19.03 (0.92) | 32.35 (2.55) | 8.96 (3.10) | 66.77 (2.54) | 3.63 (0.26) | 22.33 (0.74) | 5.71 (3.29) | 37.48 (2.53) | 4.44 (0.20) | 0.60 (0.00) | 11.50 (1.23) |
| 15 | 45 | 2 | 55.15 (1.48) | 48.10 (0.21) | 60.67 (1.15) | 46.29 (2.40) | 16.29 (2.34) | 28.93 (4.61) | 8.41 (1.10) | 55.79 (2.71) | 7.32 (0.15) | 21.57 (0.97) | 16.35 (3.39) | 36.09 (0.30) | 2.78 (0.33) | 1.11 (0.19) | 23.06 (1.04) |
| 1 | 120 | 2 | 56.39 (1.30) | 48.77 (0.77) | 73.33 (10.41) | 55.04 (2.37) | 12.79 (3.34) | 35.46 (3.01) | 18.41 (5.37) | 69.39 (0.76) | 3.79 (0.09) | 23.53 (0.49) | 4.84 (0.34) | 38.19 (0.12) | 4.00 (0.77) | 0.67 (0.00) | 9.28 (0.93) |
| 15 | 120 | 2 | 58.75 (0.54) | 48.44 (0.35) | 60.33 (0.57) | 49.21 (6.76) | 14.83 (3.70) | 32.86 (2.03) | 13.60 (8.97) | 58.85 (1.09) | 7.34 (0.15) | 22.31 (0.21) | 13.60 (1.84) | 37.02 (1.73) | 7.33 (0.01) | 1.22 (0.19) | 15.44 (2.24) |
| 1 | 82.5 | 1 | 58.74 (0.90) | 49.67 (0.17) | 88.33 (2.89) | 60.89 (2.08) | 9.93 (2.51) | 35.00 (2.07) | 24.63 (4.28) | 69.17 (1.74) | 3.60 (0.33) | 22.75 (0.03) | 4.46 (1.74) | 37.70 (2.40) | 4.10 (0.17) | 0.66 (0.01) | 5.88 (0.14) |
| 15 | 82.5 | 1 | 57.44 (1.60) | 48.93 (0.04) | 65.00 (5.00) | 54.22 (1.72) | 10.63 (2.46) | 30.00 (2.47) | 17.70 (3.96) | 56.16 (1.83) | 7.30 (0.32) | 20.94 (0.49) | 15.89 (2.12) | 36.61 (1.48) | 2.78 (0.00) | 1.22 (0.19) | 15.73 (2.45) |
| 1 | 82.5 | 3 | 61.44 (1.01) | 48.52 (0.09) | 88.33 (2.89) | 50.93 (6.02) | 16.11 (3.74) | 35.90 (0.60) | 14.60 (7.00) | 68.98 (2.62) | 3.56 (0.34) | 23.88 (0.55) | 5.74 (1.27) | 36.20 (3.39) | 7.22 (0.84) | 0.62 (0.04) | 8.12 (0.44) |
| 15 | 82.5 | 3 | 57.02 (0.86) | 47.97 (0.33) | 60.67 (1.15) | 44.36 (3.54) | 17.00 (1.65) | 31.84 (1.86) | 6.65 (2.60) | 59.28 (0.41) | 7.38 (0.08) | 22.70 (0.45) | 13.30 (1.36) | 38.37 (0.34) | 3.89 (0.19) | 1.22 (0.19) | 21.58 (0.79) |
| 8 | 45 | 1 | 59.89 (0.77) | 48.87 (0.62) | 86.67 (5.77) | 58.58 (0.10) | 9.59 (0.42) | 30.53 (0.55) | 21.88 (3.42) | 62.02 (0.97) | 6.30 (0.01) | 22.59 (1.31) | 10.52 (1.52) | 31.35 (1.48) | 5.11 (0.70) | 0.68 (0.02) | 9.61 (0.45) |

(*continued on next page*)

**Table 2.** (*Continued*)

| Independent variables | | | Response variables | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X_1$ (g) | $X_2$ (min) | $X_3$ (min) | Dia (mm) | Wt (g) | Vol (cm$^3$) | $L_{crs}$ | $a^*_{crs}$ | $b^*_{crs}$ | $\Delta E_{crs}$ | $L_{crm}$ | $a^*_{crm}$ | $b^*_{crm}$ | $\Delta E_{crm}$ | MC (%) | OC (%) | Ash (%) | Hardness (N) |
| 8 | 120 | 1 | 56.66 (1.36) | 48.51 (0.42) | 58.67 (1.53) | 63.13 (1.05) | 7.59 (0.18) | 28.58 (0.27) | 26.66 (4.21) | 59.57 (4.21) | 5.98 (0.23) | 22.46 (1.58) | 12.70 (3.47) | 37.29 (1.06) | 8.01 (0.19) | 0.67 (0.00) | 8.20 (0.28) |
| 8 | 45 | 3 | 59.16 (0.95) | 47.86 (0.63) | 86.67 (5.77) | 48.73 (4.74) | 16.73 (2.58) | 35.75 (0.78) | 12.30 (8.91) | 66.08 (1.76) | 5.61 (0.51) | 23.30 (0.16) | 7.13 (1.50) | 31.79 (3.98) | 10.11 (0.51) | 0.74 (0.02) | 12.56 (1.15) |
| 8 | 120 | 3 | 55.60 (2.61) | 48.01 (0.05) | 57.33 (2.52) | 44.94 (2.98) | 17.62 (0.66) | 31.80 (1.90) | 6.89 (6.19) | 63.57 (3.18) | 6.06 (0.61) | 23.78 (0.77) | 9.55 (2.92) | 35.40 (1.08) | 3.33 (0.00) | 0.70 (0.00) | 13.34 (1.42) |
| 8 | 82.5 | 2 | 58.22 (0.83) | 48.70 (0.42) | 90.00 (0.00) | 52.27 (3.39) | 13.87 (1.95) | 33.89 (0.83) | 15.30 (3.04) | 63.41 (1.02) | 6.17 (0.31) | 22.95 (0.37) | 9.32 (0.90) | 33.67 (1.51) | 10.00 (0.00) | 0.67 (0.00) | 11.48 (0.59) |
| 8 | 82.5 | 2 | 58.92 (0.87) | 48.60 (0.81) | 86.67 (5.77) | 47.71 (3.59) | 16.55 (2.35) | 33.08 (0.76) | 10.45 (0.83) | 62.60 (4.85) | 6.19 (0.99) | 24.07 (1.30) | 10.53 (4.16) | 30.52 (1.57) | 10.89 (0.19) | 0.71 (0.01) | 13.15 (0.69) |
| 8 | 82.5 | 2 | 56.66 (1.36) | 47.04 (0.82) | 59.33 (1.15) | 50.06 (0.09) | 16.03 (0.35) | 34.62 (0.27) | 12.77 (5.07) | 64.53 (0.81) | 5.96 (0.81) | 22.62 (1.60) | 8.15 (3.07) | 36.05 (0.61) | 10.15 (0.51) | 0.71 (0.01) | 14.26 (0.97) |

$X_1$: wheat bran incorporation, $X_2$: fermentation time, $X_3$: frying time.
Values are means of three replications. Standard deviation in parenthesis as data did not fit table using the '±' sign.
WB: wheat bran, FMT: fermentation time, FRT: frying time. Dia: diameter; Wt: weight (g); Vol: Volume (cm$^3$).
Crs: Crust of *magwinya*; crm: Crumb of *magwinya*. ΔE: colour change, MC: moisture content (%); OC: oil content (%).
Control: 0 g wheat bran, 120 min fermentation time and 3 min frying time.





https://doi.org/10.1016/j.heliyon.2019.e01364

significant differences ($p < 0.05$) among the runs (Table 3). Diameter of control sample was significantly higher ($p < 0.05$) than MMB samples with 15 g WB, fermented at 82.5 min and fried at 3 min; but not significantly different from other samples ($p > 0.05$). ANOVA of the effect of model parameters on diameter revealed that linear effects of fine WB ($p = 0.0008$), fermentation time ($p = 0.0001$), interaction between WB and fermentation time ($p < 0.05$), as well as the quadratic effect of WB and fermentation time all had significant reduction effect ($p = 0.0014$) on diameter of *magwinya*. During frying, the dough expands due to the pressure gradient formed at the core of the food. The extent of expansion is dependent on the gluten formation and gas retention in the dough during fermentation (Noort et al., 2010). Hence, magwinya with the significantly ($p < 0.05$) lowest diameter value had 15 g WB for MFB and MMB. From the ANOVA results, it can be noted that linear terms of medium WB ($p < 0.0001$) and frying time ($p = 0.01$), followed by interaction terms of WB and fermentation time ($p = 0.002$), WB and frying time ($p = 0.003$) and quadratic terms of WB and fermentation time ($p < 0.0001$) had significant effect on diameter of *magwinya* medium WB. The model probability value of $p < 0.0001$ and non-significant ($p > 0.05$) lack of fit p-value (Table 6) indicates that the developed model was adequate for predicting the response. The diameter results fall within range of previous study on *magwinya* using coarse WB (Onipe et al., 2018). It was imperative to get the approximate diameter of *magwinya* because this has not been reported before except recently in our previous study. This measurement will be useful for Food Engineers in developing a *magwinya* production machine which is currently non-existent.

### 3.1.2. Weight

Weight of MFB and MMB ranged between 47.04 g to 49.67 g (Table 2) and 47.60−49.20 g (Table 4), respectively. Weights of *magwinya* were inversely proportional to frying time. Highest (49.20 g) and lowest (47.60 g) weights for MMB were at 1 min and 3 min respectively, and these values were significantly different from each other (Table 5). The same trend was observed for highest weight for MFB. However lowest weight (47.04) was at 2 min, but it was not significantly different from the weights recorded for samples fried at 3 min, irrespective of the amount of WB. Control sample (47.83 g) was significantly different from some of the samples for both MMB and MFB. The variations in weights can also be attributed to the varying amounts of WB in the samples. Linear terms of fine WB and frying time significantly ($p < 0.05$) reduced the weight of *magwinya*. Linear terms of WB ($p < 0.05$) and frying time ($p < 0.0001$), followed by the quadratic effect of medium WB ($p = 0.0003$) had significant effect ($p < 0.05$) on weight of *magwinya*. Frying is a dehydration process (Ziaiifar et al., 2008); and as expected, there was significant reduction in weight of dough (50 g) to final product as a function of frying time. The low probability value of the model ($p < 0.05$) and non-significant ($p > 0.05$) lack of


https://doi.org/10.1016/j.heliyon.2019.e01364

**Table 3.** Mean comparison among experimental runs for fine wheat bran *magwinya* using Duncan's multiple range test.

| Independent variables | | | Response variables | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X_1$ (g) | $X_2$ (min) | $X_3$ (min) | Dia (mm) | Wt (g) | Vol ($cm^3$) | $L_{crs}$ | $a^*_{crs}$ | $b^*_{crs}$ | $\Delta E_{crs}$ | $L_{crm}$ | $a^*_{crm}$ | $b^*_{crm}$ | $\Delta E_{crm}$ | MC (%) | OC (%) | Ash (%) | Hardness (N) |
| Control | | | ab | ab | f | a | ef | abcd | | f | a | ab | | bcde | h | a | cd |
| 1 | 45 | 2 | ab | cd | cd | a | f | abcde | abc | cde | b | abc | abc | def | cd | a | cde |
| 15 | 45 | 2 | a | ab | a | abc | def | a | ab | a | d | ab | g | def | bc | b | i |
| 1 | 120 | 2 | a | bcd | bc | efg | bcd | de | cdef | ef | b | c | ab | ef | a | a | bc |
| 15 | 120 | 2 | ab | bc | a | abcde | def | bcde | abcd | ab | d | abc | fg | def | e | b | gh |
| 1 | 82.5 | 1 | ab | d | e | gh | ab | de | ef | def | b | abc | a | ef | bc | a | a |
| 15 | 82.5 | 1 | ab | bcd | ab | def | abc | ab | bcdef | a | d | a | fg | def | bcd | b | h |
| 1 | 82.5 | 3 | b | bcd | e | bcde | def | e | abcd | def | b | c | abc | def | e | a | b |
| 15 | 82.5 | 3 | ab | ab | a | ab | ef | abcd | a | ab | d | abc | g | f | bc | a | i |
| 8 | 45 | 1 | ab | bcd | de | fgh | ab | abc | def | bc | c | abc | def | ab | d | a | bcd |
| 8 | 120 | 1 | ab | bcd | a | h | a | a | f | ab | c | abc | efg | def | a | a | b |
| 8 | 45 | 3 | ab | ab | de | abcde | def | e | abcd | cde | c | bc | abcd | abc | g | a | ef |
| 8 | 120 | 3 | a | ab | a | ab | ef | abcd | a | bc | c | c | cdef | cdef | ab | a | efg |
| 8 | 82.5 | 2 | ab | bcd | e | cde | cde | cde | abcde | bc | c | bc | bcdef | abcd | g | a | cde |
| 8 | 82.5 | 2 | ab | bcd | de | abcd | def | bcde | abc | bc | c | c | def | a | g | a | efg |
| 8 | 82.5 | 2 | ab | a | a | bcde | def | de | abcd | cd | c | abc | abcde | def | a | a | fgh |

Control: 0 g wheat bran, 120 min fermentation time and 3 min frying time.


https://doi.org/10.1016/j.heliyon.2019.e01364

https://doi.org/10.1016/j.heliyon.2019.e01364





**Table 4.** Box-Behnken design with the observed responses for some physicochemical properties of *magwinya* with medium wheat bran.

| Independent variables | | | Response variables | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WB (g) | FMT (min) | FRT (min) | Dia (mm) | Wt (g) | Vol ($cm^3$) | $L_{crs}$ | $a^*_{crs}$ | $b^*_{crs}$ | $\Delta E_{crs}$ | $L_{crm}$ | $a^*_{crm}$ | $b^*_{crm}$ | $\Delta E_{crm}$ | MC (%) | OC (%) | Ash (%) | Hardness (g) |
| Control | | | 59.59 (1.66) | 47.83 (1.17) | 103.33 (5.16) | 42.76 (4.31) | 17.50 (1.78) | 30.72 (2.63) | | 72.36 (3.13) | 2.25 (0.22) | 21.64 (1.29) | | 34.28 (2.74) | 14.00 (1.09) | 0.69 (0.06) | 11.83 (2.07) |
| 1 | 45 | 2 | 59.60 (1.31) | 47.66 (0.92) | 92.00 (3.46) | 58.33 (3.35) | 12.06 (2.25) | 36.59 (1.21) | 21.78 (7.89) | 71.03 (1.12) | 3.87 (0.23) | 23.07 (0.00) | 4.14 (0.63) | 34.17 (2.65) | 6.67 (0.00) | 0.66 (0.01) | 9.55 (0.62) |
| 15 | 45 | 2 | 54.84 (0.44) | 48.21 (0.34) | 81.67 (2.89) | 43.09 (4.98) | 16.07 (1.56) | 28.30 (1.77) | 5.51 (3.23) | 56.71 (0.12) | 9.03 (0.19) | 22.36 (0.67) | 16.13 (0.81) | 36.22 (1.26) | 8.33 (0.34) | 1.26 (0.14) | 17.75 (0.64) |
| 1 | 120 | 2 | 58.21 (1.18) | 48.83 (0.35) | 95.00 (5.00) | 58.06 (3.02) | 12.54 (2.53) | 36.13 (1.07) | 21.56 (3.44) | 66.90 (7.07) | 2.83 (0.26) | 22.64 (0.77) | 6.75 (6.60) | 37.04 (1.12) | 5.44 (0.20) | 0.67 (0.01) | 9.29 (0.49) |
| 15 | 120 | 2 | 56.89 (0.55) | 48.33 (0.11) | 78.33 (2.89) | 42.60 (4.05) | 16.48 (1.26) | 29.53 (1.44) | 6.35 (4.65) | 57.03 (0.99) | 8.47 (0.19) | 21.42 (0.09) | 15.49 (0.62) | 35.45 (2.09) | 7.89 (0.19) | 1.32 (0.02) | 13.86 (0.34) |
| 1 | 82.5 | 1 | 57.92 (1.10) | 49.20 (0.39) | 63.33 (5.77) | 64.15 (3.10) | 7.67 (2.09) | 31.12 (2.69) | 27.51 (7.19) | 71.31 (4.63) | 3.01 (0.67) | 19.27 (1.95) | 3.25 (1.27) | 32.55 (0.11) | 5.45 (0.39) | 0.66 (0.01) | 5.76 (0.50) |
| 15 | 82.5 | 1 | 53.29 (1.74) | 49.09 (0.04) | 66.67 (5.77) | 47.04 (1.02) | 11.48 (1.60) | 26.00 (3.20) | 11.37 (3.76) | 46.71 (3.57) | 8.55 (0.79) | 19.54 (1.47) | 25.34 (4.28) | 36.30 (0.84) | 9.78 (1.68) | 1.27 (0.01) | 13.02 (2.58) |
| 1 | 82.5 | 3 | 56.78 (2.63) | 48.54 (0.15) | 95.00 (5.00) | 51.07 (7.49) | 15.53 (2.44) | 35.03 (2.54) | 13.97 (7.34) | 70.08 (1.34) | 3.95 (0.50) | 22.78 (0.55) | 4.13 (0.66) | 33.24 (3.69) | 4.56 (0.20) | 0.67 (0.00) | 11.57 (1.54) |
| 15 | 82.5 | 3 | 54.13 (1.40) | 48.20 (0.02) | 82.33 (2.52) | 41.05 (1.48) | 18.00 (1.66) | 28.24 (0.86) | 4.45 (1.74) | 55.97 (0.50) | 9.04 (0.15) | 22.83 (0.52) | 16.92 (1.21) | 36.20 (1.17) | 6.89 (0.19) | 1.31 (0.02) | 17.03 (0.65) |
| 8 | 45 | 1 | 58.96 (1.45) | 48.39 (0.10) | 86.67 (5.77) | 53.50 (0.27) | 12.18 (0.96) | 30.59 (1.68) | 16.58 (3.09) | 56.73 (0.43) | 7.63 (0.54) | 20.57 (0.74) | 15.41 (0.56) | 36.74 (2.08) | 7.33 (0.00) | 0.99 (0.02) | 11.31 (1.01) |

(*continued on next page*)

**Table 4.** (*Continued*)

| Independent variables | | | Response variables | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WB (g) | FMT (min) | FRT (min) | Dia (mm) | Wt (g) | Vol ($cm^3$) | $L_{crs}$ | $a^*_{crs}$ | $b^*_{crs}$ | $\Delta E_{crs}$ | $L_{crm}$ | $a^*_{crm}$ | $b^*_{crm}$ | $\Delta E_{crm}$ | MC (%) | OC (%) | Ash (%) | Hardness (g) |
| 8 | 120 | 1 | 57.05 (0.73) | 48.22 (0.49) | 86.67 (5.77) | 52.40 (2.48) | 12.78 (1.53) | 30.05 (1.37) | 14.77 (6.16) | 59.66 (0.79) | 7.35 (0.41) | 20.44 (0.45) | 12.53 (1.87) | 38.64 (0.72) | 6.67 (0.34) | 0.99 (0.00) | 10.95 (1.25) |
| 8 | 45 | 3 | 57.55 (1.60) | 48.05 (0.31) | 80.00 (0.00) | 43.42 (0.58) | 17.84 (0.28) | 32.37 (1.96) | 7.17 (3.89) | 58.35 (0.66) | 7.97 (0.26) | 21.86 (0.13) | 14.16 (1.27) | 39.57 (0.74) | 6.78 (0.19) | 1.11 (0.19) | 14.36 (1.15) |
| 8 | 120 | 3 | 59.76 (2.72) | 47.60 (0.36) | 81.67 (7.64) | 37.23 (3.90) | 17.55 (0.74) | 24.03 (4.10) | 8.02 (3.27) | 59.09 (0.89) | 6.88 (0.09) | 21.64 (0.17) | 13.09 (1.69) | 35.71 (1.65) | 7.33 (0.00) | 0.97 (0.01) | 13.14 (1.09) |
| 8 | 82.5 | 2 | 57.63 (0.53) | 48.59 (0.23) | 86.67 (5.77) | 46.47 (2.84) | 15.37 (1.37) | 32.48 (0.84) | 9.25 (5.76) | 60.53 (1.07) | 7.33 (0.09) | 21.48 (0.60) | 11.87 (1.87) | 37.22 (4.22) | 6.78 (0.51) | 1.11 (0.19) | 11.97 (0.45) |
| 8 | 82.5 | 2 | 56.47 (0.29) | 48.41 (0.59) | 80.00 (0.00) | 50.66 (1.37) | 12.82 (1.50) | 30.97 (0.77) | 13.57 (3.92) | 60.23 (0.60) | 7.08 (0.17) | 20.54 (0.49) | 11.92 (0.63) | 39.87 (0.83) | 7.34 (0.57) | 1.00 (0.00) | 11.87 (1.20) |
| 8 | 82.5 | 2 | 58.68 (0.68) | 47.61 (0.91) | 83.33 (5.77) | 45.22 (1.82) | 16.97 (1.91) | 28.65 (2.23) | 6.97 (1.03) | 57.02 (1.55) | 7.24 (0.20) | 20.15 (0.89) | 15.00 (2.41) | 37.64 (2.98) | 4.11 (0.19) | 1.09 (0.18) | 15.76 (0.72) |

$X_1$: wheat bran incorporation, $X_2$: fermentation time, $X_3$: frying time.
Values are means of three replications. Standard deviation in parenthesis as data did not fit table using the '±' sign.
WB: wheat bran, FMT: fermentation time, FRT: frying time. Dia: diameter; Wt: weight (g); Vol: Volume ($cm^3$).
Crs: Crust of *magwinya*; crm: Crumb of *magwinya*. ΔE: colour change, MC: moisture content (%); OC: oil content (%).
Control: 0 g wheat bran, 120 min fermentation time and 3 min frying time.


https://doi.org/10.1016/j.heliyon.2019.e01364

https://doi.org/10.1016/j.heliyon.2019.e01364




**Table 5.** Mean comparison among experimental runs for medium wheat bran *magwinya* using Duncan's multiple range test.

| Independent variables | | | Response variables | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X_1$ (g) | $X_2$ (min) | $X_3$ (min) | Dia (mm) | Wt (g) | Vol ($cm^3$) | $L_{crs}$ | $a^*_{crs}$ | $b^*_{crs}$ | $\Delta E_{crs}$ | $L_{crm}$ | $a^*_{crm}$ | $b^*_{crm}$ | $\Delta E_{crm}$ | MC (%) | OC (%) | Ash (%) | Hardness (N) |
| Control | | | c | ab | e | ab | d | cde | | d | a | bcd | | abc | h | a | cde |
| 1 | 45 | 2 | c | a | cd | f | b | g | de | cd | c | d | a | abc | c | a | bc |
| 15 | 45 | 2 | abc | abcd | b | ab | d | bcd | ab | b | h | d | bc | abcde | ef | cd | h |
| 1 | 120 | 2 | ab | bcd | d | f | bc | fg | de | c | ab | d | a | bcde | b | a | b |
| 15 | 120 | 2 | abc | abcd | b | ab | d | bcde | ab | b | gh | bcd | bc | abcd | def | d | efg |
| 1 | 82.5 | 1 | abc | d | a | g | a | cde | e | cd | b | a | a | a | b | a | a |
| 15 | 82.5 | 1 | a | cd | a | bcd | b | ab | abc | a | gh | a | d | abcde | g | cd | def |
| 1 | 82.5 | 3 | abc | abcd | d | cde | cd | fg | bcd | cd | c | d | a | ab | ab | a | bcde |
| 15 | 82.5 | 3 | ab | abcd | b | ab | d | bc | a | b | h | d | c | abcde | cd | d | h |
| 8 | 45 | 1 | bc | abcd | bcd | ef | b | cde | cd | b | ef | abc | bc | bcde | cde | b | bcd |
| 8 | 120 | 1 | abc | abcd | bcd | def | bc | cde | bcd | b | de | abc | bc | de | c | b | bcd |
| 8 | 45 | 3 | abc | abcd | b | ab | d | def | ab | b | fg | cd | bc | de | cd | bc | fg |
| 8 | 120 | 3 | c | a | b | a | d | a | abc | b | d | bcd | bc | abcde | cde | b | def |
| 8 | 82.5 | 2 | abc | abcd | bcd | bcd | cd | ef | abc | b | de | bcd | b | bcde | cd | bc | de |
| 8 | 82.5 | 2 | abc | abcd | b | cde | bc | cde | abcd | b | de | abc | b | e | cde | b | cde |
| 8 | 82.5 | 2 | bc | a | bc | bc | d | bcde | ab | b | de | ab | bc | cde | a | b | gh |

Control: 0 g wheat bran, 120 min fermentation time and 3 min frying time.

fit p-value implies that the model is significant. In addition, the mathematical model presented in the regression coefficients (Table 6) will give a good fit relative to the lack of fit and low p-values.

### 3.1.3. Volume

Values of volume for MFB and MMB were found to be in the range of 57.33−90.00 $cm^3$and 63.33−95.00 $cm^3$, respectively. Samples containing 8 g and 15 g WB were not significantly different from each other ($p < 0.05$). The control had significantly

**Table 6.** Regression coefficient and analysis of variance for some physico-chemical properties of *magwinya* in the Box-Benkhen design.

| | ***Magwinya* with fine wheat bran** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Diameter (mm)** | **Weight (g)** | **Volume ($cm^3$)** | **Hardness (g)** | **Moisture (%)** | **Fat (%)** | **Ash (%)** |
| Intercept | 57.93 | 48.11 | 76.31 | 13.08 | 33.41 | 7.82 | 0.70 |
| $X_1$ | −1.43 | −0.38 | −10.00 | 6.21 | −0.19 | −0.78 | 0.27 |
| $X_2$ | −1.70 | −0.074 | −0.92 | −0.61 | 1.40 | −2.28 | 0.007 |
| $X_3$ | 0.062 | −0.45 | −0.71 | 1.64 | −0.15 | 1.03 | 0.006 |
| $X_1 X_2$ | 1.04 | 0.27 | −0.33 | −3.09 | 0.054 | 1.25 | 0.028 |
| $X_1 X_3$ | −0.78 | 0.050 | | 0.56 | 0.81 | −1.11 | 0.010 |
| $X_2 X_3$ | −0.14 | 0.13 | −6.79 | 2.70 | −0.58 | −1.81 | −0.008 |
| $X_1^2$ | −0.98 | 0.52 | | | 3.52 | −1.37 | 0.23 |
| $X_2^2$ | 0.87 | 0.064 | 1.04 | | 0.26 | −1.12 | −0.006 |
| $X_3^2$ | 2.45 | 0.13 | | | 0.29 | 7.82 | 0.008 |
| Lack of fit | 1.57 | 0.9011 | 0.5080 | 0.8552 | 0.1297 | 0.9228 | 0.4286 |
| $R^2$ | 0.6352 | 0.5075 | 0.6395 | 0.9735 | 0.5168 | 0.6375 | 0.8764 |
| *Magwinya* with medium wheat bran | | | | | | | |
| Intercept | 57.59 | 48.20 | 85.02 | 12.48 | 38.25 | 6.07 | 0.99 |
| $X_1$ | −1.37 | −0.18 | −7.81 | 3.19 | 0.90 | 1.22 | 0.31 |
| $X_2$ | 0.10 | −0.006 | 0.62 | −0.72 | 0.019 | −0.22 | 0.003 |
| $X_3$ | 0.55 | −0.35 | 0.23 | 1.88 | 0.063 | −0.33 | 0.003 |
| $X_1 X_2$ | 0.86 | 0.002 | | | −0.91 | 0.20 | |
| $X_1 X_3$ | 0.99 | −0.057 | | | −0.20 | −0.24 | |
| $X_2 X_3$ | 1.43 | −0.15 | | | −1.44 | 0.30 | |
| $X_1^2$ | −2.22 | 0.47 | | | −2.81 | 0.19 | |
| $X_2^2$ | 1.69 | −0.15 | | | 0.29 | 0.82 | |
| $X_3^2$ | −0.15 | 0.093 | | | −0.86 | 0.14 | |
| Lack of fit | 0.4294 | 0.5879 | 0.0742 | 0.1100 | 0.2174 | 0.0837 | 0.4177 |
| $R^2$ | 0.9006 | 0.6177 | 0.5364 | 0.7755 | 0.4781 | 0.6302 | 0.9505 |

$X_1$: wheat bran incorporation, $X_2$: fermentation time, $X_3$: frying time.


https://doi.org/10.1016/j.heliyon.2019.e01364

(p < 0.05) higher volume than other samples for both MFB (Table 3) and MMB (Table 5). Linear terms of fine and medium WB had significant reduction effect on volume (p < 0.0001); followed by quadratic terms of fermentation time (p < 0.05) for fine WB-*magwinya* as highlighted in the 3D surface plot (Fig. 1a). However, linear and interaction terms of fermentation and frying time had no significant effect (p > 0.05) on volume of fine bran *magwinya*. This can be explained as the effect of zero inclusion of WB in the formulation which led to maximum gluten formulation and gas retention during fermentation which gave a good puffing/expansion during frying; and in turn increased volume. Moreover, WB contains arabinoxylans which reduce the extensibility of gluten, thereby causing its poor formation (Noort et al., 2010). A decrease in volume with increase in medium WB was observed in response surface plot of effect of WB and fermentation time on volume of *magwinya* (Fig. 2a). The volume-reducing effect of medium WB may be attributed to its higher fibre content (see section 3.5). The low probability value of the model (p < 0.0001) and non-significant (p > 0.05) lack of fit p-value implies that the model is significant (Table 6). These statistical values would give a relatively good fit to mathematical model represented in the regression coefficients. There are contradicting reports for the effect of WB on bread loaf volume. Result agrees with the work of Onipe et al. (2018) where coarse WB reduced the volume of *magwinya* and the findings of other authors on bread volume reduction (Noort et al., 2010). Contrarywise, Kim et al. (2012) reported doughnut volume increase as a function of WB incorporation. Volume reduction effect of WB can be explained to be the combination effect of gluten dilution, which impacts gas cell formation and microstructural changes in the fried dough.

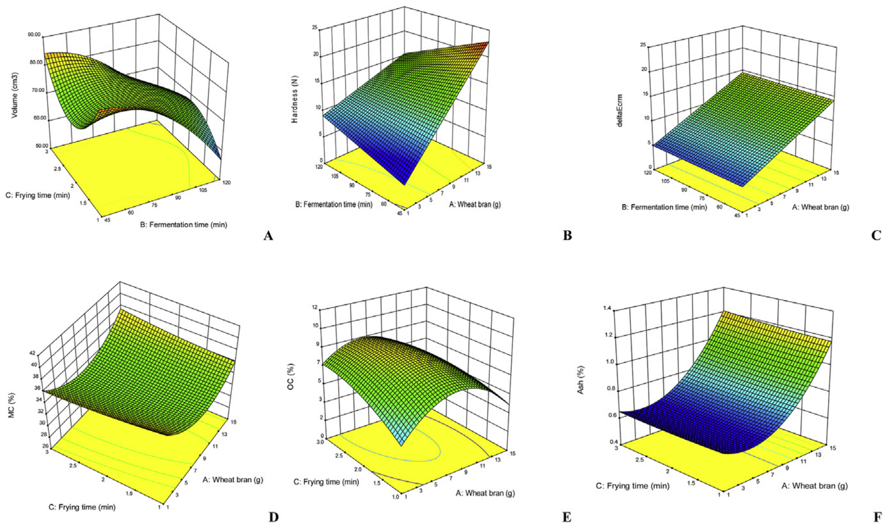


**Fig. 1.** Response surface plot of (A) volume, (B) hardness, (C) crumb ΔE, (D) moisture (E) oil, and (F) ash content of *magwinya* as affected by fine wheat bran, fermentation and frying time.


https://doi.org/10.1016/j.heliyon.2019.e01364

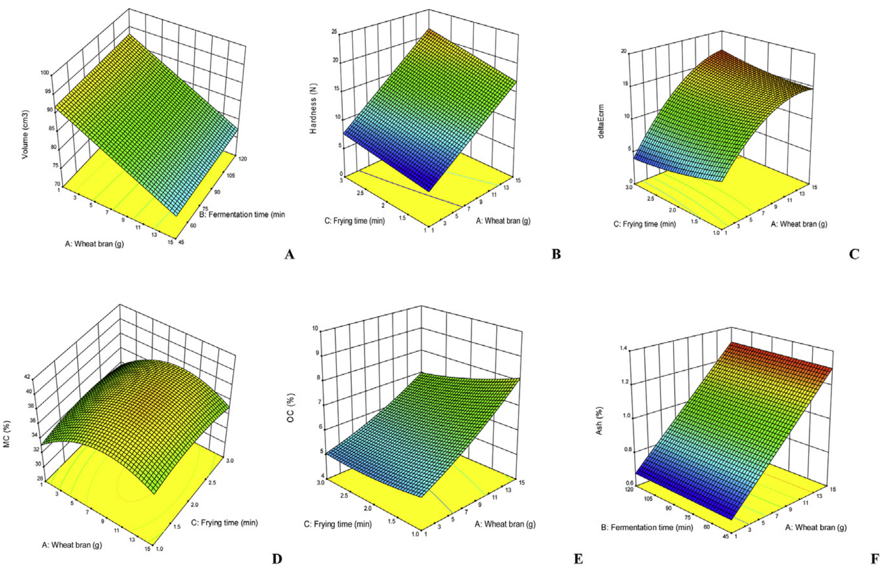


**Fig. 2.** Response surface plot of (A) volume, (B) hardness, (C) crumb ΔE, (D) moisture (E) oil, and (F) ash content of *magwinya* as affected by medium wheat bran, fermentation and frying time.

### *3.1.4. Hardness*

The hardness of MFB and MMB ranged from 5.88 N to 23.06 N (Table 2) and 5.76 N to 17.75 N, respectively (Table 4). The highest value was obtained at 15 g WB, 45 min fermentation and 2 min frying time; while the lowest value at 1 g WB, 82.5 min fermentation and 1 min frying time. Duncan's test showed that there were significant variations ($p < 0.05$) amongst the samples considering the processing factors. Significant increasing effect ($p < 0.05$) of the linear terms of WB and frying time ($p < 0.0001$), interaction terms of WB and fermentation time ($p < 0.0001$), and interaction terms of fermentation and frying time ($p < 0.0001$ was recorded for hardness of *magwinya*. Fermentation time had no significant effect on hardness ($p > 0.05$). The low model probability value of $p < 0.0001$ coupled with non-significant ($p > 0.05$) lack of fit p-value and high correlation coefficient of determination ($R^2$) value of 0.9735 (Table 6) indicates that the developed model was adequate for predicting hardness of *magwinya*. On the one hand, samples fried at 1 min were the softest for both MFB and MMB. This is because at the first minute, frying had only progressed to stage two – "surface boiling" where crust formation had just commenced (Ziaiifar et al., 2008; Oke et al., 2018), thereby leading to a softer product relative to dough fried at 3 min. Moreover, starch gelatinisation, which contributes significantly to food texture, is incomplete at 1 min, thus leaving the samples partially cooked. On the other hand, samples containing 15 g WB, fried at 3 min had the hardest texture for MFB and MMB. This is attributable to WB inclusion and dehydrating effect of the maximum frying time – where bubble-end point has been reached for the product. Texture of fried products is usually characterised by crisp crust and moist crumb


https://doi.org/10.1016/j.heliyon.2019.e01364

which is possible by a combination effect of processing and food composition which leads to physical and chemical changes in the product (Ziaiifar et al., 2008). With increase in WB from 1 to 15 g, hardness of *magwinya* also increased. This agrees with a previous study where an increase in WB addition resulted in doughnut hardness from 243 to 617 g. Irrespective of WB particle size, Kim et al. (2012) found that the hardness of doughnut increased as the amount of WB increased in the formulation. Regression coefficients presented in Table 6 show good fit of the mathematical model. Response surface plot for the effect of independent variables on hardness of *magwinya* revealed that WB had strong positive influence on the hardness of *magwinya* in the plots presented (Figs. 1B and 2B).

## 3.2. Colour properties

### *3.2.1. Colour of magwinya with fine WB*

The variable with predominant effect on crust and crumb colour of *magwinya* corresponded to the linear terms of fine WB ($p < 0.0001$), followed by linear terms ($p < 0.0001$) of frying time. Highest lightness (L*) value of 63.13 was recorded for *magwinya* with 8 g WB (1 min frying time). Crust L* of control sample (42.76) was significantly ($p < 0.05$) lower than other samples. Asides from effect of WB, crust browning at the right temperature, was a time-dependent process. For instance, crust L* values recorded in the study of Ghaitaranpour et al. (2013) ranged from 66 − 79, although there was no WB addition in their doughnut formulation. Kim et al. (2012) reported a darkening effect (showed by a decrease in L values from 66.4 to 57.9) on doughnut as the amount of WB increased. Crust colour formation in magwinya is caused by Maillard reaction because of hydrolysis of the oligosaccharides in wheat flour to reducing sugars (Zolfaghari et al., 2013). Crust redness (a*) of samples fried at 1 min were ≤10. Control crust redness was not significantly different ($p > 0.05$) from all samples fried at 1 min irrespective of the amount of WB in the sample (Table 3). Linear and quadratic terms of frying time had increasing effect on redness (a*) of *magwinya*, due to Maillard reaction. WB, fermentation and frying time all had significant decreasing effect on yellowness (b*) of *magwinya* (36.59−26.00). Crust yellowness of control was not significantly different from most of the samples. Total colour difference (ΔE) signifies the magnitude of colour change between test and control sample (Pathare et al., 2013). Increasing WB and frying time increased crust colour difference of *magwinya* from the control. Non−significance of lack of fit p-values ($p > 0.05$) of models for colour properties presented indicates fitness of the models (Table 7). Crumb colour properties of *magwinya* with fine WB denoted by L, a*, b, and ΔE were significantly altered by WB inclusion (Table 2). Crust L* and a* of control was markedly higher ($p < 0.05$) than other samples with WB. Samples with the same bran content were not statistically different from each other (Table 3). Lightness


https://doi.org/10.1016/j.heliyon.2019.e01364

**Table 7.** Regression coefficient and analysis of variance for colour properties of *magwinya* in the Box-Benkhen design.

| | ***Magwinya* with fine wheat bran** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Crust** | | | | **Crumb** | | | |
| | **L** | **a** | **b** | **ΔE** | **L** | **a** | **b** | **ΔE** |
| Intercept | 50.01 | 15.40 | 33.43 | 14.61 | 63.08 | 6.11 | 22.78 | 9.85 |
| $X_1$ | −3.31 | 0.11 | −1.89 | −2.53 | −5.53 | 1.84 | −0.62 | 4.80 |
| $X_2$ | 0.19 | −0.28 | −1.47 | 1.75 | 0.090 | 0.040 | 0.28 | 0.12 |
| $X_3$ | −5.98 | 3.71 | 1.40 | −6.30 | 1.37 | −0.071 | 0.62 | −0.98 |
| $X_1 X_2$ | −2.29 | 1.20 | 0.20 | | | −0.037 | | |
| $X_1 X_3$ | | | | | | 0.032 | | |
| $X_2 X_3$ | −2.08 | | | | | 0.19 | | |
| $X_1^2$ | −1.44 | 0.40 | 0.079 | | | −0.56 | | |
| $X_2^2$ | −0.20 | | −1.44 | | | −0.030 | | |
| $X_3^2$ | 4.03 | −2.45 | | | | −0.092 | | |
| Lack of fit | 0.3705 | 0.6711 | 0.3021 | 0.1084 | 0.3172 | 0.7920 | 0.5504 | 0.4532 |
| $R^2$ | 0.7802 | 0.7179 | 0.5930 | 0.4890 | 0.7489 | 0.9345 | 0.3763 | 0.7054 |
| *Magwinya* with medium wheat bran | | | | | | | | |
| Intercept | 47.45 | 14.36 | 30.70 | 12.59 | 59.76 | 7.21 | 20.73 | 12.93 |
| $X_1$ | −7.23 | 1.78 | −3.56 | −7.14 | −8.62 | 2.68 | −0.34 | 5.18 |
| $X_2$ | −1.01 | 0.15 | −0.51 | −0.043 | 1.15 | −0.37 | −0.21 | −0.25 |
| $X_3$ | −5.54 | 3.10 | 0.53 | −4.58 | 0.52 | 0.16 | 0.67 | −0.17 |
| $X_1 X_2$ | −0.057 | | 0.42 | | −1.23 | 0.12 | −0.13 | −0.81 |
| $X_1 X_3$ | 1.77 | | 0.009 | | 2.76 | −0.11 | 0.23 | 1.21 |
| $X_2 X_3$ | −1.27 | | −1.61 | | −0.55 | −0.20 | −0.021 | 0.45 |
| $X_1^2$ | 3.63 | | 1.43 | | 4.16 | −1.24 | 1.31 | −2.70 |
| $X_2^2$ | −0.56 | | 0.50 | | 1.34 | 0.078 | 0.34 | 0.40 |
| $X_3^2$ | −0.25 | | −1.61 | | −2.64 | 0.17 | 0.061 | 0.47 |
| Lack of fit | 0.4120 | 0.3474 | 0.1028 | 0.5632 | 0.0740 | 0.0964 | 0.3858 | 0.1274 |
| $R^2$ | 0.8430 | 0.6741 | 0.7385 | 0.6430 | 0.9868 | 0.9734 | 0.7429 | 0.8035 |

$X_1$: wheat bran incorporation, $X_2$: fermentation time, $X_3$: frying time.

of cake crumb enriched with 10–30 g of WB also diminished with increase in WB (Lebesi and Tzia, 2011). Crumb yellowness of control showed no significant difference ($p < 0.05$) from most of the samples. WB significantly influenced colour change of the products as samples with 15 g WB were higher ($p < 0.05$) than other samples, while lowest colour change was reported in samples with 1 g WB. Linear terms of WB ($p < 0.0001$) had significant effect on crumb lightness, redness, yellowness and colour change while the linear terms of frying time had significant effect (p


https://doi.org/10.1016/j.heliyon.2019.e01364

< 0.05) on lightness and yellowness on *magwinya* crumb. All models showed non-significant lack of fit values which signified fitness of model. Of the three independent variables, WB and frying time had the most significant effect of crumb colour of MFB.

### 3.2.2. Colour properties of magwinya with medium WB

Crust colour properties of MMB were within the following ranges: L: 37.23 to 64.15, a*: 7.67 to 18.00, b*: 24.03 to 36.59 and ΔE: 4.45 to 27.51 (Table 4). The highest lightness was recorded for *magwinya* with 1 g fried for 1 min. As expected, with the short frying time, caramelization reaction did not take its fullest effect. Control crust L* was not significantly different ($p < 0.05$) from samples fried at 3 min, and some fried at 2 min. The variables with significant effect on crust colour of *magwinya* with medium WB were: linear terms of WB and frying time ($p < 0.0001$) for L*, a* b* and ΔE and quadratic terms of WB ($p < 0.0001$) for L* and b*. Redness (a*) increased significantly ($p < 0.05$) with increase in WB, but there was no difference among samples with the same WB and frying time. The intensity of redness in medium WB is high (Onipe et al., 2017), hence the reason for the afore observation. Yellowness (b*) of control was not significantly different from most of the samples, except the ones fried at 1 min containing 1 and 15 g WB each. Highest crust ΔE was observed at 15 g WB, which implies that interaction terms of WB and fermentation time had significant effect ($p < 0.05$) on b* of *magwinya* crust. Residual lack of fit p values was non-significant ($p > 0.05$) and the p-values were significant ($p < 0.0001$) for colour parameters of *magwinya* with medium WB which symbolizes fitness of the models.

Crumb L, a*, b* and ΔE values of MMB had the following ranges 46.71 to 71.31, 2.83 to 9.04, 19.27 to 23.07 and 3.25 to 25.34, respectively (Table 4). There was no difference among Crumb L* of samples with 8 g WB (Table 5) but was different from control (72.36). ANOVA results indicated significance of linear terms of WB ($p < 0.0001$) on all colour parameters, followed by linear terms of fermentation time ($p < 0.0001$) on L* and a* followed by linear and quadratic terms of WB on L*, a*, b* ($p < 0.0001$) and ΔE ($p = 0.0038$). Significant p-values of models ($p < 0.0001$), followed by non-significant lack of fit p values ($p > 0.005$) implies that the models were significant for colour properties of *magwinya* with medium WB (Table 7). Previous study on the *magwinya* also showed significant impact of coarse WB on colour properties of *magwinya* (Onipe et al., 2018). Total colour difference is said to be very distinct at $\Delta E > 3$ (Pathare et al., 2013); which is the case for the ΔE values reported in this study and this can be attributed to high chroma values of fine and medium WB (Onipe et al., 2017). This implies that both fine (Fig. 1c) and medium WB (Fig. 2c) impacted distinct colour change in *magwinya* from as low as 1% addition.

 https://doi.org/10.1016/j.heliyon.2019.e01364

## 3.3. Ash, oil and moisture content of *magwinya* with fine WB

### 3.3.1. Moisture

Moisture content of MFB was mainly influenced by linear term of fermentation time ($p < 0.05$), followed by quadratic terms of WB ($p < 0.05$) and fermentation time ($p < 0.05$); while the moisture of *magwinya* with medium WB was mainly influenced by quadratic term of WB ($p = 0.0001$). Other factors had no significant effect ($p > 0.05$). Model p values were significant ($p < 0.0001$), while residual lack of fit p-value was non-significant ($p > 0.05$) which represents good fit of the models. From the 3D graph (Fig. 2D), moisture increased at 1−8 g, and then a decrease from 8 to 15 g WB addition. Moisture content MFB and MMB ranged from 30.52 to 38.37% and 32.55−39.87%, respectively; showing that MMB had higher moisture than MFB samples. This can be attributed to water retention in the larger pore size of medium WB. Moreover, larger surface area of fine WB These values were lower than those reported for *magwinya* with coarse WB (Onipe et al., 2018). An inference can be drawn from the foregoing - due to size reduction, WB with fine particle size retains less water than the medium particle size. Although different in composition, doughnut is a comparable product to *magwinya*. Tan and Mittal (2006) reported moisture content of doughnut as 23.00−32.15%. High moisture in this study relative to conventional doughnut can be attributed to higher water content of >60% in *magwinya* dough before frying.

### 3.3.2. Oil absorption

The variables with the largest effect on fat content of MFB were linear terms of fermentation time ($p < 0.05$), followed by quadratic terms of WB incorporation ($p < 0.0001$); while the linear terms of WB ($p < 0.0001$) and quadratic terms of fermentation time ($p < 0.05$) had significant effect of fat content of MMB. Interaction terms of the three independent variables showed no significant effect ($p > 0.05$) on fat content of *magwinya*. The low model probability value of $p < 0.0001$ coupled with non-significant ($p > 0.05$) lack of fit p-value (Table 6) indicates that the developed model was adequate for predicting fat content of *magwinya*. These values would give a good fit to the coefficients of the mathematical models presented in Table 6. Frying time (1−3 min) had no significant effect on the oil absorption of *magwinya* (Fig. 1e). Mean fat content values of MFB and MMB ranged from 2.78% to 10.89% and 4.11−9.78%, respectively. These values were slightly higher than the values reported in our previous study (Onipe et al., 2018). This can be because of the difference in particle sizes of WB. Fine WB contained more starchy material than medium WB, which could have hampered the barrier-forming effect of fine WB. Nonetheless, fine and medium WB markedly ($p < 0.05$) reduced fat content compared to control sample (14%). This reduction in fat content can be attributed to the barrier effect of WB during migration of oil into the dough sponge

 https://doi.org/10.1016/j.heliyon.2019.e01364

during frying. As reiterated by Kim et al. (2012), WB fibres form a barrier which reduces the absorption of oil into the dough during frying. In their study, a 2.7% decrease in OC with increase in WB content from 5 − 10 g was reported.

### 3.3.3. Ash

The predominant effect on the developed model for ash values of *magwinya* corresponded to the linear ($p < 0.0001$) and quadratic terms ($p < 0.0001$) of fine and medium WB addition. Duncan's test also showed that ash significantly increased with increase in WB for MFB and MMB. The model p-value of <0.0001 followed by non-significant lack of fit p-values ($p > 0.05$) and strong $R^2$ values of 0.8764 (fine WB) and 0.9505 (medium WB) implies that the model is significant. These values would in turn give a good fit to the mathematical model represented in the regression coefficient values (Table 6). Non-significant lack of fit p values of 0.43 and 0.42 ($p > 0.05$) implied fitness of model for ash (Table 6). Ash values for MFB and MMB were found in the ranges 0.62 to 1.22 and 0.66−1.32%, respectively at 1−15 g WB addition. Response surface plots showed an increase in ash with increase in fine (Fig. 1F) and medium WB (Fig. 2F). Ash content of a food product corresponds to the total minerals present therein. Essential nutrients in wheat kernel is concentrated in the bran portion. This is the reason for the health benefits associated with WB-enriched, and/or whole grain food products (Hemery et al., 2007; Onipe et al., 2015). An 11% increase in ash content of *poori* (an Indian fried bread) ash content at 3 g WB addition (Yadav and Rajan, 2012) was reported. Similarly, Onipe et al. (2018) also reported significant increase in ash content at 15% WB incorporation.

## 3.4. Numerical optimisation of oil and ash content of *magwinya*

Constraints and criteria for numerical optimization of the responses are presented as follows: fermentation and WB were kept in range and frying time was maximised. Simultaneously, oil content was minimised while ash was maximised. From the goals set, RSM gave several solutions with desirability values. Highest desirability value was selected as the best (Jideani et al., 2010). Optimization conditions given for the two WB particle sizes in the software-generated solutions were: 15 g WB, 3 min frying time and fermentation time of 71.66 min for MFB, and 76.43 min for MMB each with a desirability of 0.82 and 0.78. Predicted and observed values for values for oil and ash content for MFB and MMB in comparison to control samples are presented in Table 8. To validate these software-predicted values, the optimum conditions were tested experimentally to generate the observed values for oil and ash content values at 4.99% and 1.19% for MFB, as well as 7.10% and 1.27% for MMB (Table 8). In comparison to control *magwinya*, predicted values for oil content showed reduction of 44.96 and 22.92%


https://doi.org/10.1016/j.heliyon.2019.e01364

**Table 8.** Predicted and experimental values for oil and ash content of optimised *magwinya*.

| *Magwinya* samples | Process variables | | | Predicted values | | Experimental values | |
|---|---|---|---|---|---|---|---|
| | $X_1$ (g) | $X_2$ (min) | $X_3$ (min) | Oil (%) | Ash (%) | Oil (%) | Ash (%) |
| Fine bran | 15 | 71.66 | 3 | 5.02 | 1.21 | 4.99 | 1.19 |
| Medium bran | 15 | 76.43 | 3 | 7.03 | 1.31 | 7.10 | 1.27 |
| Control | 0 | 120 | 3 | - | - | 9.12 | 0.60 |

$X_1$: wheat bran incorporation, $X_2$: fermentation time, $X_3$: frying time.

for MFB and MMB, respectively. The two particle sizes of WB, significantly reduced oil content of *magwinya* at optimized processing conditions, thus validating the fitness of models generated in this study.

## 3.5. Mineral and dietary fibre content of *magwinya*

Five minerals - manganese (Mn), iron (Fe), zinc (Zn), calcium (Ca) and magnesium (Mg) were estimated in two optimised and one control sample. Results showed that mineral contents of optimised samples were markedly higher ($p < 0.05$) than the control sample. Level of minerals in medium WB were significantly higher ($p < 0.05$) than fine WB samples. The same trend was replicated in the magwinya samples (Table 9). This could have resulted from losses accrued from milling and sieving operation during particle size reduction and more starchy materials present in the fine WB and more fiber in the medium WB. Mazjoobi et al. (2014) reported similar reduction in minerals in WB with smaller particle size. Numerous studies have shown that consumption of wholegrain or bran-enriched foods offer more health benefits than foods made from refined white flour; because minerals and other nutrients are condensed in the aleurone layer of WB (Fardet, 2010; Stevenson et al.,

**Table 9.** Mineral content of wheat bran and *magwinya* samples.

| Samples | [1] Minerals (/mg/kg) | | | | |
|---|---|---|---|---|---|
| | Mn | Fe | Zn | Ca | Mg |
| Fine WB | $97.31 \pm 0.43^d$ | $104.15 \pm 0.19^a$ | $71.95 \pm 0.48^d$ | $888.17 \pm 4.30^d$ | $3947.04 \pm 32.07^d$ |
| Medium WB | $165.6 \pm 1.25^e$ | $131.28 \pm 0.77^b$ | $91.94 \pm 0.99^e$ | $1115.86 \pm 7.87^e$ | $4995.61 \pm 7.87^e$ |
| Control *magwinya* | $8.03 \pm 0.08^a$ | $147.39 \pm 1.52^c$ | $30.65 \pm 0.06^a$ | $243.65 \pm 3.27^a$ | $348.19 \pm 0.79^a$ |
| [2] MFB | $19.01 \pm 0.53^b$ | $199.41 \pm 3.10^d$ | $36.36 \pm 0.18^b$ | $318.62 \pm 3.96^b$ | $775.95 \pm 1.10^b$ |
| [2] MMB | $31.97 \pm 0.30^c$ | $386.24 \pm 2.61^e$ | $39.41 \pm 0.05^c$ | $414.47 \pm 4.71^c$ | $979.53 \pm 7.64^c$ |

[1] Values are means ± standard deviation (n = 3). Means with different superscript in each column are significantly different ($p < 0.05$) using Duncan multiple comparison test.
[2] MFB and MMB represent *magwinya* fine and medium wheat bran.


https://doi.org/10.1016/j.heliyon.2019.e01364

2012; Onipe et al., 2015). Results in this study are in general agreement with previous reports (Fardet, 2010; Winiarska-Mieczan and Kwiecień, 2011; Onipe et al., 2018). As expected, fibre content equally increased significantly ($p < 0.05$) with WB inclusion in *magwinya*. Inclusion of medium and fine WB brought about 58% and 43% increase in fibre content of *magwinya* samples (Fig. 3). WB contains up to 63% dietary fibre (dwb), which as expected increased dietary fibre content of *magwinya* samples.

### 3.6. Microstructure

Scanning electron micrographs of dough (left) and *magwinya* crumb (right) morphology are presented below (Fig. 4). Structure of wheat flour dough (Fig. 4a) and fine WB dough (Fig. 4c) show similarity in compactness of the starch cells. The control, however, has more gas cells than the latter - which is due to reduced gluten formation because of the addition of WB - which is known for dilution of gluten in wheat dough. Kim et al. (2012) observed similar trend in the microstructure of doughnut crust with 1% WB and the control. The dough of medium WB structure has looser structure than WF dough because of reduced gluten network caused by the presence of WB in the dough. The compact structure of *magwinya* dough resemble the microstructure of yeast sweetened dough in the study of Tlapale-Valdivia et al. (2010). Crumb of fried dough showed gelatinization of starch cells – a result of the exposure of starch granules to heat processing- in this case- frying (Fig. 4B, D and F). Another keen observation is the reduced gas cells in the crumb of *magwinya* with medium WB (Fig. 4f). In the microstructure of doughnut crust observed by Kim et al. (2012), there was higher rate of shrinkage in crust cell membrane at 10% WB which was because of a suction of oil into the porous crust microstructure after frying. Further probe into the crust microstructure of *magwinya* in relation to oil uptake is recommended, as this will assist in better understanding of oil uptake mechanism and how to effectively reduce it.

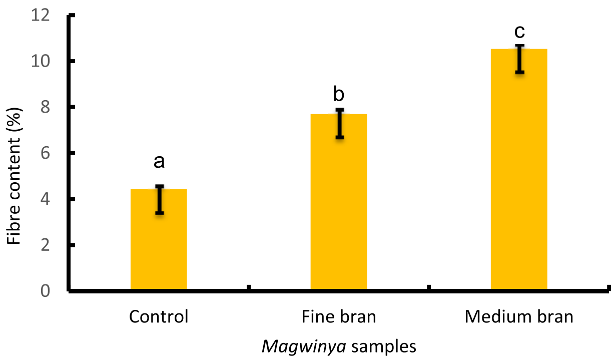


**Fig. 3.** Fibre content of *magwinya* samples. Different letters (a, b, c) indicates significant differences ($p < 0.05$) among the samples using Duncan multiple comparison test.

 https://doi.org/10.1016/j.heliyon.2019.e01364

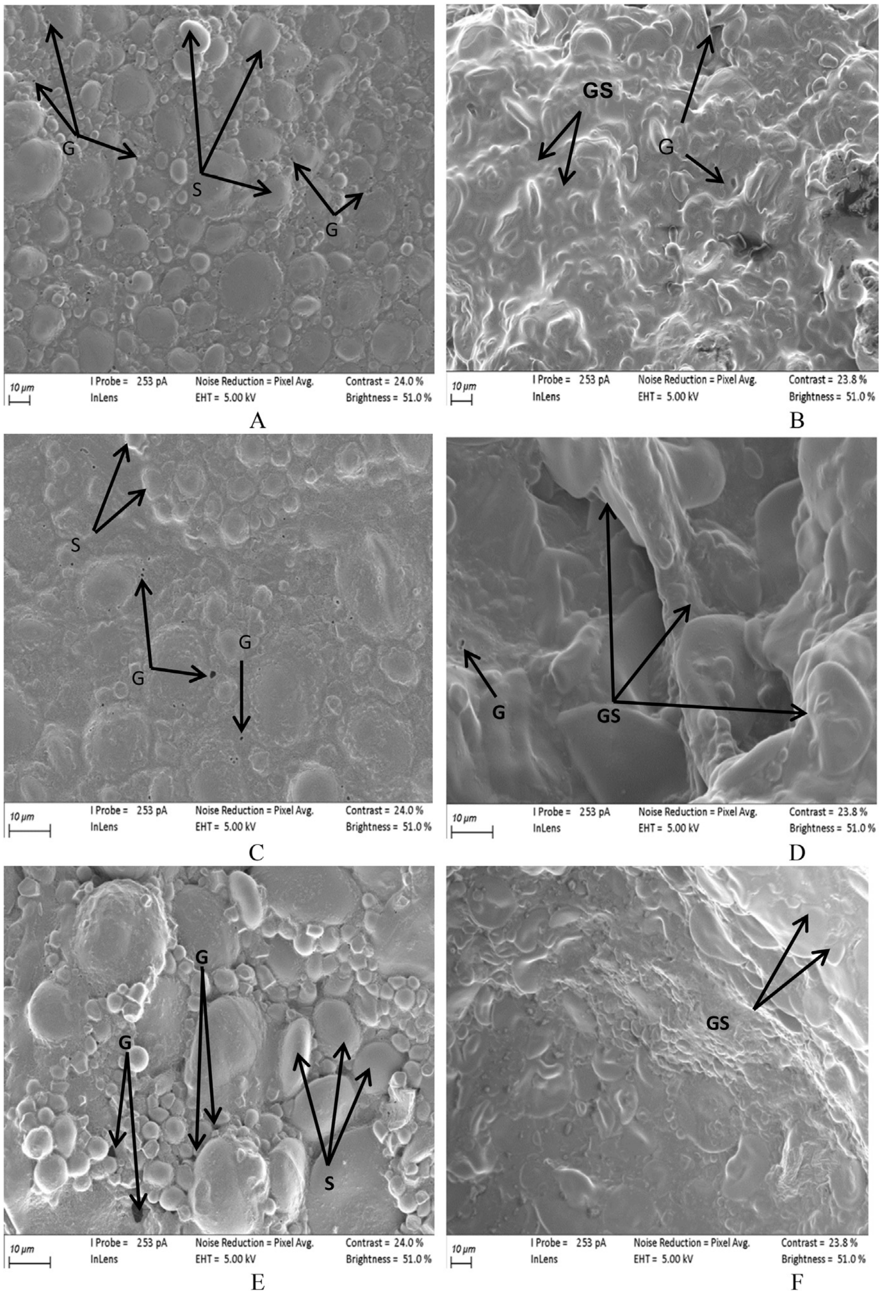


**Fig. 4.** Scanning electron micrographs of dough and crumbs of *magwinya* with wheat flour- control (A and B) fine wheat bran [WB] (C and D) and medium WB (E and F). Arrows are pointing to: G: gas cells, S: starch, GS: gelatinized starch.

## 3.7. Consumer acceptability test

Mean values for crust and crumb colour ranged between 5.48 to 6.84 and 5.70 to 7.02, respectively, with control having the highest acceptability score. This agrees with the study of Ameh et al. (2013) where control bread had highest scores than

 https://doi.org/10.1016/j.heliyon.2019.e01364

A

B

C

**Fig. 5.** Crust and crumb photographs of *magwinya* with (A) no bran (control) (B) fine, and (C) medium wheat bran.


https://doi.org/10.1016/j.heliyon.2019.e01364

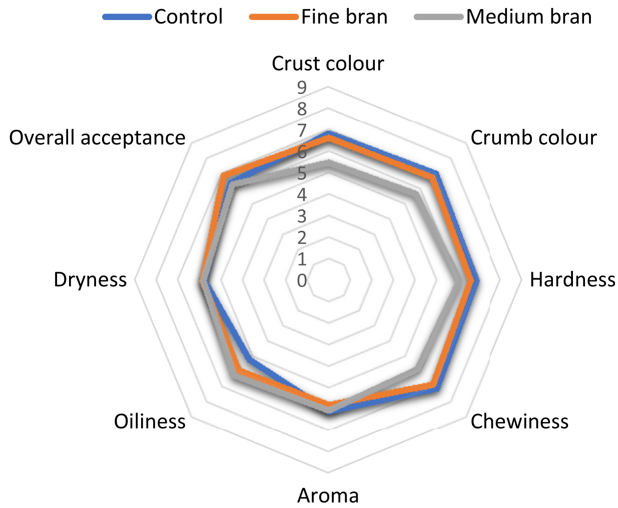


**Fig. 6.** Consumer acceptability for *magwinya* samples using a 9-point Hedonic scale.

other bread samples substituted with rice bran. Crumb and crust colour scores of control *magwinya* was not significantly different ($p < 0.05$) from samples with fine WB but was significantly different ($p > 0.05$) from medium bran samples. The low acceptance colour scores for MMB samples can be attributed to the increased visibility of WB in the product due to larger particle sizes in comparison to MFB (Fig. 5). Unlike colour attributes, there was no significant difference ($p > 0.05$) among samples for hardness, aroma, and overall acceptance (Fig. 6). Chewiness score for medium bran *magwinya* (5.82) was significantly lower ($p < 0.05$) than other samples; most probably because medium bran had the highest particle size of the three samples. Control sample was scored lowest for oiliness (5.20) and it was not significantly different from fine bran samples but was significantly different from medium bran *magwinya*. This meant that control sample was oilier than other samples and the consumers did not like the oiliness, while they preferred the less oiliness in medium bran sample. This result justifies our hypothesis that addition of WB to *magwinya* will reduce oil content.

Overall acceptance score ranged from 6.42 to 6.90. These scores were not significantly different from each other. Kaur et al. (2012) reported a significant reduction ($p < 0.05$) in acceptability from 7.4 to 4.6 when WB in pasta increased from 5 to 25%. Sharma et al. (2011) reported high acceptability scores of 8.2 and 8.0 for *balushahi* and *mathi* (Indian fried bread) at 10% WB supplementation. From the acceptability result in this study, we can conclude that all test samples were accepted, but to get a better understanding of the acceptance, consumer test of *magwinya* with a range of 1−15 g WB (from optimization experimental design) is recommended.


https://doi.org/10.1016/j.heliyon.2019.e01364

## 4. Conclusions

In this study the effects of WB, fermentation and frying time on physiochemical properties, microstructural, mineral and consumer acceptability of *magwinya* were investigated and it can be concluded that WB can reduce fat content of *magwinya*, while it increases ash content. Thus, giving *magwinya* a nutritive boost. Interaction effect of all the process variables had significant impact on some of the properties measured. RSM was an effective tool to optimize the fat and ash content of *magwinya* with regression model equations for predictive future use. Both fine and medium WB, significantly increased the amounts of mineral and fibre of *magwinya*. However, medium WB had the greatest effect. WB and fermentation had significant effect on moisture content and volume of *magwinya*. Consumers accepted *magwinya* enriched with WB in terms of oiliness which means the purpose of the study was achieved to produce low-fat, high-fibre *magwinya* that is acceptable to the consumers.

## Declarations

### Author contribution statement

Oluwatoyin Onipe: Performed the experiments; Wrote the paper.

Daniso Beswa: Contributed reagents, materials, analysis tools or data.

Victoria Jideani: Conceived and designed the experiments; Analyzed and interpreted the data.

Afam I. O. Jideani: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

### Funding statement

This work was supported by Technology Innovation Agency of South Africa (SA) and University of Venda, through its Research Grant (SARDF/14/FST/03).

### Competing interest statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

 https://doi.org/10.1016/j.heliyon.2019.e01364

## References

AACC, 1999. Approved Methods of the American Association of Cereal Chemists. American Association of Cereal Chemists, Inc, St. Paul, MN.

AACC, 2000. Approved Methods of the American Association of Cereal Chemists. American Association of Cereal Chemists, Inc, St. Paul, MN.

Ameh, M.O., Gernah, D.I., Igbabul, B.D., 2013. Physico-chemical and sensory evaluation of wheat bread supplemented with stabilized undefatted rice bran. Food Nutr. Sci. 4 (09), 43–48.

AOAC (Association of Official Analytical Chemists International), 2000. Official Methods of Analysis, fifteenth ed. AOAC International, Arlington, VA.

Fardet, A., 2010. New hypotheses for the health-protective mechanisms of whole-grain cereals: what is beyond fibre? Nutr. Res. Rev. 23 (1), 65–134.

Food and Agriculture Organisation of the United Nations, 2018. The Developing World's New burden: Obesity. Retrieved September 17 2018 from. http://www.fao.org/focus/e/obesity/obes2.html.

Ghaitaranpour, A., Elahi, M., Nagafi, M.N., Mohebbi, M., 2013. Effect of storage at ambient temperature on quality of donut. Agric. Adv. 2 (4), 139–145.

Hemdane, S., Jacobs, P.J., Dornez, E., Verspreet, J., Delcour, J.A., Courtin, C.M., 2016. Wheat (*Triticum aestivum* L.) Bran in bread making: a critical review. Compr. Rev. Food Sci. Food Saf. 15 (1), 28–42.

Hemery, Y., Rouau, X., Lullien-Pellerin, V., Barron, C., Abecassis, J., 2007. Dry processes to develop wheat fractions and products with enhanced nutritional quality. J. Cereal Sci. 46 (3), 327–347.

Ji, W., Zhao, M., Wang, M., Yan, W., Liu, Y., Ren, S., Lu, J., Wang, B., Chen, L., 2017. Effects of canagliflozin on weight loss in high-fat diet-induced obese mice. PLoS One 12 (6), 0179960.

Jideani, V.A., Oloruntoba, R.H., Jideani, I.A., 2010. Optimization of Fura production using response surface methodology. Int. J. Food Prop. 13 (2), 272–281.

Kaur, G., Sharma, S., Nagi, H.P.S., Dar, B.N., 2012. Functional properties of pasta enriched with variable cereal brans. J. Food Sci. Technol. 49 (4), 467–474.

Kemp, S.E., Hollowood, T., Hort, J., 2011. Sensory Evaluation: a Practical Handbook. John Wiley & Sons, pp. 66–137.

Kim, B.K., Chun, Y.G., Cho, A.R., Park, D.G., 2012. Reduction in fat uptake of doughnut by micro-particulated wheat bran. Int. J. Food Sci. Nutr. 63 (8), 987–995.

 https://doi.org/10.1016/j.heliyon.2019.e01364

Kwinda, O., Onipe, O.O., Jideani, A.I., 2018. The effect of oat bran and psyllium husk fibre on oil reduction and some physicochemical properties of *magwinya*—a deep-fried dough. CyTA J. Food 16 (1), 247—254.

Lebesi, D.M., Tzia, C., 2011. Effect of the addition of different dietary fibre and edible cereal bran sources on the baking and sensory characteristics of cupcakes. Food Bioprocess Technol. 4 (5), 710—722.

Malhotra, R., Hoyo, C., Ostbye, T., Hughes, G., Schwartz, D., Tsolekile, L., Zulu, J., Puoane, T., 2008. Determinants of obesity in an urban township of South Africa. S. Afr. J. Clin. Nutr. 21 (4), 315—320.

Majzoobi, M., Pashangeh, S., Farahnaky, A., Eskandari, M.H., Jamalian, J., 2014. Effect of particle size reduction, hydrothermal and fermentation treatments on phytic acid content and some physicochemical properties of wheat bran. J. Food Sci. Technol. 51 (10), 2755—2761.

Mellema, M., 2003. Mechanism and reduction of fat uptake in deep-fat fried foods. Trends Food Sci. Technol. 14 (9), 364—373.

Noort, M.W., van Haaster, D., Hemery, Y., Schols, H.A., Hamer, R.J., 2010. The effect of particle size of wheat bran fractions on bread quality—evidence for fibre—protein interactions. J. Cereal Sci. 52 (1), 59—64.

Oke, E.K., Idowu, M.A., Sobukola, O.P., Adeyeye, S.A.O., Akinsola, A.O., 2018. Frying of food: a critical review. J. Culin. Sci. Technol. 16 (2), 107—127.

Onipe, O.O., Jideani, A.I., Beswa, D., 2015. Composition and functionality of wheat bran and its application in some cereal food products. Int. J. Food Sci. Technol. 50 (12), 2509—2518.

Onipe, O.O., Beswa, D., Jideani, A.I.O., 2017. Effect of size reduction on colour, hydration and rheological properties of wheat bran. Food Sci. Technol. 37 (3), 389—396.

Onipe, O.O., Beswa, D., Jideani, V.A., Jideani, A.I.O., 2018. Optimization of processing conditions for oil reduction of *magwinya* (a deep-fried cereal dough). Afr. J. Sci. Technol. Innov. Dev. 10 (2), 209—218.

Otero, G., Gürcan, E.C., Pechlaner, G., Liberman, G., 2018. Food security, obesity, and inequality: measuring the risk of exposure to the neoliberal diet. J. Agrar. Change 18, 536—554.

Pathare, P.B., Opara, U.L., Al-Said, F.A.J., 2013. Colour measurement and analysis in fresh and processed foods: a review. Food Bioprocess Technol. 6 (1), 36—60.

 https://doi.org/10.1016/j.heliyon.2019.e01364

Prückler, M., Siebenhandl-Ehn, S., Apprich, S., Höltinger, S., Haas, C., Schmid, E., Kneifel, W., 2014. Wheat bran-based biorefinery 1: composition of wheat bran and strategies of functionalization. LWT Food Sci. Technol. 56 (2), 211–221.

Santala, O., Kiran, A., Sozer, N., Poutanen, K., Nordlund, E., 2014. Enzymatic modification and particle size reduction of wheat bran improves the mechanical properties and structure of bran-enriched expanded extrudates. J. Cereal Sci. 60 (2), 448–456.

Sharma, S., Nagi, H.P.S., Singh, B., Priya, K., 2011. Effect of cereal brans supplementation on quality characteristics of various indigenous products. J. Food Sci Eng. 1 (2), 111–118.

Sobota, A., Rzedzicki, Z., Zarzycki, P., Kuzawińska, E., 2015. Application of common wheat bran for the industrial production of high-fibre pasta. Int. J. Food Sci. Technol. 50 (1), 111–119.

Stevenson, L., Phillips, F., O'sullivan, K., Walton, J., 2012. Wheat bran: its composition and benefits to health, a European perspective. Int. J. Food Sci. Nutr. 63 (8), 1001–1013.

Steyn, N.P., Demetre, L., Johanna, H.N., 2011. Factors which influence the consumption of street foods and fast foods in South Africa- a national survey. Nutr. J. 10 (1), 104–114.

Tan, K.J., Mittal, G.S., 2006. Physicochemical properties changes of donuts during vacuum frying. Int. J. Food Prop. 9 (1), 85–98.

Temple, N.J., Steyn, N.P., Fourie, J., De Villiers, A., 2011. Price and availability of healthy food: a study in rural South Africa. Nutrition 27 (1), 55–58.

Tlapale-Valdivia, A.D., Chanona-Pérez, J., Mora-Escobedo, R., Farrera-Rebollo, R.R., Gutiérrez-López, G.F., Calderón-Domínguez, G., 2010. Dough and crumb grain changes during mixing and fermentation and their relation with extension properties and bread quality of yeasted sweet dough. Int. J. Food Sci. Technol. 45 (3), 530–539.

Winiarska-Mieczan, A., Kwiecień, M., 2011. Evaluation of the mineral composition of breadstuff and frequency its consumption. Acta Sci. Pol. Technol. Aliment. 10 (4), 487–495.

Yadav, D.N., Rajan, A., 2012. Fibres as an additive for oil reduction in deep fat fried poori. J. Food Sci. Technol. 49 (6), 767–773.

Zhang, D., Moore, W.R., 1997. Effect of wheat bran particle size on dough rheological properties. J. Sci. Food Agric. 74 (4), 490–496.

 https://doi.org/10.1016/j.heliyon.2019.e01364

Ziaiifar, A.M., Achir, N., Courtois, F., Trezzani, I., Trystram, G., 2008. Review of mechanisms, conditions, and factors involved in the oil uptake phenomenon during the deep-fat frying process. Int. J. Food Sci. Technol. 43 (8), 1410−1423.

Zolfaghari, Z.S., Mohebbi, M., Khodaparast, M.H.H., 2013. Quality changes of donuts as influenced by leavening agent and hydrocolloid coatings. J. Food Process. Preserv. 37 (1), 34−45.

 https://doi.org/10.1016/j.heliyon.2019.e01364