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Effect of Ingredient combination and post frying centrifugation on oil uptake and associated quality attributes of a fried snack

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ABSTRACT

Effects of ingredient combination and Post-Frying Centrifugation (PFC) on qualities of low-fat and high fiber-fried snacks were investigated. Wheat Flour (WF), High-Quality Cassava Flour (HQCF) and Corn Bran (CB) were combined in the ratios 92:8:0, 83:12:5, 75:15:10, 62:18:20, 50:20:30, and 40:20:40, respectively. Conditioned blends (moisture content of 37.8%) were rested, sheeted, cut and fried at 170 ± 2°C for 5 min. Some fried matrices were centrifuged for 3 min immediately after frying. Samples with the highest CB had the highest oil uptake (19.91 ± 0.04%) and Total Dietary Fiber (TDF) (20.47 ± 0.41 g/100 g) but expanded least (61.52 ± 13.78%). Oil Uptake (OU), redness, change in color and TDF increased with CB inclusion but OU decreased by 55.21% after PFC. Negative correlation existed between OU and expansion (r = −0.852) and TDF with expansion (r = −0.85) while a positive correlation existed between TDF and OU (r = 0.945). Scanning Electron Microscopy (SEM) revealed the role of CB in OU.

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Introduction

Regardless of the transition of people toward the intake of food with health benefits, fried snacks still constitute a large proportion of our everyday meal. Snacks are prepared by frying technique, which impacts its unique taste, mouth feel and appearance. It is chewy within and crunchy outside, providing short-term satisfaction and these attributes are majorly responsible for its huge acceptance by all age cohorts. According to Onipe, Beswa, Jideani, and Jideani (2019), snacks are deficient in micronutrients, dietary fiber and have a large percentage of fat. However, cardiovascular diseases and other ailment have been associated with the consumption of snacks as described by Gazmuri (2008). The increase in the incidence of non-communicable diseases (NCDs)

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in Sub-Saharan regions has become a subject of concern owing to its negative effect on health which may possibly cause death in the long run. This has increased the need to fortify snacks with ingredients of high protein, antioxidative and fiber content so as to meet consumer's nutritional demand (Dziennik, 2007). Dietary fiber is believed to be the most important ingredients that promotes health (Lorencio & Alvarez, 2016).

Corn bran, a residue derived during the processing of corn (*Zea mays)*, constitutes majorly of the outer kernel that covers corn seed and it is removed together with germ and endosperm during dry-milling as residues. The proportion of its starch content varies between 10 – 25% with cellulose, hemicelluloses and lignin ranging between 150–200 g/kg, 400–500 g/kg and 80–130 g/kg, respectively (Qiu et al., 2015; Stojceska, 2013; Yadav, Malik, Pathera, Islam, & Sharma, 2016). Products that were usually thrown away or fed to animals such as by-products of milling industries are nowadays largely used in foods as a substitute for dietary fiber, which is also an attempt of adding value. Anil (2012) reported that corn bran contains high percentage of dietary fiber than other cereal residues. Owing to the wide range of dietary fiber benefits, it has received enormous attention in the past few decades (Jha & Berrocoso, 2015). In order to reduce prevalence of cardiovascular risk such as ischemic heart diseases, stroke as well as lower risk of diabetes, intake of dietary fiber has been advocated. It has also been shown that supplementation with dietary fiber have some benefits with respect to risk factors like blood pressure, serum lipids, insulin sensitivity and diabetic metabolic control (Estruch, Martınez-Gonzalez, Corella, Basora-Gallisa, & Ruiz-Gutierrez et al., 2009). Despite these numerous advantages of dietary fiber inclusion in snacks, their presence in food matrices may disrupt the structure and subsequently affect some important quality attributes (Dueik, Sobukola, & Bouchon, 2014; Peska, Miedzianka, Kita, Tajnar-Czopek, & Rytel, 2010).

Utilization of residues obtained during processing is essential, not only in economy cost-cutting and reducing waste, but equally to develop new products with excellent sensory characteristics that will respond to customer consciousness of health-promoting products. In order to continually satisfy its customers among different age groups, the snack industry continues to develop an entirely new snack or replace some common ingredients with new substitutes. High-Quality Cassava Flour (HQCF) is one of the major products from cassava roots traded in the world food market (Shittu, Dixon, Awonorin, Sanni, & Maziya-Dixon, 2008) and its popularity in the sub-region is on the rise due high cost of wheat importation and characteristic celiac related diseases. Additionally, it is being used to take the place of wheat flour in some products in Asia, Latin America and Africa for wheat flour (Lopez, Pereira, & Junqueira, 2004; Mohamed, Abdullah, & Muthu, 2006). Development of an entirely new snack or replacement of some common ingredients with new substitutes in others is important for the snack industry in order to ensure continuous consumers satisfaction. The future of Nigeria as one of the leading HQCF exporting countries is particularly bright as its export capacity had risen. Due to the relationship between nutrition and health, particularly in NCDs, efforts must be made to develop high-fiber and low-fat snacks.

In order to exploit the advantages of incorporating corn bran in a fabricated fried product, efforts must be made in minimizing the oil content. Subsequently, air drying, edible coatings, vacuum frying and hydrocolloids treatments among others are measures taken to lower the amount of oil absorbed in fried products (Daraei Garmakhany, Mirzaei, Kashaninejad, & Maghsudlou, 2008; Daraei Garmakhany, Mirzaei, Maghsoudlou, Kashaninejad, & Jafari, 2010, 2011, 2014; Yazdanseta, Tarzi, & Gharachorloo, 2015).

Based on the established fact that oil uptake during a frying process is a surface phenomenon where the adhered surface oil percolates into the structure during the cooling stage (Akinpelu et al., 2014; Bouchon & Pyle, 2004; Dueik, Robert, & Bouchon, 2010; Oginni, Sobukola, Henshaw, Afolabi, & Munoz, 2015; Sobukola, Dueik, Munoz, & Bouchon, 2013b), there is need to introduce a post-frying centrifugation technique/de-oiling step. The final oil content of fried foods can be attributed to the combination of frying and post-frying techniques applied. Aguilera and Gloria-Hernandez (2000), Bouchon and Pyle (2005) and Moreira (2014) have earlier reported a distinction between the oil taken up by some fried foods during the frying and post-frying processes. The cooling-phase effect mechanism (post-frying) has been reported to provide the driving force that allows significant amount of oil to be absorbed when the food is lifted off the fryer (Cortés, Segura, Kawaji, & Bouchon, 2015). About 60% to 80% of the oil content in the final product is accounted by adhesion of oil to food surfaces. Due to the significance of the post-frying period on oil absorption, it has continued to receive attention. Kim and Moreira (2013) reported that shaking and centrifuging of potato chips immediately after the frying process can partially remove surface oil. Hence, reducing oil content of formulated fried foods through the application of post-frying centrifugation technique is still evolving.

The use of a de-oiling post-frying step such as centrifugation can help to remove surface oil that would have been taken up during cooling. Also, incorporating high starchy flour (High-Quality Cassava Flour-HQCF) and corn bran in a wheat-based formulated product can enhance adequate structure formation that can enhance satiety, aid digestion, and reduce caloric intake. Consequently, the objective of this study was to determine the effect of ingredient combination (wheat flour, HQCF and corn bran) on some quality attributes of a high fiber fried snack while post-frying centrifugation was applied to study its effect on oil uptake.

Materials and methods

Materials

Matrices were prepared from wheat flour (Honeywell Flours Mills, Nigeria), HQCF (Thai Farms Limited, Nigeria), corn bran (from a local market in Nigeria) and then fried using refined bleached deodorized palm olein (Kings vegetable oil, Nigeria).

Sample preparation

Samples to be fried were prepared using a similar procedure reported by Sobukola, Dueik, and Bouchon 2013a, 2013b). Table 1 shows the different combinations of ingredients as well as application of post-frying centrifugation in this work. The blends were mixed using a SAISHO hand mixer S-1496 HM, Hong Kong for 2 min. The ratios obtained were deduced from preliminary experiments based on the ability of each combination (CB, HQCF and Wheat) to form a stable structure that can withstand vigorous frying process without disintegration. This was based on the fact that incorporating dietary fiber source in snack formulation disrupts structure formation when inappropriate levels of the ingredients were used. Distilled water was added to the specific dry mixture blend (with known moisture content), ensuring a constant moisture content of 37.8% (w.b.). Half of the water was added at room temperature (25 ± 2°C) and mixed for 2 min while the remaining half was added at 100°C and mixed for 3 min. The resulting dough was allowed to rest for 1 h in a covered plastic container for proper hydration before sheeting (Eurosonic model Globe150, China) into thickness of 3 mm. The dough was then cut into 3.8 mm diameter discs while ensuring a constant weight of 3.0 ± 0.5 g before frying. Two sets of frying experiments were carried out and results presented are means on six replicates.

Table 1. Ingredient combination (Corn bran, wheat flour, high-quality cassava flour and centrifugation time) of fried matrices.

Sample Code	Wheat flour (W-%)	High Quality Cassava Flour (C-%)	Corn Bran (B-%)	Centrifugation time (-min)
W_{92}–C_8	92	8	-	-
W_{92}–C_8''	92	8	-	3
W_{83}–C_{12}–B_5	83	12	5	-
W_{83}–C_{12}–B_5''	83	12	5	3
W_{75}–C_{15}–B_{10}	75	15	10	-
W_{75}–C_{15}–B_{10}''	75	15	10	3
W_{62}–C_{18}–B_{20}	62	18	20	-
W_{62}–C_{18}–B_{20}''	62	18	20	3
W_{50}–C_{20}–B_{30}	50	20	30	-
W_{50}–C_{20}–B_{30}''	50	20	30	3
W_{40}–C_{20}–B_{40}	40	20	40	-
W_{40}–C_{20}–B_{40}''	40	20	40	3

Frying experiments

Frying was done using the modified method described by Dueik et al. (2010). This was carried out using a deep fryer (Bush glass fryer, Royton, UK) with a thermostat control. The fryer was filled with vegetable oil (2 L) and was preheated prior to frying for about 1 h and discarded at intervals of 6 h of frying. Frying was done at 170 ± 2°C for 5 min. About 12 discs were placed in the frying rack with a grid to prevent flotation of samples in the oil.

Post-frying centrifugation

The main objective of this step was to remove surface oil from the fried matrices immediately after frying. Each batch of fried samples was divided into two and a portion was centrifuged immediately after frying using a de-oiling centrifuge (FLEXI 0314–9 81 481/HP 081 233 480 480, Indonesia) at a speed of 1400 rpm for 3 min once removed from the frying oil, while the other portion was allowed to drain on its own for 3 min after frying. Time for centrifugation was chosen after trial experiments after visual observation of a near dry surface of fried products.

Sample analyses

Oil uptake and moisture loss (d/b)

The oil content of the fried matrices was determined by solvent extraction using the Soxhlet technique (AOAC, 2000). Each extracted group was dried in a forced air oven at 105°C for 24 h (to constant mass), cooled in a desiccator and then weighed to obtain the dry solids content. The oil uptake was determined by deducting the oil content of the sample from that of the blend from which the sample was obtained. The moisture content was obtained from the difference between the original weight and the dry solids plus the oil content. Moisture loss was reported on a dry basis and calculated from the difference between the moisture content of the dough before frying and the moisture content of the fried snack.

Total dietary fiber (TDF) content

TDF of fried matrices was determined using a combination of enzymatic and gravimetric methods. The matrices were dried and de-oiled with petroleum ether. Fat-free samples were first gelatinized with heat stable α-amylase. Afterward, they were digested enzymatically with protease and amyloglucosidase to eliminate protein and starch, respectively. Ethanol was added to precipitate the soluble dietary fiber. The resultant residue was then filtered with a fritted crucible-porosity #2, and washed with ethanol and acetone. The residue was dried and weighed. Half portion of the samples was analyzed for total protein content using the Kjedahl method, while the other was analyzed for ash in a muffle furnace. Subtracting the weight of protein and ash from the final residue gave the TDF content (AOAC, 1995). All dietary fiber assay kit was supplied by SIGMA, Missouri, USA.

Color analyses

Colourimeter (Chroma meter CR-410, Japan) was used in determining the lightness (L*), redness (a*) and yellowness (b*) of the samples. The color difference (ΔE*) between raw (L_0*, a_0*, and b_0*) and fried discs (L*, a*, and b*) was obtained (Mariscal & Bouchon, 2008).

$$\Delta E* = \left[(L_0* - L*)^2 + (a_0* - a*)^2 + (b_0* - b*)^2\right]^{0.5} \quad (1)$$

Texture analysis

Texture of fabricated matrices was analyzed using a three-point bending test in a Texture Analyzer (TexVol TVT 300XH, Hagersten, Sweden) with a support span of 20 mm and load cell of 2000 g. A steel blade of 2.5 mm thickness with a flat edge was used to break the samples at a constant speed of 20 mm/min. The fracture force (Newton) which is the maximum force required to break the sample was determined from the time-deformation curve.

Expansion

The expansion developed for each product was determined using a vernier caliper. Expansion was defined as the maximum height developed during frying (Gazmuri, 2008).

Scanning electron microscopy

The procedure similar to that reported by Sobukola et al. (2013a) was used. Fried matrices were immersed in petroleum ether for 4 h after frying in order to remove the surface oil before gold plating with a thin layer (20 nm) using a Varian vacuum evaporator PS 10E (Evey Engineering's warehouse, New Jersey, USA). Gold plated samples were then analyzed using a variable pressure scanning electron microscope LEO 1420VP (LEO Electron Microscopy Ltd, Cambridge, UK) at an acceleration potential of 25 kV. An oxford 7424 solid-state detector (Oxford Instruments, Oxford, UK) was used to obtain the electron micro-graphs at 500x magnifications.

Descriptive and overall acceptability tests

Descriptive sensory analyses of samples were conducted by a panel consisting of fifteen members (Post-graduate students) who had experience in sensory analyses of various food products. Prior to analyses, panel members were trained and relevant information related to formulated snacks were given to them. The panelist assessed the fried snacks and freely generated terms to describe the attributes which were then recorded. Once decided, definitions for each attribute were established by the panel leader. The samples were then evaluated using a 15 cm rule for intensity of attributes generated which include color (0 = light brown, 15 = dark brown), surface texture (0 = very smooth, 15 = very rough), expansion (0 = very flat, 15 = very puffy), oiliness (0 = not oily, 15 = very oily), crispness (0 = not crispy, very crispy), and sweetness (not sweet- very sweet). The training and evaluation were done in two sessions to prevent carry over effects (Murray, 2001). Two pieces of each of the fried snacks were served per session to prevent quick satiation, and at room temperature (25 ± 2°C). Water was used as palate cleansing material in between the samples (23). A laboratory scale sensory acceptability test was conducted with 30 untrained panelists to determine their preference on a nine-point hedonic scale (1 = dislike extremely and 9 = like extremely) in terms of texture, sweetness, crispness, oiliness, and overall acceptance among consumers.

Statistical analysis

One-way analysis of variance was carried out to establish significant differences between values obtained for the same sample. Significant means were separated by Duncan Multiple Range Test (DMRT) at 5% using SPSS version 16.

Results and discussion

Oil uptake (OU) and moisture loss (ML) (d/b)

Figure 1 shows the effect of ingredient combination and post-frying centrifugation on oil uptake of fried matrices. OU increase with increase in significant level of CB but decreased significantly ($p < .05$) with the application of post-frying centrifugation. With respect to ingredient combination prior to centrifugation, the lowest oil uptake (10.15%) was observed in fried matrices without addition of CB (W_{92}–C_8) while the highest (19.91%) was observed in samples with the highest level of CB (W_{40}–C_{20}–B_{40}). When no CB was added at significant levels, fried samples from wheat and HQCF had lowest oil uptake which can be attributed to the consistency in the particles of the flours. Hence, such fried matrices have smooth surface structure that

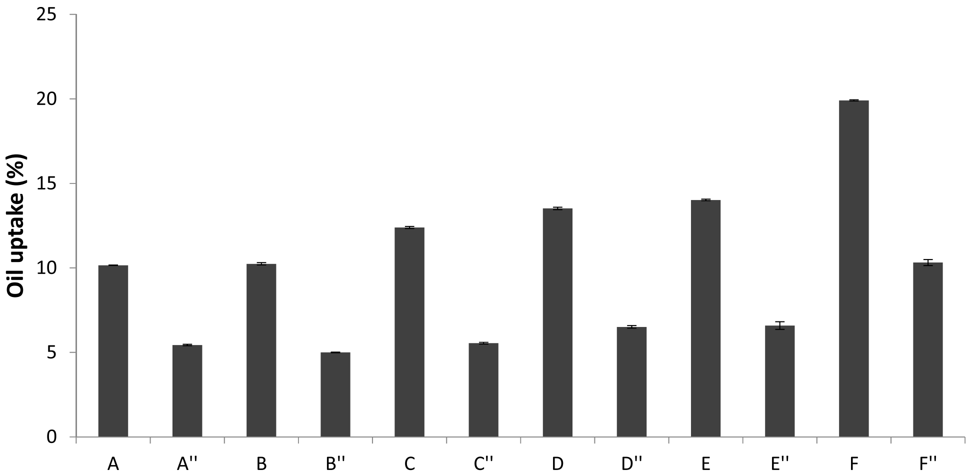
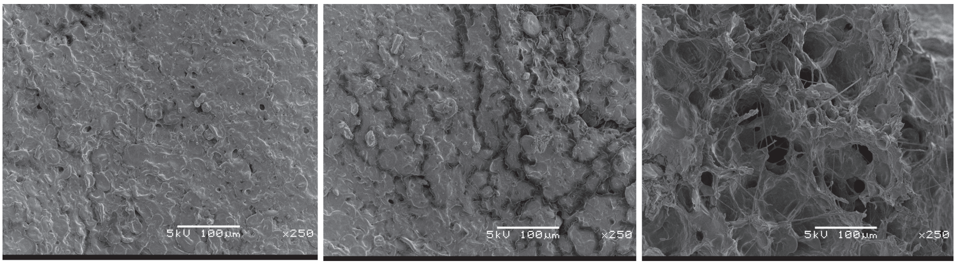


Figure 1. Oil uptake of fried matrices where A, B, C, D, E and F are samples W_{92}–C_8, W_{83}–C_{12}–B_5, W_{75}–C_{15}–B_{10}, W_{62}–C_{18}–B_{20}, W_{50}–C_{20}–B_{30}, and W_{40}–C_{20}–B_{40}, respectively while those with (") are the equivalent centrifuged samples.

discourages percolation of adhered surface oil into the samples during cooling. However, when higher levels of CB were used, the larger particles of the insoluble fibers apparently disrupted the surface structure evidenced by its roughness which encourages movement of adhered surface oil into the samples. No significant ($p > .05$) difference was observed between fried samples from W_{92}–C_8 and W_{83}–C_{12}–B_5 but as the level of CB increases beyond 5%, the corresponding OU increases significantly ($p < .05$). This result is consistent with previous studies where increasingly insoluble fibers are added to blends. Peska et al. (2010) reported an increase in oil-uptake in fried extruded potato pellets with the addition of wheat fiber. Similarly, Dueik et al. (2014) attributed increase in oil content to matrix disruption, when adding large amounts of fiber.

In fried products, surface roughness is associated with higher oil uptake because it makes oil drainage after frying difficult (Gazmuri, 2008). Surface nature is a key factor in determining the capacity of fried snack to drain oil during cooling period; hence, higher oil uptake obtained in this work can be attributed to surface roughness due to the addition of higher level of CB in the combination. Moreno, Brown, and Bouchon (2010) had earlier examined the relationship between surface roughness and oil uptake in formulated fried products, and concluded that products with higher surface roughness absorbed more oil. In order to ascertain the role of CB in surface nature and subsequently, oil uptake in the fried matrices, Scanning Electron Micrographs (SEM) of the defatted sample using the method of Sobukola et al. (2013a) was carried out. From the micrographs, decreasing level of discontinuous network of structures was observed. Thus, confirming the role played by fiber inclusion in the surface smoothness of the fried matrices and consequently, oil uptake.



(A) W_{92}–C_8, OU=10.15% (B) W_{62}–C_{18}–B_{20}, OU= 14.02% (C) W_{40}–C_{20}–B_{40}, OU= 19.91%

Figure 2. Scanning electron micrographs of fried matrices.

Increased CB level resulted in a more unbound weaker and rougher structure with larger cavities that encouraged a higher permeability to oil absorption.

Figure 2a shows micrographs of fried matrices from W_{92}–C_8 with more continuous matrix which encourages oil drainage during cooling and subsequently lowest oil uptake (10.15%). This sample does not contain corn bran in the formulation but wheat and HQCF. However, with the addition of corn bran (20 g/100 g-Figure 2b), significant ($p < .05$) higher oil uptake was obtained in the sample. This is attributed to the presence of pores which encourages oil percolation into the structure rather than draining during cooling. With increasing addition of corn bran (40 g/100 g), numerous pores were observed (Figure 2c) on the surface of the matrices with corresponding higher oil uptake. According to Daraei Garmakhany et al. (2008), two mechanisms are majorly used to explain oil uptake during deep fat frying: condensation and capillary mechanisms. In whichever of the cases, oil penetrates through the pores inside the products. Once there is increase in porosity and internal pores of fried products including formulated ones as investigated in this work, oil penetration increases. Consequently, samples with higher levels of CB have more pores which encourages infiltration of surface oil into the structure of the fried samples.

However, in order to reduce oil uptake while still retaining higher fiber content, a post-frying centrifugation step was introduced immediately after frying. This step was able to reduce oil uptake by as much as 55.21% (W_{40}-C_{20}-$B_{40'}$) (Figure 1). Dueik et al. (2014) and Dueik et al. (2010) used a similar technique for both structured (wheat starch, wheat fiber and gelatinized corn starch) and unstructured (potatoes and carrots) fried materials, respectively. In fact, irrespective of the ingredient combination, application of post-frying centrifugation significantly ($p > .05$) reduced the oil uptake of fried matrices. Hence, with the introduction of this step, it is possible to obtain a healthier high fiber fried product with lower oil content. Similar result was obtained by Khalilian, Mba, and Ngadi (2020) in their work on g-frying of eggplant. They reported 40% and 80% decrease in oil content using perpendicular and parallel centrifugal forces respectively, after frying.

Lowest moisture loss (22.94%) (Figure 3) was obtained in fried matrices from W_{92}–C_8 while the highest (31.05%) was obtained in samples from W_{40}–C_{20}–B_{40}. Percentage moisture loss was observed to increase with increased substitution. The increase in moisture loss of the matrices as corn bran inclusion increased can be attributed to the more open structure of the matrices introduced by the bran. When the frying process began, rapid moisture evaporation was observed and the rate decreases gradually until bubble-end point. Moisture loss increased with reduced WF content and increased level of HQCF and corn bran. Similar observation was made by Gazmuri (2008) in the analysis of wheat gluten and starch matrixes during deep-fat frying when higher gluten content in the fried matrices reduced moisture escape since gluten network retains water in its structure.

Total dietary fiber (TDF)

Total Dietary Fiber (TDF) of fried matrices from different combinations is as presented in Figure 4. TDF increased significantly ($p < .05$) with CB addition with the lowest value (8.17%) observed in fried matrices from W_{92}–C_8 combination while fried matrices from W_{40}–C_{20}–B_{40} combination has the highest amount of TDF (20.47%). Substitution had a significant ($p < .05$) effect on TDF. Therefore, consumption of 50 g of matrices from W_{62}–C_{18}–B_{20} can provide an individual with 30% of the WHO recommended daily intake (25 g/day). Nutritional claims for dietary fiber foods (Official Journal of

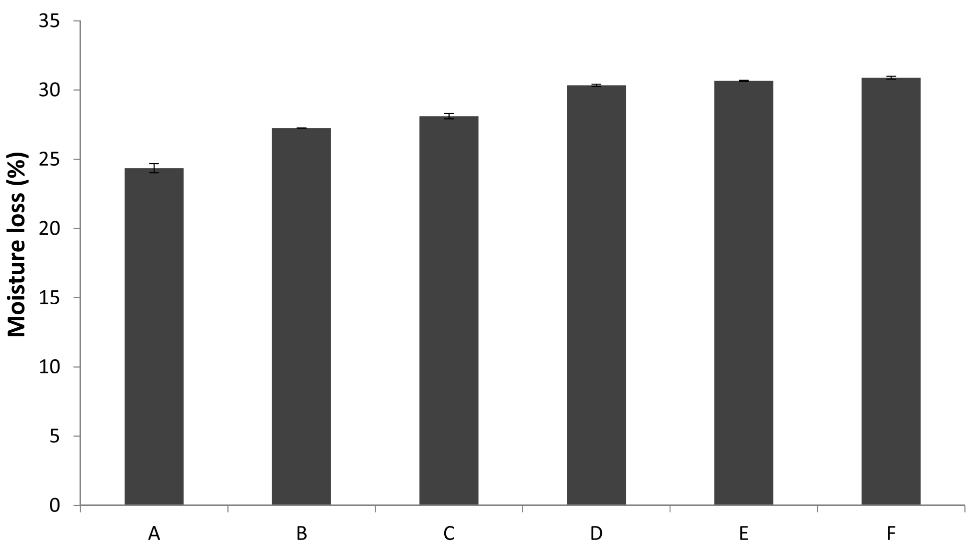


Figure 3. Moisture loss (%) of fried matrices where A, B, C, D, E and F are samples W_{92}–C_8, W_{83}–C_{12}–B_5, W_{75}–C_{15}–B_{10}, W_{62}–C_{18}–B_{20}, W_{50}–C_{20}–B_{30}, and W_{40}–C_{20}–B_{40}, respectively.

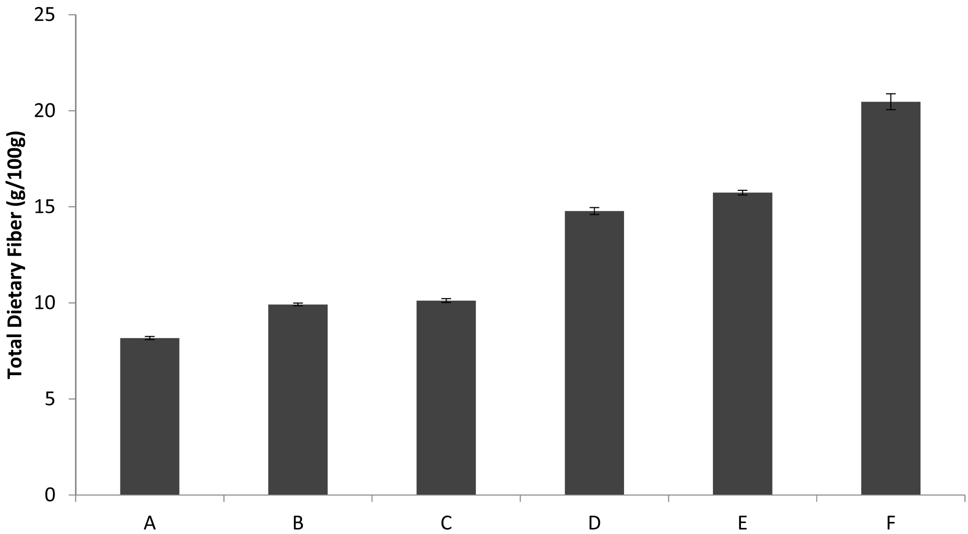


Figure 4. Total dietary fiber (g/100 g) of fried matrices where A, B, C, D, E and F are samples W_{92}–C_8, W_{83}–C_{12}–B_5, W_{75}–C_{15}–B_{10}, W_{62}–C_{18}–B_{20}, W_{50}–C_{20}–B_{30}, and W_{40}–C_{20}–B_{40}, respectively.

European Commission, 2006) recommended that for a product to be labeled as "source of" it must contain >3 g dietary fiber/100 g food. Since the matrices obtained in this study contain more than 3 g dietary fiber/100 g, they can be regarded as, "source of dietary fibre". A strong positive correlation existed between dietary fiber and oil uptake (r = 0.945).

Color analyses

Lightness (Luminosity color Component-L^*) as shown in Table 2 decreased with substitution of WF with HQCF and CB. The darkest (45.97) fried sample was observed in matrices from blend of W_{40}–C_{20}–B_{40} while of fried sample from W_{92}–C_8 was lightest (69.53). Substitution had a significant ($p < .05$) effect on lightness of the matrices. The changes in color of fried products can be attributed to Maillard reaction that depends on the level of reducing sugars and amino acids at the surface, as well as temperature and frying time (Krokida, Oreopoulou, Maroulis, & Marinos-Kouris, 2001). The chromatic color component (redness-a^*) also increased with increase in level of CB as

Table 2. Color parameters of fried snack from corn bran, wheat and high-quality cassava flours.

Sample code	Lightness (L*)	Redness (a*)	Yellowness (b*)	Change in color (ΔE)
W_{92}–C_8	69.53 ± 1.59 ^{f}	7.06 ± 0.97 ^{b}	38.24 ± 1.40 ^{c}	17.39 ± 0.33^a
W_{83}–C_{12}–B_5	66.28 ± 1.03 ^{e}	8.34 ± 0.74^b	36.66 ± 1.00^{bc}	18.47 ± 1.26^a
W_{75}–C_{15}–B_{10}	61.31 ± 2.16 ^{d}	11.87 ± 0.91^b	36.05 ± 0.01^b	20.17 ± 0.56^b
W_{62}–C_{18}–B_{20}	56.47 ± 1.10 ^{c}	12.95 ± 0.35^b	35.88 ± 1.28^b	20.97 ± 0.56^b
W_{50}–C_{20}–B_{30}	51.73 ± 0.85 ^{b}	12.90 ± 0.98^b	35.23 ± 0.37^b	24.69 ± 1.48 ^{c}
W_{40}–C_{20}–B_{40}	45.97 ± 0.03 ^{a}	15.57 ± 0.09 ^{c}	27.51 ± 0.12^a	24.86 ± 0.36 ^{c}

Mean values along the columns with the same alphabets are not significantly different at 5% level.

shown in Table 2. Dueik et al. (2014) earlier reported that addition of fiber can have a significant ($p < .05$) effect on the color of fried matrices. Lowest value of redness (7.06) was obtained in fried matrices from W_{92}–C_8 while the highest (15.57) was from fried matrices from W_{40}–C_{20}–B_{40}. Significant ($p < .05$) difference was observed in the redness values of the matrices, however, fried matrices from W_{83}–C_{12}–B_5, W_{75}–C_{15}–B_{10}, W_{62}–C_{18}–B_{20} and W_{50}–C_{20} – B_{30} blends were not significantly ($p > .05$) different in terms of redness. Similarly, yellowness values were also observed to decrease as substitution level increases. The values for color change as shown in Table 2 increased with increasing level of substitution with the lowest color change observed in fried matrices from W_{92}–C_8 while those from W_{40}–C_{20}–B_{40} changed most. In most cases, substitution level has a significant ($p < .05$) effect on change in color.

Texture (Peak force)

Texture (crispness) is a very important quality attribute of fried products as it denotes freshness. The breaking force or hardness is generally reported as an indicator of the extent of crispness of a fried food material. A lower hardness value corresponds with a higher crispness. Figure 5 shows the peak force (N) obtained for fried matrices based on the different ingredient combination. From the result obtained, fried matrices from W_{92}–C_8 combination had the lowest peak force (27.04 N) while those from W_{40}–C_{20}–B_{40} has the highest value (43.18 N). Substitution had a significant ($p < .05$) effect on the values of the breaking force. However, fried matrices with CB inclusion of between 5

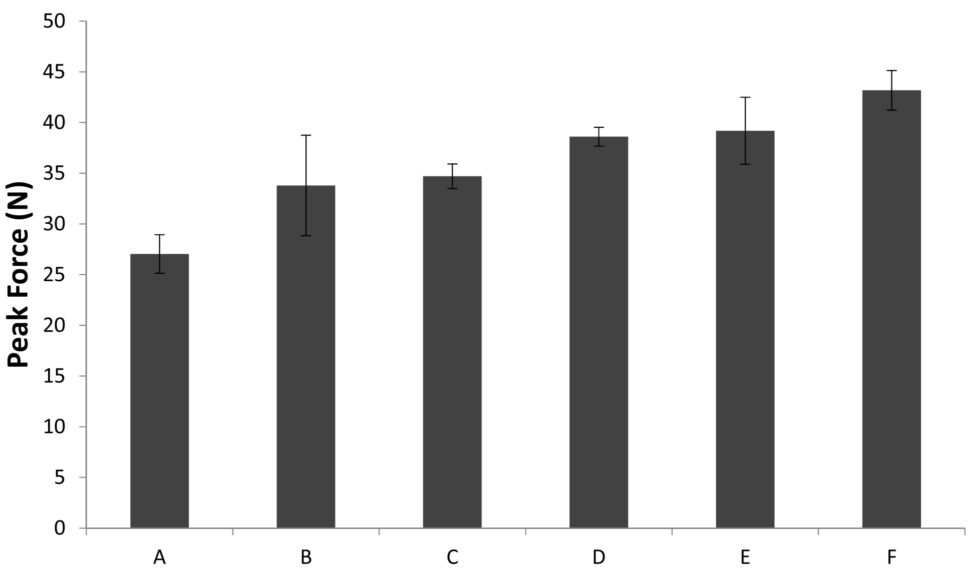


Figure 5. Peak force(N) of fried matrices where A, B, C, D, E and F are samples W_{92}–C_8, W_{83}–C_{12}–B_5, W_{75}–C_{15}–B_{10}, W_{62}–C_{18}–B_{20}, W_{50}–C_{20}–B_{30}, and W_{40}–C_{20}–B_{40}, respectively.

and 30 g/100 g and the corresponding values of HQCF are not significantly ($p > .05$) different from one another. The addition of fiber into the formulation might have conferred on the fried matrices the hard nature which makes them more difficult to break. This result was contrary to the report of Dueik et al. (2014). They reported that softer samples absorbed more oil compared to harder ones. This could be due to the fact that they used pre-gelatinized corn starch to enhance crust formation thereby preventing infiltration of adhered surface oil into the matrices' structure. In this work however, HQCF was used which although contains native starches but may not be fully gelatinized due to the rapid nature of the frying process. Hence, the effect of CB addition was more significant in terms of texture (peak force) and oil uptake as shown in the micrographs (Figure 2).

Expansion

Gazmuri and Bouchon (2009) had earlier reported that products containing high amount of gluten and water tend to expand during frying. This is due to the fact that the gluten content in the matrix helps to develop an elastic structure that traps water vapor producing an expanded product. However, in this work increasing the level of HQCF and CB in the formulation reduces the level of gluten in the matrix thus drastically reducing the expansion of the fried products. As shown in Figure 6, fried matrices from ingredients with the highest level of substitution (W_{40}–C_{20}–B_{40}) has the lowest expansion (61.52%) while fried matrices from blend of W_{92}–C_8 expanded the most (148.41%).

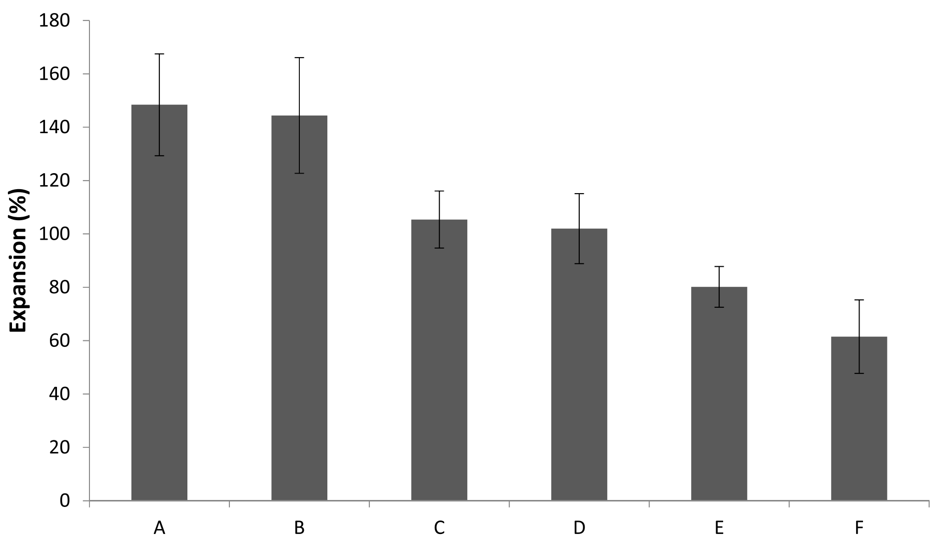


Figure 6. Expansion (%) of fried matrices where A, B, C, D, E and F are samples W_{92}–C_8, W_{83}–C_{12}–B_5, W_{75}–C_{15}–B_{10}, W_{62}–C_{18}–B_{20}, W_{50}–C_{20}–B_{30}, and W_{40}–C_{20}–B_{40}, respectively.

Expanded products result in smoother surface texture, and therefore, the more the expansion, the smoother the surface of the fried snack. Smooth surfaces encourage oil drainage as oil absorption rate is faster in porous surfaces. The effect of expansion on surface smoothness had also been observed by Bouchon and Pyle (2004) when frying formulated products based on potato flakes. Sobukola et al. (2013a) reported that concavity as a result of expansion formed by matrix from wheat starch and gluten encourages drainage of surface oil after removal from fryer resulting in samples with lower oil content. Digital pictures (Figure 7) of fried matrices from different ingredient combinations clearly show the effect of corn bran on surface roughness and subsequently, expansion and oil content. In this work, a strong negative correlation existed between oil uptake and expansion (r = −0.852) and TDF and expansion (r = −0.850) of fried matrices from WF, HQCF and CB. Fried samples with lower expansion due to higher level of substitution absorb more oil due to the percolation of surface oil into the structure of the matrix.

Sensory evaluation

Table 3 shows the descriptive sensory evaluation of fried snacks. The six samples produced based on ingredient composition clearly showed differences for all the attributes. The trained panelists developed their own descriptors for the fried snacks and were grouped into seven attributes (oiliness, expansion, surface texture, crispiness, color, sweetness and aroma). All attributes of samples were significantly ($p < .05$) different except aroma. In terms of oiliness, samples with the highest level of CB were observed to be rated as oilier (10.06 ± 1.88) while those without CB were rated lowest (4.84 ± 2.54). Similar trend was observed for surface texture, crispiness, color and sweetness. However, for expansion and sweetness, samples with the highest level of CB had the lowest values of 0.57 ± 1.01 and 2.95 ± 3.86, respectively. Post-frying centrifugation was applied in order to remove surface oil from the fried samples after removal from frying oil. Incorporating fiber-based materials into food formulation usually disrupts structure formation. For fried matrices, this disruption encourages oil absorption

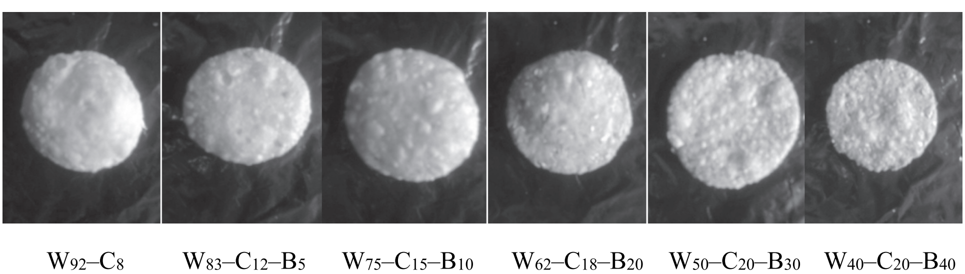


Figure 7. Digital pictures of fried matrices.

Table 3. Descriptive sensory evaluation of fried samples.

Sample	Oiliness	Expansion	Surface texture	Crispness	Color	Sweetness	Aroma
W_9–C_8	4.84 ± 2.54^{cde}	7.94 ± 3.57^{c}	7.37 ± 1.99^{a}	2.76 ± 3.03^{a}	2.63 ± 2.14^{a}	5.33 ± 3.31^{bc}	8.03 ± 2.40^{a}
W_{83}–C_{12}–B_5	5.79 ± 2.20^{cde}	5.08 ± 4.17^{b}	7.33 ± 1.98^{a}	3.36 ± 4.02^{a}	2.61 ± 1.65^{a}	4.37 ± 3.20^{abc}	6.62 ± 3.41^{a}
W_{75}–C_{15}–B_{10}	6.43 ± 1.70^{def}	4.94 ± 3.30^{b}	12.33 ± 2.05^{b}	6.65 ± 3.64^{b}	6.95 ± 3.40^{b}	5.62 ± 3.53^{c}	6.49 ± 3.02^{a}
W_{62}–C_{18}–B_{20}	7.36 ± 0.80^{ef}	3.26 ± 3.20^{b}	12.87 ± 2.54^{b}	9.68 ± 4.55^{c}	8.38 ± 4.28^{b}	3.38 ± 2.95^{abc}	6.84 ± 2.52^{a}
W_{50}–C_{20}–B_{30}	9.36 ± 2.25^{g}	1.05 ± 1.69^{a}	12.98 ± 1.99^{b}	7.10 ± 4.10^{bc}	11.26 ± 3.14^{c}	2.47 ± 3.03^{a}	5.84 ± 3.52^{a}
W_{40} – C_{20}–B_{40}	10.06 ± 1.88^{g}	0.57 ± 1.01^{a}	13.48 ± 2.83^{b}	10.71 ± 3.59^{d}	13.68 ± 2.82^{d}	2.95 ± 3.86^{ab}	6.37 ± 2.90^{a}

Mean values along the columns with the same alphabets are not significantly different at 5% level.

Table 4. Oiliness and overall sensory acceptability tests for fried samples.

Sample	Oiliness	Overall Acceptability
W_{9}–C_{8}	6.79 ± 1.72^{ef}	5.93 ± 1.50^{b}
W_{92}–C_{8}″	8.64 ± 0.78 ^{g}	6.11 ± 1.20^{b}
W_{83}–C_{12}–B_{5}	6.41 ± 1.43^{def}	6.28 ± 1.10^{b}
W_{83}–C_{12}–B_{5}″	7.86 ± 0.97 ^{g}	5.89 ± 1.57^{b}
W_{75}–C_{15}–B_{10}	5.71 ± 0.94 ^{cd}	6.14 ± 1.43^{b}
W_{75}–C_{15}–B_{10}″	7.14 ± 0.97^{ef}	6.14 ± 1.01^{b}
W_{62}–C_{18}–B_{20}	5.34 ± 0.99^{bc}	6.20 ± 1.32^{b}
W_{62}–C_{18}–B_{20}″	6.03 ± 1.96^{cde}	6.30 ± 1.64^{b}
W_{50}–C_{20}–B_{30}	4.71 ± 1.64^{b}	4.97 ± 1.91^{a}
W_{50}–C_{20}–B_{30}″	5.94 ± 1.61 ^{cd}	4.97 ± 1.81^{a}
W_{40}–C_{20}–B_{40}	3.63 ± 1.92^{a}	4.13 ± 1.81^{a}
W_{40}–C_{20}–B_{40}″	4.91 ± 1.65^{b}	4.811 ± 2.08^{a}

Mean values along the columns with the same alphabets are not significantly different at 5% level.

which is not compatible with current health trends. When panelists were asked to rate both centrifuged and un-centrifuged fried samples in terms of oiliness and overall acceptability as shown on Table 4, the former were rated better (less oily) and more acceptable than the latter (result not shown). These results have shown the possibility of producing a high fiber (20.47 ± 0.41 g/100 g) and low oil (10.32 ± 0.18%) fried snack using a combination of WF, HQCF and CB as well as a post-frying centrifugation technique. This is in accordance with the recent shifting of consumption to health and wellness. The corn bran ensures a high-level fiber while the post-frying centrifugation enhances surface oil removal. Hence, consumption of 50 g of this fried snack containing about 30 g/100 g of CB can supply as much as 30% of the recommended daily intake of dietary fiber.

Conclusions

These results have shown the possibility of producing a high fiber (20.47 ± 0.41 g/100 g) and low oil (10.32 ± 0.18%) fried snack using a combination of WF, HQCF and CB as well as a post-frying centrifugation technique. This is in accordance with the recent shifting of consumption to health and wellness. The corn bran ensures a high-level fiber while the post-frying centrifugation enhances surface oil removal. Hence, consumption of 50 g of this fried snack containing about 30 g/100 g of CB can supply as much as 30% of the recommended daily intake of dietary fiber.

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Declaration of Interest statement

There is no declaration of interest as regarding this manuscript.

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