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# Assessing the Physicochemical, Nutritional and Sensory Properties of Cake Made with Wheat and Orange-Fleshed Sweet Potatoes Flour Blend

**Gilbert Owiah Sampson***
Akenten Appiah-Menkah University of Skills Training
and Entrepreneurial Development, Kumasi

**Olivia Abiire**
Akenten Appiah-Menkah University of Skills Training
and Entrepreneurial Development, Kumasi

## ABSTRACT

**This study evaluated the replacement of wheat flour with orange-fleshed sweet potato (OFSP) flour in terms of its proximate composition, functional characteristics, and sensory properties in cakes. Five treatments were made: AA (100% wheat), AB (80:20), AC (70:30), AD (60:40), and AE (50:50 wheat: OFSP). The proximate composition data show that moisture contents ranged from 16.62% (AC) to 21.46% (AD). Crude protein levels slightly increased with substitution from 10.02% (AA) to 12.13% (AC), before decreasing at the higher levels. Crude fat showed a decline with 39.07% in AA and 28.08% in AD. Crude fibre showed a significant improvement, rising from 0.22% in AA to 1.22% in AE. Also, the carbohydrate content in AE was 39.71% in comparison to 28.28% in AA. These results indicate that OFSP improves the nutritional value of cakes by increasing dietary fibre and carbohydrate content. OFSP addition had an impact on functional properties as well. Water absorption capacity (WAC) was 140 g/g for AA and increased with substitution, while oil absorption capacity (OAC) showed its peak value at 146 g/g for AA and showed minimal change with substitution. Bulk density showed a decrease from 0.543 g/cm$^3$ in AA with increasing substitution of OFSP, which indicates lighter flour blends. Functional characteristics were affected by the inclusion of OFSP. Water absorption capacity (WAC) was 140 g/g for AA, and it increased further with the addition of OFSP. Oil absorption capacity (OAC) was highest at 146 g/g for AA. The OAC showed minimal variation afterwards with the inclusion of OFSP. Bulk density was lowest at 0.543 g/cm$^3$ for AA and increased with increasing inclusion of OFSP, showing that the flour mixtures were lighter. For analysed AA, emulsion activity (EA) was 43.88% and foam capacity (FC) was 12.92%, both of which contribute to aeration and aesthetics. Sensory evaluation pertaining to colour, aroma, taste, texture and overall acceptability was conducted by 50 semi-trained panellists using a hedonic scale of 1-9. Based upon the ANOVA, cakes where the AA was substituted at 30% OFSP received acceptability scores similar to the control when the ratings were subsequently analysed. Acceptability was found to be highest for average colour (8.39± 0.92) and taste (8.08± 1.32); however, for cakes with 40%-50% substitution, the ratings for texture and overall likeability were negatively influenced. Statistically significant differences were noted for taste ($P=0.034$) and texture ($P<.001$), while colour and aroma differences were not provable as statistically significant. It was concluded that OFSP**

**substitution at rates of 30% or less improved the nutritional quality without a reduction in sensory appeal, consistent with a current trend in health-based product development. This study has shown that OFSP has potential for utilisation in bakery products to improve nutritional quality while also reducing post-harvest waste and, at the same time, supporting local agricultural practices.**

**Keywords:** physicochemical, wheat flour, orange flesh sweet potatoes, sensory, nutritional.

## INTRODUCTION

Value addition to agricultural products has received great impetus globally, as much attention is given to enhancing the healthiness, functionality, and sustainability of foods in the face of changing consumer demand for healthful foods (Sharif, Zahid, & Shah, 2018). Diet-related health problems, including cardiovascular diseases, obesity, and micronutrient deficiencies, have been common and thus act as driving forces in the exploration of healthier alternatives to conventional foods. This is particularly so for bakery products, which have been reformulated using composite flours with the view to reducing reliance on refined wheat and adding more nutritionally valuable alternatives like legumes and biofortified tubers (Sharma et al., 2021). This is done in an effort to meet some pressing concerns of sustainability, food insecurity, climate change, and growth in population (FAO 2019). Wheat flour is suitable for the preparation of cakes and dough products due to the presence of gluten (Adegbanke & Ayomiposi, 2019). Wheat is, however, not available in all parts of the world due to climatic differences and soil types; hence, its importation to meet the increased demand for cakes and baked foods (Adegbanke & Ayomiposi, 2019). This consequence implies that bakers have to incur the major challenge of increased cost of production due to the importation of wheat, which further means an increased price for baked foods.

The dependence on the importation of wheat for bakery products places a heavy burden on the economy. Therefore, the economic burden will be minimized through the usage of substitute crops grown in the country, such as OFSP (Luo & Tanaka, 2021). OFSP has been regarded as one avenue that can help solve two major problems such as the vitamin A deficiency and agricultural development. In the bakery industries in Ghana, composite flours are increasingly made with OFSP, and studies show that bread, pastry, and cakes have increased nutritional value with the usage of such flour combinations. Replacing wheat flour with OFSP flour enriches foods with improved nutrients and falls in line with the national drive to reduce the import dependency of wheat into the country (Aidoo et al., 2019).

Composite flours are made up of wheat flours blended with other non-wheat flours, and these could be made from tubers, legumes, or cereals to enhance nutritional value and functionality in the final product (Banua et al., 2021). The application of composite flour can therefore be regarded as an effective method of nutritional improvement of bakery products, especially for countries where wheat is not homegrown or its importation cost is out of reach (Banua et al., 2021). Banua et al. (2021) state that the incorporation of locally available ingredients such as OFSP into the formulation of composite flours serves to reduce the cost while improving public health concerns associated with nutrition and food security. Several composite flours have been studied in Ghana with the dual purpose of reducing wheat imports and improving nutritional quality in commonly consumed foods. For instance, studies have indicated that partial substitution of wheat flour with puree or flour of OFSP in cakes, bread, and other sweet baked goods increases the vitamin A content of these foods, improves their fibre content, and enhances the general sensory properties of such foods (Agbemafle et al., 2020). Therefore, this current study is of great relevance in that it provides insight into strategies for food product development that will offer economic and public health benefits through the physicochemical, nutritional, and sensory investigation of cakes from wheat and orange-fleshed sweet potato flour blends (MoFA, 2018).

Micronutrient deficiencies, especially (VAD), are still a priority public health problem in developing countries. Vitamin A deficiency affects more than 190 million children under five years of age and pregnant women worldwide; impaired immune function, increased risk for morbidity and mortality, and blindness ensue as complications of vitamin A deficiency (WHO, 2009). VAD continues to be of high concern in sub-Saharan Africa, with the most vulnerable populations being children and women in reproductive age. According to a study performed by Low et al. (2017), wheat-based staple foods, which include bread and cakes, urgently require alternative sources of flour, which would help alleviate these deficiencies. Being rich in beta-carotene, orange-fleshed sweet potatoes present one such opportunity for bio fortification. Yet the use of orange-fleshed sweet potatoes in commonly consumed products like cakes is not so well explored.

Adding OFSP flour to wheat-based products has become a promising strategy for enhancing nutritional value in foods of this kind. OFSP is rich in beta-carotene, a precursor to vitamin A that helps to combat VAD through regular consumption (Low et al., 2017). Besides nutritional reasons, OFSP has functional properties that make it suitable for baked goods since it improves colour and flavour and increases the fibre content of products such as bread and cakes (Mwanga et al., 2017). Despite the benefits known about OFSP, they have yet to be fully explored in Ghana for application in baked goods, specifically in cakes. This research seeks to ascertain the physicochemical, nutritional and sensory properties of cake made with wheat and orange-fleshed sweet potatoes flour blend

## MATERIALS AND METHODS

### Source of Material

The wheat flour (soft), sugar, eggs, baking powder and margarine were bought from the Bolgatanga Municipal market. The orange fleshed sweet potatoes were bought at Bolgatanga market. Equipment such as blender, mixer, bowl, knife, digital weighing scale, measuring cup, baking pans, stirrer and oven were obtained from the food processing laboratory of St. Benedette Senior High School. All other chemicals used were of analytical grade.

### Preparation of Orange Fleshed Sweet Potato Flour

The sweet potato flour was prepared by following the method described by Singh et al., (2008). The orange fleshed sweet potato tubers were washed, peeled and sliced into thin pieces manually. The slices were then immersed first in 1% NaCl solution and in a solution containing potassium metabisulphite (1%) and citric acid (0.5%) for 30 min to arrest browning reactions for improving the color of the flour. The slices of sweet potato were then dried in an oven at 105°C for 5 hour; the resulting dry sweet potato chips were then milled into flour using the Philip's grinder, and sieved with 250 µm mesh. Pack the products into airtight containers and store them in the refrigerator for further use. Figure 1 gives a general flow diagram illustrating the processing steps followed for the production of sweet potato flour.

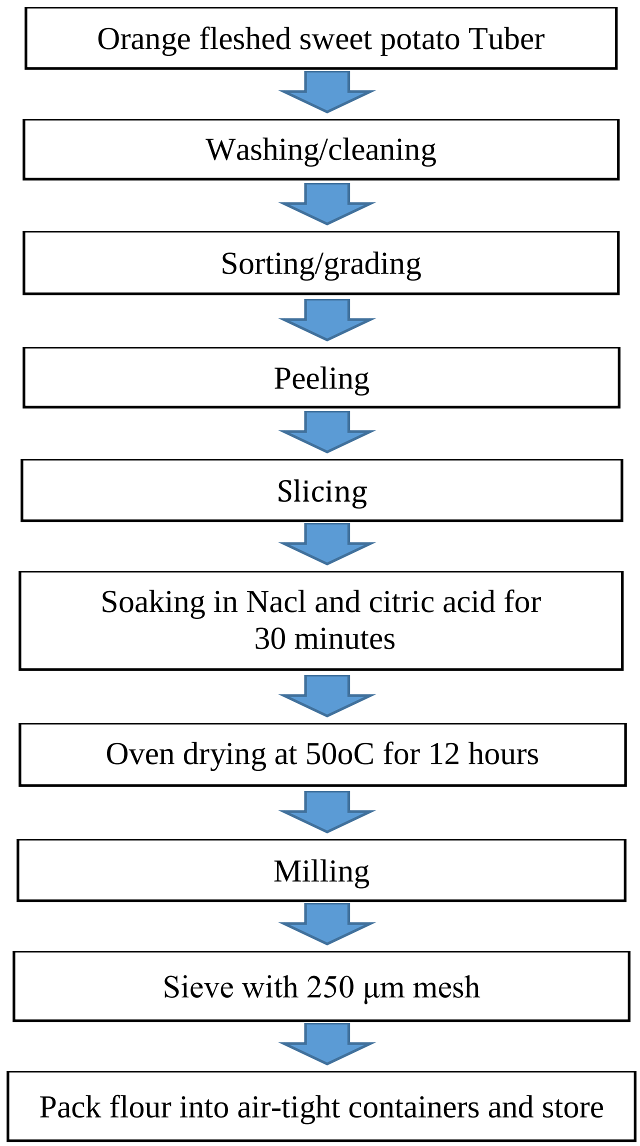


**Fig 1: flow chart for the production of orange-fleshed sweet potato flour. Source: Modified Singh et al., (2008)**

**Formulation of Composite Flour and other Ingredients for Cake Production**

Five samples of cake were prepared and labeled AA, AB, AC, AD and AE. Sample AA was the control and was made with 100% wheat. Samples AB, AC and AD and AE were wheat/potato flours and the other ingredients for cake production are shown in Table 1.

**Table 1: Flour blends formulation (%)**

| SAMPLES | | | | | |
|---|---|---|---|---|---|
| **INGREDIENTS** | **AA** | **AB** | **AC** | **AD** | **AE** |
| Wheat flour (soft) (%) | 100 | 80 | 70 | 60 | 50 |
| OFSPF flour (%) | 0 | 20 | 30 | 40 | 50 |
| Margarine (g) | 125 | 125 | 125 | 125 | 125 |
| Sugar (g) | 200 | 200 | 200 | 200 | 200 |
| Eggs (g) | 300 | 300 | 300 | 300 | 300 |
| Vanilla essence (ml) | 5 | 5 | 5 | 5 | 5 |
| Baking powder (g) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Milk (ml) | 100 | 100 | 100 | 100 | 100 |

AA= 100% wheat flour (100:0); AB = 80% wheat flour and 20% orange fleshed sweet potato flour (80:20); AC = 70% wheat flour and 30% orange fleshed sweet potato flour (70:30A); AD = 60% wheat flour and 40% orange fleshed sweet potato flour (60:40) AE = 50% wheat flour and 50% orange fleshed sweet potato flour (50:50)

## Production of Cake from Flour Blends of Wheat and Orange Fleshed Sweet Potato

This cake production was done using the method described by Ceserani & kinton (2008), with slight modification. Ingredients used include: flour (400 g), margarine (125 g), sugar (200 g), egg (300 g), milk (100 ml), baking powder (0.5 g), vanilla essence (5 mL). Sugar and margarine were creamed using an electric mixer (Model 28a-Bl England) until they become light and fluffy batter. The eggs were beaten for 5 mins with the homogenizer; liquid milk and vanilla essence added to the homogenized egg and then poured into the fluffy batter and thoroughly mixed. Thereafter, a mixture of flour and baking powder was added to the batter, mixed thoroughly to uniform texture, and then poured into greased cake pans. These were then put in the oven and in a temperature of 190°C, it is baked for 15 minutes. After baking, the cakes were cooled to room temperature, removed from the pan after 1 hour, packaged in low density polyethylene bags and sealed in an airtight transparent plastic container for further analysis.

## Proximate Composition Determination

The proximate composition of the flour was determined using the AOAC (2005) method.

### Moisture Content:

About 5g of sample was transferred to the previously dried and weighed dish. Dish was placed in an oven and thermostatically controlled at 105 degrees for 5 hours. Dish was removed and placed in a desiccator to cool to room temperature and weighed. It was then dried again for 30 minutes, cooled down again and weighed. Drying, cooling and weighing were repeated until a constant weight was reached. (Alternatively, sample could be dried in a thermostatically controlled oven for at least 8 hours where a constant weight would be achieved).

### Ash Content:

About 5g sample was weighed into a tarred crucible and was pre-dried. Crucibles was placed in cool muffle furnace using tongs, gloves and protective eyewear. The crucibles Ignited for 2 hours at about 600 degrees Celsius. Muffle furnace was turned off and opened when temperature dropped to at least 250 degrees preferably lower. The door was carefully opened to avoid losing ash that may be fluffy. Safety tongs was used to transfer crucibles to a desiccator with a porcelain plate and desiccant. Desiccator was closed and allowed crucibles to cool prior to weighing.

**Fat Content: Soxhlet Extraction Method:**

Previously dried (air oven at 100°C) 250 ml round bottom flask was weighed accurately. About 5.0g of dri6d sample to 22 ×80mm paper thimble or a folded filter paper was weighed. A small of cotton or glass wool was placed into the thimble to prevent loss of the sample. 150ml of petroleum spirit B.P 40-60°C was added to the round bottom flask and assembled the apparatus. A condenser was connected to the soxhlet extractor and reflux for 4 - 6 hours on the heating mantle. After extraction, thimble was removed and recovered solvent by distillation. The flask and fat/oil was heated in an oven at about 103°C to evaporate the solvent. The flask and contents were cooled to room temperature in a desiccator. The flask was weighed to determine weight of fat/oil collected.

**Crude Fibre Determination:**

Two-gram sample from crude fat determination was weighed into a 750ml Erlenmeyer flask. 200ml of 1.25% $H_2SO_4$ was added and immediately flask was set on hot plate and connected to the condenser. The contents were boiled within 1 minute of contact with solution. At the end of 30 minutes, flask was removed and immediately filtered through linen cloth in funnel and washed with a large volume of water. Filtrate (containing sample from acid hydrolysis) was washed and returned into the flask with 200ml 1.25% NaOH solutions. Flask was connected to the condenser and was boiled for exactly 30 minutes. It was then filtered through Fischer's crucible and washed thoroughly with water and added 15ml 96% alcohol. Crucible and contents was dried for 2 hour at 105 °C and cooled in desiccator and it was weighed. Crucible was ignited in a furnace for 30 minutes and after that it was cooled and reweighed.

**Protein Determination:**

About 2g of sample and a half of selenium –based catalyst tablets and a few anti-bumping agents were added to the digestion flask. 25ml of concentrated $H_2SO_4$ was added and the flask was shook for the entire sample to become thoroughly wet. Flask was placed on digestion burner and heated slowly until boiling ceases and the resulting solution is clear. The sample was then cooled to room temperature and digested sample solution was transferred into a 100ml volumetric flask and made up to the mark. To flush out the apparatus before use, distilled water was boiled in a steam generator of the distillation apparatus with the connections arranged to circulate through the condenser, for at least 10 minutes. The receiving flask was lowered and continued to heat for 30 seconds in order to carry over all liquid in the condenser. 25 ml of 2% boric acid was pipetted into 250ml conical flask and 2 drops of mixed indicator added. The conical flask and its contents was placed under the condenser in such a position that the tip of the condenser is completely immersed in solution. 10ml of the digested sample solution was measured into the decomposition flask of the Kejdahl unit, fixed it and add excess of 40% NaOH (about 15-20ml) to it. The ammonia produced was distilled into the collection flask with the condenser tip immersed in the receiving flask till a volume of about 150ml– 200ml is collected. Before distilling another sample and on completion of all distillations, the apparatus was flushed as in step 1 above. Steam was allowed to pass only until 5ml of distillate is obtained.

Distillate with 0.1N HCL solution was titrated. The acid was added until the solution became colourless. If additional acid is added the solution becomes pink. The nitrogen content was determined in duplicate, and run a blank determination using the same amount of all reagents as used for the sample. The blank will correct for traces of nitrogen in the reagents and should include digestion as well as distillation.

**Carbohydrate Content:**

The calculation of available carbohydrate (nitrogen-free extract-NFE) was made after completing the analysis for ash, crude fibre, ether extract and crude protein. The calculation was made by adding the percentage values on dry matter basis of these analysed contents and subtracting them from 100%.

**Functional Properties**

**Water and Oil Absorption Capacity:**

The water and oil absorption capacities were determined by the method of Sosulski *et al.*, 1986. 1 g of the flour sample was dispersed in 10ml of oil and vortex the suspension for 5 minutes. The suspension obtained was centrifuged at 3500 rpm for 30min. it was then decanted and measured the supernatant in a 10ml graduated cylinder. The density of the oil, and calculated oil absorption capacity were determined using the formula;

$$\text{Oil absorption capacity (\% OAC)} = \frac{(y\text{-}z)\times d}{x} \times 100$$

Where y= initial volume of oil added
Z= volume of supernatant collected
X= initial weight of (dried) sample taken
d= density of oil

y-z =volume of water retained by the sample after centrifugation

**Water Absorption Capacity**

About 1g of the sample in 10ml distilled water was dispersed and vortex the suspension for 5 minutes. The suspension obtained at 3500 rpm for 30min was centrifuged. It was then decanted and measured the supernatant in a 10ml graduated cylinder. Density of water was taken as $1.0gcm^{-3}$, and calculate water absorption capacity as

$$\text{Water absorption capacity (\% WAC)} = \frac{y\text{-}z}{x} \times 100$$

Where y= initial volume of water added
Z= volume of supernatant collected
X= initial weight of (dried) sample taken

y-z =volume of water retained by the sample after centrifugation.

**Bulk Density:**

The bulk density was determined according to the method described by Okaka and Potter (1977). An amount of 100g of the sample was weighed directly into 250ml capacity graduated cylinder and tap the measuring cylinder 10 to 15 times until no change in volume is observed.

$$\text{Bulk density} = \frac{\text{weight of sample (g)}}{\text{Volume of sample after tapping (ml)}}$$

**Foaming Capacity and Foaming Stability**

Foaming capacity and foaming stability were determined as described by Narayana and Narasinga Rao (1982) with slight modifications. 5ml of sample was weighed and mixed in 40ml distilled water and homogenized for 5min at high speed using a homogenizer with a suitable stirrer. The volume of foam separated was noted. For stability, the collapse in foam if any at the end of a specific time was measured (e.g. 1 minute, 2 minutes, 4 minutes and 5 minutes). Calculate the capacity and stability as follows.

$$\%\text{foaming capacity} = \frac{(vol\ after\ \text{homogenization}) - (vol\ before\ \text{homogenization})}{vol\ before\ \text{homogenization}} \times 100$$

$$\%\text{foam stability} = \frac{foam\ volume\ after\ time\ (t)}{initial\ foam\ volume} \times 100$$

**Sensory Evaluation of Samples**

Sensory properties of the cake samples were determined using the method described by Iwe 2014. The sensory properties of the cake samples were tested by a sensory panel consisting of 50 semi trained panelists of staff and students selected from the Department of hospitality management, Bolgatanga Technical University. The panelists were instructed prior to the exercise. All the cake samples were placed on different plates and presented to the panelists with glass of water for rinsing the mouth after every testing so that it will not interfere with the taste of the preceding samples. Sensory properties such as taste, appearance, aroma, texture, and overall acceptability of the cakes was scored in a 9-point hedonic scale. The degree of liking was as expressed below from 9 = like extremely, 5 = neither like nor dislike and 1 = dislike extremely.

**Statistical Analysis**

Data analyses were done using analysis of variance (ANOVA). Tukey Test was used to establish significant difference among various samples in duplicate. Data were analyzed using the software, Statistical Package for Social Science version 22.00, SPSS inc., Chicago, IL, USA at 0.05 level of significance.

## RESULTS AND DISCUSSION

**Proximate Composition of Samples**

The proximate composition of cakes made with different percentages of wheat and OFSP flour provides a good estimate of the nutritional balance in the cakes, the functional quality, and the potential impact of OFSP for dietary diversification. It is anticipated the cake compositions (i.e., moisture contents, fiber, carbohydrates, fat and protein) increases with OFSP inclusion, as the amount of gluten is diluted. Table 2 shows the proximate composition of cakes made from 100% of wheat flour (control) to up to 50% replacement of wheat flour with OFSP flour (a composite blend) at 20% levels.

**Table 2: Proximate composition of cakes made with wheat and orange-fleshed sweet potato flour**

| Sample | Moisture (%) | Ash (%) | Crude Fat (%) | Crude Protein (%) | Crude Fiber (%) | Carbohydrate (%) |
|---|---|---|---|---|---|---|
| **AA** | 18.95(0.81) | 3.46(0.08) | 39.07(0.82) | 10.02(0.11) | 0.22(0.07) | 28.28 (0.23) |
| **AB** | 19.76(0.77) | 2.25(0.92) | 36.35(0.31) | 10.61(0.32) | 0.79(0.11) | 30.25(0.35) |
| **AC** | 16.62(1.11) | 2.13(0.01) | 41.41(1.09) | 12.13(0.43) | 1.11(0.05) | 26.60(0.03) |
| **AD** | 21.46(0.88) | 1.60(0.33) | 28.08(0.76) | 11.74(0.57) | 0.55(0.01) | 36.57(0.06) |
| **AE** | 17.06(0.45) | 2.00(0.21) | 28.37(0.93) | 11.64(0.74) | 1.22(0.32) | 39.71(0.86) |

Key: AA= 100% wheat flour (100:0), AB = 80% wheat flour and 20% orange fleshed sweet potato flour (80:20), AC = 70% wheat flour and 30% orange fleshed sweet potato flour (70:30A), AD = 60% wheat flour and 40% orange fleshed sweet potato flour (60:40) and AE = 50% wheat flour and 50% orange fleshed sweet potato flour (50:50).

## Moisture Content (%)

With respect to the moisture from the cake samples, sample AB contained the highest moisture value (19.76%) and AC contained the lowest moisture value (16.62%). Tortoe et al. (2017) indicated that composite flours with sweet potato substitution had lower moisture content than 100% wheat, which is consistent with the fact that you are showing that AC and AD are also lower than AA. For the lower moisture content at high substitution levels (AC, AD) is largely due to the greater fibre and starch of OFSP, which meant that water was absorbed and bound differently, which reduced moisture after baking. A study by Korese et al. (2021) found similar results in OFSP-wheat cookies: the amount of sweet potato increased, while moisture content decreased. It is important to note that a moderate substitution (20%) will add additional moisture content because the OFSP starch utilizes water, and evaporation is less during consideration of baking. Julianti (2019) reported significant differences ($p \leq 0.05$) in the moisture content across the cake blends with OFSP, emphasizing the importance of the level of substitution. A moisture difference of about 3% between samples AB and AC was large enough to result in a significant difference, at least by the accuracy of a standard laboratory precision. Differences in moisture appear well suited to have a significant impact on microbial shelf life (Wang et al., 2023). From a sensory perspective, higher moisture (AB) likely results in softer, tender crumb, while lower moisture (AC and AD) will likely result in drier-firmer crumb, both of which will affect mouthfeel and acceptance by consumers. From a technology perspective, lower-moisture blends will need moisture-retaining strategies (emulsifiers and slight formulations) to ensure that the cakes do not become dry and crumbly (Iorgachova, et al., 2019). From a nutrition perspective, moisture impacts macronutrient density; i.e., less moisture (AC, AD) means more nutrients per 100g dry weight basis.

## Ash Content (%)

There was a significant decline in ash content shown, as an indicator of overall mineral content in food products, from 3.46 % by weight in the control sample (AA, 100 % wheat flour) to 2.00 % by weight in AD (50 % wheat and 50 % OFSP flour). This trend (i.e., overall mineral content declines with increasing OFSP proportion) exhibited by sample AA to AD was comparable with Ibe et al. (2024), who reported a significant ($p \leq 0.05$) decrease in ash content as the amounts of OFSP flour were increased, in baked goods. The progressive reduction in ash content above the AB blend level indicates that the majority of mineral dilution takes place with early OFSP substitution. This may be due to the relatively high mineral contribution of wheat flour in early blends. After a certain threshold of OFSP incorporation, the incremental OFSP contribution leads to a reduction in ash, which suggests that non-ash contributors are saturated for minerals, or variability from analysis.

**Crude Fat Content**

The crude fat content of the cake samples exhibited a non-linear trend, peaking in sample AC (30% OFSP) at 41.41%, which was higher than that of the control (AA, 100% wheat flour) at 39.07% and AB (80:20) at 36.35%, but significantly dropped in sample AD (50:50) to 28.37%. This variation echoes the report of Ehis-Eriakha et al. (2025), who noted significant differences ($p \leq 0.05$) in the crude fat content of composite flours produced from wheat and OFSP in their baked product formulations, with values oscillating between 6.26% and 8.74%. Their report highlights the sensitivity of the fat content to the exact percentage of the composite flour used, such that the levels of substitution have a determining effect on fat retention and dissemination. One of the reasons for such variation is the physical and biochemical nature of the OFSP flour, specifically its fibre and starch matrix. Korese et al. (2021) determined that the incorporation of OFSP flour in dough systems can increase the oil uptake during mixing and baking, especially with fine particle sizes. This is attributed to the hydrophilic and porous structure of the dietary fibre and starch granules of OFSP, which can entrap lipids and increase the apparent crude fat values. Beyond this point, as with the 50% substitution sample (AD), the crude fat content declines appreciably, suggesting a threshold beyond which the fibre and starch components in OFSP begin to interfere with, rather than augment, lipid retention. These findings have nutritional as well as technological significance and underscore the need for judicious formulation strategies in the quest for product quality, health value, and consumer acceptability in functional baked goods.

**Protein Content**

Crude protein content across the composite cake samples exhibited a general increase from the control through moderate substitution levels, with the values increasing from 10.02% in the control (AA, 100% wheat flour), rising progressively through AB and reaching a peak of 12.13% in AC (70:30 wheat: OFSP), before marginally decreasing to 11.64% in sample AD (50:50). The trend indicates that OFSP substitution at moderate levels could enhance the protein content in baked foods, possibly due to increased nutrient retention and beneficial ingredient interactions. Salha et al. (2023) also reported statistically significant differences ($p \leq 0.05$) in the protein content when OFSP was combined with other ingredients such as moringa seed flour, with values ranging between 12.62% and 14.74% for the composite cakes. This result supports the sensitivity of protein content to the level and nature of substitution in composite flour formulations. Although orange-fleshed sweet potato (OFSP) is not notably high in protein (generally between % and 2.2% dry weight) (Akomolafe, 2025; Giau et al., 2024), its incorporation seems to enhance the overall protein yield in the baked cakes. This is probably not a result of OFSP's protein content alone but enhanced protein retention during baking.

A number of researchers, including Liu et al. (2024), have demonstrated that some polysaccharide-rich ingredients, such as sweet potato, can create a protective matrix that minimises thermal denaturation of protein during baking, leading to greater measurable crude protein in the end products. In this instance, moderate OFSP inclusion would seem to have created such a protective environment, particularly at 30% (AC), for greater Structural entrapment and retention of wheat-derived gluten proteins. The optimum at sample AC indicates the best synergy between the OFSP fibre/starch matrix and wheat flour proteins (mainly gluten). Gluten proteins (gliadin and glutenin) are important structural ingredients in baked products atypically (but not exclusively) from wheat-based products. Substituting less than 30% or up to 30% of the gluten matrix is high enough for the structural gluten matrix to hold together, while OFSP contributes value through the addition of complementary nutrients and some limited protection against protein degradation.

At higher substitution levels (e.g., 50% OFSP in sample AD), however, the wheat flour is more diluted, decreasing the absolute quantity of gluten available. This dilution explains the minor depression in protein content as the criticality of a minimum wheat protein level is approached for nutritional as well as technological functionality. The reported ~2% increase in protein from AA (10.02%) to AC (12.13%) is considered to be a meaningful increase—probably statistically significant—and it demonstrates possibilities for very modest substitution of the OFSP and increased macronutrient density in cake formulations. In relation, this increase is a good thing, especially if protein-energy malnutrition is still a public health concern. Such composite flour cakes could thus be a functional snack, offering energy, protein, and micronutrient benefits (Adegunwa et al., 2019). Functionally, enhanced protein content in AC assists in enhanced structure and texture in the presence of sufficient gluten, which fosters gas retention and volume expansion upon baking (Storck et al., 2013). Despite the high levels of substitution, as seen in AD, it can weaken the gluten networks, leading to denser cakes with compromised crumb structure and volume (Xin et al., 2025). This is evident with the examples from Singh et al. (2025), who demonstrated that a higher level of non-glutenous flour substitution will ultimately defect the structural and textural properties of bakery foods. To sustainably boost protein content without disrupting cakes' quality, research has proposed that OFSP can be consumed together with a high-protein ingredient (such as legumes or seeds). For example, Julianti (2019) showed that OFSP consumed with moringa seed flour, a protein-rich ingredient, produced cakes that had noticeably more protein while being assessed for similar sensory quality. Other researchers have also indicated the advantages of adding soy flour, chickpea flour, or groundnut meal to OFSP-based products to increase protein content while improving amino acid profiles (Begum et al., 2023).

From a product development standpoint, the incorporation of OFSP at moderate levels (~30%) provides a beneficial compromise (Owade et al., 2018). Not only does it enhance protein content, but it also adds β-carotene (a precursor of vitamin A), dietary fibre, and potassium—improving the overall nutritional content. At this level, sensory qualities like crumb softness, moistness, and flavour are also positively affected (Ahmed & Campbell, 2012). Therefore, AC is a "sweet spot" for optimising the balance between functional and nutritional quality in OFSP-wheat composite cakes. In summary, though OFSP by itself might not be protein-rich, its strategic incorporation at moderate levels (at about 30%) enhances overall protein content, provides structural functionality, and complements the nutritional quality of cakes. Additional substitution increases without protein fortification risk dilution of gluten and reduction in cake quality. Hence, subsequent formulations that target high protein levels could involve blending OFSP with protein-rich ingredients or employ fortification strategies to maximise health benefits as well as product performance.

**Crude Fibre Content (%)**

The crude fibre content in the composite cakes increased significantly with the increase in OFSP flour content. Control sample AA (100% wheat flour) had the lowest content of 0.22%, and sample AD (50:50 wheat: OFSP) had the highest content of 1.22%. The increase in fibre content from 0.22% in the control (AA) to 1.22% in the highest substitution level (AD) is indicative of the high effect of the OFSP component on the nutritional profile of the cakes. The increase in fibre content progressed in a linear pattern in the cakes made with the OFSP and wheat flour blends, with the AB blend (80:20) having a fibre level of 0.79%. These incremental increases in the blends are likely to be statistically significant but also have nutritional significance, especially with the historically low amount of fibre available in conventional baked products. These results correspond well to the results of Khatun & Asaduzzaman, (2025), who observed substantial increases in crude fibre (1.87%–4.37%) in cakes formulated with different amounts of OFSP. Their study also supports the premise that OFSP flour is a good source of dietary fibre, can be included in wheat-based baked goods, and will always increase the fibre density in proportion to the amount replaced. Tortoe et al. (2017) also showed that wheat-sweet potato flour (WSPFCs) consistently had higher dietary fibre contents than pure wheat flour products, with acceptable sensory qualities up to 30% substitution. Taken together, these reports reinforce the current observation that OFSP flour is not only an acceptable partial substitute for wheat flour but also a functional ingredient that greatly enriches the nutritional value of baked foods. The rising fibre content even at the AB of 20% is significant, as it already presents a considerable improvement over the fibre-deficient control. An early jump indicates that even limited OFSP inclusion provides functional food value. Products with such formulations can be labelled as high-fibre or gut-friendly, and they will appeal to the growing segment of health-aware consumers who are increasingly demanding foods with health benefits.

According to Waddell & Orfila (2022), better dietary fibre consumption has been linked to enhanced digestive well-being, reduced risk for cardiovascular disease, and improved management of blood glucose levels—factors essential in the management of chronic diseases such as diabetes and obesity. Therefore, the fibre profile of OFSP not only adds bulk but also physiological value. While crude fibre analysis primarily captures cellulose and lignin, OFSP also contains soluble dietary fibres, such as pectins, which are known to reduce serum cholesterol and the moderation of glycaemic response (Ferreira et al., 2018). In addition, such fibres slow gastric emptying and nutrient absorption due to satiety sensations and support metabolic control. Therefore, if the fibre levels continue to rise in the OFSP-fortified cakes, functional foods targeted to populations struggling with non-communicable diseases would serve even better. However, there were still some technical and sensory concerns, although more fibre has positive nutritional properties. Although fibre is beneficial, it may disrupt the formation of gluten in the cakes and disturb the cake's tender crumb structure. Additionally, added fibre provides an undesirable denser and coarser structure on the final cake product's texture (Bouchon et al., 2024; Yangilar,2013), where the texture is not palatable to consumers. Thus, high substitution levels, such as AD, the inclusion in the composite matrix may not have sufficient gluten that helps hold the air and moisture created during the baking process and could therefore produce cakes that are unacceptable to consumers for having a light and airy structure instead. Food technologists must use formulation approaches such as the addition of texture-modifying agents, enzymes, emulsifiers, or hydrocolloids (such as xanthan gum or carboxymethyl cellulose) to overcome these problems. These additives can preserve the required structural and textural characteristics by counteracting gluten dilution and strengthening the cake matrix. Optimising the mixing time, hydration level, and baking conditions can also offset the negative impact of high fibre content on crumb quality (Flander et al., 2007). The clear and consistent increase in fibre with OFSP substitution creates opportunities for introducing health-positioned cake products from a product development and marketing perspective. These could be marketed as "source of fibre" or "rich in fibre" products, depending on the regulatory definitions.

**Carbohydrate Content**

The carbohydrate content in cake samples varied significantly, from 26.60% in sample AC (70:30 wheat: OFSP) to 39.71% in sample AD (50:50). This is due to the dynamic interaction of macronutrients as the proportion of OFSP flour increases. Notably, carbohydrate levels increased in AD, whereas fat and protein values decreased, which was consistent with the expected macronutrient trade-offs going from flour to AD. Julianti (2019) noted that the carbohydrate composition of a composite cake made from flour fluctuated with the addition of different nutrients and the blending ingredient ratio. Tortoe et al. (2017) & Akomolafe (2025), in their studies, found that high total carbohydrates in OFSP contribute high amounts of carbohydrates on an ingredient basis depending on substitution levels. Sweet potato flour is mostly carbohydrate, with about 89% carbohydrate content based on the dry matter content and low in protein and fat content (Johnson et al., 2010). Therefore, increasing OFSP substitution proportionally shifts the macronutrient content of the cake in the direction of carbohydrates.

Conversely, the reduced-fat, moderate-protein AD sample had the highest percentage of carbohydrates, illustrating how macronutrient partitioning varies with ingredient composition. The ~13% difference between AC and AD that was seen in carbohydrate content is noteworthy and is likely to be statistically significant. Such an observation greatly emphasises the need for tightly monitoring what happens to the effect levels of substitution, having not only an individual concentration of nutrients but also an overall nutrient balance. Nutritionally, high carbohydrate content is beneficial in populations with high energy needs, such as children, labourers, or undernutrition sufferers. In populations with low prevalence of diabetes and obesity, high carbohydrate intake—especially from readily digestible starches—OFSP contains simple and complex starches as well as simple sugars (glucose, fructose, sucrose), and thus its glycaemic index could be variable.

**Descriptive Statistics Of Functional Properties**

Descriptive statistics summarized the functional properties for the flours utilized to produce cake, conveying an impression of the potential impact of using orange-fleshed sweet potato

(OFSP) flour on characteristics such as water absorption capacity (WAC), oil absorption capacity (OAC), bulk density (BD), emulsion activity (EA) and foam capacity (FC). These properties are important determinants of the processing behavior, textural characteristics and functionality of the composite flours being utilized for baked products.

**Table 3: Functional Properties of the various flour samples**

| Samples | Parameters | Results |
|---|---|---|
| AA, Control (100% wheat flour) | Water Absorption Capacity (WAC) | 17.60 g/g |
| | Oil Absorption Capacity (OAC) | 146 g/g |
| | Bulk Density (BD) | 0.543 g/cm$^3$ |
| | Emulsion Activity (EA) | 43.88 % |
| | Foam Capacity (FC) | 12.922 % |
| AB (80% Wheat flour and 20% Orange fleshed sweet potato flour | Water Absorption Capacity (WAC) | 4.260 g/g |
| | Oil Absorption Capacity (OAC) | 3.116 g/g |
| | Bulk Density (BD) | 0.635 g/cm$^3$ |
| | Emulsion Activity (EA) | 5.00 % |
| | Foam Capacity (FC) | 3.15 % |
| AC (70% Wheat flour and 30% Orange fleshed sweet potato flour | Water Absorption Capacity (WAC) | 3.837 g/g |
| | Oil Absorption Capacity (OAC) | 2.601 g/g |
| | Bulk Density (BD) | 0.581 g/cm$^3$ |
| | Emulsion Activity (EA) | 4.60 % |
| | Foam Capacity (FC) | 2.84 % |
| AD (60% Wheat flour and 40% Orange fleshed sweet potato flour | Water Absorption Capacity (WAC) | 3.679 g/g |
| | Oil Absorption Capacity (OAC) | 2.534 g/g |
| | Bulk Density (BD) | 0.575 g/cm$^3$ |
| | Emulsion Activity (EA) | 3.15 % |
| | Foam Capacity (FC) | 2.41 % |
| AE (50% Wheat flour and 50% Orange fleshed sweet potato flour | Water Absorption Capacity (WAC) | 3.311 g/g |
| | Oil Absorption Capacity (OAC) | 2.472 g/g |
| | Bulk Density (BD) | 0.543 g/cm$^3$ |
| | Emulsion Activity (EA) | 1.20 % |
| | Foam Capacity (FC) | 1.93 % |

Table 3 summarized the functional property means and standard deviations for the control sample (100% wheat flour) and composite blends which included OFSP flour at different levels of substitution. The results show obvious differences between the samples, based on the fact that the hydration, fat-binding, and structural composition of flour blends had all been affected by the addition of OFSP. Variations between the samples, due to different compositions between wheat (which is high in gluten) and OFSP (which has higher ratios of non-gluten starch and fibre) were anticipated. The results of the study indicated clear differentiation of the samples of flours, i.e., 100% wheat flour-AA and composite flours with 20%, 30%, 40%, and 50% OFSP flour-AB, AC, AD, and AE, respectively. Thus, incorporation of OFSP has indeed brought about changes in the hydration, fat-binding, and interfacial properties. This section evaluates the functional properties of 100% wheat flour (control) and composite flours with different levels of OFSP substitution (20% to 50%), with potential applications in bakery product development.

Flour sample AB had the greatest values for all the functional parameters examined; WAC = 4.260 g/g; OAC = 3.116 g/g; BD = 0.635 g/cm$^3$; EA = 5.00%; and FC = 3.15%. Hence, this indicates that the incorporation of 20% OFSP effectively optimises the entire functional profile of the composite flour. This increase in WAC by 28.6% as compared to controls (Sample AA) indicates that the water absorption ability of the flour is greatly improved and shows that its hydration property has improved to some extent. This observation is in exact agreement with Akubor and Ishiwu (2013), where it was reported that composite flours with moderate incorporation levels, i.e., between 15% and 25% of OFSP, register high values of WAC due to the presence of a high crude fibre content and the amylopectin-rich nature of the starch in the flour, both of which result in high water binding capacity. In the same vein, Wang & Jian (2022) postulated that, by partially substituting tuber flours in conventional wheat flour, the destruction of the structural integrity of the starch granules of wheat would take place, and upon destruction, more hydroxyl groups would have been exposed to interact with water molecules. In flour, hydroxyl groups are hydrophilic and could further aid the hydration ability of the flour. The dramatic improvement in the oil absorption capacity, from 2.472 g/g (AA) to 3.116 g/g (AB), translates to a greater ability to absorb lipids. This is important in bakery applications because the retention of oils will add flavour and mouthfeel to the mouthfeel (Schubert et al., 2022). An increased OAC is a function of nonpolar amino acid side chains were found in OFSP proteins. The OAC is also a factor of the microstructural porosity generated by the flour particles, which increases the binding site density for hydrophobic molecules. This is in line with Awuchi et al. (2019), who stated that flour with higher oil absorption capacity will produce richer and more flavourful baked products due to higher oil retention during the baking.The activity measured at 5% AB was found to have emulsion action of greater than three times the control sample of 1.2%. These results indicate substantial improvement to the interfacial rheological properties of the flour used in this study.

Emulsification is a key step in the production of food products such as cakes and pancakes. It is the process where stable oil/water combinations are formed which help stabilise batters and contribute to final product volume. Zhan et al. (2022) have observed, alongside soluble fibres, tuber proteins formed viscoelastic films around oil droplets to prevent coalescence. The observation is also well in line with Kinsella's earlier postulation dating back to 1981, where it was suggested that proteins possessing high surface hydrophobicity are highly effective emulsifiers. It is highly likely that the added orange-fleshed sweet potato (OFSP) contributed both structural proteins and polysaccharides that complemented each other to improve emulsion activity in the formulation.

The foam capacity (FC) noted in AB, which was found to be 3.15%, was notably higher compared to that recorded in AA, which was 1.93%. Foam formation/stability are key processes for many products requiring aeration, especially products like sponge cakes and soufflés, where the foam characteristics are critical. In this regard, the increase in foam capacity may have been due to the interaction between proteins from orange-fleshed sweet potato (OFSP) and wheat gluten to form films that were more flexible and more stable at the air-water interface (Roy et al. 2025). Further, the presence of soluble polysaccharides from OFSP may have the effect of increasing the viscosity of foam, which in effect slows down bubble collapse.

This would mean that AB would be greatly applicable in different bakery uses that call for effective aeration with no compromise on moisture retention.

AB had the highest bulk density (BD) (0.635 g/cm$^3$) of all samples, indicating denser packing of flour particles. BD can lead to increased efficiency in packaging and stability in storage (Dereje et al., 2020), but may also produce a stiffer dough with the necessary leavening changes to obtain the desired crumb softness in breads. High BD flours can be very beneficial in baked goods such as biscuits and cookies, where the dough can yield a much denser and crisp texture. In terms of technology, the functional optimality observed in AB suggests a possible void for 20% OFSP substitution for optimising hydration, fat-binding, emulsification, and foaming but also sustainably allowing some relative gluten structuring. The addition of larger amounts of OFSP in the other samples (AC–AE) wasted the functional aspects, likely by diluting the gluten to the point that it could not adequately contain the gases produced, thus losing its overall viscoelasticity (Awuni et al., 2017).

Sample AC presented slightly lower values than AB but retained all parameters but two above the control sample AA: WAC (3.837 g/g), OAC (2.601 g/g), BD (0.581 g/cm$^3$), EA (4.60%) and FD (2.84%). Interestingly, although the hydrophilic functional benefits began to diminish with increasing OFSP inclusion, 30% inclusion still resulted in favourable functional benefits relative to AA control results. The reductions in values, specifically WAC and OAC, indicate that gluten dilution is potentially beginning and/or the protein-starch matrix is weakening, which reduces the dough's viscoelasticity and aeration properties when baking. This finding is consistent with Olatunde et al. (2015), in that when tuber flour level inclusion reached 25-30%, the hydration and inter-facial properties levelled off or decreased, where the gluten cohesive networks began to break down. WAC of AC (3.837 g/g) was still greater than AA (3.311 g/g), showing that OFSP's high fibre and disrupted starch granule structure still facilitate water binding (Akubor & Ishiwu, 2013). The diminished amount of 4.260 g/g for AB suggests that an abundance of OFSP may increase competition for water in the fibre, starch, and protein constituents to the detriment of free water content for gluten structure development. This was supported in the work of Masri et al. (2014), in which it was found that higher levels of fibre absorb high water in relation to dough expansion of the bread during proofing.

The OAC was calculated as 2.601 g/g in AC, which is still higher than AA (2.472 g/g) but also lower than AB (3.116 g/g). This may be due to the change in particle size distribution and surface hydrophobicity most likely due to increased OFSP content. Wittmüss et al. (2024) stated that generally, oil-binding ability is reduced when the protein structure is denatured, and the hydrophobic groups are less restricted but still bound. This does affect flavour and mouthfeel retention in some baked products, that is, AC will be more desirable than AA but may still not compare to AB with the richness and moistness of high-fat bakery products. Emulsion activity (EA) of AC (4.60%) is still substantial compared to AA (1.20%) and only slightly less so than AB (5.00%); still indicating that the OFSP proteins and soluble fibres are contributing factors to interfacial stability. Per Low et al. (2017) these components form viscoelastic films around oil droplets to prevent phase separation. However, levels of gluten dilution from this level of substitution may impact total film elasticity, hence the slight decrease from AB. Implicitly, even if AC is still suitable for batters and dough that should be emulsified, the end product texture may be slightly less uniform than AB.

The foaming capacity (FC) of the tested AC (2.84%) suggests an order—greater than AA (1.93%) and less than AB (3.15%). Foaming is dependent on proteins that can unfold and stabilise air bubbles, and although OFSP positively contributes via its protein and polysaccharide content (Narsimhan & Xiang 2017), the decreased gluten-protein fraction at 30% substitution restricts the development of strong and elastic films at the air-water interface. This will result in a marginal decrease in the volume and stability of foamed bakery items such as sponge cakes, although the performance will still be better than with pure wheat flour. The bulk density (BD) in AC (0.581 g/cm$^3$) is still higher than AA (0.543 g/cm$^3$) but lower than AB (0.635 g/cm$^3$). Greater BD tends to indicate tighter packing of flour particles, which can help improve packaging but potentially affect textural qualities of the end product (Dereje et al., 2020). Sample AC's BD profile suggests that it may serve an alternative purpose in terms of use in bakery items whereby a somewhat lighter and denser profile is required, for example, muffins and quick breads, where a degree of crumb openness is a positive characteristic. Technologically, AC maintains most of the functional benefit of OFSP inclusion while starting to exhibit initial signs of gluten dilution effects. Such a balance may be suitable for applications needing softer, moister textures instead of maximal volume expansion, e.g., cookies, brownies, and some pastry fillings. Moreover, nutritional enrichment through substitution of OFSP—betacarotene, fibre, and micronutrients—is still clearly visible at the 30% substitution level (Tumuhimbise et al., 2019), which makes AC appealing as a functional food. In summary, Sample AC illustrates that 30% OFSP substitution still improves hydration, fat-binding, emulsification, and foaming compared to pure wheat flour, albeit with minimal functional compromises relative to the optimum 20% inclusion in AB. This decrease, based on literature comparisons, is attributable to both gluten network weakening and heightened competition for hydration among the constituents of the flour. In spite of this, AC is still a technologically and nutritionally acceptable alternative, especially for softer baked products where intense aeration is not the key expectation.

At 40% OFSP substitution, Sample AD registered a further decrease in functional properties compared to AC (30% OFSP) and AB (20% OFSP), with WAC (3.679 g/g), OAC (2.534 g/g), BD (0.575 g/cm$^3$), EA (3.15%), and FC (2.41%). Despite this reduction, most of the measurements remain greater than those of the control sample AA (100% wheat flour), indicating that OFSP continues to be beneficial even upon being used in high proportions. Nonetheless, the declining values of the measurements suggest that the positive impacts of adding OFSP have decreased due to the compromised structural and functional role of wheat gluten. This is in support of the findings of Dereje et al., (2020) stated, that excessive levels of non-wheat substitutes, particularly in excess of 35–40%, can destabilize the gluten network, diminish viscoelasticity, and lower the capacity to hold and stabilize air and emulsions. The AD WAC (3.679 g/g) is still greater than AA (3.311 g/g) but smaller than AC (3.837 g/g) and AB (4.260 g/g). The trend is reflective of the balance between water-binding capacity of dietary fiber and starch of OFSP and water-retention capacity of gluten proteins. At greater inclusion of OFSP, the dilution effect of gluten becomes more intense, and water that has been accessible for protein hydration is increasingly bound by fiber, resulting in a less cohesive dough structure. Similar trends were established in research works by Akubor and Ishiwu (2013) and Mamat et al. (2020) highlights the impact of high fiber content on dough properties, noting that excessive fiber can cause competitive hydration. This phenomenon prevented the formation of a continuous gluten matrix, resulting in doughies that were less tender and less extensible. The present work reports on the oil absorption (OAC) in the various formulations, AD, AA, AB, and AC, and demonstrates that although the AD (2.594 g/g) has a slightly higher OAC than AA (2.472 g/g), the amount of oil absorbed by AD is very much less than that absorbed by AB (3.116 g/g) and AC (2.601 g/g). This suggests that at high concentrations of orange-fleshing sweet potato (OFSP), the capacity of proteins and fibers to absorb oil is diminished most likely because of aggregation or the reduction of the hydrophobic amino acid side chains as observed by Alam et al. (2016). The reduction in oil absorption might affect flavour retention and moisture in baked products containing large amounts of fat which suggests recipe changes through adding emulsifiers or fat replacers to keep the subsequent quality of product. The emulsification activity of AD was found to be 3.15%, which was considerably less than AC (4.60%) and AB (5.00%) which indicated functional changes in product formulation. In general, the data showed that increasing fiber and OFSP would alter physicochemical and functional properties of dough resulting in changes to product texture, moisture and flavour properties which had to be carefully adjusted in product formulation.

Such a reduction is a strong indicator of loss of protein-film-forming capacity at the oil–water interface. Dilution of gluten proteins diminishes the structural elasticity and stability of emulsions. During processing and storage, emulsions can separate. This is consistent with the findings of Low et al. (2017), who identified a strong and elastic protein network as key to maintaining emulsion stability. At this substitution level, food manufacturers may be required to add external emulsifying agents (eg., lecithin, mono- and diglycerides) to maintain product integrity.

Foam capacity (FC) of AD (2.41) decreased in the same manner—FC of AD is lower than AC (2.84%) and AB (3.15%) while still being higher than AA (1.93%). The ability to form foam is based on the flexibility and solubility of the protein and decreases significantly when gluten proteins are used instead of other proteins and polysaccharides of OFSP. Roy et al. (2025) found that the foam and Aremu et al. (2007) have reported similar decreases in foaming performance resulting from an elevated substitution of tuber or legume flour and have attributed this decrease to poor protein unfolding at the air–water interface and reduced interfacial film strength. The bulk density (BD) of AD (0.575 g/cm$^3$) was in-between the BD of AC (0.581 g/cm$^3$) and AA (0.543 g/cm$^3$), indicating a slight loss in compactness as OFSP content increased in relation to the 30% blend. The larger and more irregular sizes of particles of the OFSP flour can lead to less packing efficiency. Awuchi et al. (2019) reported that lower bulk density can increase porosity but can also affect storage and transport costs since more volume will be needed for the same weight.

From a technological standpoint, AD's functional profile implies a move towards denser, moister, and possibly more nutritious products, but with some sacrifice in aeration, emulsion stability, and fat retention. This positions AD for use in some bakery items like dense breads, crackers, and snack bars where large volume expansion is not a factor. Still, process adjustments—like enzyme supplementation, emulsifier addition, or manipulation of mix times—could be required to offset compromised gluten functionality.

At 40% OFSP replacement, Sample AD exhibited a further decrease of functional properties than samples AC (30% OFSP) and AB (20% OFSP), with WAC (3.679 g/g), OAC (2.534 g/g), BD (0.575 g/cm$^3$), EA (3.15%), and FC (2.41%). Despite this reduction, all the measurements remain greater than those of the control sample AA (100% wheat flour), indicating that OFSP remains beneficial even after it has been used in its high concentration. Nevertheless, the declining trends of the measurements indicate that the positive effects of OFSP incorporation have decreased due to the compromised structural and functional role of wheat gluten. This agreed with the findings of Shittu et al. (2007) which stated that too much non-wheat replacers, especially greater than 35–40%, could weaken the gluten network, decrease viscoelasticity, and lower the ability to retain and stabilize air and emulsions. The AD WAC (3.679 g/g) was still greater than AA (3.311 g/g) but less than AC (3.837 g/g) and AB (4.260 g/g). The trend appears to be consistent with the balance between OFSP dietary fiber water-binding capacity vs OFSP starch, and retention of water by gluten proteins. The more OFSP is included, the more pronounced the gluten dilution effect, with water to hydrate proteins being bound more closely by fiber, resulting in a weaker dough. The parallel trends were also noticed when Akubor and Ishiwu (2013) and Mamat et al. (2020) conducted their research, which puts priority on the impact of high fiber content in dough attributes, identifying that excessive fiber levels cause competitive hydration. This phenomenon also prevented the formation of a uniform gluten matrix, resulting in less extensible and less tender doughies. In this current work, oil absorption (OAC) in the various formulations, AD, AA, AB, and AC, is presented and demonstrated that although AD (2.594 g/g) has a slightly higher OAC than AA (2.472 g/g), oil absorbed by AD is significantly lower than absorbed by AB (3.116 g/g) and AC (2.601 g/g). This suggests that in the high levels of orange-fleshing sweet potato (OFSP), the capacity for proteins and fibers to adsorb oil is minimized most likely due to aggregation or the removal of the hydrophobic amino acid side chains as noted Mamat et al. (2020). Reduction in oil absorption can affect flavour retention as well as moistness in high fat content baked foods which translates to recipe adjustment via addition of emulsifiers or fat replacers for ensuring subsequent product quality. AD possessed an emulsification activity of 3.15% that was well below AC (4.60%) as well as AB (5.00%) which indicated product formulation functional alterations. In general, the findings indicated that fiber and OFSP supplementation would alter physicochemical and functional dough properties resulting in alterations in product texture, moisture and flavor attributes that must be best balanced in product formulation. Decreased such is a good measure of loss of ability of proteins to form films at the oil–water interface. Gluten protein dilution causes the structural stability and elasticity of emulsions to be lost, and this could be a factor in phase separation during processing and storage. The results are consistent with Low et al.'s (2017) reports on how strong elastic protein networks play crucial roles in maintaining emulsion stability. At this degree of substitution, production companies may have to introduce external emulsifying agents (e.g., lecithin, mono- and diglycerides) to ensure product quality. Foam capacity (FC) of AD (2.41) decreases in a like manner-FC of AD is less than AC (2.84%) and AB (3.15%) but more than that of AA (1.93%). Foaming ability is dependent on the solubility and flexibility of the protein and diminishes significantly when gluten proteins are used compared to other proteins and polysaccharides of OFSP. Malomo et al. (2011)

determined that the foam and Aremu et al. (2007) have reported matching decreases in foaming capacity as a result of greater substitution of the legume flour or tuber and attributed the decrease in foaming capacity to poor unfolding of the protein at the air–water interface and reduced interfacial film strength.

The bulk density (BD) of AD (0.575 g/cm$^3$) was intermediate between the BD of AC (0.581 g/cm$^3$) and AA (0.543 g/cm$^3$), indicating a minimal decline in compactness with a higher content of OFSP compared to the 30% mixture. Larger and more irregular particle sizes of the OFSP flour could lead to reduced packing efficiency. Dereje et al. (2020) explained that decreased bulk density will increase porosity but will also affect the storage and transport cost since more volume will be needed for the same weight.

From a technology standpoint, the functional profile of AD indicates a change towards denser, wetter, and possibly more nutritious products, but with some sacrifice in aeration, emulsion stability, and fat retention. Therefore, AD is useful for many bakery products like dense breads, crackers, and snack bars when it is not practical to expect considerable volume emergence. Although adjustments such as enzyme supplementation, use of emulsifier, or time changes to mixing will likely be needed to counter the diminished functionality of the gluten. In conclusion, Sample AD demonstrates the trade-off of nutritional improvement and functional functionality at higher levels of OFSP replacement. Even though β-carotene and fiber levels would be significantly higher at 40% replacement (Olatunde et al., 2015; Tumuhimbise et al., 2019), functional qualities experience a steep reduction compared to the 20–30% blends. This suggests that, both in terms of sensory quality and technology, a 40% OFSP replacement may require some formulation modification to offer an acceptable quality of the product while optimizing nutritional values.

**Sensory Evaluation**

The sensory evaluation represents an important factor of consumer acceptance in food product development since it is based on their actual perceptions of the qualities of the products (quality attributes) including colour, taste, aroma, texture, and overall acceptability. In the case of composite flour formulations, particularly substituting wheat flour with orange-fleshed sweet potato (OFSP) flour, it is necessary to determine how different substitution levels will influence the sensory variables. The results of a one-way ANOVA in Table 5 indicate the effect of various OFSP substitutions in the wheat flour cake on the sensory perception of the five attributes: colour, taste, aroma, texture and overall acceptability. To this effect, taste and texture presented statistical differences, i.e., $p = 0.034$ and $p < 0.001$, respectively. No statistically significant differences were observed in the colour, aroma, and overall acceptability of the treatments.

Table 5 demonstrates the mean sensory values and standard deviations for five coded cake samples (AA to AE), analysed against four sensory attributes—colour, flavour, odour, and texture—and general acceptability. Superscripts according to Tukey's HSD test indicate statistical groupings; letters in the same column for samples bearing the same letter are not significantly different from each other ($p > 0.05$). This post hoc analysis allows for more nuanced interpretation of differences between preparations of cake where the sensory properties were visibly affected by the use of OFSP flour and at which concentrations those effects were detectable by the panel are determined.

**Table 5: Mean sensory scores (± SD) for each sample by attribute with Tukey's HSD groupings**

| Sample | Attribute (Mean ± SD) | | | | Overall Acceptance |
|---|---|---|---|---|---|
| | Colour | Taste | Aroma | Texture | |
| AA | $8.43±0.78^{a}$ | $8.02±0.86^{ab}$ | $7.73±1.56^{a}$ | $8.25±0.93^{b}$ | $8.52±0.71^{a}$ |
| AB | $8.00±1.70^{a}$ | $7.92±1.23^{ab}$ | $7.82±1.45^{a}$ | $8.37±0.96^{b}$ | $8.30±1.28^{a}$ |
| AC | $8.39±0.92^{a}$ | $8.08±1.32^{b}$ | $7.96±1.66^{a}$ | $7.84±1.72^{ab}$ | $8.34±1.29^{a}$ |
| AD | $8.00±0.92^{a}$ | $7.33±1.82^{a}$ | $7.25±1.96^{a}$ | $7.31±1.79^{a}$ | $7.92±1.03^{a}$ |
| AE | $8.08±1.16^{a}$ | $8.00±1.29^{ab}$ | $7.72±1.64^{a}$ | $8.20±1.28^{b}$ | $8.18±1.29^{a}$ |

For colour, every sample was given comparably high ratings, from 8.00 to 8.43, and all were respectively given the same superscript "a" to indicate there were no statistically significant differences among them. This indicates that the amount of OFSP substitution did not impact the panellist's perceptions of colour even if it was possible this was affected by the high scores. OFSP is endowed with beta-carotenes, which impart a golden-orange colour that is both pleasing to the eye and believed to be healthy by consumers. Both Wanjuu et al. (2018) and Low et al. (2007) note that carotenoid natural pigmentation enhances the aesthetic acceptability of bakery food without the need for synthetic additives. The lack of outstanding colour difference scores may be due to the uniformly appealing appearance of all cakes, regardless of substitution level, suggesting OFSP's external benefit is robust for different formulations. Flavour, on the other hand, varied considerably across the samples. The highest flavour score (8.08 ± 1.32) was given to the AC sample, with AD getting the least (7.33 ± 1.82). The Tukey test indicated that AC differed from AD but not the other samples, as represented by the overlapping superscripts "a" and "b". This suggests that moderate levels of OFSP substitution—presumably around that included in AC—enhanced the flavour profile of the cake, while excessive levels or under inclusion (in AD) may have negatively affected palatability. OFSP contributes natural sugars and vegetal flavour compounds that, in the right proportion, contribute to the overall flavour of the end product (Carey et al., 2021; Wanjuu et al., 2018). This is in line with existing literature that shows 20–30% OFSP flour substitution maximises flavour in composite flour bread (Ndife et al., 2014).

Aroma values were closely scaled between 7.25 and 7.96 and did not statistically vary between the samples, as they shared the same superscript "a". This indicates that OFSP substitution did not impact the aromatic character of the cakes to any great extent. OFSP has a rather weak aroma that does not release intense volatiles upon baking (Zhang et al., 2024). Further, in normal cake recipes, strong aromatic compounds such as vanilla extract, sugar, and margarine typically dominate olfactory feelings. Eke-Ejiofor, (2013) & Tortoe et al. (2017) further observed that blended flours containing OFSP do not compromise the flavour of the bakery products if combined with other aromatic intensifiers. That the constant aroma ratings across treatments mean that the ingredient substitutions did not contribute off-odours or reduce the sensory acceptability of the cakes.

Texture was the attribute most affected by the variation in OFSP flour proportions. Sample AB possessed the highest texture value (8.37 ± 0.96), closely followed by AA (8.25 ± 0.93) and AE (8.20 ± 1.28), all under superscript "b", indicating superior texture quality. Sample AD possessed the lowest value (7.31 ± 1.79) and came under "a", indicating statistically inferior texture. Sample AC was intermediate with shared letters between both sets. The results support the one-way ANOVA that similarly concluded texture as the most significantly affected quality. The presence of high fibre and pectin contents in OFSP improves the moisture content and softness of the cake when best utilised (Mihály-Langó et al., 2023). However, excessive amounts may lead to gummy or dense consistencies, which apparently occurred in AD, reducing the desirable crumb structure and lowering consumer grades.

Along with variability of individual sensory attributes that were observed, overall acceptability ratings were uniformly high for all of the samples, ranging from 7.92 to 8.52, and all shared the same superscript "a". This indicates that on a global basis, all the products were similarly acceptable to the panel. This is significant since overall acceptability brings together multiple sensory inputs—taste, texture, aroma, and appearance—and is the ultimate decision of the consumer of a product's suitability. Stone and Sidel (2004) emphasise that consumers may be forgiving with minor frailties in a single dimension if others are strong, resulting in top overall scores even in cases with variation in individual characteristics. The stability of acceptability also suggests a high level of OFSP replacement flexibility without risking rejection by consumers.

The importance of these results is significant for both product development and public health. Formulation-wise, the results suggest that OFSP can be efficiently incorporated into wheat cakes with no compromise on consumer acceptability. In fact, flavour and texture may even be enhanced when substitution levels are pushed to their limits—presumably 20–30% based on this and similar studies (Afolayan & Abiose, 2018; Ndife et al., 2014). It provides bakers and food processors a true reference point to work from in creating novel, healthier, vitamin A-enriched bakery foods. In addition, from the nutrition policy, such findings justify the mainstreaming of OFSP into small-scale food enterprises, maternal nutrition diets, and school food. Low et al. (2007) and Laurie et al. (2018) suggest mainstreaming OFSP as a micronutrient-deficiency-reducing biofortified crop that does not require drastic dietary changes.

Overall, the results from Table 5 show that although single sensory traits—namely texture and taste—were moderately impacted by OFSP substitution levels, the general consumer attitude remained consistently positive. The cakes continued to be strongly acceptable across formulations, confirming the utility of OFSP as a functional ingredient with enhanced nutritional and sensory quality for baked foods. These findings not only validate the use of OFSP in cake making but also offer opportunities for its promotion as a way of improving diet diversity and combating vitamin A deficiency in Ghana and other developing contexts.

## CONCLUSIONS

The findings of this research indicate that orange-fleshed sweet potato (OFSP) flour can be replaced in wheat-based cake recipes in a feasible manner that is infinitely nutritional and sensorially valuable. Proximate analysis indicated that cakes with an OFSP substitution have increased crude fibre and carbohydrate content, contributing positively to dietary quality foods and aligning with the fight against micronutrient deficiency initiatives. Conversely, the reduction of crude fat at high levels of OFSP flour also allows consumers a healthier option for consumers who prefer bakery goods that have a lower fat content. Despite a slight reduction in protein content as the amount of OFSP was increased, this was expected as OFSP contains no gluten and did not negatively impact overall sensory acceptance of cakes at low levels of substitution.

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