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Combined Effects of Cutting Orientation and Frying Techniques on the Physicochemical Properties and Quality of Fried Sweet Potato (*Ipomoea batatas*) Chips

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ABSTRACT

Excessive oil absorption and nutrient degradation during frying are major challenges affecting the quality and healthfulness of fried root crops such as sweet potato (*Ipomoea batatas*). This study evaluated the influence of three cutting orientations—longitudinal, circular, and transverse—on the physicochemical and sensory properties of sweet potato slices subjected to deep and shallow frying. The experimental design involved analyzing antioxidant activity, total phenolic content, oil uptake, energy consumption, shrinkage, and sensory attributes. Results indicated that transverse-cut samples under deep frying (DFT) exhibited the highest antioxidant activity (86 ± 2.12) and total phenolic content, outperforming circular (DFC) and longitudinal (DFL) cuts ($p > 0.05$). Oil uptake was lowest in transverse-cut samples, particularly under shallow frying (SFT) (1.1 g/g db), indicating superior oil retention properties. Energy consumption and shrinkage differed with cutting orientation and frying method, with deep frying generally requiring less energy than shallow frying. Sensory evaluation revealed that cutting orientation significantly influenced taste, crispiness, and texture, while color preference remained consistent. Overall acceptability was highest for the shallow frying longitudinal (SFL) sample. In conclusion, transverse slicing, especially when combined with shallow frying, proved most effective in minimizing oil absorption and preserving nutritional quality, offering a practical approach for developing healthier fried sweet potato products.

1 | Introduction

Sweet potato (*Ipomoea batatas*) is a widely consumed root vegetable known for its nutritional value and unique sensory attributes. Sweet potatoes are rich sources of dietary fiber, vitamins, minerals, and antioxidants, making them important

components of a healthy diet (Scott-Smith 2015; Sanches-Silva et al. 2020). Moreover, sweet potatoes possess distinctive flavors, textures, and colors that lend themselves well to various culinary applications, including frying. The skin of sweet potatoes can be white, cream, yellow, orange, pink, red, or purple (Ayimbire et al. 2018). It is high in nutrients, particularly

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Highlights

- Study assessed how cutting style affects fried sweet potato quality.
- Cutting style affects sensory, texture, shrinkage, and energy use.
- Deep frying uses less energy but may lower nutritional quality.
- Transverse cuts with shallow frying reduce oil and boost antioxidants.
- Shallow-fried transverse cuts produce healthier sweet potato snacks.

carbohydrates, and these complex carbohydrates have a low glycemic index, making sweet potato a good diet for diabetics (Amagloh et al. 2021). It is also high in crude fiber, which is known to improve gut health and lowers the incidence of chronic diseases including colon cancer (Dahl and Stewart 2015). Sweet potato is also high in vitamins and minerals such as vitamin A, vitamin C, potassium, and iron. One medium sweet potato contains approximately 43.8% of the daily recommended dose of vitamin A, which is necessary for maintaining healthy vision and skin (Alam 2021).

Frying is a popular cooking technique used to enhance the palatability and aroma of many food products (Resurreccion and Chavez 2019). However, traditional deep-frying methods can result in the excessive uptake of oil, leading to high caloric content and potential health concerns associated with excessive dietary fat intake (de Oliveira et al. 2019). To address these issues, alternative frying methods, such as air frying and vacuum frying, have gained attention in recent years. Vacuum frying is a modified frying technique that operates at reduced pressure, typically below atmospheric levels, and lower temperatures compared to traditional deep frying (Amagloh et al. 2021). This method offers several advantages, including reduced oil uptake, minimized oxidation and degradation of heat-sensitive compounds, and improved product quality attributes (Tiwari 2016; Osaie et al. (2020); J. Wang et al. (2017)). These benefits make vacuum frying an attractive option for producing healthier and higher quality fried products.

The cutting orientation of raw materials, such as sweet potato and carrot slices, plays a crucial role in the final quality attributes of the fried products. Different cutting orientations can influence the surface area-to-volume ratio, structural integrity, and moisture distribution within the slices, thereby affecting the frying process and the resulting physicochemical properties (Kaderides et al. 2015; Zhang et al. 2024; Dehghannya and Ngadi 2021).

Studies have shown that the cutting orientation of the raw material can significantly impact the oil uptake, texture, color, and sensory attributes of fried products. For instance, Kaderides et al. (2015) observed that different cutting orientations of potato slices affected the oil content and crispness of the resulting potato chips. Zhang et al. (2024) also reported that the cutting orientation of lotus root slices influenced the texture and color of vacuum-fried lotus root chips. However, limited research has

been conducted specifically on the impact of different cutting orientations of sweet potato and carrot slices under vacuum frying conditions. Understanding the effects of cutting orientation on the physicochemical properties and quality attributes of fried sweet potato is crucial for optimizing the vacuum frying process and developing healthier and more desirable fried snacks. Therefore, this study aims to (I) examine the effect of cutting orientations on the physicochemical properties of deep and shallow frying-fried sweet potato; (II) evaluate the impact of cutting orientations on the quality attributes of the fried sweet potato, including sensory attributes, such as taste, crispiness, color acceptability, and overall consumer preference; and (III) provide insights into the optimal cutting orientation for deep and shallow frying-fried sweet potato slices to achieve desired physicochemical properties and quality attributes.

2 | Materials and Methods

2.1 | Source of Planting Material and Cutting Orientations

Two freshly harvested matured sweet potato varieties (orange flesh sweet potato) were procured from a local farmer at Yamoransa in the Abura Asebu Kwamankese District, Central Region of Ghana and stored at a temperature of $20 \pm 1^\circ\text{C}$ before use. The sweet potato varieties from the same batch were selected, washed and cleaned to remove dirt and stones. The sweet potato tubers were peeled manually using hand peeler and were cut longitudinally, circular, and transversely into cuboids of 5 ± 0.3 mm thickness and 20 ± 2 mm wide. The total quantity of processed sweet potato that was used in the experiment was 1.5 kg. The average initial moisture content of the sweet potato was 75.2% (wet basis) as determined by the AOAC (2000) method.

The sweet potato tubers were washed, peeled, and manually sliced into three distinct cutting orientations: longitudinal, circular, and transverse. In the longitudinal cutting orientation, slices were made parallel to the tuber's longitudinal axis, producing elongated strip-like pieces resembling fries. This orientation aligns with the natural fiber direction of the tuber and presents a relatively larger surface area-to-volume ratio along its length, which may influence heat and mass transfer characteristics during frying.

In the circular cutting orientation, slices were obtained by cutting the tubers perpendicular to their longitudinal axis, resulting in round disc-shaped sections of uniform thickness. This method of slicing facilitates heat distribution during frying and promotes uniform cooking and color development across the slices.

For the transverse cutting orientation, slices were made diagonally across the longitudinal axis at an oblique angle, generating oval or elliptical-shaped pieces. This orientation exposes both longitudinal and radial tissue structures, potentially enhancing oil drainage, heat penetration, and nutrient retention during frying (Figure 1).

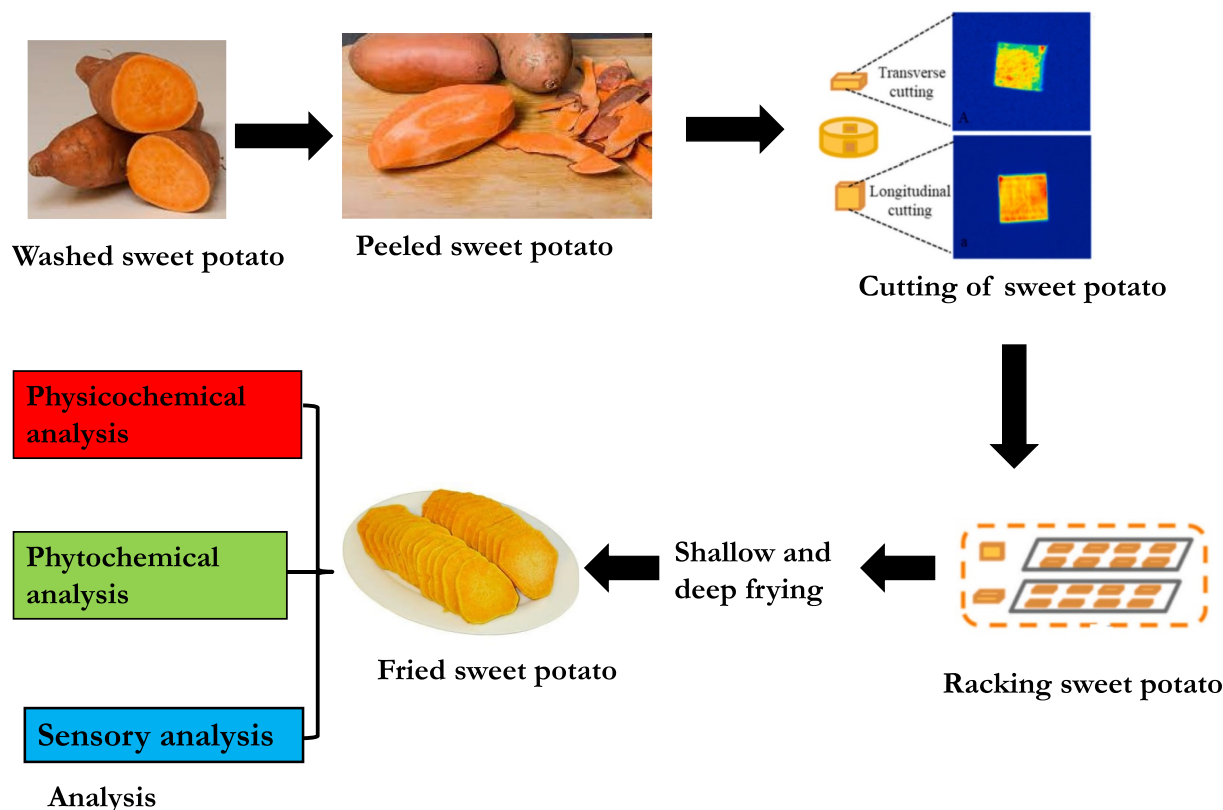


FIGURE 1 | Schematic diagram of the study.

2.2 | Frying Procedure

Deep and shallow frying of sweet potato samples, cut in different orientations (circular, transverse, and longitudinal), was performed following protocols established by Valle et al. (2024) and Korkmaz et al. (2022). Twenty slices of sweet potato were fried in preheated sunflower oil maintained at a constant temperature of 130°C, based on the method described by Oladejo et al. (2017). After frying, the slices were removed from the oil, drained, and gently blotted with absorbent paper to remove excess oil. The oil level was monitored after each batch and replenished as needed to maintain consistent frying conditions. All frying experiments were conducted in triplicate to ensure reproducibility.

2.3 | Determination of Weight Loss

The weight loss of sweet potato slices with different cutting orientations was determined using an electronic balance (Model SP402, Ohaus Co. Ltd., New Jersey, USA), following the procedure described by J. Wang et al. (2017). The calculation was performed using Equation (1).

$$\text{Weight loss (\%)} = \frac{W_0 - W_p}{W_0} \times 100, \quad (1)$$

where W_0 is the weight of fresh sweet potato slices before frying and W_p is the weight of sweet potato slices after frying.

2.4 | Determination of Shrinkage Properties

Degree of shrinkage in volume (S_v) was evaluated by the following equation:

$$S_v = 100 \left(V_a - \frac{V(t)}{V_0} \right), \quad (2)$$

where V_a is the original volume of the sample (m^3) and V_0 is the volume of the sample at time t of frying.

2.5 | Determination of Sensory Attributes

The sensory evaluation was performed in accordance with the method outlined by Kwaw et al. (2023) using a nine-point Hedonic scale. A sensory evaluation was conducted using a panel of forty-five (45) untrained assessors, comprising twenty-five (25) males and twenty (20) females. Each sample was coded with a random three-digit number and presented on plastic plates in a randomized order to minimize bias. Panelists were provided with potable water to rinse their palates between successive evaluations. The sensory attributes assessed included hardness, taste, crispness, color, and overall acceptability. Evaluations were performed using a nine-point hedonic scale, where 1 corresponded to “dislike extremely” and 9 to “like extremely.”

2.6 | Determination of Antioxidant Properties (ABTS)

The ABTS solution (7 mM) was added to potassium persulfate (2.45 mM) in a ratio of 1:1 and kept at room temperature in a dark room for 16 h. The ABTS and potassium persulfate mixture (ABTS⁺ working solution) obtained was later mixed with 80% of methanol (v/v) to achieve an absorbance of 0.70 ± 0.02 at 734 nm. The fried sweet potato extract solution (145 μ L) was added to 3 mL of ABTS⁺ working solution and the mixture was stored for 25 min at room temperature (25°C) in the dark and the absorbance (A_s) was estimated at 734 nm. About 80% of methanol (A_0) was used as the blank. The equation for calculating the ABTS radical scavenging activity (Li et al. 2016) is shown in Equation (3):

$$\text{ABTS radical scavenging(\%)} = \frac{(A_0 - A_s)}{A_0} \times 100. \quad (3)$$

2.7 | Analysis of Total Phenolic Content (TPC) and Total Flavonoid Content (TFC)

Total phenolic content (TPC) in sweet-potato fries prepared by both deep- and shallow-frying with various cutting orientations was measured using the method described by Alolga et al. (2022). Findings are reported as mg GAE g⁻¹ db.

2.8 | Energy Consumption Rate (ECR)

The energy consumption rate during the dehydration process was calculated using the method previously established by Osae et al. (2020), as presented in Equation (4):

$$\text{Energy Consumption Rate} = \frac{\text{CEV}}{W_0}, \quad (4)$$

where CEV is the cumulative energy value (in kWh), and W_0 is the initial weight of the sample (in kg).

2.9 | Oil Content Analysis

The samples were first ground using a mortar and precisely weighed into Soxhlet thimbles (Model: Whatman 2800-150; Brand: Whatman, GE Healthcare Life Sciences; Country: United Kingdom). Oil extraction was performed using petroleum ether as the solvent over a continuous 4-h period, in accordance with the AOAC standard method described by Kwaw et al. (2024). A behrotest Soxhlet extractor (Model R 256 S, Behr-Labor, Team Medical & Scientific, Malaysia) was used for the extraction. The oil content was subsequently determined and expressed on a dry weight basis (g/g db).

2.10 | Statistical Analysis

The experimental data obtained were presented as the means of three triplicate determinations and standard deviation. The data

were analyzed by one-way analysis of variance, and the Tukey test for comparison of the means was assessed at $p < 0.05$ using Minitab version 17 (Minitab Inc., Pennsylvania, USA); Origin Pro software (2018) was used for graph presentation.

3 | Results and Discussion

3.1 | Antioxidants Properties of Different Cutting Orientations of Sweet Potato Under Deep and Shallow Frying

The results of antioxidant activities of differently cut orientations of sweet potato during deep and shallow frying are presented in Table 1. Regarding antioxidant activity, deep frying (DF) resulted in statistically significant differences ($p < 0.05$) across various sweet potato cutting orientations. Among the DF samples, thin-cut tubers (DFT) exhibited the highest antioxidant activity (86 ± 2.12 mg GAE/g db), followed by large-cut tubers (DFL) at 78 ± 2.01 mg GAE/g db, whereas cube-shaped cuts (DFC) showed the lowest activity (70 ± 3.86 mg GAE/g db).

Similarly, shallow frying (SF) also produced significant differences ($p < 0.05$) in antioxidant activity among the different cuts. Thin-cut samples (SFT) recorded the highest activity (79 ± 2.45 mg GAE/g db), followed by large-cut (SFL) at 72 ± 0.88 mg GAE/g db, with cube-cut samples (SFC) showing the lowest activity (65 ± 2.36 mg GAE/g db). These findings suggest that thin slicing during both frying methods (DFT and SFT) enhances antioxidant activity compared to cube or large cuts.

The possible reasons that led to this observation include an increased surface area that enhances Maillard reactions. Thin slices (such as DFT and SFT) have a larger surface area-to-volume ratio, which promotes more intense Maillard reactions during frying. These reactions lead to the formation of Maillard reaction products (MRPs), some of which exhibit antioxidant properties (Shakoor et al. 2022). Deep frying may cause the thermal degradation of cell walls, facilitating the release of bound phenolic compounds and other antioxidants, particularly

TABLE 1 | Antioxidant activity and total phenolic content of different cutting orientations of sweet potato under deep and shallow frying techniques.

Frying techniques	Cutting orientations	Antioxidant activity (%)	Total phenolic content (TPC) mg GAE/g db)
Deep frying	DFL	78 ± 2.01^b	40 ± 2.01^b
	DFC	70 ± 3.86^c	36 ± 2.01^c
	DFT	86 ± 2.12^a	44 ± 2.01^a
Shallow frying	SFL	72 ± 0.88^b	32 ± 2.01^b
	SFC	65 ± 2.36^c	30 ± 2.01^c
	SFT	79 ± 2.45^a	36 ± 2.01^a

Note: Mean values with different superscripts (^{a,b,c}) in a column are significantly different.

Abbreviations: DFC, Deep frying circular; DFL, Deep frying longitudinal; DFT, Deep frying transverse; SFC, Shallow frying circular; SFL, Shallow frying longitudinal; SFT, Shallow frying transverse.

in thinner slices that cook more rapidly and evenly. Frying reduces moisture content, which may concentrate antioxidant compounds in the sample. Thin slices dehydrate faster, potentially retaining more concentrated antioxidant content (Bouchon and Dueik 2018). On the other hand, the decreased antioxidant retention in thicker cuts may be explained by the fact that cube-shaped cuts (DFC and SFC) are thicker and may not reach the same internal temperatures uniformly, resulting in lower Maillard reaction intensity and potentially less release or formation of antioxidant compounds (El Hosry et al. 2025).

Additionally, deep frying promotes the thermal degradation of cellular structures, disrupting cell walls and facilitating the liberation of bound phenolic compounds and other bioactive antioxidants (Franke et al. 2022). This phenomenon is particularly pronounced in thinner slices, which attain uniform heat penetration more rapidly, allowing for effective release and transformation of phenolic constituents. Moreover, the reduction in moisture content during frying can further concentrate antioxidant compounds in the matrix. Thin slices tend to dehydrate more efficiently and evenly, resulting in a higher concentration of heat-stable antioxidant compounds per unit mass (Chi 2023).

Conversely, the relatively lower antioxidant activity observed in thicker or cube-shaped slices (DFC and SFC) may be due to less uniform heat distribution within the matrix. The internal sections of thicker samples may not achieve the same temperature gradients necessary to stimulate extensive Maillard reactions or release bound phenolic compounds effectively. As a result, these cuts exhibit diminished formation of MRPs and potentially lower total antioxidant content (El Hosry et al. 2025; Putriani et al. 2022). The reduced exposure to the frying medium also limits the extent of dehydration, thereby maintaining higher internal moisture, which can dilute antioxidant concentrations and further reduce the apparent antioxidant potential.

Overall, these findings suggest that the geometry and thickness of food slices significantly influence the physicochemical transformations that occur during frying, ultimately affecting the development and retention of antioxidant compounds. This emphasizes the importance of optimizing cutting orientation and slice thickness in fried food processing to enhance nutritional and functional quality attributes.

3.2 | Total Phenolic Content of Different Cutting Orientations of Sweet Potato Under Deep and Shallow Frying

For the deep-fried samples, total phenolic content (TPC) varied significantly across the different cutting orientations. Thin-cut tubers (DFT) exhibited the highest TPC (44 ± 2.01 mg GAE/g db), followed by large-cut tubers (DFL) at 40 ± 2.01 mg GAE/g db, whereas cube-cut samples (DFC) recorded the lowest TPC (36 ± 2.01 mg GAE/g db) (Table 1).

Similarly, among the shallow-fried samples (category), thin cuts (SFT) had the highest TPC (36 ± 2.01 mg GAE/g db), followed

by large cuts (SFL) at 32 ± 2.01 mg GAE/g db. The cube-cut samples (SFC) had the lowest TPC (30 ± 2.01 mg GAE/g db). These results suggest that thinner cutting orientations preserve or enhance phenolic content more effectively during both frying methods.

The possible explanation for the results above is that thin slices (DFT and SFT) undergo more rapid and uniform heat penetration, which can facilitate the breakdown of cell walls and the release of bound phenolic compounds that would otherwise remain inaccessible (Rocchetti et al. 2022). Secondly, the increased surface area of thin slices allows for more efficient frying and phenolic retention by minimizing overexposure to high internal moisture that can leach antioxidants during frying (Boateng 2023). Shorter frying time (Table 2) in thin cuts minimizes degradation of phenolic content by reducing their exposure to prolonged high temperatures that can degrade thermolabile phenolic compounds. Additionally, phenolic loss in cube-shaped cuts (DFC and SFC), having a lower surface area-to-volume ratio, take longer to fry time and may undergo greater thermal degradation of phenolic compounds (Shukla et al. 2022).

In this study, DFT > DFL > DFC for both TPC and antioxidant activity, and likewise SFT > SFL > SFC. The parallel ranking suggests phenolics are the dominant antioxidants formed or retained. The higher antioxidant activity and TPC observed in the deep-fried samples suggest the formation of Maillard-derived compounds that enhance antioxidant activity beyond what is captured by TPC alone.

The findings of this study suggest that the selection of cutting orientation has a substantial impact on the antioxidant activity and total phenolic content (TPC) of sweet potato when subjected to deep frying and shallow frying methods. The differentiation of cutting orientations highlights the possibility of enhancing the nutritional value of fried sweet potatoes by utilizing different frying techniques.

TABLE 2 | Energy consumption rate and frying time of different cutting orientations of sweet potato under deep and shallow frying techniques.

Frying techniques	Cutting orientations	Energy consumption rate (kWh/kg)	Frying time (min)
Deep frying	DFL	0.081 ^b	3.5 ^b
	DFC	0.112 ^a	5 ^a
	DFT	0.061 ^c	2.5 ^c
Shallow frying	SFL	0.105 ^b	4.5 ^b
	SFC	0.133 ^a	6 ^c
	SFT	0.083 ^c	3.5 ^a

Note: Mean values with different superscripts (^{a,b,c}) in a column are significantly different.
Abbreviations: DFC, Deep frying circular; DFL, Deep frying longitudinal; DFT, Deep frying transverse; SFC, Shallow frying circular; SFL, Shallow frying longitudinal; SFT, Shallow frying transverse.

3.3 | Percentage Weight Loss of Different Cutting Orientations of Fried Sweet Potato Under Deep and Shallow Frying

The results shown in Figure 2A,B demonstrate the varying percentages of weight loss observed in differently cut orientations of sweet potato when subjected to both deep frying (DFL, DFC, and DFT) and shallow frying (SFL, SFC, and SFT). Significantly, sample A, which includes DFL, DFC, and DFT, demonstrated distinct weight reduction percentages of 15.5%, 20.5%, and 15%, respectively.

For the shallow-fried category, the samples demonstrated varying weight loss characteristics, with the longitudinal cut (SFL) recording a weight loss of 25.5%, the cube-shaped cut (SFC) 25.0%, and the transverse cut (SFT) exhibiting the lowest weight loss of 20.0%. These findings highlight the influence of

cutting orientation and the frying method on the extent of moisture removal and oil absorption during the frying process. The differences in weight loss observed between deep and shallow frying suggest variations in heat transfer mechanisms and the degree of water–oil exchange, which ultimately influence the physical and chemical transformations within the sweet potato matrix (Valle et al. 2024).

The results align with the findings of Drosou et al. (2024), who reported that shallow-fried potato samples exhibited lower weight loss compared to deep-fat-fried counterparts. This phenomenon can be attributed to the limited oil contact and lower immersion depth in shallow frying, which result in a more moderate dehydration rate and less pronounced structural disruption. Consequently, shallow frying tends to preserve internal moisture and reduce excessive oil uptake, offering potential advantages from both nutritional and sensory standpoints.

Moreover, the observed variations in weight loss across different cutting orientations emphasize the role of geometry in governing mass and heat transfer phenomena during frying. Thin or longitudinal slices present a higher surface area-to-volume ratio, facilitating faster moisture evaporation, while thicker or cube-shaped cuts retain water longer due to slower internal heat diffusion (Manoharan et al. 2024). The transverse cuts, which exhibited the least weight loss, may have experienced more uniform heat distribution, minimizing excessive dehydration and structural collapse (Ren et al. 2021).

These findings have important implications for culinary and nutritional sciences, as they demonstrate that both the mode of frying and the geometric configuration of food materials can be strategically manipulated to achieve desirable product characteristics. Understanding these interactions enables the optimization of cooking techniques aimed at enhancing nutrient retention, improving textural quality, and reducing undesirable oil absorption. Furthermore, such insights contribute to the broader goal of developing healthier fried food alternatives without compromising sensory acceptability or consumer appeal.

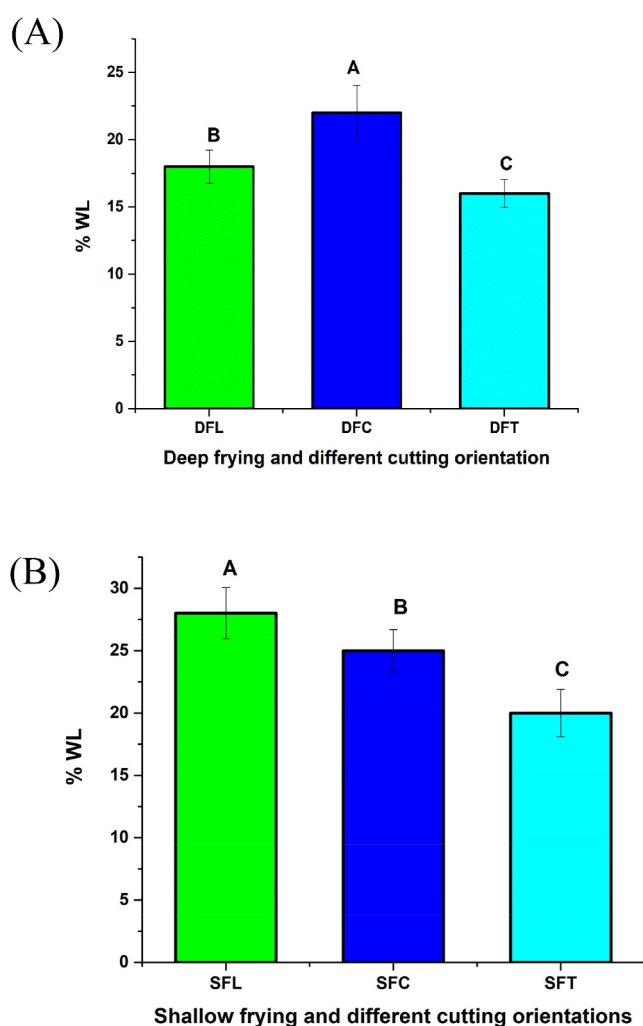


FIGURE 2 | Percentage weight loss of different cutting orientations of (A) deep frying and (B) shallow frying of sweet potato under deep and shallow frying. DFC, Deep frying circular; DFL, Deep frying longitudinal; DFT, Deep frying transverse; SFC, Shallow frying circular; SFL, Shallow frying longitudinal; SFT, Shallow frying transverse.

3.4 | Shrinkage Volume Ratio of Differently Cut Orientations of Sweet Potato During Deep and Shallow Frying

The data shown in Figure 3A,B illustrate the shrinkage volume ratios of differently cut orientations of sweet potato that were exposed to both deep frying (DFL, DFC, and DFT) and shallow frying (SFL, SFC, and SFT). In deep frying, it was realized that sample DFL demonstrated a shrinkage volume ratio of 3.0 cm³, whereas samples DFC and DFT exhibited shrinkages of 3.3 and 1.2 cm³, respectively. In contrast, the shrinkage volume ratios for the shallow fried samples show that SFL, SFC, and SFT exhibited ratios of 5.8 cm³, 6.5 cm³, and 3.0 cm³, respectively. The differences in shrinkage volume ratios reported between deep and shallow frying highlight the notable structural changes that occur in sweet potatoes throughout the cooking process.

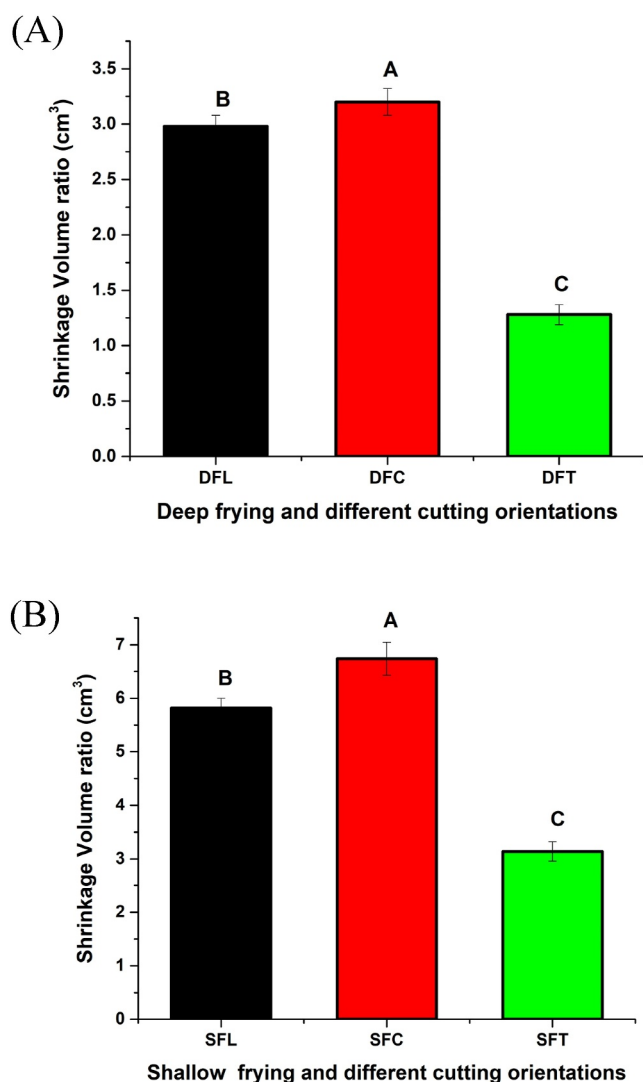


FIGURE 3 | Shrinkage volume ratio of differently cut orientations of sweet potato during deep and shallow frying. DFC, Deep frying circular; DFL, Deep frying longitudinal; DFT, Deep frying transverse; SFC, Shallow frying circular; SFL, Shallow frying longitudinal; SFT, Shallow frying transverse.

The observed differences in variance can be explained by variations in heat transmission mechanisms and moisture retention capacities associated with the two frying processes. These findings suggest that culinary practices should take into account these factors in order to achieve desired textural qualities and the final size of the end product (Rani et al. 2023). Moreover, the variations in shrinkage volume ratios (SVR) observed in different cutting orientations within each frying method highlight the intricate correlation between the geometric properties of sweet potato samples and their reaction to heat exposure (Yang et al. 2025). This particular element of the study prompts reflection on the potential impact of different cutting orientations on the total shrinkage of sweet potatoes, suggesting the potential preference by consumers to choose those that shrunk less. The extent of shrinkage may also affect the sensory attributes as observed in Figure 4.

3.5 | Sensory Analysis of Different Cutting Orientations of Sweet Potato Under Deep and Shallow Frying

As illustrated in Figure 4A,B, the DFT (9.0) was liked the most for its taste followed by DFC (7.5), and DFL as the least preferred sample in terms of taste (6.5). Again, the sample DFC was preferred the most in terms of its crispiness (7.5), followed by sample DFL and DFT scoring (5.5). In terms of texture, DFC was ranked the highest (7.5) with samples DFL and DFT ranked the lowest with (5.5) each on the scale of preference. According to the figure again, samples DFL, DFC, and DFT were all (5.5) in terms of their color. On the overall acceptability of the samples, all the samples were preferred equally (5.5).

Figure 4A,B further depicts that the SFT (7.7) was liked the most for its taste followed by SFC (6.6), and SFL as the least preferred sample in terms of taste (5.0). Similarly, the sample SFC was preferred the most in terms of its crispiness (5.2), followed by sample SFL and SFT scoring (4.5), respectively. In terms of texture, samples SFL, SFC, and SFT were ranged (4.5) accordingly on the scale of preference. All the samples received an average color score of 4.5. In terms of overall acceptability, the SFL sample received the highest rating (5.0), while both SFC and SFT were also well accepted, each scoring 4.5.

The sensory results highlight clear differences in consumer preferences based on both frying method and cutting orientation. Among deep-fried samples, the transverse cut (DFT) was preferred for taste, possibly due to its thinner profile allowing for faster heat penetration and flavor development. The circular cut (DFC) stood out for crispiness and texture, suggesting that its geometry might favor a more desirable fried crust (X. Wang et al. 2023).

The equal scores in color and overall acceptability across deep-fried samples suggest that although specific attributes such as taste or texture may vary, the overall impression of quality was balanced, perhaps due to consistent browning or oil absorption (Chang et al. 2020).

In contrast, shallow-fried samples had generally lower sensory scores, indicating a possible compromise in product quality when less oil is used. Notably, although SFT was preferred in taste, it did not perform well in crispiness or texture, likely due to limited oil exposure and uneven surface frying. The higher overall acceptability score for SFL suggests that factors beyond individual attributes such as familiarity or visual appeal may influence overall preferences.

These findings align with the understanding that frying technique and food geometry significantly influence sensory quality. Deep frying typically produces more appealing textures and flavors due to the Maillard reaction and effective crust formation (Asokapandian et al. 2020; Oke et al. 2018). Meanwhile, shallow frying, although healthier due to lower oil content, may result in compromised crispiness and mouthfeel.

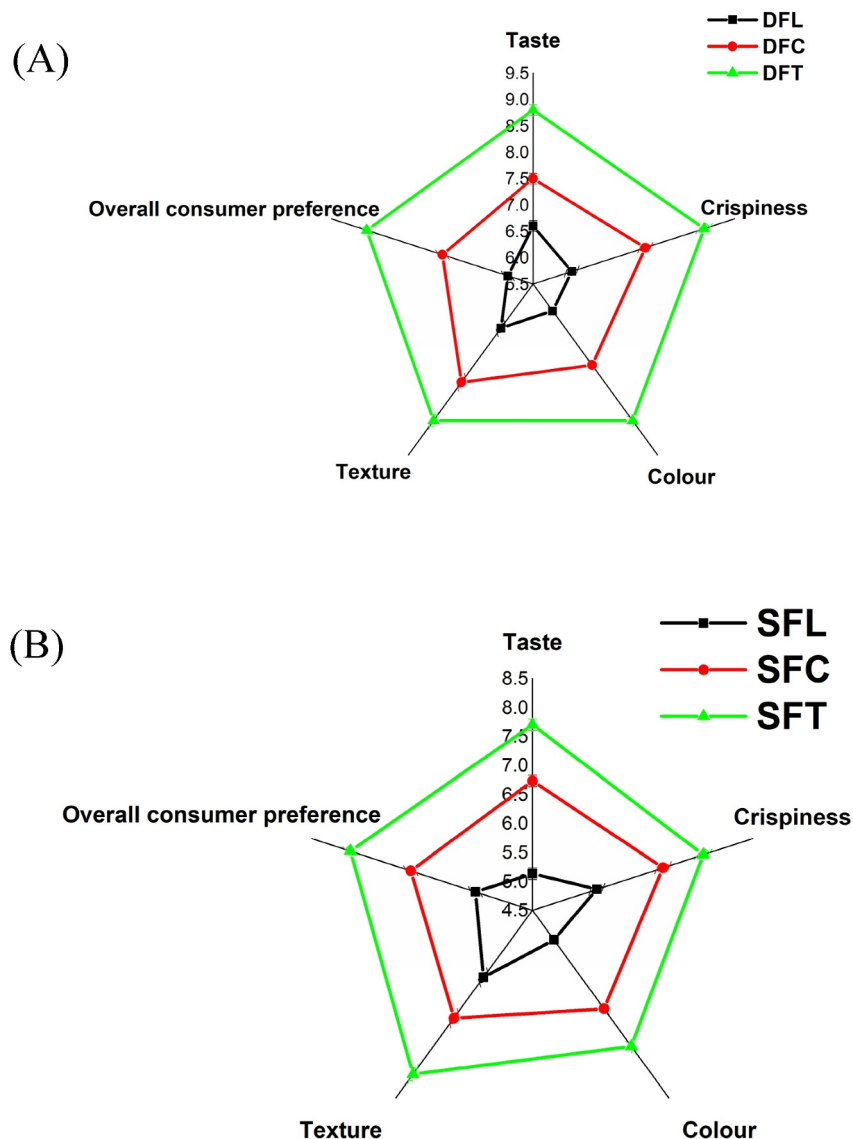


FIGURE 4 | Sensory analysis of different cutting orientations of (A) deep frying and (B) shallow frying of sweet potato under deep and shallow frying. DFC, Deep frying circular; DFL, Deep frying longitudinal; DFT, Deep frying transverse; SFC, Shallow frying circular; SFL, Shallow frying longitudinal; SFT, Shallow frying transverse.

Understanding these sensory dynamics is critical for both product development and consumer satisfaction, especially in designing fried products that balance health considerations with sensory appeal.

3.6 | Energy Consumption Rate of Different Cutting Orientations of Sweet Potato Under Deep and Shallow Frying

The energy consumption rates for different cutting orientations of sweet potato under both deep and shallow frying conditions are presented in Table 2. The results indicate that both frying methods and cutting orientations significantly ($p < 0.05$) influenced the energy consumption rate.

Under deep frying, the energy consumption rates for the longitudinal (DFL), circular (DFC), and transverse (DFT) cuts were

0.081, 0.112, and 0.061 kWh/kg, respectively. In contrast, shallow frying showed higher energy consumption rates for the same cutting orientations: longitudinal (SFL) at 0.105 kWh/kg, circular (SFC) at 0.133 kWh/kg, and transverse (SFT) at 0.083 kWh/kg.

Notably, the transverse orientation in both frying methods recorded the lowest energy consumption rate, with DFT at 0.061 kWh/kg and SFT at 0.083 kWh/kg. Conversely, the circular orientation required the most energy in both methods, especially under shallow frying (SFC: 0.133 kWh/kg).

The observed reduction in energy consumption rate across all treatments may be attributed to the differences in heat transfer dynamics associated with each frying technique and cutting orientation. Deep frying, which involves complete submersion of the sweet potato in hot oil, allows for more uniform and rapid heat transfer (Asokapandian et al. 2020). This likely explains the lower energy requirements compared to shallow frying, where

only partial immersion occurs, leading to less efficient heat distribution and longer frying times, and hence more energy use. The significant variation in energy consumption among the cutting orientations can be explained by surface area-to-volume ratio and thickness of the slices (Rani et al. 2023). Transverse cuts, typically thinner and with more surface area exposed, likely facilitate faster moisture loss and heat penetration, thereby reducing frying time and energy needed. On the other hand, circular cuts often retain more moisture and present a more compact geometry, leading to increased resistance to heat transfer and hence higher energy demands (Oke et al. 2018; Ramesh and Al-Khusaibi 2020).

These findings are consistent with previous studies (Manoharan et al. 2024; Rani et al. 2023) that show that food geometry plays a crucial role in frying kinetics and energy efficiency. The data also suggest that optimizing cutting orientation could be a cost-effective strategy for minimizing energy use in commercial and household frying operations. In summary, deep frying of transverse-cut sweet potatoes appears to be the most energy-efficient method, which has important implications for sustainable food processing and energy management in food preparation.

3.7 | Oil Content Analysis of Different Cutting Orientations of Sweet Potato Under Deep and Shallow Frying

The oil content of sweet potato subjected to different cutting orientations and frying methods is presented in Figure 5. The results clearly demonstrate that both frying technique and cutting orientation significantly ($p < 0.05$) influenced oil absorption in the fried samples. Under deep frying, oil uptake was markedly higher across all cutting orientations compared to shallow frying. The recorded oil content for deep-fried samples was DFL

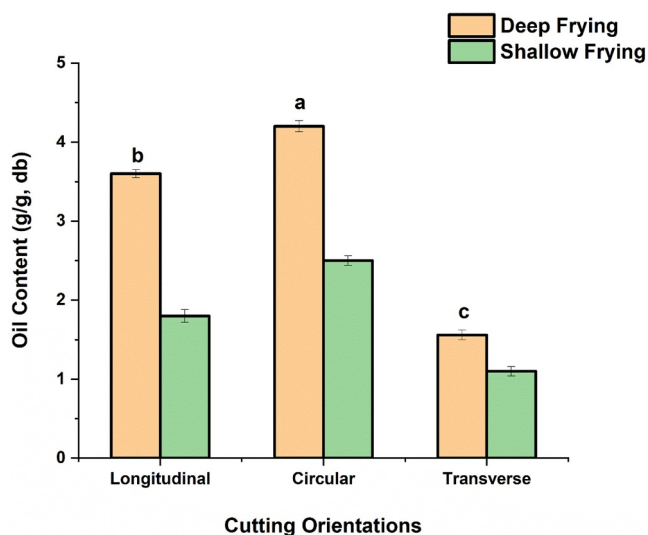


FIGURE 5 | Oil content analysis of different cutting orientations of deep frying and shallow frying of sweet potato. DFC, Deep frying circular; DFL, Deep frying longitudinal; DFT, Deep frying transverse; SFC, Shallow frying circular; SFL, Shallow frying longitudinal; SFT, Shallow frying transverse.

(3.6 g/g, db), DFC (4.2 g/g db), and DFT (1.56 g/g db). In contrast, the shallow-fried samples exhibited substantially lower oil contents: SFL (1.8 g/g db), SFC (2.5 g/g db), and SFT (1.1 g/g db). These findings indicate that deep frying leads to greater oil absorption regardless of cutting orientation, with the circular cut (DFC) absorbing the highest amount of oil among all treatments, and the transverse cut (SFT) under shallow frying showing the lowest oil content.

The significantly higher oil content in deep-fried samples can be attributed to the complete submersion in oil, which enhances oil diffusion into the food matrix due to high temperature and prolonged exposure (Zhang et al. 2024). In deep frying, moisture loss creates a porous structure that allows oil to penetrate more easily during the cooling phase. On the other hand, shallow frying limits oil contact to one surface at a time, thereby reducing overall oil uptake.

The differences among cutting orientations are closely linked to their geometrical features, particularly surface area, thickness, and internal porosity. Circular slices, often thicker and denser, may retain more oil because they experience slower moisture loss and form a more open internal structure conducive to oil entrapment (Valle et al. 2024). Conversely, transverse slices, which typically have higher surface area-to-volume ratios and thinner profiles, facilitate faster drying and crust formation, creating a barrier that restricts oil absorption (Paunović et al. 2021).

This trend aligns with earlier studies (Asokapandian et al. 2020; Chang et al. 2020), which report that oil absorption during frying is not only a function of frying conditions but also significantly influenced by the physical properties of the food and the cutting geometry. Moreover, the oil absorption behavior has nutritional implications, especially for health-conscious consumers and industries targeting low-fat fried products. In this context, transverse slicing combined with shallow frying emerges as the most effective strategy to reduce oil uptake without compromising product quality.

4 | Conclusion

The following conclusions could be drawn from the findings.

Firstly, the cutting orientation of sweet potatoes exerts a significant influence on key sensory attributes such as taste, crispiness, and texture under both deep and shallow frying conditions. The variations in these sensory parameters across different cutting orientations underscore the importance of selecting an appropriate cutting method to achieve specific consumer-desired qualities. The relatively uniform color perception observed across orientations indicates a consistent visual appeal irrespective of the frying technique employed.

Secondly, the identification of the deep-fried transverse cut (DFT) as having the highest total phenolic content (TPC) suggests that certain cutting orientations may promote the retention or even enhancement of phenolic compounds during frying. This observation has nutritional implications, highlighting how processing

geometry can influence the antioxidant potential and overall health-promoting properties of fried foods.

Furthermore, the variations in weight loss among differently cut samples reflect differences in moisture evaporation and internal structural modifications during frying. These outcomes demonstrate that the physical dimensions of the samples play a critical role in determining heat and mass transfer efficiency. Similarly, the observed differences in shrinkage volume ratios across cutting orientations indicate that structural deformation during frying is closely associated with slice geometry and frying conditions.

In summary, transverse slicing combined with shallow frying proved to be the most effective approach for minimizing oil absorption while maintaining desirable sensory and nutritional attributes. These findings provide valuable insights for both domestic cooking practices and industrial processing, offering a foundation for optimizing product quality and promoting healthier fried food options.

Author Contributions

Conceptualization and supervision: Richard Osae and Emmanuel Kwaw. Experimental: Richard Osae, Agnes Andoh and Anastasia Mensah. Data analysis: Maurice Tibiru Apaliya, John Owusu, Felix Narku Engmann and Emmanuel Kwaw. Sample provision: Richard Osae Agnes Andoh and Anastasia Mensah. Funding acquisition: Richard Osae. Initial draft of manuscript: Richard Osae, Daniel M. Anang, Felix Narku Engmann, Raphael N. Alolga and Maurice Tibiru Apaliya. Approval of final draft of manuscript: Richard Osae and Emmanuel Kwaw.

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Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The authors will make data available upon request.

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