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Evaluation of Quality and Sensory Attributes of Potato Chips Fried in Different Oils and Their Blends, and Chemical Changes Occurred in Oils During Different Frying Counts

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ABSTRACT

Physicochemical changes include peroxide value (POV), free fatty acids (FFA), and canola and sunflower moisture contents. Palm oils, a blend of three oils, oil, moisture, and salt retention, and potato chips fried in these oils during three frying counts were investigated in the current study. Results revealed that increasing the frying counts resulted in increased POV, FFA, and moisture percentage of oils, with lower values in blend oils, followed by palm olein oil. FFA and POV after the third round of frying were found to be 0.09±0.01 and 0.66±0.01%, 0.12±0.01 and 2.6±0.11%, 0.13±0.01, and 1.9±0.11%, and 0.05±0.00 and 0.59±0.01%, for palm olein, sunflower, canola and blend oils, respectively, and these were significantly higher than calculated after first frying. Analysis of chips after the first, second, and third frying showed an increment in moisture, oil, and salt retained in chips, while blend oils caused non-significant effects. The oil percentage of chips fried in palm olein, canola, sunflower, and blend oils, after third frying, was 31.47±0.38, 31.99±0.03, 31.99±0.03 and 29.48±0.30%, respectively, while moisture percentages were 1.49±0.01, 1.83±0.01, 1.83±0.01 and 1.76±0.01%, respectively, and these values were higher than of first frying. Higher sensory scores regarding overall acceptability were obtained by chips fried in sunflower oil and lower by blended oils.

1. Introduction

Since ancient times, frying has been a fundamental cooking technique to enhance the taste and texture of food. Traditional frying, which involves immersing food in heated oil at temperatures between 160–180°C, induces significant structural changes and creates appealing flavors in the final product. Due to its unique organoleptic properties, deep frying has gained popularity among consumers of all ages [1]. However, the safety of deep-fried foods is a major concern, as high frying temperatures lead to various oil degradation processes such as hydrolysis, polymerization, and thermo-oxidation. These reactions produce harmful byproducts that are absorbed by the fried food, posing significant health risks, including cancer, atherosclerosis, liver damage, and cardiovascular disease [2].

As the population of health-conscious consumers grows, there is increasing pressure on food producers to develop more nutritious options. The global demand for safer fried foods is urgent, given the harmful effects of deteriorated oils on human health. In this context, food producers and researchers are driven to find viable alternatives to traditional frying methods to produce safe fried foods without compromising their nutritional and sensory qualities [3].

Designing snack foods today is challenging and complex, aiming to meet consumer expectations for taste and quality. Snacks, defined as "hurried or light meals" consumed between meals, including potato chips, biscuits, breakfast cereals, and baby foods. The snack food industry represents a significant and ever-expanding sector worldwide, with annual sales in the United States alone estimated at $30-35 billion [4]. Potato chips, a popular snack for 150 years, are valued for their sensory properties, flavor, texture, and acceptability, often enhanced by salt-based flavorings [5]. Potatoes are the third most important crop globally for human consumption, following rice and wheat. Potato production increased significantly from 297,111 thousand tons in 2006 to 376,827 thousand tons in 2016 [6].

Potatoes, scientifically known as Solanum tuberosum, belong to the nightshade family (Solanaceae) and are a major starchy tuber crop. The edible potato tuber is rich in carbohydrates, providing a high-energy yield per unit of land, water, and time. Potatoes contain 80% water and 20% solids, with starch comprising 15-18% of their dry mass. A medium-sized potato with skin provides 45% of the daily requirement of Vitamin C, 18% of potassium (more than a banana), and 10% Vitamin B6 [7]. Potatoes are also a good source of minerals, vitamins, and fiber, making them a nutritious and easily palatable vegetable. Their chemical composition influences the processing method and is affected by factors such as cultivation area, seed type, soil and climate, agricultural practices, storage conditions, and commercialization [8]. Additionally, potatoes contain phytochemicals like phenols, flavonoids, polyamines, and carotenoids, which have beneficial health effects [9].

Frying is a food processing technique that involves cooking food in hot oil. The high temperature causes free water evaporation from the potato surface and oil absorption, forming a crispy crust while cooking the food internally. Frying improves texture and flavor, enhancing overall palatability through a heat and mass transfer process involving complex interactions between the food and the frying medium [10].

During frying, continuous heat and mass transfer between the food, oil, and air achieve the desired quality of fried food. Deep-fried potatoes absorb oil in three fractions: structural oil (absorbed during frying), penetrated surface oil (suctioned during cooling), and surface oil. Frying induces chemical reactions such as oxidation, polymerization, hydrolysis, and isomerization, influencing the final product's flavor, texture, nutritional composition, and shelf life [11]. These reactions depend on factors like the type of oil, the presence of fresh oil, food material, and antioxidants. Non-volatile antioxidants in frying oil are crucial; otherwise, high temperatures cause antioxidants to evaporate along with water vapor from the food [12]. High-temperature frying produces oxidation products collectively known as total polar materials (TPM), used globally as a discard standard for frying oils, with a maximum acceptable TPM value of 25% [13].

Common cooking oils in the subcontinent include canola, palm, sunflower, mustard, and soybean. Restaurants, fast food chains, street vendors, and households often reuse frying oil over long periods, leading to significant trans fatty acid production influenced by frying temperature and duration. This practice, especially common among street vendors in developing countries, generates toxic substances that pose severe health risks to consumers [14]. Studies comparing potato chips fried in sunflower, canola, and palm olein oil found varying levels of carcinogenic contaminants, with canola and sunflower oils containing fewer monoglycerides and diglycerides than palm olein oil [15]. Using blended oils from different vegetable sources has proven effective in producing high-quality potato chips [16]. Research comparing conventional frying, vacuum frying, and pre-drying methods has explored the physicochemical and nutritional properties of potato chips [17], [18], [19].

Given the complexities and health implications of frying, this research aims to analyze the physicochemical and sensory properties of fried potato chips, evaluate free fatty acids, moisture content, and peroxide value of vegetable oils before and after repeated frying, and assess the suitability of different vegetable oils and their blends for producing high-quality fried products with minimal oil degradation.

2. Research Methodology

2.1. Procurement of raw materials and chemicals

The variety of potato tuber (*Solanum tubersum*) used for the current study was Lady Rosetta, a specialist in crisping variety with high dry matter and low reducing sugar. Potato tubers were obtained from the Pepsi co, Lay's industry in Sunder Industrial Estate, Lahore, Pakistan. Palm olein, sunflower, and canola oil were three oil samples used to fry potato chips. The fourth oil sample used for frying potato chips was the blend of these three vegetable oils. These oils were purchased from Metro Cash & Carry, Lahore. The chemicals used for experiments were of reagent grade (Sigma Aldrich company) and were purchased from Reagents Scientific Store in Islamabad, Pakistan.

2.2. Study design

After receiving, washing, and slicing the potato into chips, the chips were fried in different oil samples; the loading temperature for frying was set to 195 to 200°C, and ultimately, the temperature after loading of potato chips was reduced to 150°C, afterward frying was carried out at 180°C. The total time for frying all the potato chips in each oil sample was 5 minutes and a few seconds. After frying, the product was cooled in a centrifuge for 3 minutes to remove the extra surface oil. This whole procedure was repeated after 1st, 2nd, and 3rd frying in four different oil samples to check the effect on physicochemical and sensory attributes of potato chips and the effect on FFA, POV, and moisture contents of the oil samples, the sample size for potato chips was 1000 g for each oil samples, which were fried in 5 liters of different oil samples. After frying the potato chips, the sample's weight was 300 g.

2.3. Methods used for the analysis

All the tests performed for the current study followed the standard procedures of AOAC (2016). Tests included in current research work were moisture analysis (potatoes), oil absorbance after frying (potatoes), salt percentage (potatoes), moisture analysis (oil samples), FFA percentage (oil samples), and POV (oil samples).

2.4. Determination of free fatty acid (oil samples)

The titration procedure Ca-5a-40 outlined in the AOCS Official Method (2011) was used to perform the FFA contents of oils after each frying, used for frying. With phenolphthalein serving as the indicator, the oil sample was combined with neutralized isopropanol. Sodium hydroxide was then gradually added to the mixture until a pink color was seen for at least 30 seconds. A percentage was given for the FFA contents calculated by following the given equation.

$$FFA\ (\%) = \frac{titration\ difference \times 0.1 \times 28.2}{weight\ of\ sample} \quad (1)$$

2.5. Determination of peroxide value (oil samples)

The AOCS (2011) official method Cd 8b-90 was used to calculate the peroxide values of selected oil samples used for frying potato chips after each frying. The acetic acid-iso-octane (60:40, v/v) solution and saturated potassium iodide solutions were combined with the oil sample. A standardized sodium thiosulfate solution (0.1 mol/L) was added when the mixture's yellowish iodine color became pale. Drop by drop, a starch solution (5 g/L) was added, and the titration was complete when the blue color disappeared.

2.6. Determination of moisture content (oil samples)

To determine the moisture contents of used oils before the onset of frying and after each frying count, protocols given by AOCS (2011) were followed. Briefly explain that the moisture analyzer machine was switched on and set the temperature at 105°C. Then, 3 g of oil sample was added to a conical flask. Then, the moisture analyzer was switched on, and the measured oil sample was placed in the aluminum foil of the moisture analyzer. After closing the lid of the moisture analyzer, an analysis time of 3 to 10 minutes was given. When the moisture analyzer beeped many times, and the reading was shown on the meter, after a few minutes, the results were noted. The procedure was repeated 2-3 times, and an average of three readings of moisture analysis was considered.

2.7. Determination of moisture content (fried potato)

To determine the moisture content of potato chips fried in each oil, the AOCS procedure (2011) was adopted. Briefly, the finished product sample (100 g) was taken in a grinder bowl; after grinding, the sample was stirred with a spatula and scratched all the sides and edges of the bowl to make a homogenous mixture of the samples. The moisture analyzer was at 105°C, and a 5 g sample was taken in cleaned aluminum foil and then placed in the moisture analyzer. After a few minutes, the analyzer displayed values of moisture analyzer displayed the readings.

2.8. Determination of oil absorbance (fried potato)

To determine oil absorbance by potato chips, following the procedure given by previous research [20], approximately 10 g of homogenized potato chips were cooked for 15 minutes in a beaker with 50 mL of 25% HCl while protected by a watch glass. The fluid was filtered over moist filter paper. Hot water was used to rinse the filter until the filtrate's pH was neutral and dried. In 4 hours, the oil was extracted using the Soxhlet method with 150–200 mL petroleum ether. The oil residue was dried to constant weight at 105°C after solvent evaporation. After Soxhlet lipid extraction, the oil uptake contents (5) of fried potato chips after each frying count, fried in each oil sample, were measured gravimetrically using a Teactor Soxtec System HT1043 (Foss Analytical Co., Ltd., Hillerod, Denmark) by following the protocols adopted by previous research [21], with required modifications.

2.9. Determination of salt percentage (fried potato)

Using silver nitrate as a precipitation catalyst, the salt concentration of potato chips fried in each oil was determined by following the guidelines provided by previous research [20]. As a result, the quantity of chlorides in an aqueous extract was calculated and associated with the amount of sodium present. Explaining in detail, two grams of sample were taken in a conical flask. Then, 100 mL of distilled water was added at a temperature of 65°C. A stay time of about 3 minutes was given. Then, 2-3 drops of phenolphthalein were added. It was Titrated with 0.1 N sodium hydroxide till a pink color appeared and neutralized the color with nitric acid (0.1 N). Then, 5 mL of potassium chromate was added and mixed thoroughly. Then, a reading of the burette was noted, and the titration was against silver nitrate (0.1 M) until a red brick color appeared. Endpoint reading as noted to calculate the amount used for titration.

2.10. Sensory evaluation of potato chips fried in different oils and their blends

Sensory evaluation of the fried potato chips was done using a nine-point hedonic rating scale described by previous research [22]. Briefly, a panel of 20 experts with an average age of 45 of both genders was provided sheets with scores from 1 to 9, in which 1 was for extremely dislike, and 9 was extremely like. Sample chips, with a sample size of 20 g for each treatment and specific codes, were provided to the experts with distilled water bottles for rinsing and neutralizing the mouth after each test. All the processes were carried out under standard laboratory conditions, keeping uniform light, temperature, air pressure, and humidity. The obtained data was collected, calculated, and analyzed.

2.11. Statistical analyses of the data

All analyses were performed in triplicate to get triplicate determinations, and results were expressed as means ± standard deviations. The statistical analysis was done using one-way ANOVA. Duncan's multiple-range test was used to differentiate between the mean values [23].

3. Results and Discussion

3.1. Physicochemical parameters of different oils and their blends used for frying potato chips

The analysis revealed significant increases in moisture content, free fatty acids (FFA), and peroxide value (POV) with repeated frying cycles across all oils. Detailed results are summarized in Table 1.

1) *Moisture Content*
   a) *Palmolein Oil: Initial moisture content was 0.08%, rising to 0.19% after the first frying, 0.29% after the second, and 0.61% after the third frying. This increase can be attributed to moisture transfer from the potato chips to the oil.*
   b) *Sunflower Oil: Moisture content increased from 0.09% initially to 0.23%, 0.37%, and 0.42% after the first, second, and third frying cycles, respectively.*

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c) *Canola Oil: Starting at 0.06%, moisture content rose to 0.09%, 0.16%, and 0.19% after the first, second, and third fryings.*
d) *Blend Oil: Moisture content increased from 0.07% initially to 0.11%, 0.15%, and 0.27% after successive frying cycles.*

The observed moisture increase is likely due to moisture transfer from the potato chips into the oils during frying, leading to potential hydrolytic rancidity [24].

2) *Free Fatty Acids (FFA)*
   a) *Palmolein Oil: FFA levels increased from 0.03% initially to 0.05%, 0.08%, and 0.09% after successive fryings. This increase is due to the breakdown of triglycerides into free fatty acids and glycerol at high temperatures [25].*
   b) *Sunflower Oil: FFA levels rose from 0.02% initially to 0.05%, 0.08%, and 0.12% after successive fryings.*
   c) *Canola Oil: FFA levels increased from 0.02% to 0.04%, 0.09%, and 0.13% after successive fryings.*
   d) *Blend Oil: FFA levels increased from 0.02% to 0.025%, 0.028%, and 0.05% after successive fryings.*

The progressive increase in FFA indicates ongoing oil degradation due to repeated exposure to high frying temperatures.

3) *Peroxide Value (POV)*
   a) *Palmolein Oil: POV remained relatively stable, increasing marginally from 0.65 meqO_2/kg to 0.66 meqO_2/kg after successive fryings.*
   b) *Sunflower Oil: POV initially increased from 0.91 meqO2/kg to 0.95, 1.10, and 2.6 meqO_2/kg after successive fryings. The significant increase in the third frying cycle indicates considerable oxidative degradation.*
   c) *Canola Oil: POV increased from 0.71 meqO_2/kg to 0.74, 0.75, and 1.9 meqO_2/kg after successive fryings.*
   d) *Blend Oil: POV increased from 0.50 meqO_2/kg to 0.55 meqO_2/kg after the first and second fryings, reaching 0.59 meqO_2/kg after the third frying.*

The peroxide value, which measures the extent of oxidation, showed an overall increase with repeated frying, indicating oxidative instability [26].

4) *Physicochemical Changes*

The excellence and superiority of any edible oil are specified by its physicochemical properties, which define quality, sensory attributes, and stability [27]. High-temperature frying results in the breakdown of fat molecules into glycerol and FFAs, leading to an increase in FFA levels [28]. Total polar materials (TPM) are a global standard for assessing oil degradation, with a discard threshold set at 25% TPM [29]. The moisture content in potato chips evaporates during frying, but some residual moisture is transferred to the frying oil, contributing to hydrolytic rancidity [30], [24]. Fresh oils' initial low moisture content indicates high quality, consistent with [31].

5) *Oil Quality and Stability*

Palmolein oil, rich in triglycerides, undergoes hydrolysis to produce FFAs and glycerol, influenced by frying duration and temperature [32]. Canola oil, valued for its nutritional benefits, contains lower erucic acid and a high proportion of triglycerides [33]. Blend oils combine attributes of various oils, enhancing the fried products' frying properties and sensory qualities [34]. Repeated frying increases FFA values, indicating oil oxidation and hydrolysis [35]. The initial low FFA and POV values indicate high oil quality, aligning with findings by previous research [34], [36]. The increase in POV with repeated frying suggests oxidative degradation, with values within acceptable limits of the Punjab Pure Food Rules [37]. The choice of frying oil is influenced by its fatty acid profile, product requirements, cost, and handling convenience. Popular oils for frying include soybean, palm, sunflower, canola, and mustard oil [14].

6) *Comparative Studies*

Studies using sunflower oil for frying potato chips showed increased POV, FFA, and moisture content with prolonged low-temperature frying, indicating higher oxidation and rancidity [38]. Previous researchers [18] reported similar trends with rapeseed oil, highlighting the formation of undesirable compounds during high-temperature frying.

Previous researchers [19] observed increased oxidation and moisture retention in oils with repeated frying, consistent with our findings. Previous researchers [39] reported lower POV in palm oil than in soybean oil, demonstrating similar trends in our study. Previous researchers [3] emphasized the need to regularly monitor POV, FFA, and moisture content to maintain oil quality during frying.

Table 1. Comparison of physicochemical parameters of different oils and their blends used for frying potato chips

Oils used	Analysis of parameters	Before frying	After 1st frying	After 2nd frying	After 3rd frying
Palmolein oil	Moisture contents (%)	0.08±0.01d	0.19±0.01c	0.29±0.01b	0.61±0.01a
	Free fatty acids (%)	0.03±0.01c	0.05±0.01b	0.08±0.01a	0.09±0.01a
	Per oxide value (%)	0.65±0.01a	0.655±0.01a	0.66±0.01a	0.66±0.01a
Sunflower oil	Moisture contents (%)	0.09±0.01d	0.23±0.00c	0.37±0.01b	0.42±0.01a
	Free fatty acids (%)	0.02±0.01d	0.05±0.00c	0.08±0.001b	0.12±0.01a
	Per oxide value (%)	0.91±0.01c	0.95±0.01c	1.10±0.06b	2.6±0.11a
Canola oil	Moisture contents (%)	0.06±0.01d	0.09±0.01c	0.16±0.01b	0.19±0.01a
	Free fatty acids (%)	0.02±0.00d	0.04±0.01c	0.09±0.01b	0.13±0.01a
	Per oxide value (%)	0.71±0.01b	0.74±0.01b	0.75±0.01b	1.9±0.11a
Blend oil	Moisture contents (%)	0.07±0.00c	0.11±0.01b	0.15±0.02b	0.27±0.01a
	Free fatty acids (%)	0.02±0.01b	0.025±0.01b	0.028±0.00b	0.05±0.00a
	Per oxide value (%)	0.50±0.01b	0.55±0.01ab	0.55±0.02ab	0.59±0.01a

3.2. Moisture, oil, and salt percentage of potato chips fried in different oil samples

Moisture Content

The results in Table 2. demonstrate a significant increase in the moisture content of potato chips with higher frying counts across all types of oils used. For palm olein oil, the moisture content rose from an average of 1.39% after the first frying to 1.42% after the second frying and further to 1.49% after the third frying, indicating a significant increase with each frying cycle. Similarly, the moisture content for canola oil increased from 1.72% after the first frying to 1.79% after the second frying and 1.83% after the third frying. Sunflower oil also showed increased moisture content from 1.72% to 1.79% and finally to 1.83% across the frying cycles. Blend oil exhibited a similar trend, with moisture content increasing from 1.63% after the first frying to 1.75% after the second frying and 1.76% after the third frying.

1) Oil Absorption

Oil absorption by the potato chips also increased significantly with each frying cycle. For palm olein oil, oil absorption increased from 29.17% after the first frying to 30.90% after the second and 31.47% after the third frying. However, there was a fluctuating trend for canola oil: oil absorption was 32.89% after the first frying, decreased to 28.66% after the second frying, and then increased again to 30.18% after the third frying. Sunflower oil consistently increased oil absorption from 30.66% to 31.76% and finally to 31.99% across the three frying cycles. Blend oil showed a decrease in oil absorption from 30.17% after the first frying to 27.99% after the second frying, followed by an increase to 29.48% after the third frying.

2) Salt Percentage

The salt percentage of potato chips fried in palm olein oil was 6.4% after both the first and second frying cycles and increased slightly to 6.8% after the third frying cycle. In canola oil, the salt percentage decreased slightly from 6.8% after the first frying to 6.4% after the second frying and then increased to 6.7% after the third frying. For sunflower oil, the salt percentage remained relatively stable at 6.3% after the first frying and 6.4% after the second and third frying cycles. Blend oil showed a similar trend, with the salt percentage remaining 6.3% after the first and second frying cycles and slightly increasing to 6.4% after the third frying.

3) Discussion

Appropriate moisture levels in potato chips are critical during the processing and frying. High moisture content can negatively influence the quality of the final product, leading to issues such as sogginess. The observed increase in moisture content across all oils used is consistent with findings by previous research [40], which noted that moisture content changes slightly due to variations in frying time and temperature. previous researchers [36] reported moisture content in the range of 0.49% to 1.95% during different storage times when using palm oil, aligning with the current findings.

Frying temperature is another critical factor affecting moisture content. Higher frying temperatures generally lead to less oil absorption and greater moisture diffusion from potato chips. The current study found that average moisture content increased with the number of frying cycles for all four oil samples, consistent with previous findings [40]. The oil that is used repeatedly will become waste cooking oil. Waste cooking oil can be converted into biodiesel [41],[42].

The frying medium and the properties of the oil used influence oil absorption in potato chips. Factors such as frying time and the number of frying cycles significantly affect oil absorption. Previous researchers [43] highlighted that longer frying times increase oil absorption. Other previous researchers [44] reported that pretreatments such as salt addition could reduce oil absorption. Previous researchers [15] observed that repeated frying with the same oil leads to increased production of contaminants, making the oil unsafe for further use.

Pretreatment techniques and appropriate frying protocols can reduce oil and salt retention in fried products [20]. The current study's findings suggest that using blend oils with different proportions of vegetable oils can improve sensory and nutritional qualities and extend the shelf life of fried products, as supported by previous research [16].

Lowering dietary sodium intake is a public health goal. Techniques such as seasoning with KCl and MSG have effectively reduced the NaCl percentage in potato chips [45]. The color of oils and fried products varies with frying time, and increased oil absorption can affect the sensory qualities of the chips [46].

Previous researchers [5] observed that lower frying temperatures for longer times lead to greater oil uptake. In contrast, another previous researcher [19] reported that pre-drying potato chips before frying could reduce oil and water retention. Previous researchers [3] found that atmospheric frying led to higher oil retention than vacuum frying. The current study's results are consistent with these findings, emphasizing the importance of adjusting frying time, temperature, and pretreatment operations to achieve high-quality fried potato chips.

Table 2. Comparison of moisture, oil, and salt percentage of potato chips fried in different oil samples

Oils used	Analysis of parameters	After 1st frying	After 2nd frying	After 3rd frying
Potato chips fried in palm olein oil	Moisture Contents (%)	1.39±0.01b	1.42±0.01ab	1.49±0.01a
	Oil Absorbance (%)	29.17±0.23c	30.9±00.04b	31.47±0.38a
	Salt Percentage (%)	6.4±0.05b	6.4±0.05b	6.8±0.07a
Potato chips fried in sunflower oil	Moisture Contents (%)	1.72±0.01b	1.79±0.01a	1.83±0.01a
	Oil Absorbance (%)	30.66±0.20c	31.76±0.14b	31.99±0.03a
	Salt Percentage (%)	6.3±0.05a	6.4±0.05a	6.4±0.1a
Potato chips fried in canola oil	Moisture Contents (%)	1.72±0.01c	1.79±0.01b	1.83±0.01a
	Oil Absorbance (%)	30.66±0.20c	31.76±0.14b	31.99±0.03a
	Salt Percentage (%)	6.3±0.05b	6.4±0.05a	6.4±0.1a
Potato chips fried in blend oil	Moisture Contents (%)	1.63±0.01b	1.75±0.01a	1.76±0.01a
	Oil Absorbance (%)	30.17±0.53a	27.99±0.57c	29.48±0.30b
	Salt Percentage (%)	6.3±0.26a	6.3±0.17a	6.4±0.23a

3.3. Sensory parameters of potato chips fried in different oils and their blends

Data regarding the sensory evaluation of potato chips fried in various oils and their blends is presented in Table 3. It is evident that as the frying counts increased, the scores for sensory parameters significantly decreased for chips fried in all types of oils and blend oils. Among the chips fried in different oils, those fried in sunflower oil received the highest sensory evaluation scores.

1) *Detailed Sensory Evaluation*
   a) *Appearance: Potato chips fried in sunflower oil were highly acceptable, receiving high ratings on the hedonic scale for their eye-appealing color.*
   b) *Aroma: Chips fried in sunflower oil are also rated highest, indicating a highly acceptable scent with extreme ranking.*
   c) *Taste: The taste of the potato chips varied with the type of oil used. Chips fried in sunflower oil were rated the highest for taste, indicating strong consumer satisfaction.*
   d) *Texture: Texture, indicating crispiness, was highest for chips fried in sunflower oil, showing high acceptability.*
   e) *Mouth Feel: This parameter, which refers to the sensory experience within the mouth, was also rated highest for chips fried in sunflower oil, indicating extreme acceptability.*

Overall, potato chips fried in sunflower oil performed best across all sensory parameters.

2) *Sensory Evaluation Insights*
   a) *Fried Potato Products: Typically, these products should have a light to golden yellow color, a crispy texture, and a pleasant taste and odor. They should be between 1.00 to 3.00 mm thick and free from blisters, dark pigments, and wet centers. They should not be greasy or rancid.*
   b) *Palm Olein Oil: Products fried in palm olein oil were acceptable and had good sensory qualities. Studies have shown that palm oil containing antioxidants exhibited better consumer preference until the end of storage.*
   c) *Canola Oil: Deep-fried potato chips in canola oil were well-received due to their pleasant taste, flavor, and crispiness.*
   d) *Sunflower Oil: Experiments showed that potato chips fried in sunflower oil exhibited excellent quality during the first frying and fair quality after the third frying.*
   e) *Blend Oils: Using a blend of oils can impart good sensory and nutritional qualities to fried products and increase their shelf life.*
   f) *Public Health: Lowering dietary sodium intake is a significant public health goal. Techniques like seasoning with KCl and MSG can effectively lower NaCl percentage in potato chips while maintaining their structure and sensory quality.*

Table 3. Comparison of sensory parameters of potato chips fried in different oils and their blends

Samples	Frying counts	Appearance	Aroma	Taste	Texture	Mouth Feel	Overall Acceptability
Potato chips fried in palm olein oil	1st Frying	8.20a ±0.030	8.26a ±0.061	8.26a ±0.065	8.24a ±0.051	8.44a ±0.036	8.24a ±0.047
	2nd Frying	7.68b ±0.081	7.91b ±0.036	8.05b ±0.030	7.57b ±0.085	7.98b ±0.045	7.89b ±0.036
	3rd Frying	7.10c ±0.025	6.98c ±0.041	7.20c ±0.091	6.95c ±0.060	7.25c ±0.041	7.34c ±0.030
Potato chips fried in sunflower oil	1st Frying	8.30a ±0.065	8.42a ±0.025	8.40a ±0.030	8.44a ±0.040	8.55a ±0.060	8.36a ±0.056
	2nd Frying	8.08b ±0.051	8.12b ±0.03	8.13b ±0.041	7.57b ±0.087	8.07b ±0.051	7.95b ±0.061
	3rd Frying	7.19c ±0.080	7.34c ±0.045	7.24c ±0.053	7.13c ±0.041	7.37c ±0.068	7.39c ±0.065
Potato chips fried in canola oil	1st Frying	8.05a ±0.040	8.38a ±0.092	8.48a ±0.080	8.31a ±0.066	8.34a ±0.052	8.19a ±0.040
	2nd Frying	7.54b ±0.051	8.03b ±0.055	8.24b ±0.052	7.42b ±0.064	7.93b ±0.041	7.56b ±0.060
	3rd Frying	6.94c ±0.055	7.18c ±0.056	7.37c ±0.068	6.89c ±0.036	7.14c ±0.050	7.023c ±0.045
Potato chips fried in blend oil	1st Frying	8.17a ±0.068	8.29a ±0.045	8.34a ±0.060	9.36a ±0.047	8.24a ±0.045	8.18a ±0.045
	2nd Frying	7.48b ±0.100	7.35b ±0.050	8.06b ±0.036	8.14b ±0.045	7.95b ±0.062	7.93b ±0.035
	3rd Frying	7.01c ±0.097	7.11c ±0.071	7.14c ±0.040	7.30c ±0.035	7.19c ±0.035	6.87c ±0.065

4. Conclusion

Fried foods are immensely popular worldwide, with their consumption increasing annually. However, repeated use of frying oils leads to changes in their quality, making controlling deep-frying fats and oils crucial. This study assessed the physicochemical and sensory attributes of potato chips and frying oils before and after the first, second, and third frying sessions.

The key findings revealed that the moisture content and oil absorbance in potato chips increased with each frying session, while the salt percentage remained relatively stable across frying sessions and was unaffected by temperature changes. For frying oils, the Free Fatty Acids (FFA), Peroxide Value (POV), and moisture content increased with the number of frying sessions. Notably, all test values, including moisture content, oil absorbance, and salt percentage of potato chips, and FFA, POV, and moisture content of oil samples, followed the Punjab Pure Food Regulations (PPFR) 2018 after each frying session.

Sensory evaluation, which covered parameters such as taste, color, texture, shape, and overall acceptability, indicated that potato chips fried in sunflower oil received slightly higher acceptance scores. However, the sensory scores for potato chips decreased with increased frying counts across all oil types, with the lowest scores observed after the third frying session.

In conclusion, properly managing frying practices, including selecting suitable oils and monitoring frying cycles, is necessary to produce safe, high-quality potato chips. It is essential to maintain records of safe and healthy oils, monitor frying oil changes, and limit the number of frying cycles in line with universal standards. This study highlights the importance of adhering to food safety regulations and maintaining quality control to ensure consumer satisfaction and health.

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