

FTIR-supported evaluation of flavor-dependent oxidative behavior in locally produced potato chips

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Abstract

The present study aimed to assess the antioxidant potential of the flavors used in locally manufactured potato chips, as well as the effects of the flavors on the oxidative stability of the product. The flavors used in the present study were eight; salt, cheese, chicken, ketchup, chili, acid, garlic, and barbecue. The proximate chemical composition, total phenolic content, lipid oxidation, and the use of the Fourier transform infrared (FTIR) method to measure the oxidation-related changes in the functional groups were used. The methods used to measure the oxidation were the peroxide value (PV), the p-anisidine value (AV), and the total oxidation index (TOTOX). Significant differences ($P \leq 0.01$) were observed among treatments in chemical composition, phenolic compound content, and oxidation indices. The highest total phenolic compound content was recorded in the acid-flavored potato chips (225 ± 5.6 ppm), whereas the garlic-flavored potato chips exhibited the highest oxidation indices, with peroxide value reaching 16.2 ± 0.24 meq O_2 /kg fat, p-anisidine value of 10.33 ± 0.37 , and a TOTOX index of 42.73 ± 0.61 , indicating the lowest oxidative stability after exposure to accelerated oxidation conditions.

On the other hand, it was found that cheese- and chili-flavored potato chips were associated with the lowest oxidation indices, indicating that they are more resistant to lipid oxidation. FTIR analysis revealed that an increased level of oxidative behavior, as inferred from the results obtained for chemical composition, was associated with an increased level of carbonyl band intensity and a reduced level of unsaturation band intensity. The results obtained from this investigation clearly indicate that flavor plays a very important role in deciding the oxidative stability of potato chips, while an increased level of oxidative behavior inferred from results obtained for chemical composition can be considered as a supporting criterion for evaluating lipid oxidation and flavor antioxidant or pro-oxidative behavior.

Keywords: Potato chips, Flavor-dependent, Oxidative behavior, Evaluation, FTIR

1.Introduction

The food industry for snacks ranks among the most widespread and rapidly developing food industries across the world, and potato chips rank among the most popular products of this industry because of their large demand and good acceptance properties for their taste and

convenience of consumption. The global consumption of potato chips has been increasing, and large amounts of these products have been produced to meet their increasing demand in local and global markets. The significance of this industry can

be attributed to its ability to supply ready-to-consume food products to meet daily consumer requirements, apart from its economic significance to create employment opportunities and develop processing industries related to potato production. Though potato chips can be categorized under foods of a recreational nature, their significance to consumers makes their quality and safety aspects a crucial issue during their production and storage processes [1]. The reason potato chips are more likely to oxidize is their high lipid content. The increase of temperature during frying and the presence of oxygen in the system may accelerate the auto-oxidation of lipids in potato chips to produce primary oxidation products such as hydroperoxides, which may degrade to produce secondary oxidation products such as aldehydes, ketones, and fatty acids [2,3] oxidation reactions may affect the quality of potato chips by producing off-flavors from the formation, and by causing color changes as pigment compounds degrade to produce brown compound. In addition, off-odors also occur, leading to a decrease in consumer acceptance [4] In most cases, a consumer can detect spoilage of fried foods, such as potato chips, before prior to microbial spoilage, indicating the major effect of oxidation on quality.

In terms of food quality and safety, not only are oxidation products known to cause undesirable changes in food properties, but they can also cause negatively affect to food consumers. Many researchers have shown that certain secondary lipid oxidation products, including malondialdehyde (MDA), have been implicated in mechanisms of oxidative stress in humans and have been suggested to have

links to higher susceptibility to chronic diseases like cardiovascular diseases, intestinal inflammation, and even certain cancers [4]. Thus, one of the biggest challenges of making potato chips has to do with controlling oxidation to maintain a certain level of quality and food safety [1]. Flavoring of potato chips is another crucial process involved in the production of these chips because it has direct impacts on consumer acceptance. The use of flavors has been recognized as a significant marketing ingredient in this market because it enables the development of different products that suit different consumer preferences from spicy to salty and sour flavors [5]. Based on their composition and sources, potato chips' flavors can be categorized into natural flavors such as Acid, chili, herbs, and spices, and artificial flavors such as cheese, barbecue, and others. The categorization is largely based on the chemical composition and sources of the compounds used as flavors. Sometimes a combination of natural and artificial flavors is used depending on the desired flavor. However, it is worth noting that flavoring not only functions in improving product quality, since some ingredients used in flavoring may have additional properties that come from bioactive components found in such ingredients. For instance, herbs and spice ingredients such as chili and garlic have been shown to contain phenolic compounds that have free radical scavenging abilities. Additionally, other aromatic ingredients used in flavoring have sulfur and volatile components that may be useful in preventing the product from undergoing oxidation, which is beneficial in improving product quality[6,4]. Hence, flavoring ingredients may have multiple functions, including improving product acceptance and product stability [4].

Recently, there has been growing scientific interest in research on the impact of natural flavors and plant extracts on the antioxidant properties of food products. Various international studies have shown that the application of certain natural flavoring substances and plant extracts with high phenolic contents can decrease the oxidation and enhance the stability of lipids during level storage, especially for fried and lipid-rich products [4]. Research on fried products and snacks such as potato chips has indicated that certain phenolic and aromatic substances from herbs and spices can be effective in inhibiting the generation of free radicals and slowing down the degradation of quality during storage [6]. Although there are many studies conducted globally in this regard, local research regarding potato chips made in conditions found in Iraq or other comparable environments has been minimal. What has been done to a large extent has been in terms of traditional parameters such as sensory analysis or oil determination, but scientific analysis regarding the antioxidant ability of flavors has been inadequately dealt with. This underlines the importance of local research being done in a laboratory setting to provide this gap in knowledge with valid data. Though there have been discussions in international research regarding the use of natural flavors and plant extracts in increasing the oxidative stability of fat-rich foods, there are still knowledge gaps regarding locally made potato chips. This is because, within most of the local research, there is an emphasis on the sensory properties and quality specifications, and there is no research that has systematically explored the antioxidant properties and oxidative

stability associated with added flavors. Furthermore, since there is a lack of detailed knowledge with respect to the characteristics of the added flavors and their ability to act as an oxidation inhibitor, research is done to fill this knowledge gap. Therefore, the research gap being targeted in this research can be explained as the lack of a comprehensive assessment being made in relation to the flavors being used in local potato chips and their antioxidant ability. This gap may help in improving product quality and may also help in adopting safer natural alternatives instead of synthetic additives being used in snack foods [4].

The purpose of this research is to assess the antioxidant capacity of the selected flavors used in locally made potato chips based on the ability of the flavors to inhibit oxidative reactions and their chemical markers. This research will also attempt to relate the antioxidant capacity of the samples to the total phenolic content and other chemical properties of the samples, to determine the most potent flavors among them for enhancing the oxidative stability and quality of the product. This is due to the local need for authentic scientific information which can contribute to the development of the production of potato chips and its enhanced competitiveness [4,6].

Novelty and Significance of the Study

While lipid oxidation in fried snack foods has been widely studied worldwide, the contribution of commercial flavor formulations in enhancing the oxidative stability in real factory conditions has hardly been studied. Few studies even have

considered models, single plant extracts, or single oxidation indices independently, and the combined linking of chemical oxidation markers, phenolic content, and spectroscopic evidence in one analytical framework has not been done so far. The novelty of the current research is based on the fact that the research provides a detailed assessment of the most commonly used industrial flavoring substances in the production of locally manufactured potato chips. The research incorporates the results of the classical oxidation parameters peroxide value, p-anisidine value, and TOTOX index, along with the determination of the total phenolic content and FTIR spectral characterization. The novelty of the research is based on the fact that the research incorporates the results of the FTIR spectral characterization of the studied flavoring substances, unlike the results of the classical chemical methods. Moreover, the novelty of the research is based on the fact that the results of the research provide original information on the flavoring substances of the studied fried snack food, manufactured according to the local conditions. In addition, this study offers new data from actual market products as processed under local processing conditions and is therefore a practical

application sure to be of importance to snack food manufacturers. The results show that flavor type can have both pro-oxidant and antioxidant effects depending on its chemical nature, which may ultimately affect product stability rather than sensory properties. The study provides scientifically valuable insights for choosing and optimizing flavor formulations that can extend the oxidative stability and shelf life of fried snacks by elucidating these differential effects. This study evaluates oxidative stability using chemical oxidation indices, supported by higher oxidative behavior inferred from chemical indices measurements in a closed system.

2. Materials and Methods

Potato chips samples were collected from local potato chips production facilities in Mosul city. The samples were formulated with industrial flavorings commonly applied in local manufacturing.

Table (1): The flavor treatments were coded and described

Source	States	Flavor name	Code
Local	Solid	Salt	F1
China	Liquid	Cheese	F2
China	Solid	Chicken	F3
China	liquid	Ketchup	F4
China	liquid	Chili	F5

China	liquid	Acid	F6
China	Solid	Garlic	F7
China	liquid	Barbecue	F8

In this study, locally produced potato chips were used as the samples. The added flavors included Acid, chili pepper, ketchup, cheese, garlic, and salt. The chemicals or solvents used in the analysis include methanol, Folin Ciocalteu reagent, sodium carbonate, iso-octane, p-anisidine solution, apart from other reagents used in chemical analysis [7].

The following instruments were used to conduct the work: a UV–Vis spectrophotometer, a Soxhlet apparatus for fat extraction, a drying oven, an analytical balance and an FTIR instrument, following the standard guidelines and recommendations for the proper use of such equipment.

2.1 Proximate analysis

Proximate analysis was carried out to determine the main chemical composition of the samples. The moisture content analysis was done using the oven-drying method at 105°C until a constant weight was reached [8]. The total fat was extracted using a Soxhlet apparatus along with a suitable organic solvent, such as hexane or petroleum ether [9]. The Kjeldahl method was employed to determine crude protein by estimating total nitrogen, and the protein content was

calculated using the appropriate conversion factor ($N \times 6.25$). The ash content was measured by incinerating the sample in a furnace at a high temperature until its weight remained constant. This is a widely followed process in food analysis [10]. Crude fiber was estimated using the classic acid and alkali digestion method, and carbohydrates were estimated by difference from the other proximate components [7].

2.2 Total Phenolic Content (TPC)

Total phenolic compounds were determined using the Folin–Ciocalteu method as described by [28] with slight modifications. Briefly, 10 g of the sample were extracted with 50 mL of a hydro-alcoholic solvent. An aliquot of the extract was reacted with Folin–Ciocalteu reagent followed by sodium carbonate solution for color development. The absorbance was measured at 765 nm using a UV–Vis spectrophotometer. A standard calibration curve was prepared using gallic acid solutions at different concentrations (100, 120, 140, 160, 180, 200, 220, and 240 mg/L), and the regression equation obtained was:

$$y = 0.0108x + 0.0005 (R^2 = 0.9977),$$

where y represents the absorbance and x represents the gallic acid concentration (mg/L). The concentration of total phenolics in

the extracts was calculated from the measured absorbance using the equation:

$$x = (y - 0.0005)/0.0108,$$

and the results were expressed as mg gallic acid equivalents (GAE) per 100 g of sample [28]

2.3 The peroxide value of fat: which is a measure of oxidation, was determined by employing the standard iodometry titration method, and it was expressed in /kg of fat. The values were expressed in me/kg of fat, and the values were expressed in me/kg of fat, as mentioned in [11] The p-anisidine values were determined by measuring the absorbance at a wavelength of 350 nm after the oil sample reacted with a solution of p-anisidine in iso-Octane. The total oxidation values, which are a combination of peroxide and anisidine values, were calculated by using the following equation:

$$\text{TOTOX} = 2\text{PV} + \text{AV}$$

This index was calculated based on commonly used practices for evaluating lipid oxidative stability under the studied conditions [27].

2.4 Accelerated Oxidation Context

The oxidation indices evaluated in this study (peroxide value, p-anisidine value, and TOTOX index) reflect oxidative changes developed under the analytical and processing conditions applied during sample preparation and measurement. Although no independent accelerated storage experiment was conducted, the combined effects of thermal exposure during frying, solvent extraction, and analytical procedures provide an oxidative stress context that allows comparative

differentiation among flavor formulations. Accordingly, the observed oxidation data should be interpreted as relative indicators of oxidative behavior rather than absolute shelf-life predictors. This comparative approach is widely accepted for screening formulation-dependent oxidation trends in lipid-rich food systems and provides useful insight into the potential pro-oxidant or antioxidant influence of added flavors.

2.5 FTIR analysis of extracts

Fourier Transform Infrared Spectroscopy (FTIR) with an ATR technique was utilized to obtain IR spectra for the alcoholic extract of the samples within a range of 400-4000 cm^{-1} . The presence of functional groups associated with active compounds, such as phenolic, carbonyl, hydroxyl, and other specific groups, was identified according to their specific absorption bands.

2.6 Statistical design

A completely randomized design (CRD) was applied with three replicates for each treatment. Analysis of variance (ANOVA) was performed to test significant differences among treatments, and Duncan's multiple range test was used for post-hoc comparisons at a significance level of ($P \leq 0.01$). In addition, Pearson correlation coefficients were calculated to evaluate the relationships between chemical composition parameters and oxidation indices.

3. Results and discussion

Results about the chemical composition of the potato chips samples Table (2) showed a

significant difference ($P \leq 0.01$) in moisture, fat, and carbohydrate contents

Table (2) chemical composition of flavored potato chips samples %

Carbohydrates	Fiber	Ash	Protein	Fat	Moisture	
12.47*	1.8	0.77	2.08	5.93*	75.88*	

*

Based on Table (3) it was found that there are significant differences in the chemical composition of potato chips samples, especially in terms of the moisture content of the potato chips subjected to different treatments. The moisture content ranged from 12.5%, which was the garlic flavor, up to 17.2% of the chicken flavor, while the other flavors were within the range of 13.6% to 15.0%.

From these findings, it can be concluded that the flavor added to potato chips has a significant effect on their moisture content. The relatively higher moisture content of chicken-flavored potato chips can be attributed to the characteristics of the seasoning powder used for flavoring, which has a water-binding effect and improves the moisture retention capability of potato slices [12]. On the other hand, lower moisture content was recorded for the garlic flavor, which could be attributed to volatile sulfur-containing compounds in garlic, which have a moisture loss-promoting effect [13]. Regarding fat content, no significant differences were observed for different treatments, with values ranging between 42.0% for chili flavor and 44.5% for Acid flavor. From Duncan's multiple range test, all treatments were classified under the same group designated as 'A', indicating the addition of flavors did not have a significant effect on fat content.

This can be explained by the fact that the fat content in potato chips generally comes from deep-fat frying, which was applied to all samples. The amount of added flavoring is also expected to have a limited effect on oil gain or loss during frying. Research shows that oil absorption in fried products is governed mainly by frying conditions (such as oil temperature and time), pore structure development, and heat-mass transfer processes, rather than by minor formulation changes after frying [14]. Consequently, there were no statistical differences in fat content across treatments, which could be due to the dominant physical and processing factors.

Since MSG is the sodium salt of glutamic acid, a non-essential amino acid, it inherently contains nitrogen atoms. Glutamic acid, like other amino acids, is an organic compound that inherently contains nitrogen atoms, and it is one of the compounds that contribute to total nitrogen, a parameter measured in food analysis techniques such as the Kjeldahl method, which measures all nitrogen-containing compounds [15]. This means that when MSG is present in seasoning powders, it inherently has a chemical composition that includes nitrogen atoms, and it is one of the

compounds that contribute to total nitrogen, a parameter measured in food analysis techniques such as the Kjeldahl method, which measures all nitrogen-containing compounds.

The range of fiber content in the samples was from 1.9% in the chicken-flavored treatment to 2.3% in the chili-flavored treatment. The statistical analysis indicated that chili flavor formed a separate significant group (A) with the highest value, while ketchup and chicken flavors were in the lower group (B). The salt, cheese, garlic, acid, and barbecue treatments have shown similar amounts of fiber content per sample. These five treatments (AB) are statistically insignificant from both extreme treatment groups (A and B). The fiber contents in potato chips were from 1.9% in a sample that was flavored with chicken to 2.3% for a sample that was flavored with chili. The analysis showed that the chili flavor was classified as a separate distinct group (A) while the ketchup and chicken flavorings were both classified into the lower group (B). In summary, the results to date suggest that certain types of flavor may have relative effects with regard to the overall amount of fiber present in the potato chips. In respect to the fiber content observed in potato chips that were flavored with chili, the amount of fiber was greater in the chili flavor due to the presence of powdered chili which contains the remnants of plant tissue and has high levels of dietary fiber primarily as insoluble fibers and the plant wall components. This has been demonstrated by several of researchers who examined the chemical composition of dried hot pepper powders and products derived from the *Capsicum annum* species [16,17]. The lower fiber content found in the chicken-

flavored samples, on the other hand, can be attributed to the fact that these flavors are usually made from industrial seasoning blends that primarily include flavoring agents, salts, flavor enhancers, and carrier materials, with very little contribution from plant-based ingredients high in dietary fiber. This explanation is backed by research that looks into the composition of industrial spice blends and ready-to-use seasonings found in snack foods. Even though there are some statistically significant differences, the overall fiber content in all the treatments is still quite low. Previous analytical studies and technical reports on fried snacks suggest that this outcome is expected for fried products like potato chips, which primarily consist of peeled potatoes and vegetable oils rather than ingredients that are typically considered good sources of dietary fiber [18].

The ash content in samples that were flavored with ketchup was 1.6% and that in samples flavored with acid was 2.3%. The results showed that the Acid flavor stood out with a higher ash content, placing it in its own significant group (A). On the other hand, salt, ketchup, chicken, chili, cheese, and barbecue flavors all had lower ash contents and were grouped together (B). Garlic, with an average ash content of 2.1%, fell somewhere in between, sharing characteristics with both groups (AB).

Some flavorings can change the mineral content of potato chips, which shows up as differences in ash levels. For instance, seasonings with acid-based powders may add minerals like acetates or buffering salts, causing the ash content to rise. Simpler flavors, such as plain salt or ketchup, don't seem to have much effect on minerals.

Overall, potato chips have very low ash content, which fits with earlier research showing their mineral levels are quite low compared to other nutrients, and that frying in oil doesn't add minerals [19,20].

The carbohydrate content differed quite a bit between the chip flavors. Cheese and garlic varieties had the highest amounts, about 36.2% and 36.3%, so they ended up in the same group. On the other hand, chicken-flavored chips had the lowest carbohydrate level at 30.9%, which set them apart from the others.

Acid-flavored chips formed a comparatively lower group (B), while the remaining treatments (salt, ketchup, chili, and barbecue) fell into an intermediate statistical group (AB).

The composition of the additional flavorings is responsible for the observed variations in carbohydrate content. The presence of fillers or starch-based carrier powders, which are frequently used to enhance texture and stabilize flavors and add extra carbohydrates to the finished product, may be connected to the higher values found for samples with garlic and cheese flavors [21]. On the other hand, the chicken-flavored samples' lower carbohydrate content indicates that their industrial formulation depends more on proteins and flavoring agents than on carriers based on carbohydrates.

From an applied standpoint, these results are a crucial indicator when assessing the product's nutritional value because some flavorings can dramatically raise the carbohydrate content, which is reflected in the snack's total energy value [21].

Table Chemical composition of samples of flavored potato chips

*Carbohydrates %	*Fiber %	*Ash %	*Protein %	Fat % NS	*Moisture %	
35.2 ±0.8 AB	1.7 ±0.25 B	2.1 AB ±0.27	3.8 ±0.63B	43 ±0.82A	14.2 ±0.23B	F1
36.2 ±0.99 A	1.9 ±0.18 B	2.2 AB ±0.18	3.6±0.58B	42.5 ±0.76A	13.6 ±0.27B	F2
30.9 ±1.2 C	1.8 ±0.16 B	1.9 ±0.28 B	4.2 ±0.56 *A	44 ±0.48A	17.2 ±0.31*A	F3
35A±0.85 B	1.6 ±0.35 B	2 ±0.32 B	3.9 ±0.76B	42.5 ±0.93A	15 ±0.24 B	F4
35.5 ±0.76 AB	1.9 ±0.26 B	2.3 ±0.38 *A	3.8 ±0.83B	42 ±0.28A	14.5 ±0.42 B	F5
33.2±0.63 B	2.3 ±0.41	2.1 ±0.42	4.1 ±0.29A	44.5 ±0.64A	13.8 ±0.37	F6

	*A	AB			B	
36.3 ±0.54 * A	2.1A ±0.28 B	2.2±0.25 AB	3.9 ±0.46B	43 ±0.88 A	12.5 ±0.19 C	F7
35.1±0.89 AB	1.9 ±0.36 B	2.1±0.46 AB	3.8B ±0.55	42.5A ±0.39	14.6 B ±0.26	F8

Different letters in a column to every trait indicate significant differences at ($P \leq 0.01$)

F1 = Salt ,F2 Cheese flavor ,F3 = Chicken flavor ,F4 = Ketchup flavor ,F5 = Chili flavor,F6Acid flavor,F7 Garlic flavor,F8 Barbecue flavor.

It can be observed from Table (4) which presents the analysis of variance (ANOVA) for the oxidation indices of potato chips samples, that there were significant differences among all the studied parameters.

Table (4) Oxidation indices

TOTOX index	p-Anisidine Value	Peroxide Value (meq/kg Oil)	Phenolics (gallic acid equivalents / 100g)	
176.71*	87.2*	903.6*	299.9*	F value

Duncan's multiple range test for total phenolic content in samples of flavored potato chips showed distinct and statistically significant differences between the different flavors at a significance level of ($p \leq 0.05$), as shown in Table 5. The cheese-flavored samples (F2) had comparatively lower phenolic content than the acid-flavored samples (F6), indicating the presence of phenolic compounds or natural additives with antioxidant activity in these flavors. The garlic-flavored samples (F7) exhibited intermediate phenolic values, which is in line with their constituents' high concentration of sulfur-containing compounds and some aromatic compounds with antioxidant qualities.

These results support the idea that a higher phenolic content is directly linked to better oxidative stability of the product. Phenolic compounds are key natural antioxidants. They help slow down Lipid oxidation can be slowed down, which reduces the formation of both primary and secondary oxidation products. The differences in phenolic content across various flavors highlight how natural phenolic compounds help keep products stable under the tested conditions. They also help preserve sensory qualities such as color, flavor, and aroma. For example, studies on fried potato products show that higher levels of phenolics link to stronger antioxidant effects and less oxidative damage [22]. In general, phenolic compounds protect food by donating hydrogen atoms or scavenging free radicals, which

improves oxidative stability. These natural phenolics also limit unwanted oxidation products, helping maintain the overall sensory quality [23]. Peroxide values (PV) differed across the samples. The ketchup-flavored ones had the lowest value at 8.2, while the garlic-flavored samples showed the highest at 16.2. This difference was clear and statistically significant, with garlic flavor driving the increase. Acid-flavored samples came next, and ketchup and cheese flavors stayed on the lower side. The higher peroxide value in garlic-flavored samples suggests more primary oxidation products, especially hydroperoxides, are forming. This likely happens because garlic contains volatile sulfur compounds that can interact with lipids, encouraging oxidation under the test conditions. Interestingly, previous studies have found that some garlic compounds act as antioxidants in certain foods but may promote lipid oxidation in others, depending on the type of fat and environment [24]. The acid-flavored samples had higher peroxide values, which might be because organic acids can affect how stable fats are. These acids may cause fats to break down or speed up oxidation under the test conditions. On the other hand, flavors like ketchup and cheese showed lower peroxide values, likely due to antioxidants that slow down the formation of oxidation products like hydroperoxides. For example, ketchup, made from tomatoes, contains phenolic compounds and lycopene, a carotenoid that helps protect fats from oxidizing during storage. Cheese flavors contain bioactive compounds that act as antioxidants, which helps explain why foods with these flavors show less chemical oxidation. Interestingly, some flavors like acidic garlic may actually promote oxidation by encouraging oxidative reactions. In contrast, flavors such as ketchup and cheese

seem to slow down oxidation, which can help extend shelf life and keep the product fresh longer. When looking at the p-anisidine values (AV), chili flavor had the lowest at 6.60, while ketchup topped the list with 11.24, followed by garlic. The other flavors fell somewhere in between, each showing statistically different values. The p-anisidine value is commonly used to measure secondary oxidation products in fats and oils, especially unsaturated aldehydes. These compounds cause the unpleasant flavors and odors that develop when lipids break down during heating[25,26]. The higher acid values in the ketchup and garlic flavors suggest these seasonings have ingredients that react with lipids when heated, possibly speeding up the formation of aldehydes. In contrast, the chili flavor shows a lower acid value, which might mean its phenolic compounds and capsaicinoids help slow down the production of these oxidation products. From a quality standpoint, ketchup and garlic seem less stable under heat, while chili flavor holds up better in the conditions tested

The flavor treatments resulted in different average TOTOX values. The garlic flavor produced the highest TOTOX value (42.7), and was assigned to a separate statistical group (A). The acid flavor produced a TOTOX value of 32.9 and was assigned to group (B). The chicken flavor generated a TOTOX value of 30.4 and was assigned to group (C). The TOTOX values of salt (29.0), barbecue (28.5), and ketchup (27.6) flavors fell into the group (CD–D). The chili (25.2 TOTOX value) and cheese (24.7 TOTOX value) flavors produced the lowest TOTOX overall, and were assigned to their own distinctive statistical group (E).

The TOTOX total oxidation index is an overall assessment of the degree of lipid

oxidation in a sample that provides an overall assessment of all primary (PV) and secondary (AV) oxidation components present via the two sample tests [27]. As substantiated by primary and secondary oxidation results; the High TOTOX (42.7) produced by garlic flavor indicates that this treatment, had greater oxidizability than the other samples. The oxidizability found in the garlic flavor treatment is likely due to the presence of sulphur-related compounds found in garlic that promote oxidation related to both storage and/or frying conditions. Similarly, the elevated TOTOX results of the acid flavor treatment may be attributed to the acid/lipid interaction effect of the organic acids in relation to lipid degradation and the formation of new oxidized materials occurring at elevated temperatures.

In contrast, the chili and cheese flavors have a lower TOTOX score that is indicative of the

ability of that flavor to protect against oxidation. The presence of flavonoids and capsaicin in the chili, along with peptides and/or phenolic compounds in the cheese flavors, could provide antioxidant activity to those flavors. The remaining flavors (salt, ketchup and barbecue) showed intermediate levels and had no significant difference from one another, indicating they do not have a major effect on oxidative deterioration compared to each other.

The results of these analyses confirm that the type of flavor will significantly affect the oxidative stability of lipids. Certain flavors (such as garlic and acid) promote rancidity, while other flavors (such as chili and cheese) provide antioxidant effects that improve the stability of the product and improve the oxidative stability and quality of the product.

Table (5) oxidation indices in flavored potato chips samples

TOTOX index	p-Anisidine Value	Peroxide Value (meq O ₂ /kg fat)	Phenolics (ppm)	
28.985 ±0.6871 CD	9.385 ±0.25 BC	9.8 ±0.32 C	195 ±3.2 B	F1
24.725 ±1.2442 E	7.525 ±0.45 D	8.6 ±0.58 D	197 ±2.5B	F2
30.4475 ±0.7841 C	9.6475 ±0.62 BC	10.4 ±0.24 C	130 ±4.6 E	F3
27.645 ±0.7839 D	11.245 ±0.31* A	8.2 ±0.36 D	185 ±2.4 C	F4
25.2075 ±0.6261 E	6.6075 ±0.28 E	9.3 ±0.28 D	160 ±3.8 D	F5
32.91 ±0.5445 B	7.91 ±0.39 D	12.5 ±0.19 B	225 ±5.6 *A	F6
42.7325 ±0.6061 *A	10.3325 ±0.37 B	16.2 ±0.24* A*	131 ±2.9 E	F7
28.53 ±0.7539 D	8.41 ±0.28 CD	10.06 ±0.35 C	155 ±1.9 D	F8

Different letters in a column to every trait indicate significant differences at ($P \leq 0.01$)

F1 = Salt ,F2 Cheese flavor ,F3 = Chicken flavor ,F4 = Ketchup flavor ,F5 = Chili flavor,F6Acid flavor,F7 Garlic flavor,F8 Barbecue flavor.

Figure (1) shows the correlation coefficients between the primary and secondary components and the oxidation indices. The carbohydrate content (%) demonstrated a strong negative correlation with moisture ($r = -0.63$) and poultry fat content ($r = -0.77$), which indicates that an increase in the amount of carbohydrates corresponds to a decrease in the amount of moisture and the amount of fat present in the birds as would be expected due to the way carbohydrates are calculated by difference. The phenolic content of the birds exhibited a moderate negative correlation with moisture ($r = -0.31$) along with a weakly positive correlation to the amount of ash present in the birds ($r = 0.25$). This may be because as phenolic levels increase in the birds, the mineral content in the birds increases. The peroxide value (PV) had a moderate negative correlation with moisture ($r = -0.46$), moderate positive correlations with fat content ($r = 0.35$), and moderate positive correlations with ash content ($r = 0.36$). The p-anisidine value (AV) was weakly positively correlated with the amount of protein ($r = 0.12$) and fat ($r = 0.07$) in the birds, and showed a moderate negative correlation with ash content ($r = -0.46$). The TOTOX index showed trends similar to the PV in that it had a moderate negative correlation with moisture (r

$= -0.42$), and a moderate positive correlation with fat content ($r = 0.33$).

In general, the data suggest that increased phenol levels correspond to lower oxidation levels (PV, TOTOX); therefore, the antioxidant activity of phenols helps to support the original hypothesis. In addition, potato chips with higher fat content had higher PV and TOTOX values (indicating greater oxidation potential), while those with more moisture had lower PV and TOTOX values, possibly due to either dilution effects or a reduced rate of oxidative reactions. Chemical oxidation parameters and FTIR spectra were used as measures to determine the degree of oxidative behavior. No direct oxygen consumption or kinetic data were obtained, and as such, the results should be viewed from a comparative standpoint with respect to oxidative response rather than as kinetic parameters.

A multi-variable visualization of chemical composition variables and oxidation indices was developed using a correlation heatmap (Figure 1) that communicates the negative correlation observed between phenolic content and respective oxidation indices (PV and TOTOX) and also the positive correlation between fat content and oxidative degradation consistent with trends seen in the univariate correlation analysis.

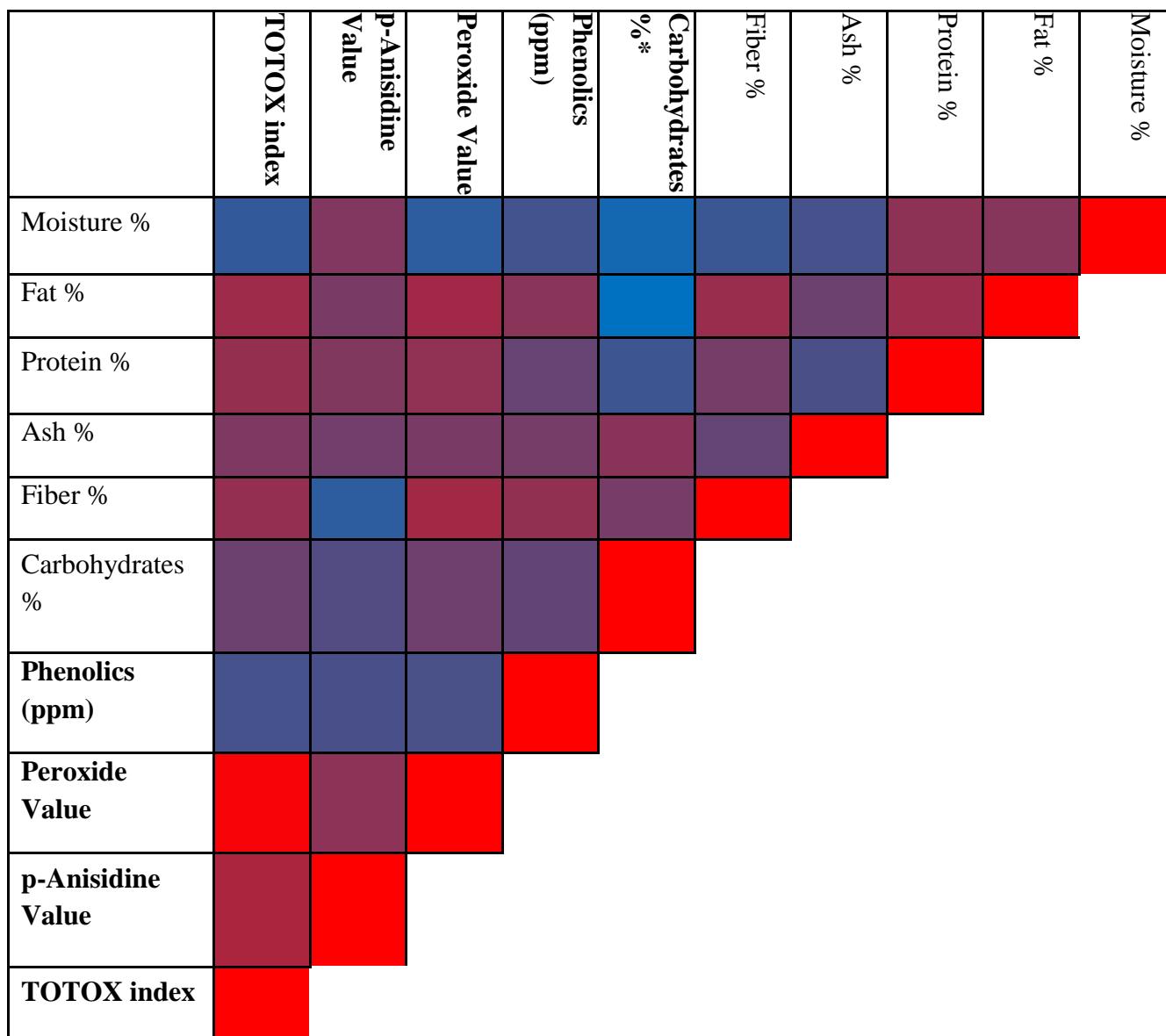


Figure 1. Heatmap of Pearson correlation coefficients between chemical composition parameters and oxidation indices of potato chips samples. Red colors indicate positive correlations, whereas blue colors indicate negative correlations. Color intensity represents the strength of the correlation coefficient ranging from -1 to $+1$.

FTIR spectral features of flavored potato chips extracts

Figure 2 presents an FTIR spectrum of potato chip flavor extracts; F1, the salted potato chip flavor, has a prominent carbonyl peak (1740 cm^{-1}) due to oxidation, with the intensity indicating moderate levels of primary oxidation products. A relatively significant

amount of unsaturated fatty acids have been preserved (3010 cm^{-1} for $\text{C}=\text{C}-\text{H}$) and have not undergone complete oxidation, and the weak phenol and aromatic antioxidant signals (1600 and 1510 cm^{-1}) coincide with the presence of phenolic and aromatic

antioxidants in this flavor; supports that the salted potato chip flavor (F1) exhibited less stability compared to flavors containing higher levels of phenolic antioxidants yet was not the lowest in terms of oxidation levels during storage; moderate stability exhibited throughout storage period. The FTIR spectrum of the cheese flavor (F2) showed a moderate carbonyl band at 1740–1745 cm^{-1} and a limited broadening of the O–H band, along with a noticeable retention of the =C–H signal near 3010 cm^{-1} . These features are consistent with the relatively low TOTOX and PV values and with lower chemical oxidation indices, compared with more degraded samples. This supports the hypothesis that the composition of the cheese flavor—possibly including protein/peptide carriers limits carbonyl accumulation and relatively preserves unsaturation. The FTIR spectrum of the chicken flavor (F3) showed a clear band at 1740 cm^{-1} , which points to oxidation-related carbonyl groups. This band was stronger here than in flavors like cheese, suggesting more primary oxidation products. There was also a decrease in absorption around 3010 cm^{-1} , linked to double bonds (C=C–H), indicating that unsaturated fatty acids were being used up under the test conditions. Peaks at 1600 and 1510 cm^{-1} , connected to aromatic vibrations, appeared but were weaker than those in acid or chili flavors, which fits with the lower phenolic content in chicken flavor. Along with the peroxide value (PV), anisidine value (AV), and TOTOX measurements, the FTIR data show that the chicken flavor experienced noticeable oxidation and is less resistant to it compared to some other flavors.

The FTIR analysis of the ketchup flavour (F4) indicated a significant increase in the intensity of the carbonyl band (1740 - 1745 cm^{-1}) and

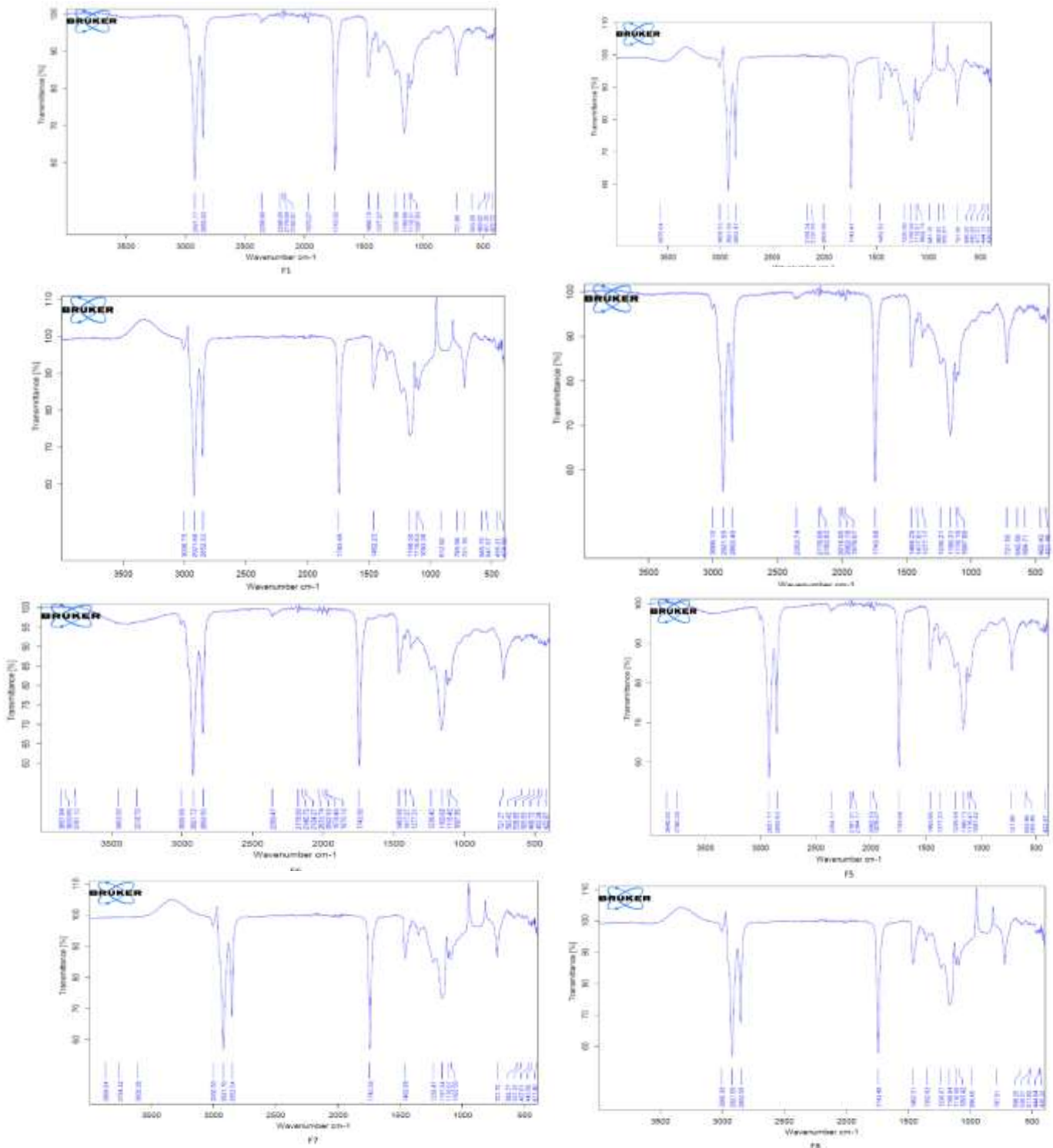
a drastic widening of the O–H region around (3200 - 3600 cm^{-1}), together with a decrease in intensity of the = C - H signal at (3010 cm^{-1}). The combination of these spectroscopic features is indicative of the presence of oxidized products from the ketchup flavour and significantly reduced unsaturation consistent with its relative high AV and TOTOX values. Therefore, the ketchup flavour is less stable than those of cheese or chicken flavours, which further illustrates that there are fewer phenolics present in this ketchup flavour system compared to other relatively stable flavour systems.

The FTIR spectrum of the chili flavor (F5) revealed prominent phenolic/aromatic bands at 1600 and 1510 cm^{-1} and C–O bonds in the ranges 1260–1230 and 1020–1150 cm^{-1} , along with a notable increase in carbonyl intensity at 1740–1745 cm^{-1} and broadening of the O–H region (3200–3600 cm^{-1}). These features indicating that unsaturated components and capsaicinoids in chili undergo oxidation and associated with higher oxidative behavior inferred from chemical indices which may partially counteract oxidation but was insufficient to confer higher oxidative stability compared with more stable flavors such as cheese and chicken.

The FTIR analysis of the Acid flavour (F6) indicated the presence of a broad O–H peak around (3200 - 3600 cm^{-1}) and a moderate carbonyl peak (1705 - 1745 cm^{-1}) which suggests that the Acid flavour contains organic acids and oxidized carbonyl compounds. These observations correspond to the Acid flavour's chemical values of peroxide value (12.5) and TOTOX (32.9), while still showing some degree of oxidation protection (high phenolic content, 225 ppm) as compared to

other more severely oxidised flavour systems

(garlic/chili).



Figure[saf.1] 2.The FTIR spectrum of the potato chips flavors extracts

F1 = Salt ,F2 Cheese flavor ,F3 = Chicken flavor ,F4 = Ketchup flavor ,F5 = Chili

flavor,F6Acid flavor,F7 Garlic flavor,F8 Barbecue flavor.

Garlic flavor has pronounced increases in carbonyl and sulfur bands, indicating that they have higher oxidation indices. Garlic also has higher oxidation indices PV and TOTOX because it has sulfur compounds associated with the formation of oxidation reactions and oxidative behavior that can be inferred from chemical indices.

Barbecue has a medium intensity of carbonyl bands (1740-1745 cm^{-1}) and little broadening

5. Conclusion

From this research, snack foods (such as potato chips) will find specific recommendations about how to optimize their flavor formulations using less synthetic preservatives based on the presence of the following enjoyable flavors: Chile; cheese; and so on - which provide a barrier against lipid oxidation by showing relatively low levels of peroxide, p-anisidine, and TOTOX for this study. Other flavors such as garlic and acid-based formulations should be used with caution, as they had the highest apparent level of oxidation (e.g., pro-oxidant) based on the results of this investigation. For manufacturers, this suggests that they may wish to optimize their formulation of flavor based on pH level, minimizing the number of sulfur-containing compounds that promote

References

1. Marasca, E., Greetham, D. Herring, S.D. & Fisk, I.D. (2016). Impact of nitrogen flushing and oil choice on the oxidative stability of potato crisps. *Food Chemistry*, 199, 81-86
<https://doi.org/10.1016/j.foodchem.2015.11.136>
2. Ujong, A. E., Emelike, N.J.T., Owano, F. & Okiyi, P.N. (2023). Effect of frying cycles on the physical, chemical and antioxidant

of O-H bands (3200-3600 cm^{-1}). It also has a greater presence of aromatic and phenolic signal (1600 and 1510 cm^{-1}) as well as C-O (1260 and 1020-1150 cm^{-1}). Barbecue has moderate intermediate values for PV (10.1) and TOTOX (28.5). Therefore, some components of the barbecue provide partial oxidative protection, but not enough to prevent greater oxidative deterioration than in garlic.

oxidation and/or combining these flavors with natural antioxidant ingredients with similar sensory properties so as to minimize the oxidative effects associated with the use of these flavors.

This study shows that commercial flavorings are not just added flavorings, but also play a major role in oxidation. Snack food manufacturers should consider how a flavor reacts when mixed with other ingredients, and take this into account when selecting flavors and formulating the product. This will help to increase the quality and stability of products and decrease the use of synthetic antioxidants, when using commercial flavorings in the context of real world manufacturing conditions.

properties of selected plant oils during deep-fat frying of potato chips. *Food Chemistry Advances*. 3 (2023), 100338.

<https://doi.org/10.1016/j.focha.2023.100338>

3. Li, C., Zhang, J., Li, Z. & Yu, X. (2019). Quality assessment of packaged fried foods during storage based on oven storage test. *International Journal of Food Science &*

Technology. 54(2), 558–566.

<https://doi.org/10.1111/jjfs.13971>

4. Wang, F., Sun, Y., Li, S., Yan, J., Qin, W., Saleh, A. S. M., & Zhang, Q. (2023). Plant phenolic extracts for the quality protection of frying oil during deep frying: Sources, effects, and mechanisms. *Grain & Oil Science and Technology* .6(2023), 148-161. <https://doi.org/10.1016/j.gaost.2023.08.001>.

5. Hurst, K. E., Hewson, L., & Fisk, I. D. (2022). Sensory perception and consumer acceptance of commercial and salt-reduced potato crisps formulated using salt reduction design rules. *Food Research International*. 155(7), 111022. <https://doi.org/10.1016/j.foodres.2022.111022>

6. Redondo-Cuevas, L., Castellano, G., Raikos, V., & McLoughlin, A. (2017). Natural antioxidants from herbs and spices improve the oxidative stability and frying performance of vegetable oils. *International Journal of Food Science & Technology*. 52(11), 2422–2432. <https://doi.org/10.1111/jjfs.13526>

7. AOAC. (1980). *Official methods of analysis* (13th ed.). Association of Official Analytical Chemists. Washington D.C. 376-384.

8. Ahn, J. Y., Kil, D. Y., Kong, C., & Kim, B. G. (2014). Comparison of oven-drying methods for determination of moisture content in feed ingredients. *Asian-Australasian Journal of Animal Sciences*. 27(11), 1615–1622. <https://doi.org/10.5713/ajas.2014.14305>

9. Pearson, D. (1973). *Laboratory techniques in food analysis*. Butterworth, London, Boston, pp. 50-57.

10. Pearson, D. (1976). *The chemical analysis of foods* (7th ed.). Churchill Livingstone, London.

11. American Oil Chemists' Society (AOCS). (1990). *Official method Cd 18-90: p-Anisidine value*. AOCS Press.

12. Michalska-Ciechanowska, A. (2020). The influence of maltodextrin and inulin on the physico-chemical properties of food powders. *Chem Engineering*. 4(1)12. [doi:10.3390/chemengineering4010012](https://doi.org/10.3390/chemengineering4010012) .

13. Sunanta, P., Kontogiorgos, V., Pankasemsuk, T., Jantanasakulwong, K., & Rachtanapun, P. (2023). The nutritional value, bioactive availability and functional properties of garlic and its related products during processing. *Frontiers in Nutrition*. 10, 1142784. <https://doi.org/10.3389/fnut.2023.1142784>

14. Li, Y., Guo, Q., Wang, K., Nverjiang, M., Wu, K., Wang, X., & Xia, X. (2022). Monitoring the changes in heat transfer and water evaporation of French fries during frying to analyze its oil uptake and quality. *Foods*. 11(21), 3473. <https://doi.org/10.3390/foods11213473>

15. Loi, C., & Cynober, L. (2022). Glutamate: A safe nutrient, not just a simple additive. *Annals of Nutrition and Metabolism*. 78(3), 133–146. <https://doi.org/10.1159/000522482>

16. Zou, Y., Ma, K., Tian, M., & Liu, Y. (2015). Chemical composition and nutritive value of hot pepper seed (*Capsicum annuum*) grown in Northeast China. *Food Science and Technology (Campinas)*. 35(4), 689–694. <https://doi.org/10.1590/1678-457X.6803>

17. Hamed, M., Kalita, D., Bartolo, M. E., & Jayanty, S. S. (2019). Capsaicinoids,

polyphenols and antioxidant activities of *Capsicum annuum*: Comparative study of the effect of ripening stage and cooking methods. *Antioxidants*. 8(9), 364 .

<https://doi.org/10.3390/antiox8090364>

18.Liu, Y., Tian, J., Zhang, T., & Fan, L. (2021). Effects of frying temperature and pore profile on the oil absorption behavior of fried potato chips. *Food Chemistry*. 345, 128832.

<https://doi.org/10.1016/j.foodchem.2020.128832>

19.Benkhoud, H., Mrabet, Y., Nasraoui, N., Bellazreg, W., Daly, F., Chaabane, N., & Hosni, K. (2022). Chemical compositions, fatty acid profiles and selected contaminants in commercial potato and corn chips sold in the Tunisian market. *Discover Foods*, 2(30).

<https://doi.org/10.1007/s44187-022-00030-8>.

20.Harmankaya, M., Özcan, M. M., & Endes, Z. (2013). Mineral contents of several corn and potato chips. *Journal of Agroalimentary Processes and Technologies*. 19(2), 222–227.

21.Adetoro, A. O. (2020). Effect of carrier agents on the physicochemical and technofunctional properties and antioxidant capacity of freeze-dried pomegranate juice (*Punica granatum*) powder. *Foods*.9(10), 1388. <https://doi.org/10.3390/foods9101388>

22.Bravo, C., Peña, F., Nahuelcura, J., Vidal, C., González, F., Jiménez-Aspee, F., Bustamante, L., Contreras, B., & Ruiz, A. (2023). Stability of phenolic compounds, antioxidant activity and color parameters in colored-flesh potato chips. *Molecules*. 28(16), 6047.

<https://doi.org/10.3390/molecules28166047>

23.Kalogianni, N., Lazou, T., Bossis, I., & Gelasakis, A. I. (2020). Natural phenolic compounds for the control of oxidation, bacterial spoilage, and foodborne pathogens in meat. *Foods*. 9(6), 794.

<https://doi.org/10.3390/foods9060794>

24.Park, S. Y., & Chin, K. B. (2014). Effect of fresh garlic on lipid oxidation and microbiological changes of pork patties during refrigerated storage. *Korean Journal for Food Science of Animal Resources*. 34(5), 638–646.

<https://doi.org/10.5851/kosfa.2014.34.5.638>

25.Shahidi, F., & Zhong, Y. (2010). Lipid oxidation and improving the oxidative stability. *Chemical Society Reviews*. 39(11), 4067–4079.

<https://doi.org/10.1039/B922183M>

26.Abeyrathne, E. D. N. S., Nam, K., & Ahn, D. U. (2021). Analytical methods for lipid oxidation and antioxidant capacity in food systems. *Antioxidants*, 10(10), 1587.

<https://doi.org/10.3390/antiox10101587>

27.Moigradean, D., Poiana, M.-A., & Gogoasa, I. (2012). Quality characteristics and oxidative stability of coconut oil during storage. *Journal of Agroalimentary Processes and Technologies*. 18(4), 272–276.

28.Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic–phosphotungstic acid reagents. *American Journal of Enology and Viticulture*, 16(3), 144–158. DOI:

[10.5344/ajev.1965.16.3.144](https://doi.org/10.5344/ajev.1965.16.3.144)

