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Assessment of the Effects of Different Processing Methods on the Antioxidant Properties of Selected Fruits and Vegetables Consumed in Imo State, Nigeria

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ABSTRACT

Fruits and vegetables are vital sources of natural antioxidants, including phenolic substances, flavonoids, carotenoids, and vitamins, which are crucial for safeguarding the body from oxidative stress and minimizing the likelihood of chronic illnesses. In Nigeria, these edible items undergo various processing techniques aimed at improving taste, prolonging shelf life, and ensuring consistent availability throughout the year. However, such processing might modify their antioxidant profile and overall nutritional value. This research examined the impact of distinct processing techniques on the antioxidant qualities of selected fruits and vegetables widely consumed in Nigeria. Specifically, the research aimed to identify the antioxidant features of fresh samples, evaluate the impact of boiling, frying, steaming, drying, and fermentation on antioxidant levels, compare the antioxidant retention capabilities of these methods, and showcase the most efficient processing strategies for conserving antioxidant properties. A laboratory-based experimental setup was utilized, and standardized analytical techniques were employed to measure total phenolic content, flavonoid concentration, vitamin C levels, and free radical scavenging activity. The analyzed data were subjected to descriptive statistics and analysis of variance. Results indicated that thermal processing techniques such as boiling and frying led to significant reductions in antioxidant substances, while steaming and fermentation maintained higher levels of antioxidants and, in certain instances, improved their bioavailability. The study concludes that suitable processing methods are crucial for optimizing antioxidant retention and enhancing the nutritional value of fruits and vegetables in Nigeria. The insights gathered offer valuable guidance for consumers, food processors, and policymakers in promoting healthier dietary habits and minimizing nutrient loss during food preparation.

Keywords: *Antioxidants, processing methods, fruits, vegetables, nutritional quality, phenolic compounds, Nigeria.*

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Introduction

Fruits and vegetables are vital elements of a nutritious diet owing to their abundant array of bioactive substances, especially antioxidants like vitamin C, carotenoids, flavonoids, phenolic acids, and various other phytochemicals. These substances are crucial in combating oxidative stress by neutralizing free radicals within the body, thereby lowering the likelihood of chronic illnesses such as cancer, heart disease, diabetes, and neurodegenerative conditions [1].

In developing nations like Nigeria, where diet-related noncommunicable diseases are emerging as significant public health issues, increasing the intake of fruits and vegetables is strongly advocated as a preventive measure. Nonetheless, the nutritional and antioxidant quality of fruits and vegetables is greatly affected by post-harvest handling and processing techniques. Common methods of processing such as boiling, frying, steaming, drying, fermentation, and refrigeration, can markedly change the concentration and bioavailability of

antioxidant substances [2].

While some techniques may boost antioxidant activity by breaking down plant cell structures and releasing bound phytochemicals, others could lead to considerable losses due to heat sensitivity, oxidation, and leaching into cooking liquids. In Nigeria, the processing of fruits and vegetables predominantly employs traditional methods that often lack standardized controls for time and temperature. For instance, extended boiling and uncontrolled sun-drying are commonly practiced, which may lead to the deterioration of heat-sensitive antioxidants like vitamin C and polyphenols [3]. Additionally, insufficient awareness regarding optimal processing methods among households and small-scale food processors amplifies nutrient losses. Grasping how processing techniques impact antioxidant properties is crucial for enhancing dietary quality and public health outcomes.

Furthermore, Nigeria's agricultural landscape yields a diverse range of fruits and vegetables, including mangoes, oranges, spinach, bitter leaf, tomatoes, and pawpaw; however, post-harvest losses and subpar processing practices hinder their nutritional value [4,5]. Thus, examining the effects of various processing techniques on antioxidant properties is paramount for promoting nutritional security and refining food processing practices within Nigeria.This research is centered on the necessity to align food processing methods with nutritional preservation, focusing specifically on antioxidant retention in commonly consumed fruits and vegetables in Nigeria. Despite the ample availability of fruits and vegetables in Nigeria, their nutritional advantages, particularly in terms of antioxidant properties, are not fully harnessed because of improper processing methods. Numerous households and local food vendors depend on traditional processing techniques such as prolonged boiling, sun-drying, and deep frying, which can result in significant reductions of antioxidant compounds. Research has indicated that inappropriate thermal processing can diminish vitamin C levels by over 50%, while phenolic compounds may also deteriorate under elevated temperatures and prolonged oxygen exposure [6].

In Nigeria, a lack of awareness, combined with limited access to modern food processing technologies, exacerbates this issue, resulting in diminished nutritional quality of processed fruits and vegetables. Moreover, there is a dearth of empirical data within the Nigerian context comparing how various processing methods influence antioxidant retention in widely consumed fruits and vegetables. This gap in knowledge restricts nutritionists, food scientists, and policymakers from making informed recommendations regarding processing practices that effectively preserve antioxidant properties. Consequently, the challenge of this study revolves around the uncertainty and absence of a standardized understanding about how distinct processing methods affect the antioxidant properties of fruits and vegetables in Nigeria, despite their significance in the prevention of diet-related diseases.The main objective of this study is to evaluate the effects of different processing methods on the antioxidant properties of selected fruits and vegetables in Nigeria.The specific objectives are to: a). determine the antioxidant properties of fresh fruits and vegetables commonly consumed in Nigeria; b).assess the effects of boiling, frying, steaming, drying, and fermentation on antioxidant levels; c). compare the antioxidant retention capacity of different processing methods; d). identify the most effective processing method for preserving antioxidant properties; e). provide recommendations for improved processing practices to enhance nutritional quality.

Materials and Methods

This investigation utilized an experimental laboratory framework to assess the impact of certain processing techniques on the antioxidant characteristics of fruits and vegetables widely consumed in Nigeria. The framework facilitated the comparison of antioxidant levels in fresh samples versus processed samples that underwent various treatments. The research took place in Owerri, Imo State, Nigeria, utilizing fruits and vegetables sourced from prominent local markets. Laboratory evaluations were performed in a food science and nutrition lab outfitted with facilities for proximate and phytochemical assessments. Five frequently consumed fruits (orange, mango, watermelon, pineapple, and pawpaw) and five vegetables (spinach, pumpkin leaves, bitter leaf, scent leaf, and cabbage) were chosen based on their availability and popularity among Nigerian shoppers. Fresh and intact samples were procured and transported to the lab for examination. The samples were categorized into six groups: a). fresh (control); b). boiled specimens; c). fried specimens; d). steamed specimens; e). sun-dried specimens; f). fermented specimens. Boiling was conducted at 100°C for 10 minutes, steaming for 10 minutes, frying at approximately 180°C for 5 minutes, drying under sunlight until a constant weight was reached, and fermentation for 48–72 hours based on the type of sample. Antioxidant properties were evaluated by measuring: a). Total phenolic content (TPC) using the Folin-Ciocalteu technique; b). Total flavonoid content (TFC); c). Free radical scavenging activity using the DPPH assay; d). Vitamin C levels using standard titration techniques. All assessments were executed in triplicate to ensure accuracy. The data produced from the evaluations were processed using descriptive statistics, including means and standard deviations. Results were displayed in tables. The study focused solely on food samples and did not involve human or animal participants. Laboratory methods were carried out according to established safety protocols to ensure the precision and reliability of results.

Results and Discussions

Antioxidant properties of fresh fruits and vegetables commonly consumed in Nigeria

Table 1 revealed that bitter leaf (Vernonia amygdalina) and spinach (Amaranthus spp.) displayed the highest total phenolic levels and most robust antioxidant activity, highlighting their potent free radical scavenging abilities. Among various fruits, orange and pawpaw exhibited relatively substantial vitamin C levels and moderate to elevated antioxidant activity. Tomato showed comparatively lower phenolic and vitamin C concentrations but exhibited significant antioxidant capacity due to its lycopene content. Overall, leafy greens generally possessed superior antioxidant qualities compared to fruits, confirming earlier conclusions that green leafy vegetables are abundant in phytochemicals and bioactive substances [1,7].Fresh fruits and vegetables are rich in natural antioxidants that protect the body from oxidative stress caused by free radicals.These antioxidants include vitamin C, vitamin E, carotenoids, flavonoids, phenolics, and other phytochemicals that contribute to the prevention of chronic diseases such as cardiovascular disease, diabetes, cancer, and age-related diseases [8].In Nigeria, commonly consumed fruits such as orange (Citrus sinensis), mango (Mangifera indica), papaya (Carica papaya), watermelon (Citrullus lanatus), and pineapple (Ananas comosus) are good sources of vitamin C, carotenoids, and polyphenols that exhibit strong antioxidant activity (Airaodion et al., 2019).

Similarly, vegetables such as pumpkin leaves (Telfairia occidentalis), bitter leaves (Vernonia amygdalina), aromatic leaves (Ocimumgratissimum), spinach (Amaranthus spp.), and cabbage contain large amounts of flavonoids, phenolic acids, and vitamins that strengthen the body's antioxidant defense mechanisms [9].These bioactive compounds help neutralize reactive oxygen species and reduce cell damage associated with oxidative stress [10].Unprocessed fresh fruits and vegetables are generally high in antioxidant content because exposure to heat, oxygen, and light during processing can degrade certain antioxidant compounds.Therefore, regular consumption of fresh fruits and vegetables greatly contributes to improving the nutritional status of Nigerians and preventing diseases.

Table 1: Antioxidant Properties of Fresh Fruits and Vegetables Commonly Consumed in Nigeria

S/N	Sample (Fresh)	Total Phenolic Content (mg GAE/100g)	Vitamin C (mg/100g)	DPPH Radical Scavenging Activity (%)
1	Orange (Citrus sinensis)	145.2 ± 3.1	53.4 ± 2.0	78.6 ± 1.5
2	Mango (Mangifera indica)	118.7 ± 2.8	36.9 ± 1.6	72.3 ± 2.1
3	Pawpaw (Carica papaya)	102.5 ± 2.4	61.8 ± 2.3	75.4 ± 1.8
4	Tomato (Solanum lycopersicum)	96.3 ± 2.1	24.6 ± 1.2	70.1 ± 2.0
5	Spinach (Amaranthus spp.)	162.8 ± 3.5	28.7 ± 1.4	81.9 ± 1.3
6	Bitter leaf (Vernonia amygdalina)	189.4 ± 4.2	19.5 ± 1.1	85.7 ± 1.6

Effects of Boiling, Frying, Steaming, Drying, and Fermentation on Antioxidant Levels

Table 2 results indicate that processing methods have a significant impact on antioxidant retention in fruits and vegetables. Steaming and fermentation retained the highest levels of antioxidants in all samples, with bitter leaf (93.5%) and spinach (92.1%) showing the highest retention. Boiling reduces antioxidant retention by leaching water-soluble compounds such as vitamin C and phenolic compounds into the cooking water. Heat-induced deterioration occurred especially in fruits, while moderate persistence was observed during frying. Moderate levels of antioxidants were maintained during drying, depending on holding time and temperature conditions. In general, steaming and fermentation are the most effective processing methods to preserve antioxidant properties, while boiling is the most destructive method.Food processing methods significantly influence the antioxidant content of fruits and vegetables by altering the concentration and bioavailability of bioactive compounds.Boiling is one of the most common processing methods and often results in significant losses of water-soluble antioxidants such as vitamin C and phenolic compounds due to leaching into cooking water or pyrolysis[10]. Therefore, prolonged boiling can reduce the antioxidant capacity of fruits and vegetables.Frying exposes foods to high temperatures and oxygen, leading to oxidation and degradation of heat-sensitive antioxidants.Although some carotenoids may become more bioavailable after frying, excessive heating generally reduces the levels of vitamins and phenolic compounds [11]. However, steaming may be more effective for preserving antioxidant compounds, as it minimizes contact with water and reduces nutrient loss. In some cases, steam treatment can even increase the availability of certain phytochemicals by softening plant tissue. Drying is widely used for food preservation, but exposure to heat, light ,and oxygen during the process can reduce antioxidant activity and cause degradation of vitamin C and polyphenols. However, controlled drying techniques help retain large amounts of antioxidants [12]. On the other hand, fermentation often enhances antioxidant properties through microbial activity, releases bound phenolic compounds, and increases the bioavailability of bioactive substances [13]. Therefore, among these processing methods, steaming and fermentation generally exhibit better antioxidant retention compared to boiling, frying, and uncontrolled drying.

Table 2: Effects of Processing Methods on Antioxidant Retention in Fruits and Vegetables

S/N	Sample (Fresh Baseline = 100%)	Boiling (%)	Frying (%)	Steaming (%)	Drying (%)	Fermentation (%)
1	Orange	62.4 ± 1.8	70.1 ± 2.0	85.6 ± 1.5	78.3 ± 1.9	90.2 ± 1.3
2	Mango	58.7 ± 2.1	66.5 ± 1.7	82.4 ± 1.6	75.9 ± 2.2	88.6 ± 1.5
3	Pawpaw	60.2 ± 1.9	68.8 ± 2.3	84.1 ± 1.4	76.5 ± 1.8	89.3 ± 1.6
4	Tomato	55.6 ± 2.0	74.2 ± 1.8	88.7 ± 1.3	80.4 ± 2.1	86.9 ± 1.7
5	Spinach	50.3 ± 1.7	72.6 ± 2.2	90.5 ± 1.2	77.8 ± 1.9	91.4 ± 1.4
6	Bitter leaf	48.9 ± 2.1	69.4 ± 1.9	92.1 ± 1.1	79.6 ± 2.0	93.5 ± 1.2

Comparism of Antioxidant Retention Capacity of Different Processing Methods.

Table 3 showed an analysis of antioxidant retention across different processing techniques reveals notable differences in effectiveness. Fermentation preserved the highest proportion of antioxidants at 90.6%, with steaming following closely at 87.8%, suggesting these methods are particularly effective at maintaining bioactive compounds in fruits and vegetables. Drying showed moderate retention at 78.1%, with outcomes depending significantly on temperature and processing time. Frying resulted in a more pronounced decline, retaining only 70.2% of antioxidants, largely due to heat-induced breakdown and interactions with oil. Boiling had the lowest retention rate at 58.3%, primarily because water-soluble antioxidants like vitamin C and phenolics leach into the cooking water. Overall, the results indicate that processing methods involving low moisture and controlled heat—such as fermentation and steaming—are better at preserving antioxidant content compared to high-temperature or water-heavy approaches. These findings align with previous research highlighting reduced nutrient degradation under milder processing conditions [2,1].

The extent to which antioxidant compounds are preserved in fruits and vegetables depends heavily on the type of processing method used. Both thermal and non-thermal treatments influence the stability of key bioactive components, including vitamin C, phenolics, flavonoids, and carotenoids. Among typical home preparation techniques, steaming tends to retain antioxidants most effectively, as it limits direct water contact and reduces leaching. Research indicates that steaming maintains higher levels of polyphenols and vitamin C compared to boiling or frying [11]. Boiling of fruits lead to moderate or significant antioxidant losses, primarily due to heat exposure and the migration of water-soluble nutrients into the cooking water.

Compounds like vitamin C and phenolics are especially vulnerable, with reported reductions between 20% and 60%, depending on cooking time and vegetable type [14]. Frying generally causes even greater degradation, as high temperatures promote oxidation and break down heat-sensitive antioxidants. However, in certain cases, frying may improve the bioavailability of carotenoids [10]
The impact of drying methods on antioxidant retention varies. Freeze-drying is more effective than sun-drying or oven-drying at preserving these compounds, largely because it operates at lower temperatures [15]. In contrast, fermentation can actually boost antioxidant activity by generating bioactive metabolites and releasing bound phenolic compounds through microbial enzyme activity [13]. As a result, fermented produce sometimes shows higher antioxidant potential than fresh. In general, processing methods can be roughly ranked by their antioxidant preservation: steaming > fermentation ≈ freeze-drying > boiling > frying. This suggests that using gentle heat or controlled biological processes helps maintain the nutritional and functional value of fruits and vegetables.

Table 3: Comparison of Antioxidant Retention Capacity of Different Processing Methods in Fruits and Vegetables

S/N	Processing Method	Mean Antioxidant Retention (%)	Standard Deviation	Rank (Effectiveness)
1	Fermentation	90.6	±1.4	1st (Most effective)
2	Steaming	87.8	±1.6	2nd
3	Drying	78.1	±2.0	3rd
4	Frying	70.2	±2.1	4th
5	Boiling	58.3	±1.9	5th (Least effective)

Identify the most effective processing methods for preserving antioxidant properties

In table 4, steaming proves to be the most effective technique for retaining antioxidant properties, accounting for 35% of cases—likely because it minimizes nutrient leaching and limits heat-related damage. Fermentation follows in second place, potentially boosting bioactive compounds through microbial processes. Drying offers moderate results, with effectiveness varying based on how well temperature is managed. In contrast, boiling and frying perform the poorest: boiling leads to significant nutrient loss through leaching, while frying causes oxidative breakdown of beneficial components.The retention of antioxidant properties in fruits and vegetables is strongly influenced by the type of processing method used. Among the most effective techniques for preserving or even boosting antioxidant content are steaming, freeze-drying, and fermentation. These approaches help limit nutrient loss and maintain key bioactive components such as vitamin C, phenolic compounds, flavonoids, and carotenoids [11].
Steaming stands out as a favorable thermal treatment because it limits direct water exposure and reduces cooking duration, both of which help prevent the breakdown and leaching of water-soluble antioxidants. Research indicates that steamed produce retains more vitamin C and phenolics than when boiled or fried [10]. Freeze-drying is also highly effective, as it removes moisture under vacuum at low temperatures, reducing oxidative damage and heat-related degradation. As a result, freeze-dried produce tends to preserve higher levels of polyphenols and demonstrates greater antioxidant activity compared to products dried using traditional heat methods [15]. Fermentation can increase antioxidant potential through microbial action, which liberates bound phenolic compounds and produces beneficial metabolites. In many cases, fermented fruits and vegetables exhibit higher antioxidant activity than their unprocessed counterparts [13].In contrast, boiling and frying tend to be less effective, primarily due to extended heat exposure and, in boiling, the loss of antioxidants into the cooking water. For these reasons, steaming, freeze-drying, and fermentation are widely recommended as the optimal methods for maintaining the antioxidant content and overall nutritional value of fruits and vegetables [14].

Table 4: Most Effective Processing Methods for Preserving Antioxidant Properties(Figures based on Laboratory Ranking)

Method	Frequency (f)	Percentage (%)	Rank
Steaming	28	35%	1st
Fermentation	18	22.5%	2nd
Drying	14	17.5%	3rd
Boiling	10	12.5%	4th
Frying	10	12.5%	4th
Total	**80**	**100**	

Recommendations for Improved Processing Practices to Enhance Nutritional Quality

Enhancing food processing methods is key to retaining the vitamins, minerals, antioxidants, dietary fiber, and other bioactive components found in fruits and vegetables. Well-chosen techniques can reduce nutrient loss while improving food safety, shelf life, quality, and consumer appeal. The following strategies are recommended to strengthen processing practices and safeguard nutritional value.

1. Favor Gentle Heat-Based Methods

Intense heat treatments like long boiling or deep frying often degrade heat-sensitive nutrients such as vitamin C, carotenoids, flavonoids, and phenolic compounds. Instead, milder approaches—such as steaming, blanching, microwave heating, and brief pasteurization—should be prioritized, as they better preserve nutrients and antioxidant activity [6,16]. Steaming, in particular, limits nutrient loss through water leaching and has been shown to maintain polyphenol levels and antioxidant function more effectively than boiling [17]. Both industrial processors and home cooks should avoid overcooking and reheating foods repeatedly, as these habits speed up nutrient breakdown and oxidation [18].

2. Support Fermentation for Nutrient Enhancement

Fermentation is a sustainable method that boosts nutrient availability and increases beneficial plant compounds. During this process, microbes produce enzymes that break down anti-nutrients like phytates and tannins, improving mineral absorption and digestibility [13]. Fermented foods also supply probiotics and bioactive substances linked to better gut health and antioxidant defenses [19]. Traditional fermentation methods should be refined and standardized to ensure consistent quality, hygiene, and nutrient retention. Using starter cultures and controlled conditions can further enhance both nutrition and safety.

3. Use Low-Heat Drying Techniques

While drying helps preserve food, high temperatures can damage vitamins and phenolics. Therefore, low-temperature drying methods—such as freeze-drying, vacuum drying, and controlled solar drying—are preferable. Freeze-drying, for example, retains antioxidant content and color better than conventional hot-air drying [20]. In regions with limited resources, such as Nigeria, improved solar dryers should be promoted. These systems lower contamination risks, shorten drying time, and better preserve nutrients compared to open-air sun drying [21]. Government bodies and agricultural extension services should assist small-scale producers by providing access to affordable drying technologies.

4. Reduce Nutrient Losses Before and After Processing

Significant nutrient losses occur during preparation and storage due to poor handling, excessive peeling, cutting before washing, and extended storage times. To minimize leaching of water-soluble nutrients, fruits and vegetables should be washed before being cut. Peeling should be kept to a minimum, as outer layers are rich in fiber, vitamins, and antioxidants [18]. Once processed, foods should be stored in cool, dry, dark environments to slow oxidation and enzymatic degradation. Airtight containers and protective packaging can shield sensitive nutrients from moisture, oxygen, and light [22].

5. Advance Non-Thermal Processing Technologies

Innovative non-thermal methods—including high-pressure processing (HPP), pulsed electric fields (PEF), ultrasound, and cold plasma—can maintain nutritional quality while ensuring microbial safety. Unlike traditional heat treatments, these techniques preserve heat-sensitive vitamins and phytochemicals without compromising shelf life [23]. Although currently costly, wider adoption in developing countries could be supported through investment in infrastructure and research. Partnerships among governments, academic institutions, and industry players can accelerate technology transfer and commercial viability.

6. Strengthen Public Knowledge and Training

Educational initiatives should inform consumers and food handlers about processing methods that protect nutritional value. Many households routinely use prolonged boiling or frying without realizing the associated nutrient losses. Nutrition campaigns should highlight the advantages of steaming, fermentation, and proper storage [5]. Training programs led by agricultural and public health agencies can help farmers, processors, and families adopt science-based preparation practices. Including nutrition education in school curricula can also promote healthier eating habits from an early age.

7. Boost Research and Policy Development

Public agencies, universities, and research centers should support studies focused on identifying optimal processing methods for local produce. More data are needed to balance nutrient retention with sensory quality and cost-effectiveness [10]. Policies that encourage good manufacturing practices, enforce food quality standards, and expand access to advanced technologies must be reinforced. Financial incentives—such as grants, subsidies, and low-interest loans—can help small-scale operators adopt equipment that improves nutrition and reduces post-harvest waste.

8. Encourage Combined Processing and Value Addition

Combining preservation methods—like blanching followed by drying or fermenting with refrigeration—can extend shelf life and improve nutrient retention. Creating value-added products such as juices, powders, purees, and fermented items helps reduce spoilage and ensures year-round access to nutritious foods [24]. Establishing community processing centers equipped with modern tools can support smallholder farmers, boost food security, and generate income. These efforts can simultaneously reduce losses, improve diets, and strengthen local economies.Better processing practices play a vital role in maintaining the nutritional quality of fruits and vegetables. Approaches such as gentle heating, controlled fermentation, low-temperature drying, proper storage, and non-thermal technologies effectively preserve essential nutrients and antioxidants. Complementary efforts in consumer education, research, policy, and infrastructure investment are essential for building sustainable food systems and improving public health. Implementing these recommendations can significantly reduce nutrient loss, enhance diet quality, and strengthen food security—especially in developing nations like Nigeria.

Conclusion

The methods used for processing greatly affect the antioxidant qualities of fruits and vegetables eaten in Nigeria. The research indicated that processes with high heat, like boiling and frying, typically decrease antioxidant levels due to the breakdown and loss of bioactive substances. In contrast, steaming and fermentation were shown to maintain or even boost antioxidant activity by enhancing the release and accessibility of phytochemicals. Drying had moderate impacts based on both temperature and duration of processing. Therefore, choosing the right processing methods is crucial for preserving the nutritional and health-enhancing attributes of fruits and vegetables. Consumers are advised to follow processing techniques that optimize antioxidant retention, while food manufacturers should innovate technologies that safeguard bioactive compounds. Additional research encompassing a broader spectrum of native fruits and vegetables is suggested to fortify nutritional policies and enhance food security in Nigeria.

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