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Revolutionizing of Food Preservation with Vitamin C: Applications and Impacts of Vitamin C in Food Products

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Abstract*— Vitamin C, an essential nutrient and versatile antioxidant, plays a transformative role in food preservation, fortification, and overall food quality enhancement. This review provides a comprehensive exploration of Vitamin C's unique chemical properties, including its role as a reducing agent and its ability to neutralize free radicals, make it a key component in combating oxidative stress and preserving food freshness, its mechanisms of action in stabilizing food systems, and its potential to enhance the shelf life, flavor, color, and nutritional profile of various food products. With its ability to combat oxidative stress and microbial spoilage, Vitamin C has become indispensable in modern food technology. This includes about the methodologies and techniques employed to optimize Vitamin C retention in food products, including blanching, encapsulation, high-pressure processing, and freeze-drying. These techniques are critical for minimizing nutrient degradation during processing and storage. Recent innovations, combined with regulatory frameworks and safety considerations, underscore the importance of adhering to global food safety standards while maximizing the benefits of Vitamin C in food systems. Ultimately, Vitamin C stands at the forefront of both food preservation and nutritional enrichment, offering immense potential to improve food quality and safety in the modern food industry.

***Index Terms:** Food safety, Microbial Contamination, Preservation Methods, Temperature, vit C.*

I. INTRODUCTION

The acidic and reducing qualities of L-ascorbic acid (AA) are caused by its 2,3-enediol moiety [1]. AA is an extremely polar, water-soluble substance that resembles carbohydrates. One of the water-soluble vitamins, vitamin C, has been demonstrated to have a number of beneficial functions in the body, such as serving as an enzyme cofactor for biochemical reactions and promoting the production of collagen, which is necessary to stop scurvy from developing, keep the immune system functioning normally, and offer defense against oxidative stress [2]. In any case, AA and L-isoascorbic acid are widely used as food ingredients in the food industry because of their reducing and antioxidant qualities. Vitamin C's role as a preservative goes beyond just preventing oxidation and microbial growth. Additionally, it maintains a variety of nutrients that are susceptible to deterioration when exposed to heat, light, and air. For example, vitamin C helps maintain the nutritional value and color of beverages and processed foods, guaranteeing that vitamins and minerals hold up well during handling and storage. Additionally, Vitamin C can enhance the effectiveness of other preservatives, working synergistically to provide more comprehensive protection against spoilage and maintaining the food's overall quality [3].

This wide range of functions has made Vitamin C an indispensable ingredient in both fresh and processed food industries, from fruit juices to meat products. Its natural properties help food producers meet consumer demands for longer-lasting, safer, and healthier food options, without relying heavily on synthetic preservatives.

A. Chemical Properties of Vitamin C:

Vitamin C, often referred to as ascorbic acid, is a water-soluble nutrient with the molecular formula $C_6H_8O_6$, as shown in Figure 1. It is commonly used in food preservation because of its antioxidant abilities. This vitamin naturally occurs in two primary forms: ascorbic acid in its reduced state and dehydroascorbic acid in its oxidized state [4]. This redox activity helps protect food from oxidative damage, particularly by stabilizing fats and oils in food, which is important for maintaining their freshness and taste [5].

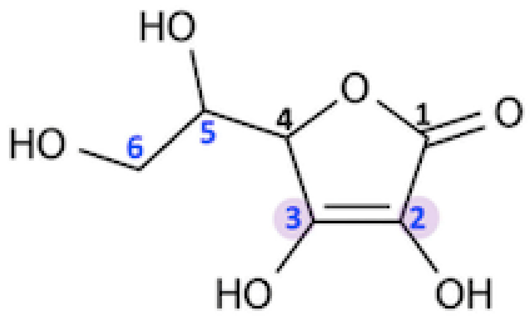

Figure 1. Structure of Ascorbic acid [6]

Vitamin C's molecular structure is similar to glucose and has hydroxyl groups (-OH) that make it capable of donating electrons. This ability allows it to neutralize free radicals, which helps prevent oxidation in food [2]. However, Vitamin C is quite sensitive to factors such as light, heat, and oxygen, which can degrade its antioxidant properties. Therefore, it needs to be stored properly, for example, by keeping it in dark, cool environments or in airtight containers to preserve its effectiveness in food [7].

Another key aspect of Vitamin C in food preservation is its acidic nature. This acidity reduces the pH of food, which can inhibit or slow down the growth of certain harmful microorganisms, thereby extending the shelf life of products like fruits and vegetables [8]. Additionally, Vitamin C can interact with metal ions such as iron and copper, preventing these metals from accelerating oxidation reactions in food, thereby enhancing its preservative effects [9].

II. MECHANISMS OF ACTION OF VITAMIN C IN FOOD PRESERVATION

A. Preservation Strategies for Enhanced Vitamin C Stability in Fruit and Vegetable-Based Products: An Exploration of Alternative Methods and Storage Protocols.

Vitamin C is an essential nutrient and a powerful antioxidant found in many fruits and vegetables. However, it is highly sensitive to processing conditions, and factors like heat and oxygen exposure can cause it to break down, leading to a loss of nutritional value. Because of this, Vitamin C is often used as a measure of overall quality in food products, especially during processing, storage, and handling. Traditional preservation methods—such as heating, drying, and freezing—are known to cause significant Vitamin C loss. To tackle this issue, researchers have been exploring new preservation techniques and combining multiple methods (a strategy called the "hurdle approach") to maximize Vitamin C retention from farm to table. A key part of this effort involves understanding how each preservation step affects Vitamin C levels and using mathematical models to predict its stability under different conditions. More advanced models now also consider uncertainties, helping scientists and food manufacturers make better decisions to optimize processing and storage while keeping as much Vitamin C intact as possible.[10]

B. Impact of Emerging Technologies on Vitamin C Stability and Bio availability in Processed Fruits and Vegetables

Thermal treatments are commonly used in the food industry to extend the shelf life of fruits and vegetables by eliminating harmful microorganisms and deactivating enzymes. However, while heat processing helps preserve food, it also comes with drawbacks—it can lead to nutrient loss, color changes, and alterations in flavor and aroma. Because of these downsides, the food industry is increasingly exploring gentler, non-thermal preservation methods that help retain the quality and nutritional value of fresh produce.

In recent years, several non-thermal technologies have been developed as alternatives to traditional heat treatments. These methods aim to preserve food while maintaining its original structure and maximizing the bioavailability of nutrients like Vitamin C. Some of the most promising techniques include minimal processing (MPFV), high-pressure processing (HPP), high-pressure homogenization (HPH), ultrasound (US), and pulsed electric fields (PEF). This review focuses on how these modern food processing technologies impact the stability and absorption of Vitamin C, ensuring that consumers receive the most nutritional benefits from their fruits and vegetables.[11]

C. Microbial Inhibition by Vitamin C

Vitamin C is known to exhibit antimicrobial activity, which plays a role in restricting the growth of various bacteria. This makes it useful not only in food preservation but also in protecting against harmful pathogens. For instance, Vitamin C has demonstrated activity against common human bacterial pathogens by interfering with their growth and survival [12]. It disrupts the cell wall of bacteria, which weakens their ability to multiply and cause infections [13]. Moreover, Vitamin C’s antiviral properties have also been explored. It may help in reducing viral infections by boosting the immune system and directly interfering with viral replication [14]. These findings suggest that Vitamin C could be a valuable agent in inhibiting microbial growth, particularly in the context of food safety and health. Its natural antibacterial effects can help prevent foodborne illnesses by limiting the spread of harmful bacteria.

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Table I: Mechanisms Action of Vitamin C [15]

Aspect	Description
1. Antioxidant Properties	Vitamin C helps restore the function of other antioxidants, such as vitamin E, improving their ability to protect food from oxidative spoilage.
2. Inhibition of Enzymatic Browning	Vitamin C reduces discoloration in fruits and vegetables, preserving their quality by inhibiting enzymatic browning.
3. Microbial Inhibition	Exhibits antimicrobial properties, inhibiting the growth of harmful bacteria and reducing foodborne illnesses. Disrupts bacterial cell walls and may interfere with viral replication.

III. REVIEW OF LITERATURE:

There are numerous food products, including noodles, baby foods like fruits, vegetables, and cereal-based baby foods, as well as techniques for improving the quality of pineapple, like high pressure processing, steaming, and blanching, among others. For determining whether vitamin C in food products increases or decreases, research is integral and is centered on such papers, which include, A staple of the modern diet, noodles are a simple and popular food choice for millions of people. The need to fortify noodles with vital nutrients has become more apparent as dietary choices change and nutritional inadequacies continue to exist. The nutrient content of noodles enhanced with a high-fiber powder made from freeze-dried and oven-dried bamboo shoots was contrasted with the control. groups in the current study. This study shows how fortification and processing techniques affect the amount of vitamin C in noodles supplemented with bamboo shoots. The vitamin C level of freeze-dried powder-fortified noodles (N1) was somewhat higher than that of control noodles (N0), which had 1.36 mg/100 g. Noodles with oven-dried bamboo shoot powder (N4, N5, and N6) had the highest vitamin C levels among the fortified varieties; N4 had 2.91 mg/100 g. This suggests that oven-drying is more effective than freeze-drying for retaining vitamin C during fortification. the vitamin C improvements in fortified products and vitamin C degradation due to cooking processes. The study highlights the significance of processing techniques in enhancing nutrient retention in fortified foods. The maximal vitamin C concentration of the fortified noodles was 2.91 mg/100 g, which was higher than the vitamin C content of the control noodles. In comparison to the control noodles (7.4, 7.6, and 7.0, respectively), the fortified noodles had higher sensory scores for texture (7.5), taste (7.7), and overall acceptability (7.2). An effective way to improve the nutritional value of this well-liked food item is to fortify noodles with essential nutrients. Bamboo shoots, which are abundant in micro- and macronutrients, may be necessary to improve the nutritional content and health advantages of fortified products.16].

According to this study, pineapple quality can be preserved and improved by the use of high-pressure processing (HPP). This technique not only stabilizes vitamin C levels but also increases its content, with a maximum 40% improvement observed under 300 MPa for 20 minutes. Unlike non-HP processed samples, which suffer nutrient loss due to reduced firmness and juice leakage, HPP enhances cellular permeability, facilitating the release of vital nutrients like vitamin C. Additionally, HPP improves firmness, color, total polyphenols, and flavonoids, while also ensuring better microbiological quality. The study concludes that HPP at 300 MPa for 10 minutes effectively maintains pineapple quality for up to 16 days under refrigeration, making it a promising method for enhancing nutrient retention and extending shelf life in the food industry [17].

In recent years, the bio-accessibility of vitamins in baby foods has gained considerable attention, as vitamin C plays an essential role in infants' growth and immune function. A study assessing the in vitro bio-accessibility of vitamin C in commercially available fruit, vegetable and cereal-based baby foods. Their research found significant variability in vitamin C bio-accessibility depending on the food matrix, which influenced the release and absorption of added vitamin C during digestion. Studies have previously emphasized the challenges of ensuring vitamin stability and bio-availability in processed baby foods, especially under varying pH conditions and thermal treatments**.** This study contributes to the literature by highlighting how different food formulations and processing techniques affect vitamin C retention, suggesting a need for further research to optimize nutrient delivery in infant food products [18].

IV. METHODOLOGY

The Philippines is a tropical country with abundant indigenous berries that contain health-promoting bioactive components such as vitamin C. The vitamin C content of a few native Philippine berries, including bignay and lipote, was assessed in this study in relation to fruit ripeness and processing method. Three maturity phases (unripe, half-ripe, and completely ripe) of the fruits of two bignay (Antidesma bunius Linn Spreng) types, "Common" and "Kalabaw," as well as lipote (Syzygium polycephaloides (C. B. Rob Merr)) were obtained in Laguna, Philippines. Vitamin C along with other substances that improve health are abundant in berries.

The samples were processed using two distinct techniques: steaming (105 ± 5 °C, 5 minutes) and blanching (90 ± 5 °C, 2 minutes). There was no processing done on the control samples. The amount of vitamin C contained was measured using reversed-phase high performance liquid chromatography while the flesh and seeds were separated, lyophilized, and extracted.The findings indicated that processing, maturity and their interaction all had a significant impact on the vitamin C contents of both fruits (P < 05). In general, as fruit maturity increased, both the flesh and the seeds' vitamin C content increased as well (by 0.3 to 1.7 times). In contrast, the vitamin C content of lipote seeds declined by 0.6 times as they matured. Additionally, the largest amount of vitamin C was retained in the fruit samples (247% at most) after blanching the fruits as shown in fig 2. Overall, this study's findings demonstrated that using these native berries in future functional product development of the ripe fruits must be combined with blanching the fully mature fruits as a pre-treatment procedure to achieve higher vitamin C contents [19].

Blanching Methodology:

- Clean the vegetables or fruits thoroughly. Cut them into uniform pieces if needed.
- Bring a large pot of water to a boil.
- Add the food to the boiling water for the required time (1-5 minutes depending on the food).
- Quickly transfer the blanched food to a bowl of ice water to stop the cooking process.
- Drain the food, pat it dry, and store it for later use (freeze or refrigerate).

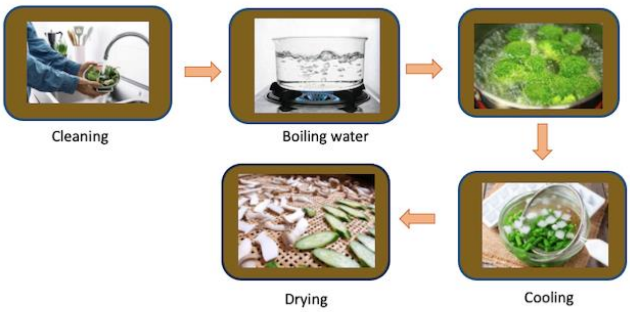

Figure 2. Blanching Methodology

A. Techniques to retain Vitamin C in Food Product:

a. Microencapsulation:

Vitamin gummies have gained popularity for their easy consumption and appealing flavors. However, exposure to oxygen, moisture, light, heat, and pH variations can cause water-soluble vitamins, such as vitamin C, to degrade. In order to improve vitamin stability, they manufactured "micro cheese powder" (MCP) by microencapsulating vitamin C in casein gel [20]. Storage tests showed that encapsulated vitamin C retained 92% of potency over ten weeks, compared to 79% in unencapsulated gummies. Enhancing vitamin stability in gummies may be possible with encapsulated vitamin C, which also showed improved retention under a variety of environmental conditions and a slower release in simulated gastric and intestinal fluids.

b. Pulse Electric Field:

In order to investigate the impact of pasteurizing orange juice from a Siam cultivar on its nutritional, physical, chemical, and microbiological characteristics, PEF technology was used. From June to September 2021, the study was carried out in Jember and tested PEF at five minutes (1 cycle), ten minutes (2 cycles), and fifteen minutes (3 cycles). Vitamin C, density, pH, soluble solids, and microbial counts all showed only slight alterations from the untreated juice, according to the results. Vitamin C was best preserved in the 10-minute treatment (2 cycles). PEF effectively retained vitamin C, taste, and aroma, avoiding the oxidation and nutrient loss typically caused by heat-based methods [21].

c. Drying:

Cashew apples, typically a by-product of cashew nut production, are nutrient-rich but underutilized due to their acrid taste. They developed a dried jelly product from cashew apples by optimizing blanching, osmotic dehydration, and drying processes [22]. The best conditions were to blanch the food in 6 mm slices, osmotically treat it for 1.5 hours at 35°C with a 2:1 sugar syrup-to-ingredient ratio (60 Bx), and add 0.6% citric acid and 0.02% $CaCl_2$. High amounts of ascorbic acid (TAA), total phenolic content (TPC), and tannins were retained after 267 minutes of drying at 55°C, which produced a tasty and nutrient-dense product. The process achieved a 21.45% recovery efficiency, with thicker slices (10 mm) retaining more TAA than thinner slices, likely due to slower heat transfer. This product enhances the value of cashew by-products, providing a nutritious and organoleptically acceptable option.

Using redox titration as an analytical tool, the various cooking techniques affected the vitamin C content of eight vegetables from the local market [23]. According to the findings, heat treatment significantly reduced vitamin C levels: 33–95% when frying, 6–93% when boiling, and 5–92% when steaming. Vitamin C retention was highest in fresh samples, with chili showing the highest vitamin C content (241.3 mg/100g) and brinjal the lowest (2.64 mg/100g). The findings confirm that vitamin C, being heat-sensitive and water-soluble, degrades significantly with increased cooking time and higher temperatures.

V. APPLICATION OF VITAMIN C IN FOOD INDUSTRY

To increase the shelf life of minimally processed pears, developed an antioxidant-rich packaged film in 2020 that was

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Vol 12, Issue 04, April 2025

based on papya edible film and contained ascorbic acid and Moringa olifera for food preservation [17]. Ascorbic acid, chitosan coating, and water plasma are used to preserve the quality of red grapes [24]. Ascorbic acid and jackfruit rind were combined to make a cookie that was high in antioxidants. Ascorbic acid addition improved the texture and sensory appeal of cookies with 40% JFR added [25]. Ascorbic acid is a commonly used natural color retention agent in meat products that can prevent lipid oxidation and preserve color stability [26].

Table II: Application of Vitamin C [15]

Applications of vitamin C	Description
Edible Films	Created an antioxidant-rich edible film with ascorbic acid and Moringa olifera, extending shelf life of minimally processed pears.
Chitosan Coating	Used in combination with ascorbic acid to maintain the quality of red grapes, enhancing their preservation.
Cookie Texture Improvement	Combined ascorbic acid with jackfruit rind to create antioxidant-rich cookies, improving texture and sensory appeal.
Color Retention in Meat	Commonly used as a natural colour retention agent in meat products, preventing lipid oxidation and preserving colour stability.
Browning Prevention Method	Investigated a method of soaking porang tuber chips in ascorbic acid solutions to prevent browning.

VI. BENEFITS OF VITAMIN C IN FOOD INDUSTRY

Vitamin C has antioxidant properties that can reduce o-quinone levels in food, delay oxidative food degradation, and stop fruits and vegetables from browning enzymatically [27] Many diseases caused by oxidative stress in the body, such as cancer, heart disease, aging, and cataracts, can be avoided by taking ascorbic acid, the strongest natural antioxidant with the fewest side effects [28]. When it came to protecting the quality of cured meat, ascorbic acid outperformed other organic acids like tartaric, citric, and malic acids. It is therefore a suitable component for products made from cured meat [29]. Pork surfaces treated with ascorbic acid and a combination of it and rosemary extract were able to maintain their color, water content, and pH after freezing [30].

Table III: Dietary factors determining vitamin C [31]

Factors	Recap and commentary
Dietary consumption	Dietary intake, particularly fruit consumption, is linked to a lower prevalence of deficiency and a higher vitamin C status. Vitamin C levels vary depending on the type of food, frequency, and quantity consumed. Reduced intake and status of vitamin C are linked to high dietary fat and sugar consumption.
Staple foods	Consuming low-vitamin C staple foods like grains (rice, millet, wheat/couscous, and corn) and some starchy roots and tubers may result in a population consuming less vitamin C overall.
Traditional cooking practices	Because water-soluble vitamins are lost when food is boiled or steamed, and because prolonged cooking destroys vitamin C, some social or ethnic groups may have lower vitamin C status. The water-soluble vitamins in leafy vegetables are also reduced when they are dried.
Supplement use	Supplement users have significantly higher vitamin C levels and are less likely to be vitamin C deficient. The likelihood of having inadequate and deficient vitamin C status is two to three times higher for non-users.

VII. IMPACT OF PRESERVATION METHODS ON VITAMIN C RETENTION IN FOOD PRODUCTS

A vital ingredient for many multicellular organisms, particularly humans, is vitamin C, commonly referred to as ascorbic acid (AA). Fruits, vegetables, and organ meats (such as liver and kidney) contain different levels of the water-soluble vitamin ascorbic acid. Vitamin C is most abundant in fresh fruits and vegetables [32]. The main objectives of food preservation are to increase crop

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Vol 12, Issue 04, April 2025

productivity, develop value-added products, and offer variety in diets as shown in flow chart in fig 3 . The demand from consumers for more convenient and healthful foods has an impact on food preservation methods [33]. There are numerous methods for preservation such as freezing, blanching, canning, drying, freeze- drying, irradiation and pasteurization. For example, the impact of pasteurization on vitamin C content in salmorejo. The study also found that intermediate pasteurization temperatures (80-95°C) yielded the highest total vitamin C levels. Overall, the heating procedure had a minimal impact on vitamin C retention in salmorejo, indicating that it remains a good source of vitamin C even after pasteurization [34]. The majority of the vitamin C deteriorated after one month of cool storage. For the product to retain vitamin C, pasteurization treatment seems to be less important than storage duration at the time of consumption. A high temperature can lead to severe nutrient loss, particularly in heat-sensitive vitamins such as B vitamins and vitamin C. For instance, higher processing temperatures accelerate the deterioration of several vitamins, reducing the nutritional value of the meal [35]. Furthermore, vegetables' antioxidant potential, which includes their vitamin C concentration, drastically decreases after 15 minutes of boiling, typically dropping below 50% [36]. Steaming is typically regarded as a kinder method that preserves more nutrients than boiling. Steaming preserves water-soluble vitamins and antioxidants better than boiling or frying [37]. The Chopping and grinding expose nutrients to oxygen, leading to oxidation of sensitive components such as vitamin C, while juicing removes essential fibre [38&39]. Heat-sensitive vitamins, such as vitamin C, may also be lost during the juicing process due to exposure to air and light [40]. Maintaining fiber intake and improving nutrient retention are frequently achieved more successfully by consuming entire fruits and vegetables [41]. Vitamin C is most abundant in fresh fruits and vegetables [32]. These processes can lead to the loss of nutrients and the production of harmful chemicals, which can have a significant effect on consumers' health [42].

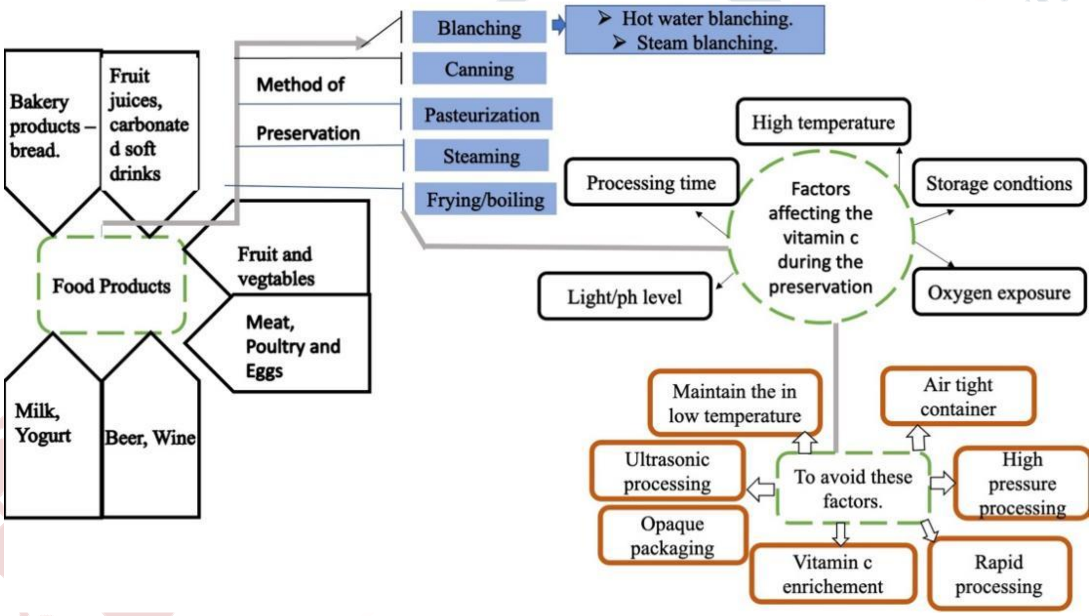

Figure 3. Flowchart for food preservation

VIII. RECENT ADVANCES AND INNOVATIONS

A. A Recent advances of vitamin C:

Vitamin C drives market growth across various industries.

New process technologies include the Reichstein process, two-step fermentation, and one-step fermentation.

Downstream processes like purification and recovery require attention. This review covers vitamin C's properties, applications, and intake recommendations.

Vitamin C deficiency is widespread, affecting many populations. This review examines vitamin C stability and delivery systems. [43]

B. Revolutionizing Citrus-Based Beverages: Exploring Cutting-Edge Processing Technologies for Enhanced Functionality and Nutritional Value:

The demand for functional products is increasing, driven by consumers seeking healthier options. Citrus-based beverages are gaining popularity due to their high concentration of bioactive compounds (BCs), which have potential health benefits.

Preserving the quality and safety of these beverages while maintaining their nutritional properties is a challenge. Traditional preservation methods involving high temperatures can damage sensitive BCs.

New processing technologies offer a solution. Techniques like pulsed electric fields, high-pressure processing, and ultrasound processing can preserve BCs while ensuring safety and quality.

This review explores the use of these technologies in functional citrus-based beverages, discussing their impact on functional properties, safety, and consumer acceptance. It also examines using citrus by-products to promote sustainable citrus processing. [44]

C. Effect of Processing Techniques on Vitamin C of Processed Fruit and Vegetable Products:

Vegetable cooking methods impact nutrient retention. Brief cooking times and alternative methods like steaming help minimize loss.Vitamin C supports collagen production, immune function, and wound repair. Its antioxidant properties protect cells from damage. [45]

D. Improving Vitamin C Retention in Edible-Coated Cherry Tomatoes with Parijoto Extract: A Promising Approach to Traditional Food Preservation

Medinilla speciosa Blume, commonly known as Parijoto, is rich in anthocyanins and has been traditionally used in food preservation. Edible coatings play a crucial role in extending the shelf life of food, making them an important part of traditional preservation methods. This study, in line with the principles of the *Journal of Traditional and Indigenous Food*, aimed to compare the vitamin C levels in cherry tomatoes preserved with edible coatings infused with Parijoto extract, coatings without the extract, and those left uncoated.

To measure anthocyanin content in the Parijoto extract, researchers used UV-Vis spectrophotometry, a widely used method in traditional food analysis. Vitamin C levels were determined through titration, following established indigenous food science practices. The findings showed that the Parijoto extract contained 0.05065% w/w (0.5065 mg/g) of anthocyanins.

Vitamin C retention was monitored over 4, 6, and 10 days, with study durations guided by traditional preservation techniques. Tomatoes coated with Parijoto extract maintained vitamin C levels of 0.31%, 0.30%, and 0.29% over time. Those with unfortified coatings had slightly higher initial levels at 0.34%, 0.31%, and 0.27%. However, the biggest decline was observed in uncoated tomatoes, reinforcing the importance of preservation techniques. The results highlight how traditional knowledge and modern food science can work together to improve food stability and nutrient retention [46].

E. Optimizing the Drying Process and Vitamin C Retention in Carambola: Effects of Storage and Temperature

Carambola (star fruit) is rich in vitamin C and offers many nutritional benefits. This study examined how moisture interacts with dried carambola, its drying behavior, and vitamin C loss during blanching, storage, and drying.Fresh carambola contained 91.44% moisture and 24.2 mg of vitamin C per 100 g. Drying experiments showed that higher temperatures increased drying speed, while thicker samples dried more slowly. Pretreatment with citric acid reduced drying time and vitamin C loss during blanching. Vitamin C degradation followed first-order kinetics, with prolonged exposure at a constant temperature leading to greater losses.During storage, vitamin C dropped by 13.7% in 3 days and 41.2% in 12 days at room temperature. Blanched samples retained more vitamin C in refrigeration, while frozen storage preserved it best. Scanning electron microscopy (SEM) revealed how temperature and pretreatment affected the fruit's surface structure.[47]

F. Vitamin C Stability in Plant and Vegetable Juices Under Various Storage Conditions

This study explored how different environmental conditions impact vitamin C retention in plant and vegetable juices. Researchers tested samples from chives, dandelion, nettle, tomato, carrot, cucumber, red and white peppers, and cabbage to assess the effects of storage time, temperature, and packaging materials on vitamin C stability.

Vitamin C levels were monitored over 21 days using an iodometric method, with juices stored at 4°C (refrigerated), 23°C (room temperature), and -18°C (frozen) in either glass or plastic containers. The results showed that refrigeration at 4°C and storage in glass containers significantly slowed vitamin C degradation, making them the best options for preserving the nutrient.

As expected, longer storage times led to greater vitamin C loss, and plastic containers were less effective than glass at maintaining its stability. High temperatures during processing and storage also accelerated vitamin C breakdown.

Overall, the study highlights that keeping juices refrigerated and using glass containers is the most effective way to retain vitamin C, ensuring better nutritional quality over time [48].

G. Impact of Drying on Apple Preservation and Its Vitamin C Content

Drying is a common food preservation method that removes moisture to slow down spoilage and maintain product quality. This study examined how drying affects both the microbial load and vitamin C content in Golden Delicious apples.

To enhance vitamin C retention, apple slices were pretreated by soaking in an ascorbic acid solution for 10 minutes before drying. The drying process took place in an oven at 60°C for 10 hours. Researchers measured moisture levels, microbial count, and vitamin C content before and after drying, with an additional vitamin C test conducted after the ascorbic acid pretreatment.

The results showed a significant reduction in microorganisms—from 11 x 10^3 CFU/ml to no detectable growth—due to moisture loss. This was confirmed by the final moisture content of the dried apples, which was 22.93%. Vitamin C levels initially increased from 41.5 mg/100ml in fresh apples to 46.5 mg/100ml after pretreatment, but after drying, it dropped to 13.25 mg/100g. The extended exposure to high temperatures led to this vitamin C loss.

In summary, while drying effectively reduced microbial growth by lowering moisture content, the prolonged heat exposure significantly decreased vitamin C levels, highlighting the trade-off between microbial safety and nutrient retention in dried fruit.[49]

H. Vitamin C Content in Orange Juice Extracted Using Different Methods

Proper nutrition plays a vital role in maintaining health, and vitamin C is a key nutrient involved in many metabolic processes. Fruits and vegetables are excellent sources of vitamin C, but its content varies depending on factors such as origin, season, processing, and storage conditions. This study focused on analyzing how different juicing methods and storage durations affect vitamin C levels in freshly squeezed orange juice.

Three varieties of oranges—Valencia, Salustiana, and Navelina—were tested using three extraction methods: a juicer, a slow-speed squeezer, and a manual squeezer. Vitamin C content was measured immediately after squeezing, one hour later, and 24 hours after storage in the refrigerator. The Tillmans titration method was used for vitamin C analysis, while a pH meter and a digital refractometer were used to measure acidity and sucrose levels.

Results showed that hand-squeezed Salustiana oranges had the highest initial vitamin C content. However, over time, vitamin C levels dropped significantly, with an average loss of 37.8% after 24 hours. The method of extraction also influenced vitamin C retention, with statistically significant differences observed between manual and machine-squeezed juices. Additionally, Valencia oranges had the highest pH, while Navelina had the lowest.

This study highlights that vitamin C degrades over time, even when stored in a refrigerator. To maximize its benefits, fresh orange juice should be consumed immediately after extraction, and hand-squeezing may help retain more nutrients compared to other methods.[50]

I. Evaluation of Vitamin C (Ascorbic Acid) Content in Orange Fruit (Citrus reticulata Blanco) Under Varying Temperature and Storage Duration

West Sumatera, Indonesia, produces a variety of fruits, with oranges being one of the most popular due to their rich vitamin C content, great taste, and affordability. However, how oranges are stored—whether at room temperature or in a refrigerator—can significantly impact their vitamin C levels. This study aimed to analyze how different storage temperatures (room temperature at 30°C and refrigeration at 8°C) and storage durations (1, 3, and 7 days) affect vitamin C retention in oranges.

To measure vitamin C content, the oranges were juiced, filtered, and diluted before being analyzed using a UV-visible spectrophotometer at a 264 nm wavelength. The results showed that vitamin C levels declined over time, with higher temperatures causing a faster rate of degradation. Oranges stored at room temperature lost vitamin C more quickly than those kept in the refrigerator, and after seven days, the vitamin C content had dropped significantly compared to shorter storage durations.

This research highlights that vitamin C is highly sensitive to temperature and storage conditions. To preserve its nutritional benefits, it is best to consume oranges fresh or store them in the refrigerator for a short period. Prolonged storage, especially at room temperature, leads to rapid vitamin C loss, reducing the fruit's health benefits.[51]

J. Vitamin C Levels in Selected Philippine Indigenous Berries: Influence of Fruit Maturity and Processing Treatments

As a tropical country, the Philippines is home to many indigenous berries that are rich in vitamin C, an essential micronutrient crucial for human health. The amount of vitamin C in fruits varies depending on factors such as species, maturity, and processing methods. This study focused on the vitamin C content of two local berries—bignay (*Antidesma bunius*) and lipote (*Syzygium polycephaloides*)—at different stages of ripeness and after undergoing various processing treatments.Fruits were collected at three maturity stages: unripe, half-ripe, and fully ripe. They were then either left raw or subjected to blanching (90°C for 2 minutes) or steaming (105°C for 5 minutes). The vitamin C content was measured using high-performance liquid chromatography (HPLC). Results showed that as bignay and lipote ripened, their vitamin C levels generally increased, with up to a 1.7-fold increase in the flesh and seeds. However, lipote seeds showed a slight decrease in vitamin C as they matured. Among the processing methods, blanching retained the highest levels of vitamin C, with some samples even showing a 247% increase compared to their raw counterparts.

This study highlights the importance of proper processing techniques in maximizing the vitamin C content of indigenous berries. To fully benefit from their nutritional potential, it is best to consume these fruits at full ripeness and undergo blanching before use in food products. These findings emphasize that traditional fruits like bignay and lipote can be valuable sources of vitamin C, especially when processed correctly.[52]

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IX. REGULATORY AND SAFETY ASPECTS OF VITAMIN C IN FOOD PRESERVATION

Due to its antioxidant properties, Vitamin C, commonly refer to as ascorbic acid, is essential for preservation of food. To guarantee consumer safety and product efficacy, it's use is subject a number of regulatory and safety considerations.

A. Regulatory Aspects

- **Food additives status:** The European Union recognises vitamin c as a food additive with the code E300.Ascorbic acid as *Generally* Recognizes *as Safe (GRAS)* by the FDA. Because of its potent antioxidant properties and it's ability to interact with many
- Elements, it has become important key ingredients for development of food additives. This has prompted industries to incorporate it into a wide range[53].
- **Labelling Requirement**: According to FDA vitamin c does not require labelling unless vitamin c is included in the product and the regulation pertaining to labelling should be followed by food products. This encourages transparency and well-informed decision-making by ensuring that the consumers are wary of the contents in the food goods they purchase.

B. Safety Aspects

- **Toxicity and Side Effects:** When consumed in appropriate amounts, Vitamin C is generally considered safe. The most common issues include diarrhea, nausea, stomach cramps, and other digestive discomforts, which occur due to the osmotic effect of excess, unabsorbed Vitamin C [54]. However, consuming more than 1 gram of Vitamin C orally has been associated with a 41% increased risk of kidney stone formation [55].
- **Quality Control Measures:** Control procedures of the highest standard are essential to ensure the effectiveness of Vitamin C in food preservation. These measures include monitoring Vitamin C levels in food products during production and throughout their shelf life. To improve food preservation strategies, mathematical models have been proposed to predict Vitamin C stability under various conditions [56].

X. CHALLENGES AND CONSIDERATION

Stability issues**:** Vitamin C can degrade its benefits since it is susceptible to environmental variables including heat, light and air. As vitamin c has a short shelf life, manufacturer must deal storage and packaging issues. To assure that vitamin c keeps working as a preservative for the prolongation of the product's shelf life, future improvements will need to solve these stability difficulties [57].

Despite having many obstacles, the future of Vitamin C in food preservation is bright. As research into its possible perk and drawback continues, its employment in the food sector is likely to expand. By harnessing the power of this natural antioxidant, the food makers may prompt safer, healthier, and more eco-friendly goods that satisfy the demands of today's discerning consumers.

XI. FUTURE PROSPECTS OF VITAMIN C IN FOOD PRESERVATION

Vitamin C holds great potential for the future of food preservation. However, challenges remain, primarily due to its instability during processing and storage, leading to significant degradation. For instance, conventional preservation techniques such as drying and heat processing often result in increased losses, making it necessary to explore alternative approaches.

Future advancements may involve the integration of innovative preservation methods, such as **pulsed electric fields (PEF), high-pressure processing (HPP), and ultrasound,** which have shown promise in preserving Vitamin C content. Additionally, nanotechnology-based encapsulation techniques could enhance the stability and bioavailability of Vitamin C in food products.

XII. CONCLUSION

Vitamin C, a powerful antioxidant and reducing agent, plays a pivotal role in maintaining the safety, nutritional quality, and overall integrity of food products. Its ability to prevent oxidation and degradation stems from its unique property of forming bonds with reactive molecules, thus inhibiting harmful chemical reactions. This makes Vitamin C indispensable in food preservation, where it not only enhances shelf life but also protects against nutrient loss. Understanding the factors affecting Vitamin C stability, such as exposure to heat, light, oxygen, and pH fluctuations, is crucial for minimizing losses during food processing. Techniques like blanching, pasteurization, freezing, and the use of protective agents, such as antioxidants and encapsulation methods, have proven effective in retaining Vitamin C in food products.

Advancements in food technology offer exciting opportunities for preserving and enhancing Vitamin C stability. Innovative approaches such as advanced encapsulation technologies, microencapsulation, and nanotechnology have opened new avenues for improving its delivery, bioavailability, and shelf life in food systems. Emerging methods like high-pressure processing, cold plasma treatment, and pulsed electric fields are also being explored for their potential to retain Vitamin C while minimizing nutritional and sensory quality losses. These technologies not only improve the nutrient retention of food but also align with the growing demand for minimally processed and nutrient-rich food products.

Equally important are regulatory frameworks that ensure the safe use of Vitamin C in food applications. Adhering to guidelines on maximum allowable levels in various food products prevents potential health risks, while proper labeling and consumer education inform buyers about its presence and benefits. By adhering to these safety and quality standards, manufacturers can maintain consumer trust while providing products that are both safe and nutritionally superior.

Further research into novel food processing methods and the application of sustainable practices to preserve Vitamin C is essential. Additionally, integrating Vitamin C into functional foods and fortification strategies can play a significant role in addressing public health challenges like nutrient deficiencies. By embracing these advancements and adhering to strict safety protocols, the food industry can continue to revolutionize Vitamin C applications, ensuring its contribution to enhanced food quality, extended shelf life, and improved human health.

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