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Review Article

# Advances in the Extension of Shelf-Life for Fresh-Cut Bananas

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## Abstract

The search for new products drives the development of alternatives to extend food shelf-life. Fresh-cut fruits like bananas deteriorate due to browning, texture loss, microbial growth, and enzymatic activity. This study reviewed 24 articles on technologies to preserve fresh-cut bananas, with data retrieved from Scopus and Web of Science and analyzed using Bibliometrix in R. Modified atmosphere packaging and dielectric barrier discharge stood out. Other methods included Lantana camara extract, ozonized water, chemical compounds, and chitosan, aiming to meet the growing demand for convenient, stable food products.

**Keywords:** Barrier technology; Industrial alternatives; Preservative; Technologic innovation

## Introduction

Minimally Processed Products (MPPs), such as vegetables and fruits, are processed foods that have been physically changed without the application of processing such as cooking in fruits and vegetables [1]. These products are more important in the diet of consumers since they provide benefits such as guaranteed food safety, nutritional values, and attractive appearance [2]. Among minimally processed products, many fruits presented important characteristics, since they present themselves as sources of vitamins and minerals [3].

Bananas (Musa acuminata Colla cv. AAA Cavendish) are the most important tropical and subtropical fruit and are more consumed and cultivated around the world [4]. In all the world, India is presented as a major producer of bananas (34,528.00 tons), and Brazil occupies the fifth position as the largest producer of bananas, with production of 6,923.744 tons produced in 2022 [5]. In the country, the major production is observed in São Paulo, Minas Gerais, Santa Catarina, Bahia, and Pará, with an average production of 1,499.324 tons, resulting in a gain of U$ 2.251.816,3435 in 2023 [6].

Bananas contains a rich presence of compounds with different potentials, such as phenolic compounds (flavonoids, carotenoids, and ascorbic acid) that are beneficial for human health. Moreover, bananas have properties for cancer prevention, gut health promotion, cardiovascular disease improvement, and anti-aging action [7]. Even though it presents several beneficial characteristics, the bananas postharvest management process can favor the occurrence of contamination and diseases in the matrices, and processes such as peeling, cutting, or slicing favor the reducing of shelf-life proving opportunities for extensive losses of the fruits [8]. Still, in the process of exportation, the quality and shelf-life diminished due to different climatic conditions in the origin country and the destination country [2].

Many techniques for conservation are implicated for increasing the shelf-life of MPPs, such as application of active packaging [9,10]; modified atmosphere [11-13]; juice [14]; dielectric barrier discharge [15-17]; essential oil [18]; ozonized water [19]; Ethyl 3-Amino-3-Thioxopropanoate (EAT) [20]; combination of calcium propionate and chitosan [21]; and more mechanisms are studied for the development of new techniques. In this sense, the application of safe techniques is a concern of modern consumers, thus, the interest in natural preservatives over synthetic preservatives, is related to consumers concerns about the risks that may be involved with synthetic preservatives [22]. Thus, the search for safe techniques for the conservation of fresh-cut bananas is an alternative for the improvement of products and favors the market potential of the Brazilian products. Therefore, this review seeks to present the main preservation techniques of fresh-cut bananas, their effect in matrices, in the time of storage, in shelf-life and safe characteristics of each technique.

## Techniques of Fresh-Cut Bananas Preservation

### Statically Analyzes of Dates with Bibliometrix

Researchers assessment various techniques to control the degradation of fresh-cut bananas. In this study, a search was conducted on two platforms for evaluation of principal methodologies applied in papers and principal results for these methods. It was realized for obtaining articles with different characteristics and promising results about the technique applied. For that, the search was realized with two keywords (Banana and Fresh cut). All articles returned were

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read, and a total of 25 articles were obtained in Scopus and 9 articles in Web of Science in the period of 2015 to 2024. For evaluation of this article, the methodology of Aria and Cuccurullo [23], was utilized to remove duplicated articles and statistical analysis based on the use of Bibliometrix. After removing duplicated articles, a total of 24 documents were obtained for analysis.

For evaluation of principal keywords present in all articles obtained, a Word Cloud was prepared for understanding the central topics presented in the works and for evaluating the principal techniques described by those authors, figure 1 presented the result obtained. It is possible to observe that the occurrence of different alternatives/techniques can be applicable to conservation, such as pickering emulsions, essential oils, active packaging, fruit packaging, fruit ethanol extracts, antioxidant activity, freeze-frying, and others. Many these techniques will be explained along this work.

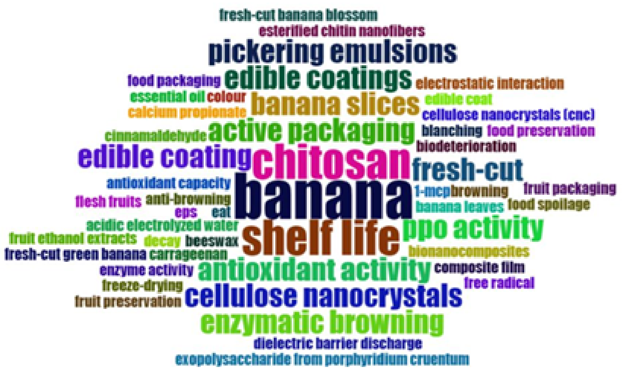


**Figure 1:** Principal authors keywords present in different articles evaluated.

Moreover, an alternative for evaluating the coupling of the articles favored the observation of correlation with different methods of preservation (Figure 2), this characteristic is more important for evaluating the potential of new methodologies development. In this case, it was possible to observe that major clustering for interaction with chitosan, active packaging, and fresh-cut. Chitosan is one of the polymers main applicate in the process of fruit preservation and presented promising results in your application. Edible coating is a technique that is very applicable for the conservation of different matrices, the different characteristics of the formulation can be favored by the shelf-life of the products.

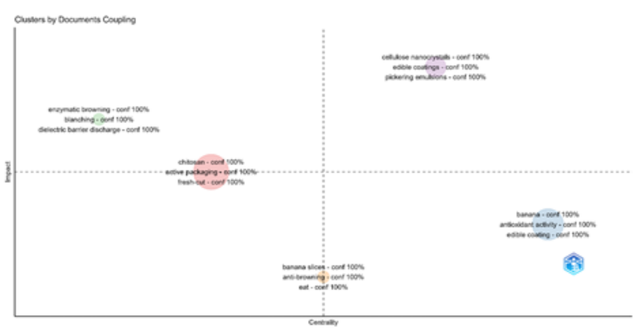


**Figure 2:** Clustering by coupling of principal results in articles obtained.

In relation to that publication citation per country, China presents the major concentration of citation articles published about fresh-cut banana preservation, figure 3 presents the principal countries with principal authors and keywords used in your papers. It is possible to observe that other countries, such as Australia, Bangladesh, and India, are those that publish the most on this subject. Moreover, it is possible to observe the application of chitosan and active packaging, it is realized by the principal authors of China. This behavior is expected because this method appeared more frequently in the two evaluations realized, and this result is proven when analyzing the list of main countries publications.

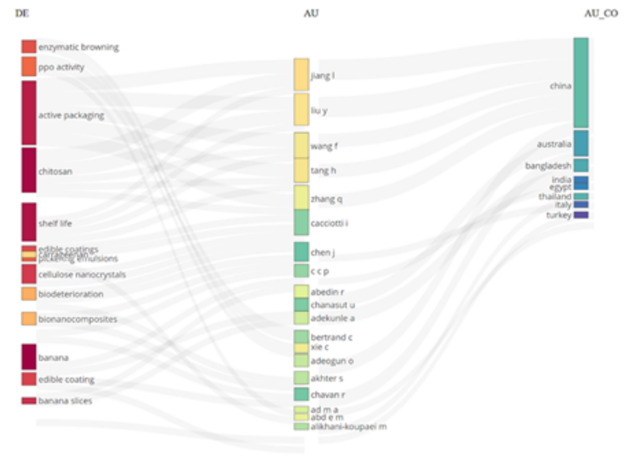


**Figure 3:** Evaluation of three field about major keywords, authors and country publication.

Thus, the statistical evaluation proves the application of different methodologies for the preservation of fresh-cut bananas. Still, as noted, the evaluation of synergism could be favored for the application of different methodologies together, acting as a tool of enrichment for the potential of reaction, resulting in a process with potential for conservation, with reduced enzymatic browning, reduced contamination potential, and favored shelf-life of the interest products.

## Preservative Methods of Fresh Cut Bananas

**Active Packaging:** The packaging is an important component in food, it is used to protect foods against chemical, biological, and physical agents, besides protecting the matrix against deterioration caused by ultraviolet light, water vapor, and oxygen [24]. Wrapping acts like a physical barrier that minimizes food alterations and increases the shelf-life, resulting in a product with ideal characteristics and with a wealth of natural compounds [25]. The formulation of classic packaging was developed with petroleum-derived polymers, due to their mechanical properties, cost of processing, and lightness [26]. However, this product presents harmful effects for nature and human health due to the potential of concentration in soil, plants, and oceans as microplastics [27].

The concern of consumers about the quality and security of food matrices has favored the change in market characteristics. This factor favored the search for new alternatives for developing safe products enriched with biological matrices [28]. In this sense, many components are incorporated in the development of packaging, such as antimicrobials, antioxidants, moisture regulators, $CO_2$ absorbents, and $O_2$ scavengers [29]. Still, synthetic and natural polymers are normally applied in the process for the development of biodegradable packaging [30]. Figure 4 shows a schematic illustration of the packaging compositions and interaction with the environment.

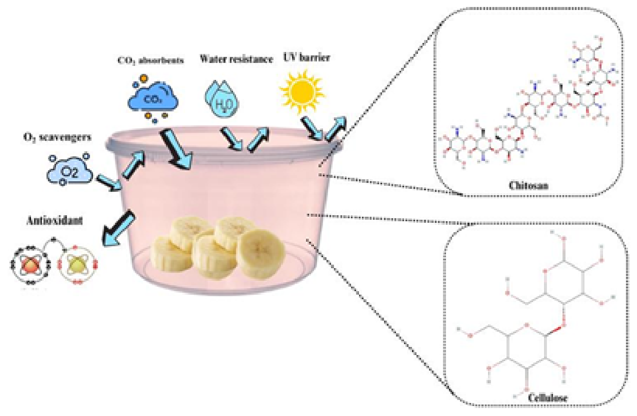


**Figure 4:** Schematic illustration of the interaction of packaging with the environment, mechanism favoring of shelf-life and possible composition materials.

The use of natural polymers favors strategies to improve functional parameters of films, such as blend, composite technique, cross-linking technique, and multi-layer technique [31-33]. Polymers such as polysaccharides (chitosan, cellulose, and starch), proteins, and lipids are normally applied for obtaining food packaging [34,35]. Disadvantages of the natural polymers are related to water vapor permeability and low mechanical strength in polysaccharide-based film and sensitivity to moisture in film prepared with protein and carbohydrates [36-38].

In this sense, the development of new alternatives for food preservation is a tool for the enrichment of the packaging to increase the shelf-life of different matrices such as fresh-cut bananas. In general, bananas undergo oxidation reactions caused by enzymatic browning that favor loss in product quality, color and texture alteration, and nutritional value. An alternative for controlling this process is the application of antioxidant compounds in the packaging. Villa-Rodriguez [39], classified the antioxidant technologies as follows coating-containing antioxidants, packaging material with antioxidant activity, antioxidants immobilized on the surface of the packaging, and antioxidants within the packaging matrix.

The antioxidant compounds are capable of kidnapping free radicals and hydrogen donation, reducing the oxidation in the matrix where they are applied [40]. In fruits, Reactive Oxygen Species (ROS) are caused by singlet oxygen, hydroxyl free radicals, singlet oxygen, and others. Antioxidant agents, such as tannic acid, glutathione, phenolic compounds, and ascorbic acid, can remove the ROS and increase the shelf-life of products [41]. Likewise, the control of microorganism contamination is necessary in the development of packaging as an alternative for degradation control, since they favor the shelf-life reduction of the food matrix.

The fresh-cut fruits are highly susceptible and vulnerable to rapid deterioration, this factor is reiterating the limitations of the microorganism control. In this sense, alternatives for reduced occurrence of microbiological contamination are being developed to break this barrier [42]. Antibacterial agents are alternatives for enrichment packaging and favor reducing microorganism growth. These compounds can be divided into organic, inorganic, and natural and have other antimicrobial agents based on chemical properties and sources [41].

Among the biological possibilities, the phenolic compounds have been applied as an alternative for growth microorganism control. Extracts of fruits, plants, leaves, and bark are alternatives for obtaining bioactive compounds rich in tannins, phenolic acids, and flavonoids with potential for preservation, safety, nontoxicity, and with antibacterial and fungi potential [43-46]. The presence of oxygen, water vapor, ethylene, and light in packaging can promote the microorganism growth, fat degradation, and vitamin degradation. Thus, the level of concentration of these compounds can be controlled in food packaging [47,48].

The oxygen permeability is an alternative for the available index of observed and controlled oxidation reactions that favored the parameters of food packaging [49]. The oxygen is capable of promotes degradation of vitamins, oxidation of fats, and growth of microorganisms. Many techniques are developed for control of the passage of oxygen and carbon dioxide. Different mechanisms of oxygen control can reduce the respiration of matrix and hamper the rate of ripening and senescence processes [47,50]. Also, the reduction of water vapor activity is an important alternative for protecting the fruits from spoilage and reducing food quality induced by this parameter. Packaging with a restricted water vapor barrier favors food organizational structure and biochemical reactions, resulting in reduced shelf-life of food [41,51].

Ethylene is a volatile hormone in plants, the release is related to their spoilage of fruits and vegetables, favoring reduced shelf life of these products. This hormone is produced as an effect of physiological reactions to the stages of ripening, dormancy, and blooming [52,53]. The high production of ethylene is observed after picking, the loss of quality of products is observed in concentrations of $0.10 \mu L^{-1}$ [54]. Normally, the ethylene regulation is realized by means of oxidation, blocking of ethylene, and adsorption [55].

Industrial processes apply ethylene scavengers as an alternative for controlling the process of the losses in quality of fruits and vegetables. The application of incorporating nanoparticles (Ag NPs, Cu NP, and $TiO_2$ NPs) is also an alternative for ethylene control, these nanoparticles can be incorporated into biodegradable packaging and achieve ethylene removal [56]. The alumina-supported potassium permanganate incorporated in bags can reduce the level of ethylene in the package, but the effectiveness of the compounds in packaging reduces over time due to oxidant depletion [57]. Actually, a promising alternative to ethylene control is the use of Metal-Organic Frameworks (MOFs) [58].

Due to the fresh-cut fruits and vegetables presenting a high surface area and porosity, the application of materials with the potential of concentration control of ethylene is necessary to extend the shelf-life of these products. The MOFs present excellent gas adsorption and desorption properties [59]. Due to the porous supramolecular framework of MOFs, the adsorption and desorption of ethylene are more efficient and selective in comparison to the usual methods, such as ethylene oxidizers and ethylene inhibitors [52].

Xia et al. [10], evaluated the effectiveness of multilayer zein/gelatin films for preserving freshly cut bananas. Five different film formulations were tested, including combinations of zein and gelatin at varying ratios (2:1, 1:1, and 1:2). The bananas were wrapped in the films and stored at 4°C for up to 14 days. The study assessed the films' impact on the Total Plate Count (TPC) and Yeast and Mold growth (Y%M). Results indicated that the multilayer films, especially those with higher zein content, provided better UV light protection and controlled Water Vapor Permeability (WVP), reducing bacterial growth and browning. The Z-TP/ZG-TP/G films had the lowest microbial counts and Y%M throughout the storage period. Additionally, the films with antioxidant properties were effective in slowing down water loss and extending shelf life, with the multilayer films showing improvements in transparency and barrier properties depending on the zein/gelatin ratio.

Apicella et al. [9], investigated the use of active coated films to reduce browning in fresh-cut bananas, with Polylactide/Poly (Butylene Adipate-co-Terephtalate) (PLA/PBAT), and Polyethylene Terephthalate (PET) film. Four film types were tested: uncoated PLA/PBAT, PLA/PBAT, uncoated PET, and PET. Bananas were sliced, vacuum-packed, and stored at 4°C for up to 3 days. The PLA/PBAT film had lower oxygen permeability, while uncoated PLA/PBAT showed lower water vapor permeability. The study found minimal microbial growth, with enterobacteria slightly increasing during storage, but no significant changes in pH. Firmness decreased over time, and color changes were noted, with *a** values increasing and *b** values decreasing. Browning was observed in PLA/PBAT films, but the PET film with a 5% active phase of PLA/PBAT showed less browning. The results suggest that active coatings can help delay browning and preserve the quality of fresh-cut bananas.

**Modified Atmosphere:** Modified Atmosphere Packaging (MAP) is an alternative for food preservation, this alternative is capable of reducing the oxidation process in foods through the control of proportion-specific gases inside packages [60,61]. Resulting in an equilibrium atmosphere, entering the product and packaging favoring the reduction of respiration, rate of deterioration, and slow down, extending the product shelf-life. Among the main benefits of this technique, the following stand out: reduced water loss, inhibition of microorganism growth during storage, and safety from skin abrasion [62].

However, due to different characteristics of fruits and vegetables, the interaction enters MAP and matrix, in conditions where the $O_2$ concentration decreases below the critical threshold and the anaerobic respiration and fermentation are affected, the reactions in matrix food can result in off-flavors [63,64]. In this sense, the high $O_2$ concentration can result in different variations in the food that affect the quality and commercial interest [65]. But when applied in ideal conditions, the films may prevent the flow of respiratory gases due to the relative permeability of packaging films that favoring the reduction in respiration rate by lowered $O_2$ and higher $CO_2$ concentrations inside the package, resulting in prolonged shelf-life [66]. Figure 5 presents a schematic operation of MAP.

In this sense, MAP can be defined as an active or passive dynamic packaging system, applicable as an alternative for modifying the gas concentration in the headspace of food packaging [67]. Passive MAP is related to the selective permeability of the film to gases, resulting in an equilibrium state of low $O_2$ and high $CO_2$ through spontaneous adjustment [68]. For active MAP gases with required compositions, they are flushed into the packaging until reaching the rapid equilibrium atmosphere [67].

After the application process of MAP, it is necessary to store the product at lower temperatures (0-5°C), this procedure is necessary to maximize the food shelf-life. Besides that, the increase of temperature favoring the $O_2$ requirements from tissues, in the same way, the tolerance to $CO_2$ decreased [69]. In this sense, the application of modified atmosphere is related to different characteristics of the matrix of application and the conditions of MAP preparation. It is necessary to evaluate the principal necessary features for obtaining controlled conditions of temperature and equilibrium atmosphere and know the singularities of the application matrix.

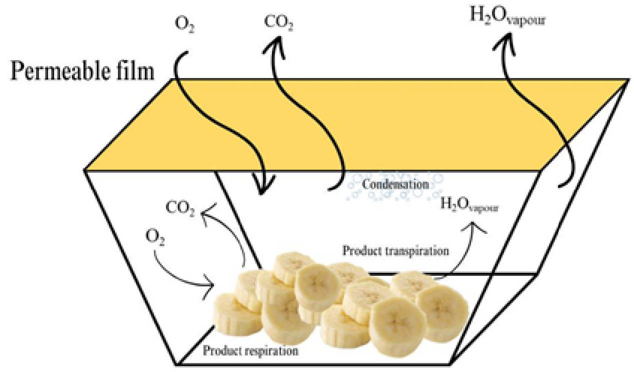


**Figure 5:** Schematic illustration of the interaction of packaging with modified atmosphere and your mechanism of favoring product shelf-life.

In the study by Chiabrando and Giacalone [11], modified atmosphere was used as an alternative to control enzymatic browning and quality preservation of fresh-cut banana. The treatments included ascorbic acid as a control, L-cysteine, calcium chloride (3%), and ascorbic acid (3%) at 1% ($T_1$) and 5% ($T_5$), stored at 4°C for 7 days in Polyvinyl Chloride (PVC) packaging. Weight loss was approximately 0.3% for T5 and 0.25% for the control and $T_1$. The $O_2$ concentration decreased from 20% to around 10%, and the $CO_2$ concentration increased from 0% to about 12% for the control and $T_1$, and 10% for $T_5$. The *C** value decreased in all treatments, with the largest reduction in the control (8.27). The $h^0$ parameter showed the greatest reduction in the control (18.08) and the smallest in $T_5$ (4.03). Thus, treatments $T_1$ and $T_5$ showed promising results, with $T_5$ being the most effective in preserving characteristics.

Utama [13], evaluated the effect of heat treatment and Modified Atmosphere (MAP) on the fruit firmness of fresh-cut banana. Four treatments were applied: MAP with 73.70% argon gas and heat treatment at 40°C for 5min ($P_1$), heat treatment at 40°C for 5min ($P_2$), MAP with 73.70% argon gas ($P_3$), and control ($P_4$), with storage at 10°C. Hardness decreased in all treatments, with the largest reduction in $P_3$ (0.11Nmm$^{-2}$) and the smallest in $P_1$ (0.08Nmm$^{-2}$) after 10 days. Total titratable acidity varied significantly after 6 days, and after 10 days, the highest concentration was in $P_4$ (1.20%) and the lowest in $P_1$ (0.80%). Reducing sugar increased in $P_3$ (9.0%) and decreased in $P_2$ (6.5%) after 10 days. Phenolic concentration decreased in all treatments, reaching 0.16ppm. Overall, $P_1$ showed the best results compared to the other treatments.

**Juice:** The minimally processed affects the structure of the matrix, favoring the mechanism of interaction between peroxidase and oxidant compounds. It is possible because these fruits are commercially available in slice format. The process of obtaining these characteristic advances the maturation process due to the membrane rupture of fruits [70]. In this sense, the browning process is observed in a rapid time, affecting the sensorial characteristics and reducing commercial interest in the product. Still, it is observed the reduction of nutritional parameters of the matrix [71-73].

An alternative to controlling this process is applying compounds with natural agents. These compounds are named bioactive compounds, and a diversity of them exist in different vegetable matrices [71,74,75]. The bioactive compounds are secondary compounds synthesized for plants, such as protection against injuries, climate and different factors that can affect your growth [76,77]. Thus, a diversity of studies proves the potential of these compounds against different diseases, such as diabetes, hypertension, Alzheimer's and others. Furthermore, many studies available show the potential of these compounds in the growth control of microorganisms, obtained promising results [78-80].

In addition, bioactive compounds have a high potential antioxidant that favors the reduction of peroxidase and polyphenoloxidase activity. The bioactive compounds can be divided into phenolic acids, flavonols, tannins, stilbenes, and others [81,82]. These compounds are present in different concentrations in plants, and your extraction can be realized with different solvents, such as ethanol, methanol, and water [83-85]. In a process where the application will be realized on minimally fresh-cut fruits, normally the application of extract is realized by means of a slice of fruit dipped in the juice obtained with water of interest matrix [75]. This process favors the interaction with matrix and bioactive compounds present in the juice, resulting in the reduction of the browning reaction and favoring the shelf-life of products [14].

Due to the biological characteristics of juice, it is possible that the material affects the flavor of the product. Thus, it is necessary to evaluate the concentration where a high potential of compounds and low changes in the final product can be observed [14,75]. An alternative is dissolving the juice in water to obtain a controlled concentration and reduce this factor [75]. Furthermore, the presence of ascorbic acid, calcium chloride, cysteine, and citric acid favors the reduction of browning [86]. The process by immersion is common in fruit salads and is possible to evaluate in different locales, such as supermarkets, coffee shops, airports, and hotels, and is realized in salads with different fruits [87].

The immersion can be variable to process application, in mechanism with sucrose, the characteristic anti-browning of the solution can be observed in a short-term period. Immersions realized for 1 or 2 minutes it is possible to observed the permanence of the conservation barrier throughout shelf-life evaluation [88]. To be obtained from a biological matrix, the juice presents better conditions for the human system, resulting in the reduction of the use of synthetic compounds in the study of shelf-life enrichment. Furthermore, the application of the juices presents innocuous characteristics and is a low- cost alternative [87]. Figure 6 presents a schematic interaction of juice and sample in the process of immersion.

In a study, Sarkar et al. [14], evaluated the prevention of enzymatic browning of fresh-cut banana by immersed in normal water, lemon juice, and coconut water. The samples were immersive in 500mL of all solutions for 1min at 28°C and stored at 4°C for 12 days. The lemon juice and coconut water presented better results in comparison with water for enzymatic browning reduction, the same results were observed for $L^*$ value, with better results for these solutions. The $a^*$ value increased for all samples, and the $b^*$ value presented a delay in increase with lemon juice and coconut water. In general, the whiteness index followed the comportment: Raw <Normal water <Lemon juice <Coconut water. The results prove the potential of ascorbic acid and antioxidant compounds present in different solutions applied in this study.

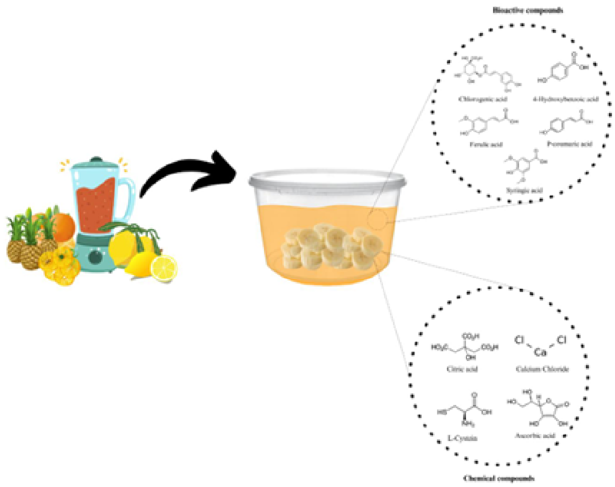


**Figure 6:** Schematic illustration of the interaction that juice and sample and your mechanism of favoring product shelf-life.

**Dielectric Barrier Discharge:** The Cold Plasma (CP) is an emergent alternative used in various industries in the shelf-life food enrichment. This technology can be divided into thermal or high-temperature and nonthermal plasma, this second has different applications in industries due to not causing alterations in the food matrices sensitive to heat, which has favored interest in the research on this technology [89-92]. Plasma is considered the fourth stage of matter, it presents itself as an ionized gas composed of electrons, positive and negative ions, photons, and free radicals [91,93]. Energy, such as gamma radiation, electromagnetic radiation, UV light, and electrical energy, can produce plasma [92].

The application of plasma can be realized in different forms, many studies evaluated the application of this technology, such as packaging modification, microbial inactivation through reactive oxygen species, cell damage, enzyme inactivation, DNA cleavage, and toxin degradation [94-96]. The plasma has presented the potential of reducing the browning enzymatic in fruits, favoring the shelf-life through the favor parameters such as of color and flavor in fruits and vegetables [97]. There are different methods of application of this technology, such as Dielectric Barrier Discharge (DBD) and corona discharge [98].

The DBD is emitted by the application of dielectric material such as plastic, ceramic, glass, polymer layers, or quartz that is submitted to a current emitted by the application of two metal electrodes [91]. The application of BDB is recognized as the safest discharge method, with the potential to reduce spark and arc discharges through the use of limited current [92]. In general, the BDB can operate in gas pressures variably from $10^4$ to $10^6$ Pa and an electrode distance of 0.1 to several centimeters and requires high ignition voltages of 10 kV, in these cases certain precautions of isolations are necessary depending on the narrow electrode gap [91,99].

There are different types of dielectric barrier discharge. The surface DBD consist of a wispy and long electrode linked to a dielectric surface, opposed to an elongated counter-electrode. In general, about this arrangement, there is not a defined distinct discharge [100]. While in the volume DBD, the microdischarges are initiated in the 3-D region observed by the gap between the electrodes. In this case, one or the two electrodes can be coated with dielectric material, and the discharge can present planar or coaxial configurations. In a planar discharge the electrodes run parallel, and in coaxial arrangements, one electrode encases the other, with one or two dieletric barriers positioned in the system [101]. Other forms can be Co-Planar DBD [102]; Floating- Electrode DBD [103,104]; Micro-Hollow BDB [105]; and BDB Plasma Jets [106,107].

The application of DBD presents high efficiency at short-term treatments, with results less than 1 min. While applicate on large scales, the operating costs can be reduced while noble gases (argon or helium) are applicable [108]. This method is applicable as an alternative for oxidation of the double bond with ROS sensitive, it is possible because the oxygen and nitrogen plasma is generated by ROS, including $NO_2$, $O_3$, O, NO, OH. These compounds interact with unsaturated fatty acids in the cell membrane, this process causes oxidative stress due to the biomolecules being prevented from moving [109,110].

In fruit applications, a possible Log reduction count of microorganism was observed in DBD treatments with a short time [111,112]. The application of microsecond- pulsed DBD can be used as an alternative to inhibit mold growth and activate the air on the surface of bananas during storage, resulting in shelf-life extension [113]. Still, some studies conclude that the treatment with plasma does not cause significant differences in quality parameters (color, pH, and texture) and nutrition [111,113,114]. However, other studies resulted in variation of parameters in the matrices after plasma treatment independent of treatment time, such as degradation of phenolic compounds, increased cell permeability, and plasmolysis and breakdown of organelles [111,115,116]. Figure 7 presents a schematic interaction of DBD and the sample in the treatment process.

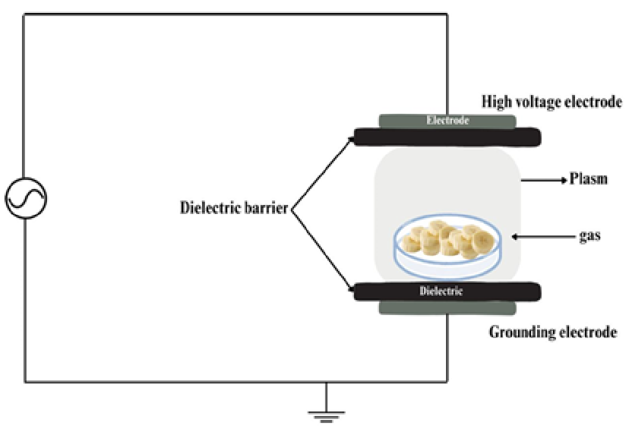


**Figure 7:** Schematic illustration of dielectric barrier discharge and your mechanism of operation.

In a study by Zhang et al. [17], the effect of plasma activated water on fresh-cut banana quality was evaluated. The process used a plate-plate electrode with positive and negative circular electrodes of 550mm in diameter. The discharge voltage was 40 V, with a current of 0.8 A and a discharge distance of 6mm, applied for 15, 30, 60, and 90 seconds. Peroxidase (POD) and Polyphenol Oxidase (PPO) activity increased during the first 2h of storage, then decreased after 4 and 6h. The largest POD reduction occurred with a 90-second treatment, while the greatest PPO reduction was at 60 seconds. Color measurements showed a decrease in $L^*$ and $b^*$ values over time, and $a^*$ values increasing at 8h. Compared to the control, the treated samples maintained higher color values. These findings suggest that the treatment effectively inactivates POD.

Similarly, Gu et al. [15], studied the effect of cold plasma enzyme inactivation in banana slices. The treatment was realized with an input voltage set at 40 V, an input current at 0.6A, air in atmospheric conditions, and time intervals of 1min, 1.5min, and 2min. The research observed a decrease in the Polyphenol Oxidase (PPO) activity while increasing the treatment time, with a major reduction in the third treatment (169.80U-2min), Peroxidase (POD) activity also decreased in the same time (237.30U). The difference in the results can be related to the presence of different structures and isoenzymes. For color parameters, significant changes were observed in $L^*$ and $a^*$ values between control and untreated, but not in $b^*$, which can be related to the impact caused in these parameters after treatment. In general, $L^*$ and $b^*$ values decreased gradually during storage (5h), while $a^*$ values increased inversely.

Still, Pour et al. [16], assessed the effect of atmospheric cold plasma on the quality of banana slices. The authors evaluated the effects of two factors, voltage (4.8-6.9 kV) and time of cold plasma treatment (35-155s), the voltage was 4.8 to 6.9kV and frequency were 12 to 22kHz for 35-155s. The activity of Polyphenol Oxidase (PPO) decreased while increasing time and voltage, the PPO activity decreased from 86% to 30%, while voltage increased from 4.8 to 6.9kV. Same, the time from 35 to 155s reduced the PPO activity from 80% to 29%. Likewise, it was observed that the time and plasma voltage affect the antioxidant activity, being observed to increase from 40% to 90% of this potential in high levels of time with voltage variation from 4.8 to 6.9kV.

**Essential Oil:** Essential Oils (EO) have been applied for medicinal and health purposes for many years by different cultures [117]. The use of these compounds is related to the capacity of the plants to produce secondary metabolites for your protection, these compounds can be divided into alcoholic compounds (geraniol, linalool, and menthol), acidic compounds (myristic acids, benzoic, and cinnamic), phenols, terpenes, aldehydes, and others [118]. Due to the concentration of different compounds in the matrices, the EO began to be used as an additive in food matrices, pharmaceutical processes, agriculture, and cosmetic industries [119]. Still, to be obtained from biological matrices, the EO are recognized as safe (Generally Recognized as Safe-GRAS) for the U.S. Food and Drug Administration (USFDA) [120].

The EO can be obtained from different parts of plants, such as leaves, barks, seeds, flowers, and peels, and different extraction methods result in the obtention of this material, such as distillation, hydrodistillation, fermentation, and effleurage [121-123]. Due to the concentration of bioactive compounds, the EO are recognized for their antimicrobial and antioxidant potential, which characterizes them as alternatives for partial or total substitutes for synthetic preservatives [124]. In this case, it is necessary to observe that the bacterial control can be variable by plant origin and concentration of interesting compounds in the structure [125]. Still, other characteristics influence the biological potential, such as ring structures, chemical groups, and side chains of the EO [126].

Many factors can vary the shelf-life of fruits, exposure to light, heat, moisture, transmission of gases, contamination by microorganism, and mechanical stresses, that result in degradation of the matrices [127,128]. The EO are capable of interacting with the matrix and reducing bacterial or fungal ontamination, such as *B. cinerea* [129]; *Clostridium perfringens* [130]; *P. expansum* [131]; *Staphylococcus aureus*; and *E. coli.* [132]. In general, Gram-positive bacteria are more susceptible to essential oils than Gram- negative, this is justified by hydrophilic Lipopolysaccharides (LPS) present in the membrane of Gram-negative bacteria that act as a barrier to hydrophilic compounds and macrolecules, reducing the potential of EO [133].

Still, it is possible observed reduction of EO potential application in samples where the microorganism can have undergone mutation or genetic variations among species is necessary, in this case, it is necessary to evaluate different conditions of EO application and observe the obtained results [134]. While antifungal potential, the EO increases the membrane permeability, and the biocompounds present in the oil can dissolve in cell membranes, resulting in membrane swelling, consequently, the membrane function is reduced. The EO is also capable of disintegrating fungal hyphae by the mono- and sesquiterpene present in your composition [135]. Figure 8 presents a schematic interaction of EO and the microorganism cell in the treatment process. The EO can be applied in different forms, some studies presented the use of EO in edible coatings. This alternative is capable of extending the activity of EO and limiting the possible alterations in sensorial parameters that the EO can occasion in the product when applied in low concentration [136]. Another alternative is the application of EO microcapsules, these alternative favors the loss reduction of the biological potential of the compounds. It is possible because the EO will be retained in a structure with the potential to preserve functional activity, controlled release properties, and favor physicochemical stability [137]. Furthermore, this application can reduce possible contamination and growth of microorganisms in the matrix due to the enrichment of antimicrobial and mechanical properties related to the composition of essential oil and the mechanisms of application [138].

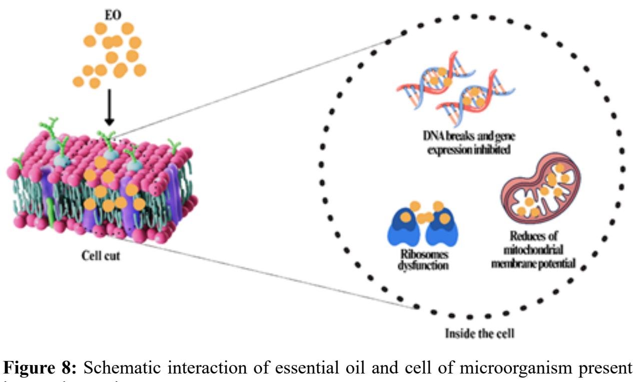


**Figure 8:** Schematic interaction of essential oil and cell of microorganism present in sample matrix.

Alikhani-Koupaei [18], evaluated the application effect of essential oils on the storage of fresh-cut bananas. In general, four experiments were applied: [(1) slices dipped in distilled water (control); (2) rosemary oil with 0.1mgmL$^{-1}$ concentration alone (Ro); (3) rosemary oil plus mucilage of cactus stems (Mu+Ro); and (4) liposomal rosemary oil plus mucilage of cactus stems (Mu+LipoRo)]. The author observed that the parameters of color $L^*$ and $c^*$ decrease after 9 days of storage, lower browning was observed for Mu+LipoRo. Similarly, the Mu+LipoRo presented the lowest rates of firmness. While Polyphenol Oxidase (PPO) and Lisil Oxidase (LOX) activities were observed, it was noted that Mu+LipoRo provided lower PPO (37,400Uming$^{-1}$FW) and LOX (41,300Uming$^{-1}$ FW) activities after 9 days of storage. For microbial growth, the Mu+LipoRo and Mu+Ro treatments resulted a lower count (<400CFUg$^{-1}$) during storage analyses.

**Other Alternatives:** Many alternatives favor the shelf-life of different matrices food. As noted in this work, fresh-cut banana presents a lower duration, due to with of the different enzymes and the processing effects, in this sense, the search for different alternatives for enrichment of this matrix has been realized. The evaluation of leaf extract of *Lantana camara* with Maize-base coating in fresh-cut banana, resulted in low change in of total soluble solids (16-19.67°Brix), the pH varied that 4.84-5.07, was observed increase in the antioxidant potential after 9 days of storage (31.96mgTE 100g$^{-1}$ after 15 days), and the concentration of phenolic compounds was superior in comparison with all other experiments. Likewise, the browning potential was low in comparison with others after 9 days, and the weight loss was also smaller [139].

The application of ozonized water (1ppm) in fresh-cut banana was realized as alternative for fungal decontamination. During the evaluation of the samples, was identified fungal count that 51CFUg$^{-1}$, being *Alternaria alternata*, *Colletotrichim musae* and *Fusarium culmorum*. Still, was identified concentration of the mycotoxins Altenariol (377,2µgkg$^{-1}$) and Zwaralenone (377,2µgkg$^{-1}$) in the sample. The treatment was realized with ozonized water applied for 1 and 2min. Was observed that the percentage reduction of fungal count reduced by 100% in both tests, as well as mycotoxins concentrations [19].

In the appraisal of the Ethyl 3-Amino-3-Thioxopropanoate (EAT) effect on the browning fresh-cut banana. Was observed that the browning increased from 0.82 to 3.89, less in comparison with the control (3.79 to 14.98). The same was observed in visual quality, with significantly increase in the $L^*$ and $b^*$ parameters, and significantly declined in $a^*$ parameter. The Polyphenol Oxidase (PPO) and Peroxidase (POD) exhibited increased in your activity, that was suppressed by the treatment. Already Phenylalanine Ammonia-Lyase (PAL) activity was higher in comparison with control, while the Lisil Oxidase (LOX) activity was diminished over time. The treatment also resulted in higher DPPH radical scavenging activity, indicated that the efficiency of the EAT in the mitigation membrane peroxidation and oxidative stress [20].

Combination of calcium propionate and chitosan could be an alternative for preservation of minimally processed banana. In evaluation of 1% Calcium Propionate (CaP), 1% chitosan (Chit), and 1% CaP+1% Chit, was observed that respiration ration in the samples treated with Chit and CaP+Chit was lower in relation with control. The same was observed to firmness, when CaP+Chit present better firmness in comparison with the others samples. For antioxidant activity the treatment with CaP and CaP+Chit presented higher levels in relation to the control. After 5 days of storage, the treatment with Chit and CaP+Chit presented significantly less browning, with $L^*$ parameters decreased during storage. The PPO and POD activities was lowest after 2 and 5 days storage with Chit and CaP+Chit, treatment, but increase during storage for all treatments [21].

## Conclusion

Among technologies applied in industrial processes, fresh-cut fruits emerged as an alternative for a modern society that searches for practicality in everyday life. However, such products can suffer different processes related to your matrix. As assessed throughout this work, the fresh-cut banana may suffer consequences after it is processed, such as browning, texture and firmness loss, and oxidation. In this sense, it is necessary to evaluate alternatives for enrichment of this matrix that result in a final product within consumption standards and with high technological potential. All techniques discussed in this work present different characteristics of operation and conditions processes. In that regard, the application of these must be evaluated in terms of the parameters that enable its operation. Among the methods evaluated, the modified atmosphere presented as a good alternative for the color parameters evaluation, while the dielectric barrier discharge is applied in the evaluation of enzymatic activity. Still, the study with multilayer zein/gelatin films, presented major product life extension (14 days). Thus, the appraisal of the enrichment process for fresh-cut bananas is an alternative for increased availability of this product for the purpose of establishing it in a potential market that seeks practicality and technology in its meals.

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