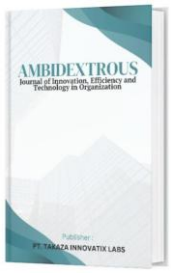
Ambidextrous: Journal of Innovation, Efficiency and Technology in Organizations

https://journal.takaza.id/index.php/ambidextrous

Vol. 6, no. 1, 2026 , pp. 33-40
E-ISSN: 3031-7002

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Cell Wall and Cellular Membrane Integrity of Postharvest Tropical Fruits and Its Implications for Minimal Post-Processing Damage (Fresh-Cut): A Narrative Literature Review

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Article History:
Received: 31-10-2026
Revised: 07-11-2026
Accepted: 07-11-2026

Keywords: Cell Integrity; Pectin Degradation; Fresh-Cut Fruit; Narrative Literature Review; Cytosolic Leakage

Abstract :*Tropical fruits are commodities prone to post-harvest quality degradation, particularly when minimal processing (fresh-cut) involves peeling, cutting, and the formation of new tissue surfaces. This mechanical damage can accelerate changes in cell wall and membrane structures, thus affecting the texture, freshness, and stability of fruit tissue. This article aims to analyze the relationship between cell wall pectin degradation and cell membrane damage with textural changes and cytosolic leakage in post-harvest tropical fruit. The method used is a narrative literature review with a literature search through Google Scholar using keywords related to cell integrity, pectin, cell membrane, post-harvest, and fresh-cut fruit. Literature was selected based on topic relevance, year of publication, and its relationship to post-harvest physiology and fruit processing and storage technology. The results of the study indicate that tissue softening is related to changes in cell wall components, especially pectin, while membrane damage can increase cell permeability and cause the release of cytosolic components. Storage temperature, mechanical injury, water loss, and atmospheric conditions during storage can accelerate these changes. Temperature control, packaging, storage atmosphere, and coating technology can be used to slow the decline in tissue integrity. This study emphasizes the importance of maintaining cell wall and membrane structures simultaneously in managing the quality of fresh-cut fruit.*

How to Cite : Salma Karima Husna Khatidjah, Nauval Yusuf Fathin, Ujik Fero Adin Nugroho, Syafara Hautni Ramadhani Putri, Almas Shofia Hanifah, Khofifah Yasmin Ulaya, Yunita Satya Pratiwi. (2026).

Cell Wall and Cellular Membrane Integrity of Postharvest Tropical Fruits and Its Implications for Minimal Post-Processing Damage (Fresh-Cut): A Narrative Literature Review. 6(1). Pp 33-40 https://doi.org/10.61536/ambidextrous.v6i01.992

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Introduction

Tropical fruit is a food commodity that is prone to quality changes after harvest because physiological processes within the tissue are still ongoing. These changes can be seen in the texture, color, aroma, taste, and freshness of the fruit during storage. Post-harvest handling is crucial because environmental conditions and post-harvest treatment can influence the rate of quality decline.(Sofyaningsih et al., 2024)Food technology is then used to control these changes through temperature control, packaging, atmosphere control, and other preservation methods.(Gunawan, 2025). Attention to post-harvest quality is also increasingly important because tropical fruit has a long distribution chain and involves various stages before it reaches consumers.(Larasati et al., 2022)This situation becomes even more complex when the fruit is marketed fresh-cut because the peeling and cutting processes directly damage the fruit tissue.

Fresh-cut produce has the advantage of being more convenient and ready to eat, but minimal processing can accelerate quality degradation. Cutting exposes the surface tissue, making the fruit's interior more susceptible to air, water loss, and other environmental factors. Damage caused by processing can also affect the characteristics of food during storage.(Miksusanti et al., 2025)These changes can cause the tissue to lose its firmness and result in a softer texture. At the cellular level, this condition is related to changes in the structure of the cell walls and membranes that maintain the components within the tissue. Therefore, understanding these changes in cell structure is crucial to explaining why fresh-cut fruit deteriorates more rapidly than whole fruit.

The cell wall is a crucial structure that plays a role in maintaining the shape and strength of fruit tissue. Pectin is a cell wall component that is associated with tissue compactness and intercellular bonds. Changes in cell wall components during ripening and storage can lead to changes in the physical characteristics of the fruit.(Hayati et al., 2025)When the cell wall structure degrades, the tissue can become weaker and the fruit's texture can deteriorate. These changes are more visible in cut fruit because the tissue has already been mechanically disrupted. Therefore, changes in texture in fresh-cut fruit can be attributed to changes in cell wall structure, particularly in the components that maintain tissue strength.

In addition to the cell wall, the cell membrane plays a crucial role in maintaining the cell's internal components and regulating the movement of substances. An intact membrane can restrict the release of various components from the cell into the surrounding environment. Conversely, membrane damage can increase permeability, allowing cell components to more easily escape. This condition can be seen through the leakage of tissue fluid or increased leakage of components originating from the cytosol. Changes in cell integrity are part of the structural changes that can occur during food handling and storage.(Helilusiatiningsih et al., 2024)In fresh-cut fruit, membrane damage is important because cutting can increase tissue exposure to environmental conditions and accelerate the deterioration process.

The decline in cell wall and membrane integrity does not occur independently of post-harvest conditions. Storage temperature is one factor that can influence the rate of fruit quality changes during storage. Changes in temperature and storage duration can affect the chemical characteristics of the fruit, as demonstrated in a post-harvest study of avocados.(Kasim et al., 2024). Unsuitable temperature conditions can also cause physiological disturbances in certain fruits during cold storage. In tomatoes, the development of chilling injury during storage can be accompanied by decreased freshness and changes in tissue quality.(Zainal et al., 2025)This condition indicates that temperature control needs to consider the physiological characteristics of each type of fruit so that tissue integrity can be maintained.

Various technologies have been developed to prevent post-harvest fruit quality degradation. Packaging and edible coatings can be used to help maintain fruit quality by controlling conditions around the surface of the fruit.(Hariyanto et al., 2026)Hypobaric storage can also be used as an approach to maintain fruit quality by regulating pressure conditions during storage.(Lastriyanto et al., 2022).

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Atmospheric control through Controlled Atmosphere Storage and Modified Atmosphere Storage technologies can help control the storage conditions of tropical fruit.(Rahmadhan et al., 2025)Ethylene control can also be used to slow the ripening process in certain fruits so that changes in quality can be suppressed.(Silvia et al., 2023)These various approaches demonstrate that post-harvest environmental management plays an important role in maintaining the quality of fruit tissue.

Although various studies have addressed fruit storage and preservation technologies, discussions of the relationship between cell walls, cell membranes, texture, and cytosolic leakage still need to be integrated into a single study. Some studies focus more on fruit quality based on physical, chemical, organoleptic, or shelf-life changes. Post-harvest handling of commodities such as oranges is also more focused on technical steps to maintain quality during distribution.(Hendrawan et al., 2025). Studies on pineapples show the importance of proper handling from post-harvest to processing.(Insani et al., 2024)Meanwhile, the presence of pests and microorganisms can accelerate the damage to fruit tissue during storage.(Jihadi et al., 2025)This condition indicates the need for studies that link changes in network structure with more specific quality indicators in fresh-cut products.

Based on these conditions, this article uses a Narrative Literature Review approach to synthesize various findings regarding cell wall and cell membrane integrity in post-harvest tropical fruit. The main focus of the study is directed at cell wall pectin degradation, cell membrane damage, textural changes, and cytosolic leakage in fresh-cut fruit. This study also examines post-harvest factors that can accelerate these changes, particularly temperature, water loss, atmosphere, and mechanical treatment. Various post-harvest technologies are then compared to identify approaches that can help maintain tissue integrity. The novelty of this study lies in the arrangement of the relationship between cell wall and cell membrane changes and indicators of fresh-cut product damage within a single discussion framework. The purpose of this article is to analyze this relationship and identify post-harvest approaches that can be used to slow the decline in fresh-cut fruit quality.

Literature Search Method

This study used the Narrative Literature Review method to identify and synthesize various research results relevant to the postharvest tissue integrity of tropical fruit. Literature searches were conducted through Google Scholar because the database provides various scientific articles and academic sources related to food technology and postharvest. The search was directed at literature discussing cell wall structure, pectin, cell membrane, texture, cell leakage, storage, and minimal processing of fruit. Keywords used included fresh-cut fruit, cell wall integrity, pectin degradation, cell membrane, membrane integrity, cell leakage, fruit texture, postharvest quality, and tropical fruit. The combination of these keywords was used to obtain literature that had a direct or supporting relationship to the focus of the study. The obtained literature was then grouped based on the appropriate theme before being used in the synthesis process.

Inclusion criteria were established to ensure the literature aligns with the study objectives. The selected literature included sources discussing tropical fruits, food technology, postharvest quality, storage, texture changes, tissue structure, packaging, coatings, or minimal processing technologies. Literature published between 2021 and 2026 served as the primary sources to ensure the study reflects relatively recent research developments. Books discussing the fundamentals of food technology were retained to strengthen the conceptual foundation of food structure and changes. Literature unrelated to fruit, unrelated to postharvest quality, or unsupportive of tissue changes was not used as the primary basis for the synthesis. Following the selection process, literature meeting the criteria was analyzed based on themes and relationships between findings.

The literature analysis was conducted using a thematic and descriptive approach. The first stage identified information regarding changes in cell wall structure and pectin components in fruit after harvest. The second stage focused on changes in cell membrane integrity and the possible release of cytosolic components from the tissue. The third stage compared the relationship between these structural changes and changes in fruit texture and freshness. The next stage identified environmental factors and post-harvest treatments that could accelerate or slow these changes. Findings from each theme were then

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compared to produce a synthesis of damage mechanisms and quality control approaches for fresh-cut fruit.

Results and Discussion

1. Cell Wall Integrity and Textural Changes

Cell walls play a crucial role in maintaining the shape, strength, and compactness of fruit tissue. This structure is composed of various components that interconnect to form a relatively strong network. Pectin is one component that plays a role in maintaining intercellular bonds and the characteristic texture of fruit.(Hayati et al., 2025)During ripening and storage, changes in cell wall components can cause the tissue to soften. These changes are a form of quality degradation that can be physically observed in fruit. In fresh-cut produce, textural changes become more significant because the cutting process has already caused initial damage to the tissue structure.

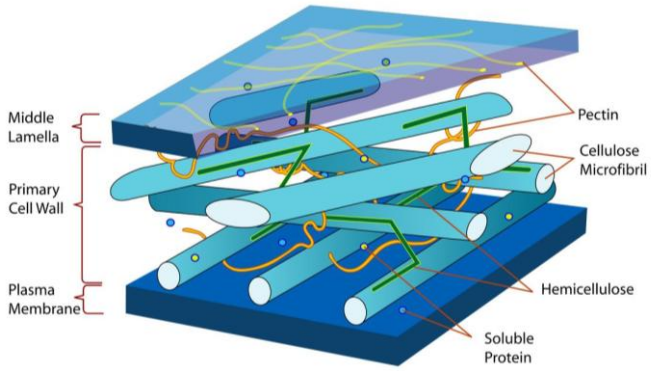


Figure 1. Cell Wall Structure in Plant Tissue

Figure 1 shows the structure of the cell wall in plant cells, which plays a crucial role in maintaining cell shape and strength. The cell wall is located outside the cell membrane and serves to provide protection and mechanical support to the cell. The cell wall structure is composed of several interconnected components, including cellulose, hemicellulose, and pectin. Pectin is primarily found in the middle lamella and plays a role in helping maintain intercellular adhesion in plant tissue.(Hayati et al., 2025)This structure also forms the basis for understanding the characteristics of fruit tissue, as fruit is a plant organ composed of cells with cell walls. Changes in cell wall components during ripening, storage, and processing can affect the strength and texture of fruit tissue.

Tissue softening can be influenced by storage conditions after the fruit is harvested. Temperature and storage duration can influence chemical changes and quality characteristics of the fruit during the post-harvest period.(Kasim et al., 2024). Changes in biophysical and organoleptic quality can also occur in horticultural commodities due to different storage temperature conditions.(Pangestika et al., 2026)These conditions indicate that texture changes are influenced not only by the natural ripening process but also by the storage environment. In cut fruit, these effects can be more pronounced because the tissue has a more exposed surface. Therefore, temperature control is a crucial factor in maintaining the texture of fresh-cut produce.

2. Pectin Degradation and Tissue Softening

Pectin degradation is a process associated with changes in the strength of fruit tissue. When the pectin structure changes, intercellular connections can become weaker, causing the tissue to lose its cohesiveness. This condition is evident through decreased tissue hardness and increased tissue softness. Food processing can also affect the structure of the material through mechanical treatment and environmental conditions during processing.(Miksusanti et al., 2025)In fresh-cut products, the cutting process can accelerate the appearance of changes because the tissue has been directly damaged. The relationship between cell wall structure and texture is important in explaining changes in product quality during storage.

Efforts to maintain tissue structure can be achieved by controlling the environment around the fruit. Edible coatings can form a layer on the surface of the material that helps reduce water loss and control gas exchange during storage.(Hariyanto et al., 2026)This control has the potential to help slow changes in tissue characteristics during storage. However, fresh-cut produce has a larger surface area

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due to the cutting process, so its protection needs differ from those of whole fruit. This situation suggests that coating technology needs to be tailored to the surface characteristics and type of fruit used. Therefore, controlling pectin degradation cannot be separated from managing environmental conditions during storage.

3. Cell Membrane Integrity and Cytosolic Leakage

The cell membrane functions to maintain the cell's internal components while also regulating the movement of substances between the cell and its environment. An intact membrane helps maintain the balance of components within the tissue. When the membrane is damaged, its permeability can increase, allowing cell components to more easily escape. These changes can lead to the leakage of fluids and cytosolic components into the intercellular space or tissue surface. This condition is more likely to occur when the tissue experiences mechanical damage due to cutting. Therefore, cytosolic leakage can be used as an indicator to help describe decreased membrane integrity in fresh-cut products.

Changes in membrane integrity can also be related to physiological conditions during storage. Inappropriately low temperatures can cause physiological disturbances in certain fruits and affect tissue freshness. The development of chilling injury in tomatoes demonstrates that cold storage can induce detrimental changes when temperature conditions are not compatible with the characteristics of the commodity.(Zainal et al., 2025). Frozen or cold storage conditions can also result in differences in post-harvest quality of tomatoes.(Rahmawati et al., 2025)These findings demonstrate that the stability of cell tissue is significantly influenced by temperature conditions during storage. For fresh-cut fruit, temperature control requires careful consideration because the cut tissue is more vulnerable.

4. The Relationship between Cell Membranes and Cytosolic Leakage

Cytosolic leakage is a consequence that can occur when the cell membrane is no longer able to optimally retain internal components. Under normal conditions, the membrane functions as a barrier that regulates the movement of components between the inside and outside of the cell. Membrane damage can increase the movement of these components, allowing cellular fluids to leak out of the tissue. This condition can cause the surface of the product to become wetter and potentially lead to a decrease in tissue firmness. In fresh-cut fruit, mechanical damage from cutting can be the beginning of this change. Thus, cytosolic leakage can be considered an indicator of changes in tissue integrity related to product quality.

Membrane damage is influenced not only by the cutting process but also by subsequent handling conditions. Proper post-harvest handling is necessary to minimize physical damage and maintain fruit quality during distribution.(Hendrawan et al., 2025)Post-harvest processing stages in pineapples also demonstrate the importance of proper handling to maintain quality before the product reaches the next stage (Insani et al., 2024). Tissue damage that occurs during handling can increase the likelihood of quality changes during storage. In addition to mechanical damage, infestation by organisms can also accelerate fruit tissue deterioration. The presence of post-harvest fungi in tomatoes demonstrates that biological factors also need to be considered in maintaining tissue condition during storage.(Simamora et al., 2022).

5. Storage Factors on Network Integrity

Temperature is a major factor influencing the rate of post-harvest fruit quality changes. Storing at the appropriate temperature can slow physiological processes and help maintain tissue quality. Conversely, temperatures that are too high can accelerate quality changes, while temperatures that are too low can cause physiological disturbances in certain commodities. The use of controlled atmosphere storage technology can help control the environmental conditions surrounding the fruit. Controlled atmosphere storage and modified atmosphere storage can be used to regulate gas composition, thereby slowing physiological processes during storage.(Rahmadhan et al., 2025)This regulation is important for fresh-cut fruit because tissue changes can occur more rapidly once the fruit surface is exposed.

In addition to temperature and atmospheric conditions, the ripening process also influences changes in fruit tissue structure. Ethylene is one factor associated with the ripening process in various

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fruit commodities. Ethylene control can be used to delay ripening and thus reduce quality loss. The use of $KMnO_4$, clay, and zeolite as ethylene oxidizers in bananas represents one approach to delaying post-harvest ripening.(Silvia et al., 2023)For fresh-cut products, ripening control is essential, as this process can be associated with changes in texture and tissue structure. Furthermore, integrated storage environmental control is essential to prevent physiological changes from occurring too rapidly.

6. Fresh-Cut Damage Control Technology

Various post-harvest technologies can be used to maintain fruit quality by controlling environmental conditions and slowing physiological changes. Hypobaric storage is one technology that can be used to maintain fruit quality by regulating pressure and storage conditions.(Lastriyanto et al., 2022)Packaging can provide physical protection while also helping control the microenvironment surrounding the product. Edible coatings can also be used as a protective layer to help maintain the surface condition of the fruit during storage.(Hariyanto et al., 2026). Hot water treatment on mangoes shows that temperature and treatment time settings can be used in post-harvest fruit handling.(Hakim et al., 2025)However, applying this technology to fresh-cut products requires consideration of the sensitivity of the tissue that has undergone cutting.

Post-harvest technology control also needs to consider the characteristics of each commodity. Bananas, mangoes, pineapples, oranges, avocados, and tomatoes have different physiological responses during storage. Education on post-harvest banana handling demonstrates the importance of understanding how to maintain quality and shelf life at the household level.(Jannah et al., 2026)On a broader scale, tropical fruit supply chain management also requires consistent management from production to distribution. This is related to the importance of maintaining product quality during movement between stages in the tropical fruit value chain.(Larasati et al., 2022)Therefore, the technology used to maintain cell wall and membrane integrity needs to be tailored to the fruit type, ripeness level, cut shape, temperature, and storage duration.

7. Synthesis of the Relationship between Cell Wall, Membrane, Texture, and Cytosolic Leakage

Based on the literature synthesis, changes in the quality of fresh-cut fruit can be understood as a series of interrelated processes. The cutting process causes initial mechanical damage, making the tissue more exposed to the environment. Subsequently, changes in the cell wall and pectin can weaken intercellular bonds and reduce tissue strength. At the same time, membrane damage can increase cell permeability, allowing cytosolic components to leak more easily. Both changes can be seen through decreased texture, fluid leakage, and reduced product freshness. Thus, changes in texture and cytosolic leakage can be used as complementary indicators to understand the decline in tissue integrity.

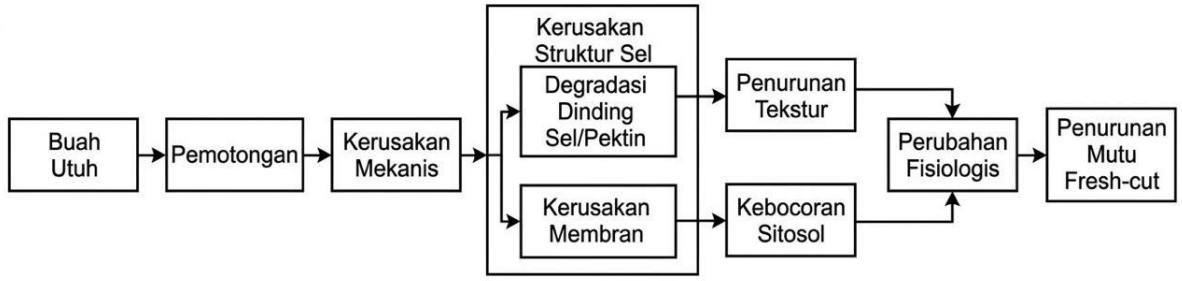


Figure 2. Cell Wall and Membrane Damage in Fresh-Cut Fruit

Figure 2 illustrates the sequence of changes that can occur in fruit tissue after fresh-cutting. Cutting causes mechanical damage to the tissue, creating a new surface that is more exposed to the environment. This damage can be accompanied by changes in cell walls and pectin, weakening intercellular bonds, resulting in decreased tissue firmness. At the same time, membrane damage can increase cell permeability and allow cytosolic components to escape from the tissue. These conditions can contribute to the appearance of fluid on the cut surface and a decrease in the texture and freshness of the product. The relationship between these two pathways suggests that fresh-cut quality degradation must be understood through changes in the overall tissue structure.

This synthesis demonstrates that fresh-cut quality control should not be directed solely at one aspect of deterioration. Temperature control is necessary to control physiological processes and reduce

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the risk of deterioration due to inappropriate storage conditions. Packaging and edible coatings can help protect surfaces and control the microenvironment surrounding the product. Atmospheric control can also be used to slow physiological activity during storage.(Rahmadhan et al., 2025). Controlling biological factors needs to be considered because fungi and pests can accelerate damage to fruit tissue.(Jihadi et al., 2025). Therefore, the best approach based on the synthesis of the literature is a combination of mechanical, temperature, atmospheric, humidity, and surface protection controls tailored to the characteristics of each fruit.

Implications and Limitations

1. Implications

This study provides theoretical implications that changes in the quality of fresh-cut fruit need to be understood through the relationship between cell wall and membrane structures. The cell wall is primarily associated with tissue strength and texture, while the cell membrane plays a role in maintaining the cell's internal components. Changes in both structures can occur simultaneously after fruit is cut and stored. This understanding can help explain why textural changes are often accompanied by fluid release from the tissue. Practically, the study results can be used as a basis for determining storage and packaging strategies that maintain tissue integrity. A food technology approach needs to consider material characteristics and processing conditions to ensure that treatments do not accelerate deterioration.

Another implication relates to the choice of technology to extend the quality of fresh-cut produce. Temperature control can be used to slow physiological processes, but needs to be tailored to the tolerances of each commodity. Packaging, edible coatings, and atmospheric conditions can be combined to control the environmental conditions surrounding the fruit tissue. These approaches can help maintain texture while reducing the possibility of fluid leaching from cells. At the industrial level, understanding the relationship between cell structure and quality can be used to determine storage and distribution parameters. This study can also serve as a basis for future research to more accurately measure changes in pectin, membrane integrity, hardness, and electrolyte leakage.

2. Limitations

This study has limitations because it used a Narrative Literature Review approach, meaning the literature selection and synthesis process did not follow systematic review or meta-analysis procedures. The literature search was conducted through Google Scholar, so the sources obtained depended on indexing results and the availability of publications in that database. Some of the references used discussed post-harvest quality in general and did not specifically examine fresh-cut products. Some sources also emphasized aspects of storage technology, handling, or commodity quality rather than direct measurements of pectin and membrane integrity. Therefore, the relationships between pectin degradation, membrane damage, textural changes, and cytosolic leakage in this study are the result of a synthesis of various interrelated findings. Further experimental research is needed to directly test these relationships across different tropical fruit species, ripeness levels, cutting methods, and storage conditions.

Conclusion

Cell wall and membrane integrity are two crucial aspects in maintaining the quality of tropical fruit after harvest, particularly in fresh-cut produce. The cutting process can cause initial tissue damage, followed by structural changes in cell walls and membranes during storage. Pectin degradation can weaken intercellular bonds and lead to decreased tissue strength and texture. Membrane damage can increase cell permeability and lead to leakage of cytosolic components, which is evident through fluid leakage and decreased freshness. Factors such as temperature, atmosphere, water loss, ripening, and biological damage can accelerate these processes. Therefore, quality control of fresh-cut fruit requires an integrated approach through temperature, atmosphere, packaging, coating, and handling management tailored to the characteristics of each commodity.

Thank-you note

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The author would like to express his gratitude to all parties who have provided support in the process of compiling this article, both in literature searches, information processing, and completion of the manuscript.

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