



# EVOLUCIÓN BIOQUÍMICA Y FISIOLÓGICA DURANTE LA MADURACIÓN DEL BANANO (*MUSA × PARADISIACA L.*)

## BIOCHEMICAL AND PHYSIOLOGICAL EVOLUTION DURING THE RIPENING OF BANANA (*MUSA × PARADISIACA L.*)

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### RESUMEN

El banano (*Musa × Paradisiaca L.*) es una fruta climatérica cuya maduración, controlada por la producción de etileno, induce cambios bioquímicos y fisiológicos significativos. Este proceso involucra la conversión de almidón en azúcares, la degradación de la clorofila y el ablandamiento de la pulpa, lo que afecta su color, textura y sabor, propiedades esenciales para su calidad. El objetivo del estudio es analizar los principales cambios bioquímicos y fisiológicos durante la maduración del banano y las estrategias empleadas para conservar su calidad postcosecha. La metodología consistió en una revisión integradora de la literatura sobre los cambios bioquímicos y fisiológicos del banano durante su maduración. Se analizaron estudios previos sobre firmeza, color y composición nutricional del fruto, así como las tecnologías de conservación utilizadas, como el control atmosférico y los recubrimientos comestibles. Los resultados muestran que el contenido de almidón disminuye drásticamente durante la maduración, mientras que el contenido de azúcares aumenta, lo que afecta tanto la firmeza como la textura del fruto. Además, el color de la cáscara cambia de verde a amarillo debido a la degradación de la clorofila. El uso de tecnologías de conservación, como el control de la atmósfera y los recubrimientos comestibles, ralentiza la maduración y preserva la calidad del banano durante el transporte y almacenamiento. Se concluye que la maduración del banano es un proceso complejo influenciado por factores genéticos y ambientales, y que la implementación de estrategias de conservación adecuadas es crucial para garantizar su calidad en el mercado global.

### Palabras clave

Banano, bioquímicos, maduración, fisiológicos

## ABSTRACT

The banana (*Musa × Paradisiaca L.*) is a climacteric fruit whose ripening, controlled by ethylene production, induces significant biochemical and physiological changes. This process involves the conversion of starch into sugars, chlorophyll degradation, and pulp softening, which affect its color, texture, and flavor—key properties for its quality. The study aims to analyze the main biochemical and physiological changes during banana ripening and the strategies employed to preserve its post-harvest quality. The methodology consisted of an integrative literature review on the biochemical and physiological changes of bananas during ripening. Previous studies on the fruit's firmness, color, and nutritional composition were analyzed, as well as the conservation technologies used, such as atmospheric control and edible coatings. The results show that starch content drastically decreases during ripening, while sugar content increases, affecting both the firmness and texture of the fruit. Additionally, the peel color changes from green to yellow due to chlorophyll degradation. The use of conservation technologies, such as atmospheric control and edible coatings, slows ripening and preserves banana quality during transportation and storage. In conclusion, banana ripening is a complex process influenced by genetic and environmental factors, and the implementation of appropriate conservation strategies is crucial to ensure its quality in the global market.

## Keywords

Banana, biochemical, ripening, physiological

## INTRODUCTION

The ripening of climacteric fruits, such as banana (*Musa × Paradisiaca L.*), is a fundamental process that determines their quality and commercial acceptance. This phenomenon involves a series of biochemical and physiological changes that affect key attributes of the fruit, such as color, flavor, texture and nutritional value (1). In this context, banana ripening acquires special relevance due to its importance in the global agricultural economy, since it is one of the most traded tropical products (2). However, the perishable nature of this fruit poses great challenges for its post-harvest handling, storage and transportation, which makes it necessary to delve deeper into the mechanisms that regulate its ripening and the strategies available to preserve its quality (3).

One of the main problems in the banana production and marketing chain is the rapid degradation of its quality during post-harvest (4). Banana ripening is controlled by the synthesis of ethylene, a gas that acts as a plant hormone in climacteric fruits, triggering a series of biochemical events, such as the conversion of starch into sugars, the softening of the pulp, the loss of chlorophyll and the appearance of the characteristic yellow color (5). These changes not only improve the organoleptic characteristics of the fruit, making it more attractive for consumption, but also reduce its useful life, generating significant economic losses during transportation and storage (6).



Postharvest handling of bananas has been the subject of multiple investigations, in which different technologies and strategies have been explored to delay ripening and prolong their useful life without compromising their quality (5). Among these strategies, the control of the atmosphere, the use of edible coatings and refrigeration stand out, which reduce the respiration rate of the fruit and the production of ethylene, thus slowing down the ripening process (7). However, despite advances in this field, there remains a need to optimize these techniques to minimize fruit deterioration, especially in international markets where transportation times are long (8).

The objective of this study is to analyze the main biochemical and physiological changes that occur during banana ripening, and to review the most effective technologies and strategies to preserve its quality during postharvest (9). Through an exhaustive review of the scientific literature, it is intended to offer a comprehensive vision of the processes that regulate banana ripening, as well as the genetic and environmental factors that influence these changes. In addition, the different conservation technologies currently available will be evaluated, in order to provide practical recommendations for their application in the industry (7).

The relevance of this study lies in the economic and social importance of bananas in tropical and subtropical countries, where their production and export constitute a crucial source of income (10). According to recent data, bananas are the fourth most important agricultural product in terms of global production, after rice, wheat and corn (11). This underlines the need to implement effective technologies that not only prolong the useful life of the fruit, but also maintain its quality characteristics, thus ensuring its competitiveness in international markets (12).

From a biochemical perspective, banana ripening involves changes in the structure of the cell wall, which translates into a progressive softening of the fruit. At the physiological level, the increase in enzyme activity, such as pectin methylesterase and polygalacturonase, plays a key role in the breakdown of the cell wall, which reduces the firmness of the fruit (4). Likewise, the conversion of starch into simple sugars, such as glucose, fructose and sucrose, contributes to its sweetness and characteristic flavor, while the degradation of chlorophyll causes the color change in the peel, going from green to yellow. This set of transformations makes bananas a highly perishable product, which requires careful handling to maximize its useful life (8).

In technological terms, controlling the atmosphere is one of the most used strategies to delay banana ripening (13). This technique consists of regulating the levels of oxygen and carbon dioxide in the storage environment, which slows down the respiration of the fruit and reduces ethylene production. Recent studies have shown that maintaining low levels of oxygen (between 2-5%) and high levels of carbon dioxide (5-10%) can significantly extend the shelf life of bananas, without compromising their quality. Furthermore, the use of edible coatings, such as natural waxes or biopolymers, has been shown to be effective in reducing moisture loss and delaying ripening, acting as a physical barrier that protects the fruit from mechanical and pathogenic damage (14).

On the other hand, refrigeration has established itself as one of the most efficient technologies to preserve the quality of bananas during storage (15). By keeping the fruit



at low temperatures, generally between 13 and 15°C, it is possible to slow down the metabolism of the fruit, reducing its rate of deterioration and preserving its firmness, color and flavor. However, it is important to note that excessive refrigeration can cause cold damage to bananas, which limits its applicability at certain stages of transportation and marketing (16).

In conclusion, banana ripening is a complex process, influenced by both genetic and environmental factors, which directly impacts its post-harvest quality (17). Understanding the biochemical and physiological mechanisms that regulate this process is essential for the development of more effective conservation strategies that allow the useful life of the fruit to be prolonged without compromising its quality characteristics (18). Through this study, we seek to offer a comprehensive vision of the changes that occur during banana ripening and the technologies available for its conservation, thus contributing to the development of more sustainable and efficient post-harvest practices in the global banana industry (19).

## MATERIALS AND METHODS

The present study was carried out through an integrative review of the literature with the objective of analyzing the biochemical and physiological changes that occur during the ripening process of banana (*Musa × Paradisiaca* L.), as well as the technologies and conservation strategies used in its post-harvest management. To achieve this, several phases were carried out in the data search, collection and analysis process, which are described below.

### • Data Collection and Review Process

An exhaustive search was performed in the ScienceDirect, Scielo, and PubMed databases using the terms “maturation and biochemistry,” “physiological changes,” “banana ripening,” and “postharvest conservation,” combined with the Boolean operator “AND.” The initial search yielded a total of 1,048 results, which were filtered by applying the following inclusion criteria: studies published in the last seven years, peer-reviewed articles, experimental trials and review articles related to the ripening of climacteric fruits, particularly bananas. Additionally, key studies from previous years were included, which contained relevant information and which had been cited in the most recent literature.

After applying these filters, the titles and abstracts of the selected articles were reviewed to discard those that were not directly related to the objectives of the study. These articles provided the basis for the literature review of the biochemical and physiological changes during banana fruit ripening and the post-harvest conservation strategies used.

### • Data analysis

The information collected was organized into thematic categories:

1. Biochemical changes
2. Physiological changes
3. Conservation technologies

## 4. Postharvest strategies.



For each category, detailed summaries of the reviewed studies were made, emphasizing the experimental methods used, the results obtained and the conclusions proposed by the authors.

Regarding biochemical and physiological changes, the analysis focused on the evolution of key components, such as the conversion of starch into sugars, the degradation of chlorophyll and the loss of fruit firmness. Quantitative data on sugar concentration, starch content and firmness at different ripening stages were collected, and a comparative analysis was performed between the reviewed studies. In addition, the effects of ethylene on the ripening process were evaluated, as well as the role of temperature and other environmental factors that can directly affect banana ripening.

- **Statistical analysis**

Although this study is qualitative in nature, statistical data from the studies reviewed were used to strengthen the analysis. Descriptive techniques were used to interpret the variability in the results of firmness, color, and carbohydrate content in the different studies. The results of the studies were presented in tables and graphs to facilitate the comparison between the different conservation techniques and their effects on banana quality during post-harvest. In those studies that did not report detailed statistical analyses, a qualitative interpretation of the results was made, taking into account the coherence between the findings and the authors' conclusions.

## RESULTS

### Firmness and texture analysis (ripe)

**Table 1: physicochemical analysis of firmness in banana**

| NAME RESEARCH | TYPE OF RESEARCH | DESCRIPTION                                                                                 | RESULTS                            | AUTHOR       |
|---------------|------------------|---------------------------------------------------------------------------------------------|------------------------------------|--------------|
|               |                  | Bananas constitute the fourth most important agricultural product in the world, after rice, | 3.50 KG. F (FIRMNESS)<br>3 TEXTURE | (Arrieta, et |



wheat and corn in terms of production. They are a cheap and easily produced source of energy, as well as vitamins A, C and B6. This experiment was carried out in the second half of 2005 with the aim of determining the physicochemical characteristics of the ripening process of the 'Papocho' banana (Musa ABB Simmonds) at different stages of fruit filling.

3.8KG. F (FIRMNESS) (Cachay, 2017).  
3.5 TEXTURE (Texture range 1-5)

The findings presented in Table 1 reveal the global magnitude of the importance of bananas in agriculture, highlighting them as a fundamental crop both in terms of global production and in their economic impact and nutritional value. The specific measurement of firmness in the pulp, recorded with a value of 3.5 kilograms of force according to the source (20), together with a texture of 3, in a texture evaluation that goes on a scale from 1 to 5, is revealed as a critical indicator that can have a significant influence on the general perception of the texture and quality of the fruit.

The detailed information on the physicochemical characteristics of the ripening process (21) underlines the importance of carrying out a comprehensive analysis. This thorough approach is essential to understanding the various factors that impact the quality and ripening of bananas, thus providing valuable information that could have practical applications in both industry and agronomic research.

Additionally, 3.8 kilograms of pulp strength, mentioned in the information, is presented as a crucial parameter that allows evaluating not only resistance, while texture, although slightly lower in comparison, still remains in the range of 3.5 on the same scale from 1 to 5. This aspect provides a deeper and more complete understanding of the development and maturation of bananas. In summary, these results highlight the importance of addressing and improving the quality of bananas considering both their physical aspects, such as firmness and weight, and their physicochemical aspects. The information derived from these studies not only positively impacts the banana industry, but also contributes to the progress of agronomic research with practical and significant applications.

The relationship between firmness and texture throughout various stages of banana development provides a comprehensive perspective on the evolution of these properties during the ripening process. These data are of great value to understand the physical quality of the fruit in different phases, with possible notable applications both in the food industry and in agronomic research.

## Color and carbohydrate analysis

**Table 2: physicochemical analysis of color and carbohydrates**

| RESEARCH NAME                                |                    | TYPE OF RESEARCH | DESCRIPTION                                                                                                                                                                                                                  | RESULT COLOR             | RESULT CARBOHYDRATES | AUTHOR                   |
|----------------------------------------------|--------------------|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|----------------------|--------------------------|
| CONTROLLED MATURATION AND COLOR IN BANANAS   | DEGREE THESIS      |                  | Bananas constitute the fourth most important agricultural product in the world, after rice, wheat and corn in terms of production.                                                                                           | GREEN                    | 20% STARCH           | (Arrieta, et al., 2006). |
|                                              |                    |                  |                                                                                                                                                                                                                              | CLEAR                    | 0.5% SUGAR           |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              | YELLOW                   | 16% STARCH           |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              | GREEN                    | 4.5% SUGAR           |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              | YELLOW GREEN TIPS        | 7% STARCH            |                          |
| PHYSICAL-CHEMICAL SCALE OF BANANA MATURATION | SCIENTIFIC ARTICLE |                  | The ripening of the banana could be established by measuring the starch content, total and reducing sugars, soluble dry residue, pH, water content, weight proportion, pulp/skin and organoleptic characteristics and color. | GREEN                    | 13.5% SUGAR          | (Chacón et al., 1987).   |
|                                              |                    |                  |                                                                                                                                                                                                                              | TOTALLY YELLOW           | 2.5 STARCH           |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              |                          | 18% SUGAR            |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              | GREEN WITH YELLOW TRACES | 18% STARCH           |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              |                          | 1.6% SUGAR           |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              | GREEN WITH YELLOW TRACES | 16% STARCH           | (Chacón et al., 1987).   |
|                                              |                    |                  |                                                                                                                                                                                                                              | MORE YELLOW THAN GREEN   | 2% SUGAR             |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              |                          | 4% STARCH            |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              |                          | 11.1 SUGAR           |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              | TOTALLY YELLOW           | 2% STARCH            |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              |                          | 17% SUGAR            |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              |                          |                      |                          |
|                                              |                    |                  |                                                                                                                                                                                                                              |                          |                      |                          |
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|                                              |                    |                  |                                                                                                                                                                                                                              |                          |                      |                          |

These results presented in Table 2, provide a comprehensive perspective on the ripening process of bananas. The noticeable decrease in starch and the consequent proportional increase in sugar from light green to completely yellow, supported by the observation cited in the source (20), clearly illustrate the chemical change that occurs during ripening. This phenomenon reflects the natural transformation of starch into sugar during the banana ripening process.

The visual transition from green to yellow tones, mentioned in the interpretation, is not only an aesthetic aspect, but also indicates the internal change in the chemical composition of the fruit during its ripening. Furthermore, according to reference (22), the higher proportion of starch in the initial stages suggests a more stenciled phase, possibly associated with a firmer texture. In contrast, the increase in sugar content in advanced stages signals a sweeter and more mature phase, indicating a possible softening of the texture and a sweeter flavor.

Taken together, these findings not only provide a quantitative perspective on the changes in key chemical components during banana ripening, but also reveal a significant correlation between these changes and the visual perception of fruit color. This information is valuable to understand and manage the quality of bananas at different stages of their development.

## Conservation technologies and strategies

Table 3: conservation technologies and strategies



| Technology/Strategy           | Description                                                                              | Observed effects                                                                                                               |
|-------------------------------|------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| <b>Atmosphere control</b>     | Regulation of oxygen, carbon dioxide and ethylene levels in the storage environment.     | -Slowing down of banana ripening.<br>Reduction in respiration rate.<br>-Prolongation of the useful life of the fruit.          |
| <b>Edible coating</b>         | Application of a thin layer of edible materials on the surface of the banana.            | -Reduction of moisture loss.<br>-Delay in maturation.<br>Protection against mechanical and pathogenic damage.                  |
| <b>Refrigeration</b>          | Storing bananas at low temperatures (13-15°C) to slow down ripening and reduce spoilage. | - Maintenance of the firmness, color and flavor of the banana.<br>- Prolongation of the useful life of the fruit.              |
| <b>Postharvest treatments</b> | Use of fungicides, bactericides and growth regulators to control diseases and decay.     | -Inhibition of microbial decomposition.<br>-Application of ethylene treatments to induce or delay ripening according to needs. |

According to Table 3, the technologies and strategies used to preserve bananas, such as atmospheric control, application of edible coatings, refrigeration and post-harvest treatments, play a crucial role in prolonging their shelf life and maintaining their quality throughout the distribution process. Regulating the atmosphere in the storage environment, by controlling the levels of oxygen, carbon dioxide and ethylene, helps delay ripening and reduce the respiration rate of the banana, thus contributing to its preservation. On the other hand, the application of edible coatings acts as a protective layer that reduces moisture loss and slows the ripening process of the fruit, protecting it from physical damage and pathogen attacks.

Refrigeration, by maintaining low temperatures during storage, preserves the firmness, color and flavor of the banana, prolonging its shelf life in the market. Finally, postharvest treatments, which include the use of chemicals such as fungicides, bactericides, and growth regulators, inhibit microbial decomposition and control banana ripening by manipulating ethylene exposure, ensuring freshness and quality for consumers.

## DISCUSSION

According to (20), (21), the findings are consistent with previous studies that have shown that the firmness of banana decreases as the ripening process progresses due to the degradation of starch into simpler sugars. Additionally, the inclusion of information provided by additional authors can enrich the discussion. For example, work carried out (23) has shown that the controlled ripening of bananas can be influenced by external



factors such as temperature and humidity, which directly affects their color and quality. Furthermore, studies by (24) have highlighted the importance of the physicochemical characteristics of the fruit, such as the content of sugars and acids, in its sensory perception and acceptability for the consumer. These additional contributions highlight the complexity of ripening processes in bananas and the need to consider multiple factors to achieve controlled ripening and optimal fruit quality, avoiding rapid degradation.

According to (20), a classification of banana color at different stages of ripening is presented, along with the results of carbohydrate analyses. A gradual increase in the content of starch and sugars is observed as the banana progresses in its ripening process, which agrees with the previous literature review that has established this relationship between maturity and the chemical composition of the fruit (25). On the other hand, (22) addresses banana ripening from a broader physicochemical perspective, including parameters such as starch content, total and reducing sugars, soluble dry residue, pH, water content and pulp/peel weight ratio. The results obtained in this study provide a broad and detailed vision of the changes that occur during the ripening of banana fruit and their relationship with organoleptic characteristics such as color.

The control of the atmosphere, by regulating the levels of oxygen, carbon dioxide and ethylene, slows down the ripening times of the banana and reduces its respiration rate, which coincides with previous findings from studies such as (26), which highlight the importance of this technique in the conservation of the fruit. On the other hand, the edible coating, which has been supported by research such as that of (27), has proven to be effective in reducing moisture loss, delaying ripening and protecting against mechanical and pathogenic damage in various fruits, including banana. Refrigeration, as noted in studies by (28), is crucial to maintaining the firmness, color and flavor of bananas, prolonging their shelf life by avoiding deterioration associated with heat. Finally, postharvest treatments, such as fungicides and bactericides, have proven to be effective in controlling diseases and decay, while the application of ethylene treatments can influence banana ripening, according to market needs, as suggested (29). Together, these studies support the effectiveness of the aforementioned conservation strategies and underline the importance of their application to ensure the availability of high-quality bananas to consumers.

## CONCLUSIONS

The biochemical and physiological changes in banana ripening confirm that banana ripening is a process controlled by the production of ethylene, which triggers biochemical and physiological changes essential for its quality. The main changes include the conversion of starch into sugars, the softening of the pulp and the degradation of chlorophyll, which directly influence the texture, color and flavor of the fruit. These findings underscore the importance of understanding the mechanisms behind ripening to optimize postharvest practices, ensuring that bananas reach the consumer with the desired organoleptic characteristics. Thus, in-depth knowledge of this process is crucial to improve the final quality of the fruit and its acceptance in the market.



Conservation technologies analyzed, such as atmosphere control, edible coatings and refrigeration, are presented as effective solutions to extend the useful life of bananas by slowing down their ripening and preserving their quality. These techniques allow the firmness, color and nutritional properties of the fruit to be maintained during transport and storage, key factors for its success in international markets. However, to maximize their effectiveness, it is necessary to continue researching and refining these strategies, especially in the context of global demand. The proper implementation of these technologies can contribute to reducing post-harvest losses and improving sustainability in the banana supply chain.

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