

Analysis of Degradability of Blackberry (*Rubus glaucus*) Subjected to Different Storage Conditions

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Abstract: The purpose of this study was to assess how different storage conditions and types of containers affect blackberries (*Rubus glaucus*), fruits that are particularly susceptible to post-harvest deterioration. Comparisons were made between two temperature conditions: room temperature (19°C) and refrigeration (4°C), and three types of container materials: low-density polyethylene (LDPE), polypropylene (PP), and polylactic acid (PLA). The findings indicated that refrigeration is the most effective strategy for maintaining the quality of blackberries during storage. This method significantly preserved the weight and stability of the fruit, with PLA standing out in this respect. Additionally, a considerable reduction in microbial activity was observed under refrigeration, with LDPE proving to be the most effective at inhibiting mold growth. These results underscore the importance of properly controlling both temperature and container materials type to extend shelf life and preserve the quality of blackberries, which is crucial not only for the food industry, where maintaining freshness and flavor is imperative, but also for consumers who seek high-quality fruit products.

Keywords Storage · Degradability · *Rubus glaucus* · Refrigeration · Maturity index

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1 Introduction

The growing demand for fresh, high-quality, and long-lasting foods has significantly boosted research and development in this area [1,2]. Fresh fruits and vegetables, vital sources of vitamins, minerals, and antioxidants, suffer physical and microbial deterioration, causing losses of up to 30% during post-harvest and storage stages [3,4]. Specifically, crops such as roots, tubers, and oilseeds experience the highest loss rates at all stages of the supply chain due to their high perishability [5,6]. Fruits, highly susceptible to physiological and physicochemical changes such as weight loss, respiration, transpiration, pulp softening, and alterations in sugar and acidity levels, see their shelf life reduced [7]. In other words, the period during which fresh foods remain suitable for sale and human consumption is limited [8].

Fruits are classified into two categories based on their behavior towards ethylene during ripening: climacteric and non-climacteric [9,10]. Climacteric fruits can continue to ripen after harvest and are capable of producing ethylene, a gas that triggers biochemical and physical changes resulting in complete ripening [11,12]. On the other hand, non-climacteric fruits do not produce ethylene and thus have limited ability to soften or change flavor after harvest, also being more prone to damage during transport and having a shorter shelf life compared to climacteric fruits [13].

Currently, a variety of materials are used to package fresh products, with the use of Polyethylene Terephthalate (PET) and Polystyrene (PS) for rigid containers, and polyolefins for bags, PS for foam trays, and Polyvinyl Chloride (PVC) for wraps standing out [14]. All these materials are derived from petroleum polymers [15] and are essential for ensuring product quality during transport, storage, sale, and use [16]. The packaging industry is currently focused on developing solutions that extend the shelf life of foods, ensuring their nutritional, microbiological, and organoleptic quality [17, 18, 19].

The Blackberry (*Rubus glaucus*) is a non-climacteric fruit valued for its nutritional and antioxidant properties, pleasant color and flavor, and the health benefits it provides to humans [20,21,22,23]. However, its quality rapidly deteriorates after harvest, and it has a shelf life of only 3 to 5 days, with losses that can reach up to 70% due to its high water content and active metabolism, as well as its susceptibility to mechanical damage and microbial attack, requiring special care during storage [24, 25, 26, 27, 28].

Various post-harvest initiatives have been proposed to improve the conservation of blueberries, raspberries, and blackberries throughout the entire supply chain [29]. These include physicochemical methods such as heat treatments, ultraviolet radiation application, sanitization, and edible coatings, as well as packaging solutions such as Modified Atmosphere Packaging (MAP) and active packaging with ethylene control [30]. The combined application of these technologies has contributed to extending the shelf life of berries, meeting the growing global demand, and improving consumer satisfaction [31,32].

The use of various packaging materials, both bio-based and petroleum-derived, oriented polylactic acid (OPLA) and biaxially-oriented polystyrene (OPS), has been suggested [33] to reduce the mechanical impact on “Cancaska” and “Chester” blackberry varieties. Although these fruits lost weight, altered their solid content and pH, their nutritional characteristics, according to US standard No. 1, remained suitable for commercialization for more than 12 days at 3 °C [14].

In contrast to using single-material packaging, initiatives have also been explored to assess the impact on the quality and shelf life of blackberries stored at 4 °C for 20 days in packaging with a prebiotic edible coating based on starch with nystatin addition [34,35,36]. This coating has reduced microbial contamination compared to the control blackberries and those coated with starch only. The starch and starch-nystatin coatings have proven effective in delaying pH increase, maintaining firmness, and the anthocyanin content of the fruits, which has improved their market acceptance [37].

With the goal of assessing the degradability of Blackberry in polymeric packaging, this study experimentally investigated the fruit’s characteristics under different environmental and packaging conditions. The effect of storing the fruit in Low-Density Polyethylene (LDPE), Polypropylene (PP), and Polylactic Acid (PLA) packaging under laboratory and refrigeration conditions was analyzed. Analyses of the fruit’s physicochemical and microbiological properties were conducted. The document is organized as follows: Section 1 includes the Introduction, Section 2 the Methodology, Section 3 the

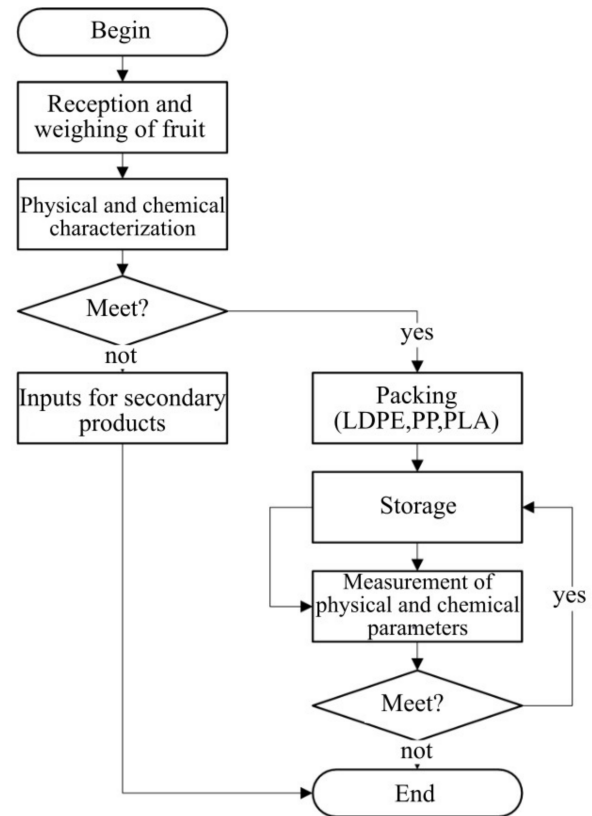


Fig. 1 General outline of the experiment.

Results, Section 4 the Discussion, and Section 5 the Conclusions.

2 Material and Methods

The methodology used in this research starts with the harvesting process, followed by weighing, characterization, packaging, and concludes with a physicochemical analysis after the experiment. Figure 1 shows a general schematic of the procedure.

2.1 Description of the experiment environment

The Basic Sciences Laboratory at Universidad Indoamérica served as the venue for conducting the experiment on the ripeness index of the Blackberry. This study focused on assessing the fruit’s response under two different storage conditions: in a laboratory setting at 19.0 degrees Celsius with a relative humidity of 59%, and in a refrigeration chamber at 4 degrees Celsius with a relative humidity of 97%. These conditions aim to mimic real storage scenarios, allowing for the analysis of the fruit’s behavior in both contexts [38,39]. The lighting in the laboratory was maintained constant at 500 lux,

ensuring an appropriate environment for all necessary measurements, which contributed to the reliability and validity of the results obtained.

2.2 Reception and weighing

For the harvest, Blackberries at ripeness levels 3 and 4 were selected, all of uniform size and free from physical damage or microbial contamination [40]. These blackberries were picked during the early hours of the experiment day to ensure their freshness and prevent chemical or microbiological changes that could influence the results. The harvesting was conducted by berry producer associations in Canton Tisaleo, Ecuador. Containers with a capacity of 7 kg were used to transport the product from the cultivation area to the laboratory, taking an average time of 30 minutes.

2.3 Physicochemical characterization

As initial physicochemical parameters of the blackberries, titratable acidity was determined using the potentiometric method in accordance with the methodology established by ISO 750:1998, Fruit and vegetable products - Determination of titratable acidity - ISO 750:1998, and the results were expressed as a percentage of citric acid (%). Soluble solids were measured following the instructions of ISO 2173:2003, Determination of soluble solids - Refractometric method ISO 2173:2003, using a refractometer. The maturity index was calculated by the ratio of soluble solids to acidity [43].

2.4 Packaging

To begin the study, the blackberries were packaged in three different types of containers: LDPE, PP, and PLA as seen in Figure 2. In addition, the characteristics of the containers are detailed in Table 1.

3 Results

3.1 Morphological analysis

The Blackberry can reach lengths of up to 3.5 cm and diameters of up to 2.3 cm, with a weight ranging between 6.1 and 7.8 g. These fruits are generally conical in shape. The seed, wedge-shaped with a reticulated surface, measures between 4 and 6 mm in length and about 2 mm in width. Each fruit contains around 70-85 drupes, with yields that can reach up to 15 t/ha

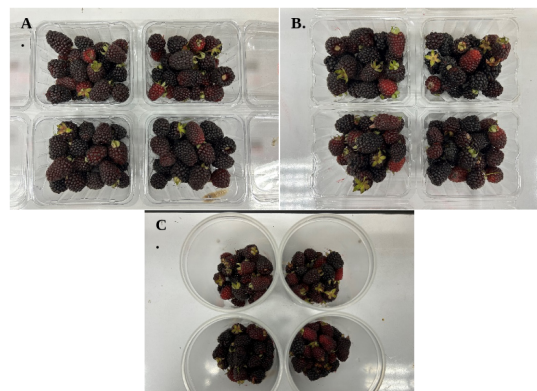


Fig. 2 Experiment containers: A). LDPE, B). PP, C). PLA

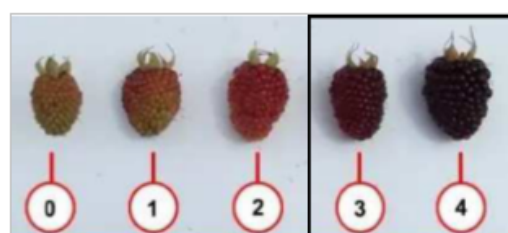


Fig. 3 Colorimetry according to the state of maturity of the Blackberry.

[44,45]. In Ecuador, the cultivation of blackberries, primarily represented by *Rubus glaucus* and other species of the *Rubus Genus*, is spread throughout the Inter-Andean valley, specifically at altitudes ranging from 2000 to 3100 meters above sea level. This crop plays a significant role in the local economy due to its high demand both for fresh consumption and processing [46, 47]. Blackberries are cultivated in the provinces of Tungurahua, Cotopaxi, Bolívar, Chimborazo, Pichincha, Imbabura, and Carchi, with average annual yields increasing from 2.19 t/ha in 2000 to 6.80 t/ha in 2016, primarily destined for fresh consumption and the agro-industry. Although producers are interested in varieties that offer high fruiting, yield, and quality, blackberry cultivation has not yet reached the desired development in the country, partly due to the lack of promising materials that improve or complement traditionally cultivated ones [48,49,50].

According to Ecuatoriana Nte Inen 2204, the color of the Blackberry, based on its ripeness, follows a color scale ranging from 0 to 4, as detailed in Table 2.

In this research, blackberries in color scale 3 and 4 were used; Figure 3 Ecuatoriana Nte Inen 2204, shows the colorimetry of the blackberries.

Table 1 Storage materials specifications

Material	Description	Dimensions (mm)	Weight (g)	Closed type
LDPE	This material is notable for its flexibility, impact resistance, and translucence, attributes that stem from its branched-chain structure. This structure gives it a low density, making it lightweight and easily moldable. Its widespread use in the production of bags, containers, and toys is due to its versatility and excellent chemical resistance [41].	10.95x95,00x61.00	18.28	Lid with pressure and hinge
PP	It is a type of thermoset plastic known for its strength, lightness, and versatility. Commonly used in packaging, textiles, and automotive components, its durability and malleability make it extremely popular across various industries [42].	10.95x95.00x61.00	19.10	Lid with pressure and hinge
PLA	PLA is a bioplastic derived from renewable sources such as cornstarch or sugarcane. It is noted for its biodegradability and compostability, making it an environmentally friendly option. Its versatile properties make it suitable for the manufacture of packaging, 3D printing filaments, and disposable products.	Diameter 1: 99.00 x Diameter 2: 112.00 x 120.00	19.38	Lid with pressure and hinge

Table 2 Color scale according to state of maturity.

Color	Description
0	Full green fruit or with few brown drupes because of exposure to light with well-formed drupes.
1	Light green fruit with some pink or red drupes.
2	Red fruit with some yellow drupes.
3	Intense red fruit with some purple drupes.
4	Dark purple, almost black fruit.

3.2 Physicochemical evaluation

Figure 4 displays the results of the weight of the blackberries according to the type of packaging and storage temperature. It is observed that blackberries stored at refrigeration temperature (4°C) maintain a slightly higher weight compared to those stored at laboratory temperature (19°C). This suggests that lower temperatures help to slow down weight loss in blackberries, a phenomenon associated with a decrease in respiration rate and fruit degradation.

Figure 5 shows the results of the weight variable according to the type of study environment. Under laboratory temperature conditions (19°C), blackberries stored in LDPE and PLA tend to maintain a higher weight compared to those stored in PP. However, under refrigeration conditions (4°C), the weight differences between the different types of packaging are less significant. This

suggests that low temperatures may minimize the differences in air permeability and moisture between different types of packaging.

Figure 6 presents the results of the Maturity Index according to the type of packaging and storage temperature. A decrease in the maturity index over time is observed under both temperature conditions. However, blackberries stored at refrigeration temperature (4°C) tend to maintain a slightly higher maturity index compared to those stored at laboratory temperature (19°C). This suggests that refrigeration helps to slow down the degradation process of the blackberries.

Figure 7 presents the results of the Maturity Index according to the type of study environment. It was observed that PLA outperformed other materials such as LDPE and PP in terms of fruit stability, particularly under refrigeration conditions. This suggests that PLA has effective barrier properties against moisture and gas loss, which is beneficial for fruit preservation. At room temperature, LDPE maintained a higher maturity index, indicating a greater ability to delay fruit degradability.

3.3 Microbiological evaluation

Figure 8 displays the microbiological results according to the type of study environment. Optimal storage conditions for blackberries were evaluated in relation to microbial activity. The results highlighted how temper-

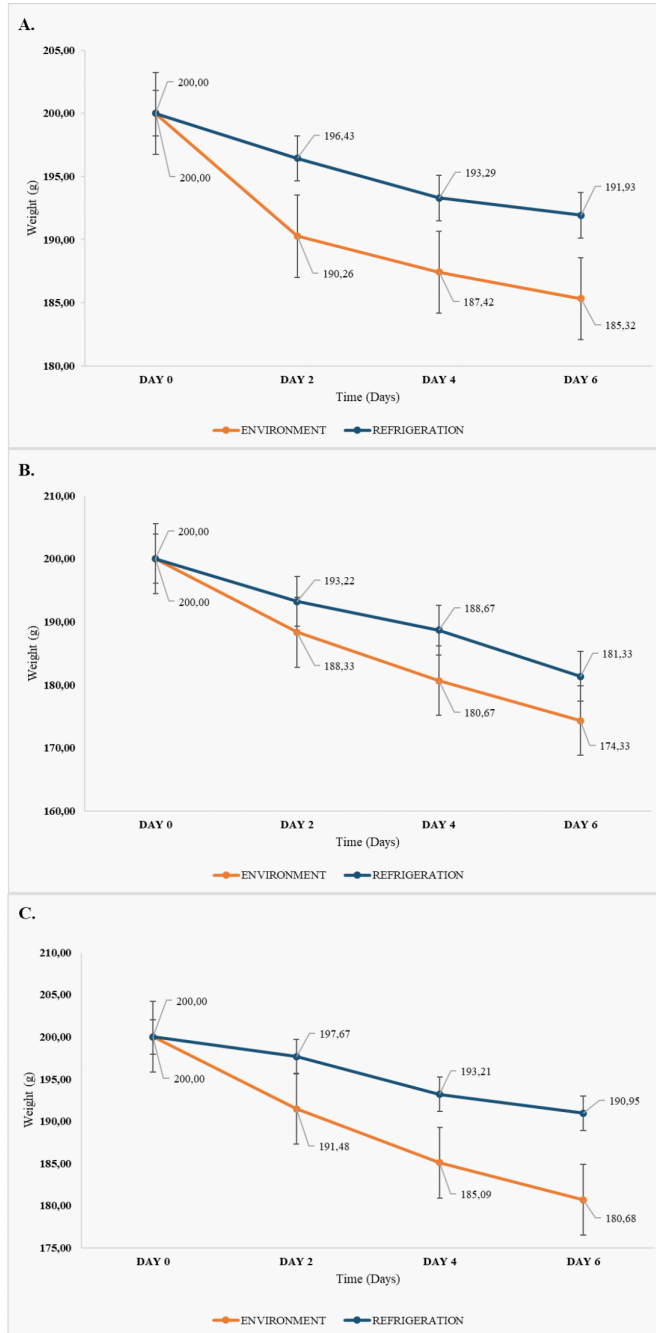


Fig. 4 Weight variation results: A.) LDPE, B.) PP, C.) PLA.

ature and the type of packaging influence this activity. At room temperature, the conditions favor the development of microbial activity, primarily due to the barrier properties of the polymer used. In contrast, under refrigeration conditions (4°C), all packaging materials demonstrated a significant reduction in microbial activity.

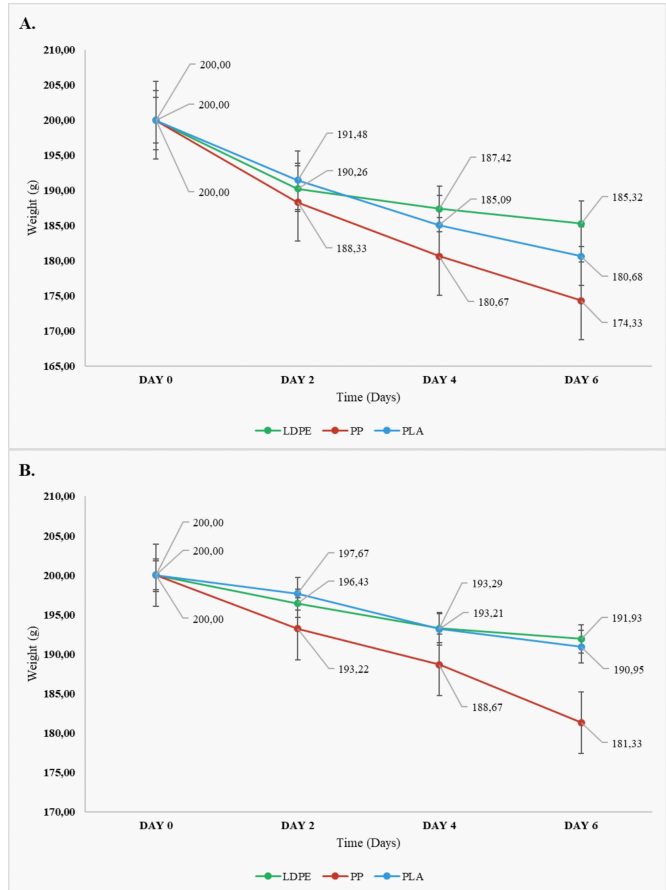


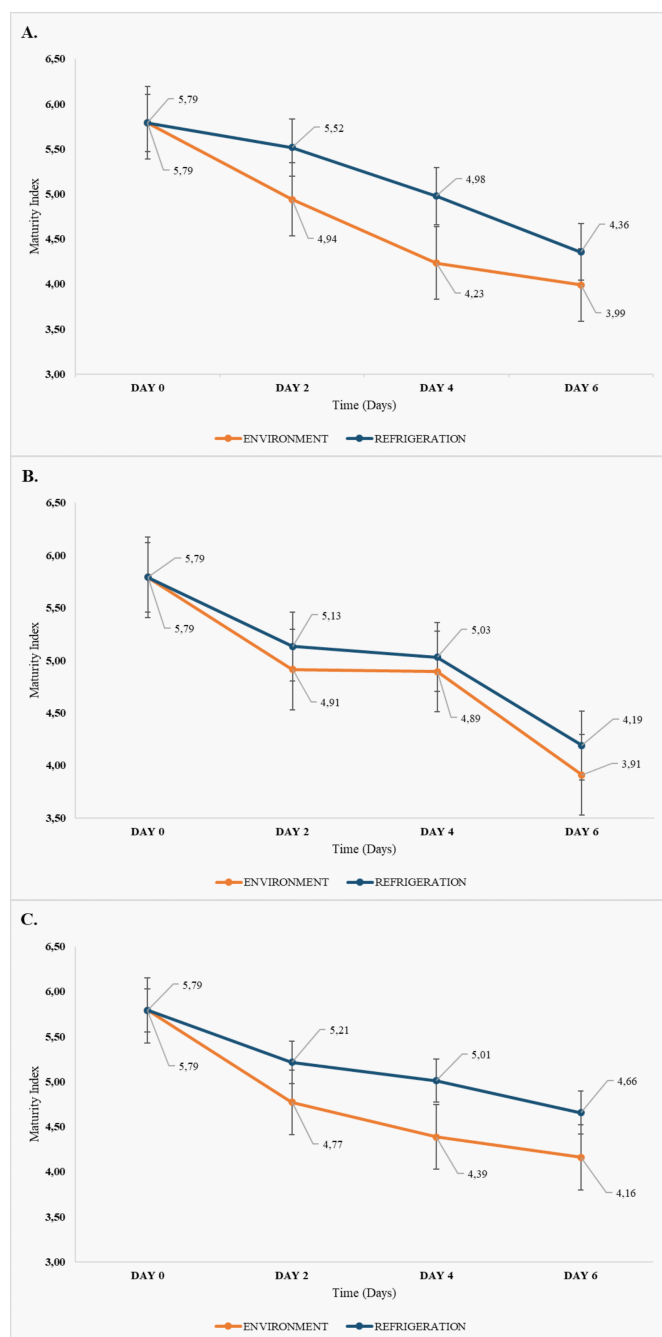
Fig. 5 Results of weight variation according to the type of environment: A.) Environment, B.) Refrigeration.

4 Discussion

When comparing temperatures, it was found that refrigeration (4°C) is more effective for preserving the quality of blackberries compared to laboratory temperature (19°C). This is due to the reduction in the respiration and transpiration rates of the fruit, which is crucial for non-climacteric fruits that do not experience a peak in enzymatic activity during ripening [51]. Nonetheless, these enzymatic activities persist and can influence changes in the texture and flavor of the fruit [52,53]; lower temperatures slow these reactions.

Under refrigeration conditions, PLA outperformed other types of packaging (LDPE and PP) in terms of weight retention and maturity index stability. This indicates that PLA possesses superior barrier properties against moisture and gas loss, benefiting fruit preservation [54]. At room temperature, although LDPE and PP had similar performance in weight retention [55], LDPE maintained a higher maturity index, suggesting a better ability to delay ripening [56].

The high relative humidity in refrigeration (97%) helped reduce weight loss due to the smaller difference



between the moisture content of the fruit and the environment, thus reducing transpiration. In summary, the ideal storage for blackberries depends both on temperature and packaging material. PLA stands out as the most promising material under controlled refrigeration conditions, while LDPE provides better results at room temperature [57]. These findings underscore the importance of considering the interactions between en-

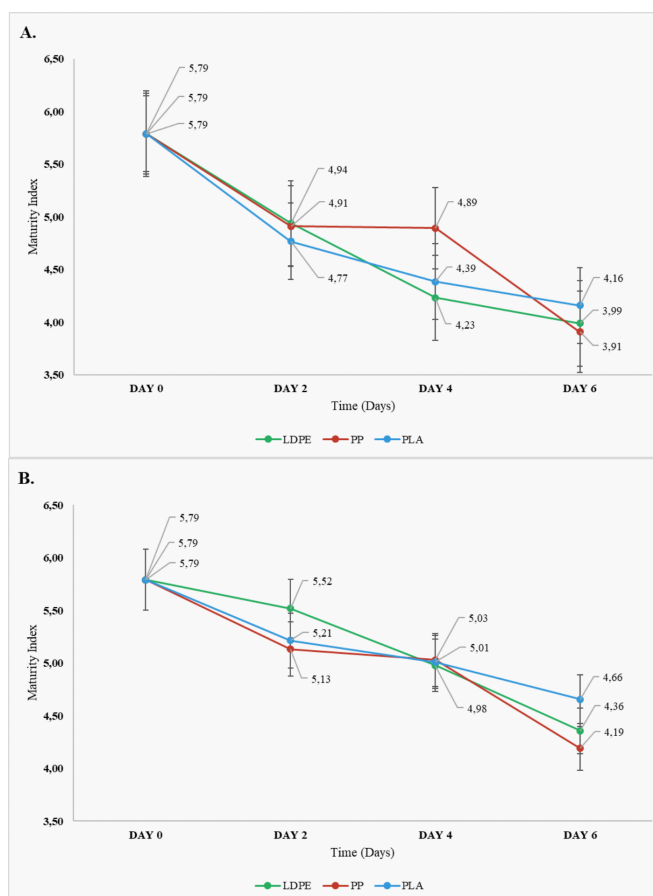


Fig. 7 Results of variation of the Maturity Index according to the environment: A.) Environment, B.) Refrigeration.

vironmental factors and packaging type to maximize the shelf life and postharvest quality of blackberries.

Optimal storage conditions for blackberries were also analyzed in terms of microbial activity. At room temperature (59% relative humidity), the environment is more conducive to microbial development. PLA proved to be more effective in inhibiting mold growth, followed by LDPE and PP, due to its barrier properties that limit moisture and gas transfer, creating a less favorable environment for microbial growth [58,10].

In refrigeration (4°C), all materials showed a significant reduction in microbial activity. The permeability to oxygen and water vapor of the different packaging types can influence the amount of mold present [59,60]. LDPE, being less permeable, provides a more effective barrier against the entry of mold spores from the outside. Although PLA initially shows less mold, it can become less effective over time due to its greater permeability, allowing more spore entry [61,62]. The high relative humidity in refrigeration helps maintain turgor and reduce fruit dehydration, decreasing osmotic stress and, therefore, susceptibility to microbial attack. The combination of low temperature and high relative hu-

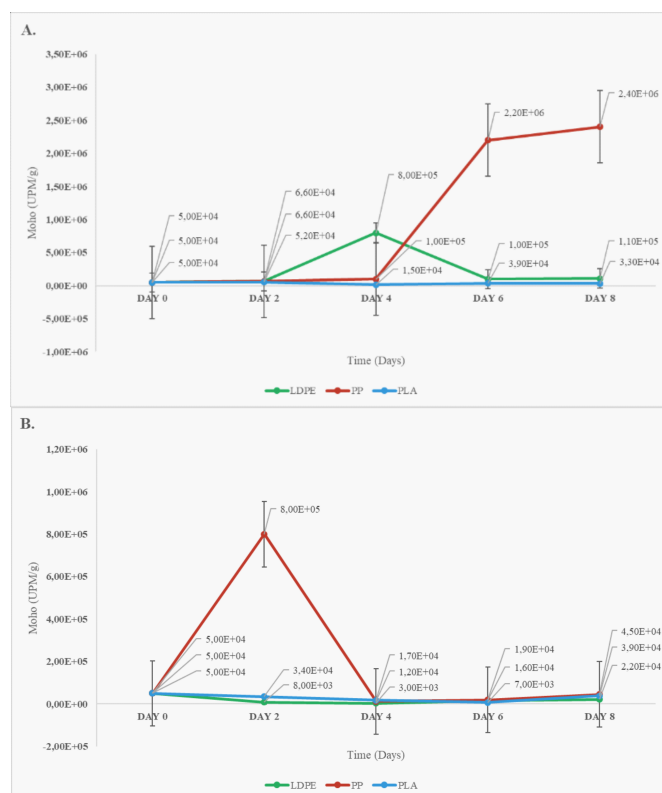


Fig. 8 Results of the microbiological evaluation by environment: A.) Environment, B.) Refrigeration.

midity in refrigeration seems to be the most beneficial for preserving postharvest quality and minimizing microbial activity in blackberries. These findings highlight the importance of integrated control of packaging type and environmental conditions to extend shelf life and maintain the quality of non-climacteric fruits.

5 Conclusions

The characteristics of blackberries (*Rubus glaucus*) were evaluated under various environmental and packaging conditions to analyze their impact on the physicochemical and microbiological properties of the fruit. The results provided valuable information for the development of effective storage and preservation strategies. In terms of physicochemical characteristics, it was found that refrigeration better preserves the quality of blackberries compared to room temperature. The reduction in the fruit's respiration and transpiration rates at lower temperatures significantly contributed to weight retention and stability of the maturity index, suggesting that refrigeration, combined with appropriate packaging, extends shelf life and maintains the quality of blackberries during storage.

Regarding microbiological characteristics, it was demonstrated that both temperature and type of packaging significantly affect microbial activity in blackberries. At room temperature, conditions favor microbial development; PLA was the most effective material in reducing mold growth, followed by LDPE and PP. Under refrigeration, a significant reduction in microbial activity was observed in all packaging types, with LDPE standing out for its ability to provide an effective barrier against the entry of mold spores from the outside.

A limitation of this study is the lack of analysis of parameters such as antioxidant content, texture, or flavor of the fruit. Including these parameters could provide a more comprehensive understanding of how different storage and packaging conditions affect fruit quality.

Conflict of interest

The authors declare that they have no conflict of interest.

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