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

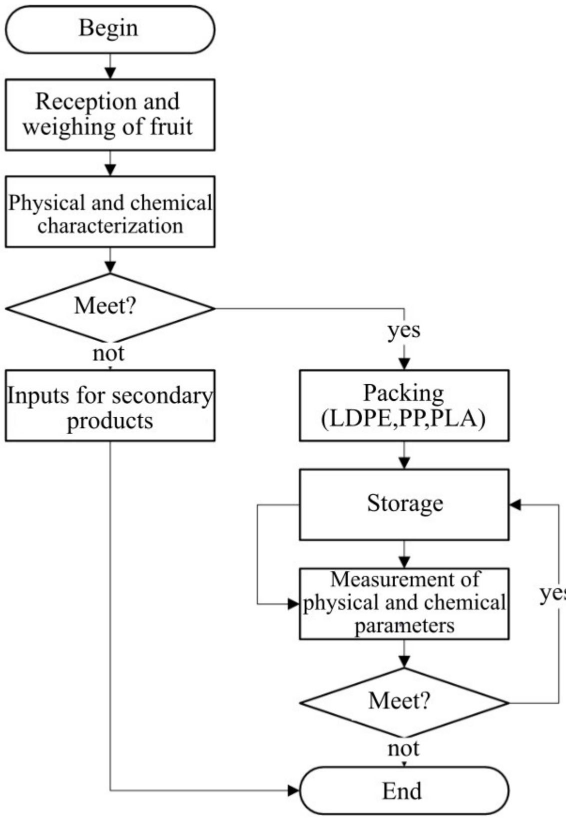

Fig. 1 General outline of the experiment.

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.

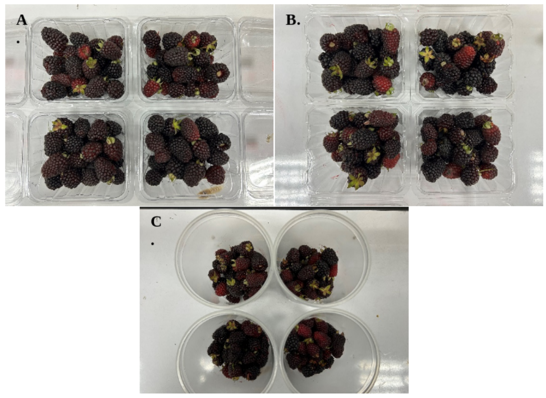

Fig. 2 Experiment containers: A). LDPE, B). PP, C). PLA

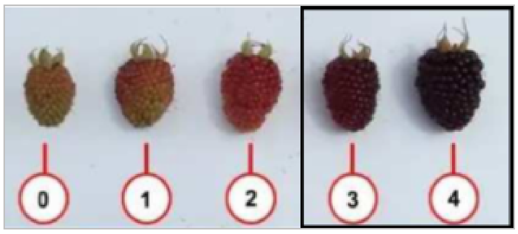

Fig. 3 Colorimetry according to the state of maturity of the Blackberry.

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 [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-

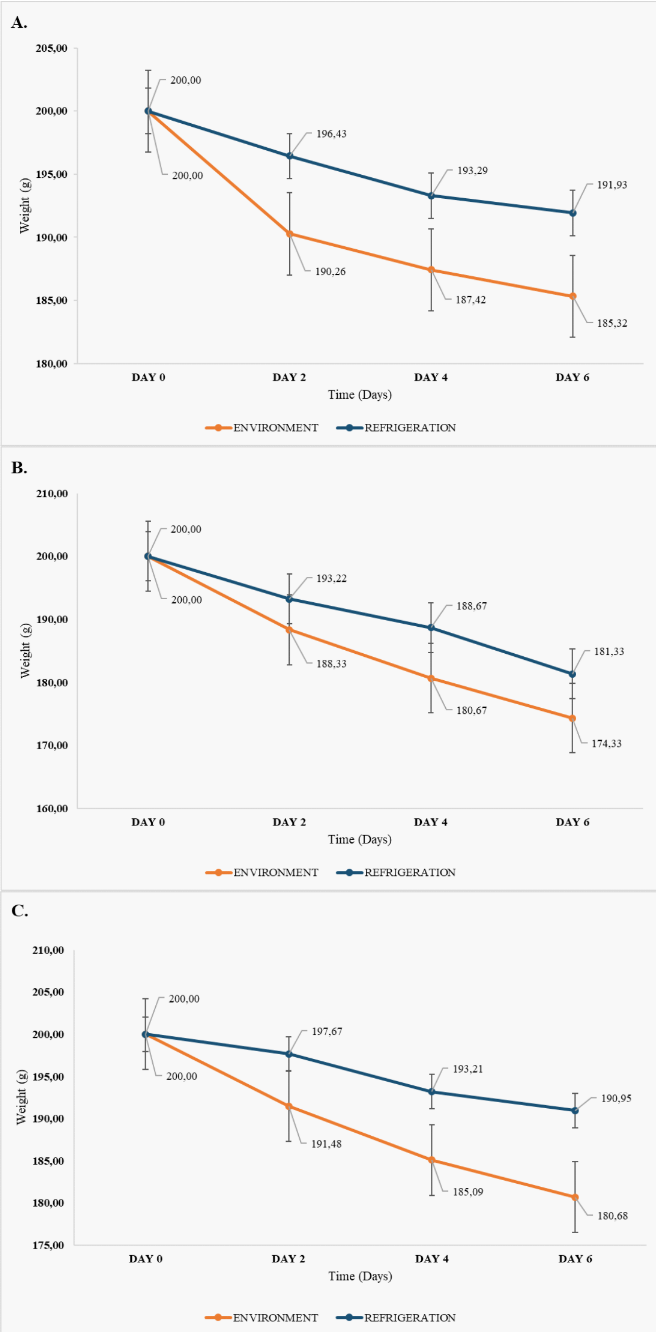

Fig. 4 Weight variation results: A.) LDPE, B.) PP, C.) PLA.

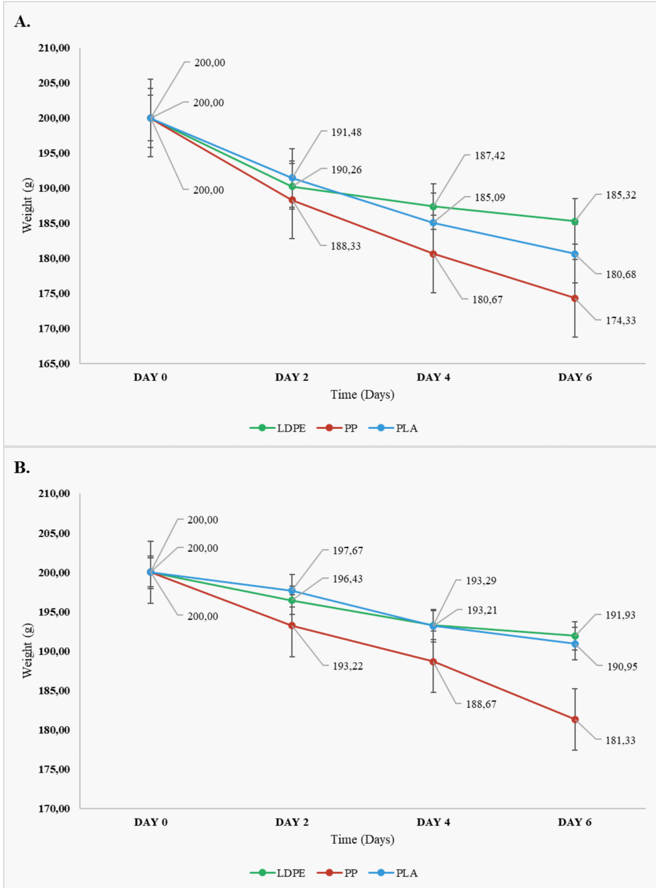

Fig. 5 Results of weight variation according to the type of environment: A.) Environment, B.) Refrigeration.

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.

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

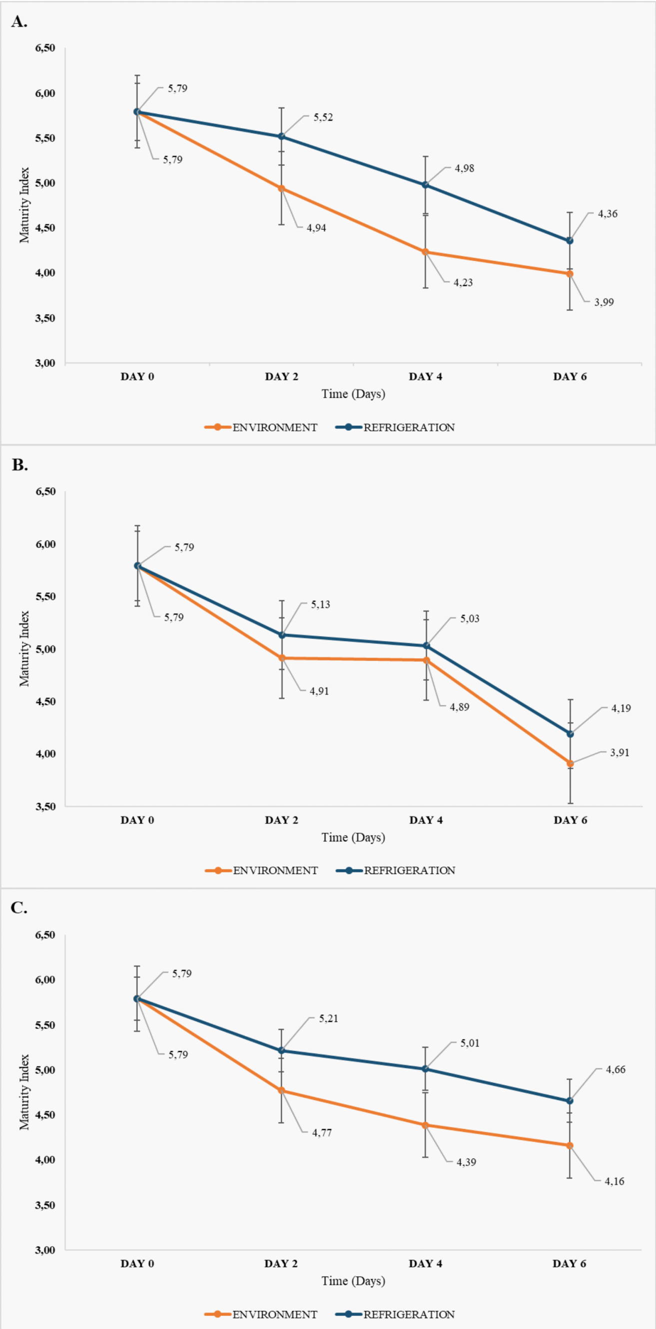

Fig. 6 Results of the variation in the Maturity Index according to the type of packaging and storage environment: A.) LDPE, B.) PP, C.) PLA.

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-

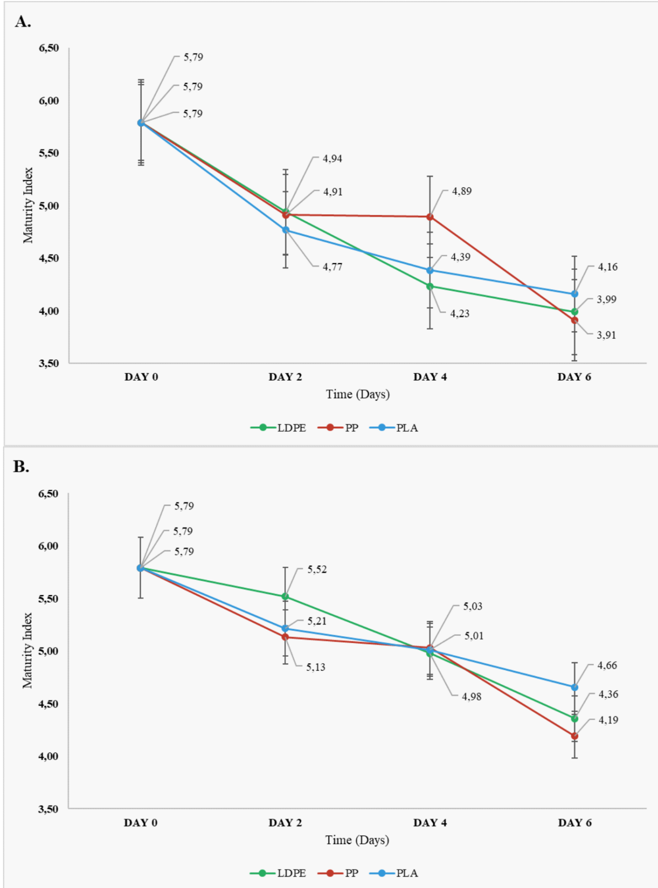

Fig. 7 Results of variation of the Maturity Index according to the environment: A.) Environment, B.) Refrigeration.

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-

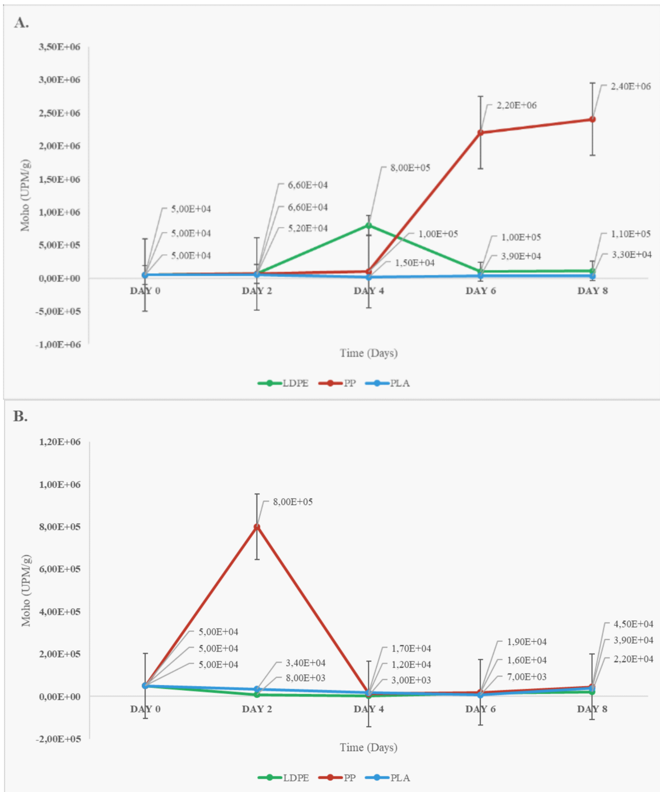

Fig. 8 Results of the microbiological evaluation by environment: A.) Environment, B.) Refrigeration.

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.

References

1. W. Wang, Z.-J. Ni, K. Thakur, S.-Q. Cao, and Z.-J. Wei, "Recent update on the mechanism of hydrogen sulfide improving the preservation of postharvest fruits and vegetables," *Current Opinion in Food Science*, vol. 47, p. 100906, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2214799322001084
2. J. A. Toscano Ávila, D. A. Terán, A. Debut, K. Vizuete, J. Martínez, and L. A. Cerda-Mejía, "Shelf life estimation of blackberry (rubus glaucus benth) with bacterial cellulose film coating from komagataeibacter xylinus," *Food Science & Nutrition*, vol. 8, no. 4, pp. 2173–2179, 2020. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/fsn3.1525
3. M. Palumbo, G. Attolico, V. Capozzi, R. Cozzolino, A. Corvino, M. L. V. de Chiara, B. Pace, S. Pelosi, I. Ricci, R. Romaniello, and M. Cefola, "Emerging postharvest technologies to enhance the shelf-life of fruit and vegetables: An overview," *Foods*, vol. 11, no. 23, 2022. [Online]. Available: https://www.mdpi.com/2304-8158/11/23/3925
4. G. N. Tenea, P. Reyes, D. Molina, and C. Ortega, "Pathogenic microorganisms linked to fresh fruits and juices purchased at low-cost markets in ecuador, potential carriers of antibiotic resistance," *Antibiotics*, vol. 12, no. 2, 2023. [Online]. Available: https://www.mdpi.com/2079-6382/12/2/236
5. U. D. Corato, "Improving the shelf-life and quality of fresh and minimally-processed fruits and vegetables for a modern food industry: A comprehensive critical review from the traditional technologies into the most promising advancements," *Critical Reviews in Food Science and Nutrition*, vol. 60, no. 6, pp. 940–975, 2020, pMID: 30614263. [Online]. Available: https://doi.org/10.1080/10408398.2018.1553025
6. O. Chauhan, S. Lakshmi, A. Pandey, N. Ravi, N. Gopalan, and R. Sharma, "Non-destructive quality

monitoring of fresh fruits and vegetables," *Defence Life Science Journal*, vol. 2, p. 103, 05 2017.
7. S. Sinha, M. Kader, M. A. Jiku, A. Rahaman, A. Singha, M. Faruquee, and M. Alam, "Post-harvest assessment of fruit quality and shelf life of two elite tomato varieties cultivated in bangladesh," *Bulletin of the National Research Centre*, vol. 43, p. 185, 12 2019.
8. Onethird, "The ultimate guide to fresh produce shelf life prediction," pp. 1–17, 2022. [Online]. Available: https://onethird.io/ultimate-guide-to-fresh-produce-shelf-life-prediction
9. M. E. Martínez-González, R. Balois-Morales, I. Alia-Tejacal, M. A. Cortes-Cruz, Y. A. Palomino-Hermosillo, G. G. López-Gúzman, M. E. Martínez-González, R. Balois-Morales, I. Alia-Tejacal, M. A. Cortes-Cruz, Y. A. Palomino-Hermosillo, and G. G. López-Gúzman, "Poscosecha de frutos: maduración y cambios bioquímicos," *Revista mexicana de ciencias agrícolas*, vol. 8, no. SPE19, pp. 4075–4087, dec 2017. [Online]. Available: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-09342017001104075&lng=es&nrm=iso&tlng=eshttp://www.scielo.org.mx/scielo.php?script=sci_abstract&pid=S2007-09342017001104075&lng=es&nrm=iso&tlng=es
10. M. Cabrera, V. Peralta, F. Rodríguez, T. Herrera, and J. Herrera, "Evaluación "in vitro" de la actividad antifungica del aceite esencial de canela (cinnamomum zeynalicum) sobre botrytis sp aislado de mora de castilla (rubus glaucus)," *European Scientific Journal ESJ*, vol. 15, 04 2019.
11. A. Martiñón, S. Chavez, C. Veloz, J. Espinosa, and D. Guerra-Ramírez, "Extractos de persea americana mill. que retrasan maduración en frutos de aguacate," *Revista Mexicana de Ciencias Agrícolas*, vol. 9, pp. 1639–1650, 12 2018.
12. M. J. A., M. ., and J. ., "Evaluación fisicoquímica y antioxidante de naranjilla (solanum quitoense lam.) durante la maduración," *Revista Iberoamericana de Tecnología Postcosecha*, vol. 22, 2021. [Online]. Available: https://www.redalyc.org/articulo.oa?id=81369610003
13. C. Figueroa, C. Concha, N. Figueroa, and G. Tapia, "Frutilla chilena nativa - fragaria chiloensis," 01 2018.
14. M. Joo, N. Lewandowski, R. Auras, J. Harte, and E. Almenar, "Comparative shelf life study of blackberry fruit in bio-based and petroleum-based containers under retail storage conditions," *Food Chemistry*, vol. 126, no. 4, pp. 1734–1740, 2011. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0308814610016924
15. C. G. Otoni, R. J. Avena-Bustillos, H. M. C. Azeredo, M. V. Lorevice, M. R. Moura, L. H. C. Mattoso, and T. H. McHugh, "Recent advances on edible films based on fruits and vegetables—a review," *Comprehensive Reviews in Food Science and Food Safety*, vol. 16, no. 5, pp. 1151–1169, 2017. [Online]. Available: https://ift.onlinelibrary.wiley.com/doi/abs/10.1111/1541-4337.12281
16. T. Ahmed, M. Shahid, F. Azeem, I. Rasul, A. A. Shah, M. Noman, A. Hameed, N. Manzoor, I. Manzoor, and S. Muhammad, "Biodegradation of plastics: current scenario and future prospects for environmental safety," *Environmental Science and Pollution Research*, vol. 25, no. 8, pp. 7287–7298, mar 2018. [Online]. Available: https://link.springer.com/article/10.1007/s11356-018-1234-9
17. M. K. Verma, S. Shakya, P. Kumar, J. Madhavi, J. Murugaiyan, and M. V. Rao, "Trends in packaging material for food products: historical background, current scenario, and future prospects," *Journal of Food Science and Technology*, vol. 58, no. 11, pp. 4069–4082, nov 2021. [Online]. Available: https://link.springer.com/article/10.1007/s13197-021-04964-2
18. N. K. Dubey and R. Dubey, "Chapter 27 - edible films and coatings: An update on recent advances," in *Biopolymer-Based Formulations*, K. Pal, I. Banerjee, P. Sarkar, D. Kim, W.-P. Deng, N. K. Dubey, and K. Majumder, Eds. Elsevier, 2020, pp. 675–695. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780128168974000278
19. A. Prakash, R. Baskaran, N. Paramasivam, and V. Vadivel, "Essential oil based nanoemulsions to improve the microbial quality of minimally processed fruits and vegetables: A review," *Food Research International*, vol. 111, pp. 509–523, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0963996918304356
20. Z. Diaconeasa, C. I. Iuhas, H. Ayvaz, D. Rugină, A. Stanilă, F. Dulf, A. Bunea, S. A. Socaci, C. Socaciu, and A. Pintea, "Phytochemical characterization of commercial processed blueberry, blackberry, blackcurrant, cranberry, and raspberry and their antioxidant activity," *Antioxidants*, vol. 8, no. 11, 2019. [Online]. Available: https://www.mdpi.com/2076-3921/8/11/540
21. F. Velázquez-Contreras, N. García-Caldera, J. D. Padilla de la Rosa, D. Martínez-Romero, E. Núñez-Delicado, and J. A. Gabaldón, "Effect of pla active packaging containing monoterpene-cyclodextrin complexes on berries preservation," *Polymers*, vol. 13, no. 9, 2021. [Online]. Available: https://www.mdpi.com/2073-4360/13/9/1399
22. C. M., M. J. ., A. ., A. ., and A. ., "Efecto del uso combinado de radiaciÓn uv - c y atmÓsfera modificada sobre el tiempo de vida Útil de mora de castilla (rubus glaucus) sin espinas." *Revista Iberoamericana de Tecnología Postcosecha*, vol. 17, pp. 71–78, 2016. [Online]. Available: https://www.redalyc.org/articulo.oa?id=81346341010
23. S. Santos, L. Rodrigues, S. Costa, and G. Madrona, "Antioxidant compounds from blackberry (rubus fruticosus) pomace: Microencapsulation by spray-dryer and ph stability evaluation," *Food Packaging and Shelf Life*, vol. 20, p. 100177, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2214289417301989
24. M. Hadadinejad, K. Ghasemi, and A. A. Mohammadi, "Effect of storage temperature and packaging material on shelf life of thornless blackberry," *International Journal of Horticultural Science and Technology*, vol. 5, no. 2, pp. 265–275, 2018.
25. E. L. Potma da Silva, T. C. de Carvalho, R. Antonio Ayub, and M. C. Menezes de Almeida, "Blackberry extend shelf life by nanocellulose and vegetable oil coating," *Horticulture International Journal*, vol. Volume 4, no. Issue 2, pp. 54–60, apr 2020. [Online]. Available: https://medcraveonline.com/HIJ/HIJ-04-00158.phphttps://medcraveonline.com/HIJ/HIJ-04-00158.pdf
26. C. Villegas and W. Albarracin, "Edible coating application and effect on blackberry (rubus glaucus benth) shelf life," *Vitae*, vol. 23, pp. 202–209, 09 2016.
27. Sandhya, "Modified atmosphere packaging of fresh produce: Current status and future needs," *LWT - Food Science and Technology*, vol. 43, no. 3, pp. 381–392, 2010. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0023643809001546

28. A. Ascencio-Arteaga, S. Luna-Suárez, J. G. Cárdenas-Valdovinos, E. Oregel-Zamudio, G. Oyoque-Salcedo, J. A. Ceja-Díaz, M. V. Angoa-Pérez, and H. G. Mena-Violante, “Shelf life of blackberry fruits (rubus fruticosus) with edible coatings based on candelilla wax and guar gum,” *Horticulturae*, vol. 8, no. 7, 2022. [Online]. Available: https://www.mdpi.com/2311-7524/8/7/574
29. N. K. Huynh, M. D. Wilson, A. Eyles, and R. A. Stanley, “Recent advances in postharvest technologies to extend the shelf life of blueberries (Vaccinium sp.), raspberries (Rubus idaeus L.) and blackberries (Rubus sp.),” *Journal of Berry Research*, vol. 9, no. 4, pp. 687–707, jan 2019.
30. M. D. Wilson, R. A. Stanley, A. Eyles, and T. Ross, “Innovative processes and technologies for modified atmosphere packaging of fresh and fresh-cut fruits and vegetables,” *Critical reviews in food science and nutrition*, vol. 59, no. 3, pp. 411–422, feb 2019. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/28891686/
31. P. Joshi, N. Becerra-Mora, A. Y. Vargas-Lizarazo, P. Kohli, D. J. Fisher, and R. Choudhary, “Use of edible alginate and limonene-liposome coatings for shelf-life improvement of blackberries,” *Future Foods*, vol. 4, p. 100091, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2666833521000812
32. Y. Tumbarski, N. Petkova, M. Todorova, I. Ivanov, I. Deseva, D. Mihaylova, and S. Ibrahim, “Effects of pectin-based edible coatings containing a bacteriocin of bacillus methylotrophicus bm47 on the quality and storage life of fresh blackberries,” *Italian Journal of Food Science*, vol. 32, pp. 420–437, 05 2020.
33. N. R. Giuggioli, R. Briano, and C. Peano, “Packaging in the fresh fruit and vegetable supply chain: Innovation and sustainability,” *Italus Hortus*, vol. 25, no. 1, pp. 23–38, 2018.
34. G. T. Bersaneti, S. H. Prudencio, S. Mali, and M. A. Pedrine Colabone Celligoi, “Assessment of a new edible film biodegradable based on starch-nystose to increase quality and the shelf life of blackberries,” *Food Bioscience*, vol. 42, p. 101173, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2212429221002984
35. M. V. Alvarez, A. G. Ponce, and M. R. Moreira, “Influence of polysaccharide-based edible coatings as carriers of prebiotic fibers on quality attributes of ready-to-eat fresh blueberries,” *Journal of the Science of Food and Agriculture*, vol. 98, no. 7, pp. 2587–2597, 2018. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/jsfa.8751
36. R. Porat, A. Lichter, L. A. Terry, R. Harker, and J. Buzby, “Postharvest losses of fruit and vegetables during retail and in consumers’ homes: Quantifications, causes, and means of prevention,” *Postharvest Biology and Technology*, vol. 139, pp. 135–149, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0925521417309559
37. M. F. Bambace, M. V. Alvarez, and M. del Rosario Moreira, “Novel functional blueberries: Fructo-oligosaccharides and probiotic lactobacilli incorporated into alginate edible coatings,” *Food Research International*, vol. 122, pp. 653–660, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0963996919300407
38. F. Arguello, X. Rojas-Lema, and F. Iza, “Línea base de la calidad de la mora de castilla (rubus glaucus) en su cadena alimentaria (quality baseline of the castilla blackberry (rubus glaucus) in its food chain),” 09 2016.
39. R. Saltos Espín, M. González Rivera, V. González Rivera, F. Cofre Santos, I. Hidalgo Guerrero, L. García Zambrano, and E. Borja Borja, *Revista de Investigación Talentos*, vol. 7, no. 2, pp. 33 – 45, oct. 2020. [Online]. Available: https://talentos.ueb.edu.ec/index.php/talentos/article/view/222
40. M. Cortés Rodríguez, C. Villegas Yépez, J. H. Gil González, and R. Ortega-Toro, “Effect of a multifunctional edible coating based on cassava starch on the shelf life of andean blackberry,” *Heliyon*, vol. 6, no. 5, p. e03974, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2405844020308197
41. V. Siracusa and I. Blanco, “Bio-polyethylene (bio-pe), bio-polypropylene (bio-pp) and bio-poly(ethylene terephthalate) (bio-pet): Recent developments in bio-based polymers analogous to petroleum-derived ones for packaging and engineering applications,” *Polymers*, vol. 12, no. 8, 2020. [Online]. Available: https://www.mdpi.com/2073-4360/12/8/1641
42. X. Zhong, X. Zhao, Y. Qian, and Y. Zou, “Polyethylene plastic production process,” *Insight - Material Science*, vol. 1, p. 1, 08 2018.
43. J. Lee, *Chapter 4. Blackberry fruit quality components, composition, and potential health benefits*, 10 2017, pp. 49–62.
44. L. M. Arbeláez-Arias, J. C. Lucas-Aguirre, and L. G. Gutiérrez-López, “Induction and multiplication of thornless rubus glaucus callogenesis from leaves,” *Journal of Hunan University Natural Sciences*, vol. 50, no. 10, 2023.
45. J. Fernandez-Salvador, B. C. Strik, Y. Zhao, and C. E. Finn, “Trailing blackberry genotypes differ in yield and postharvest fruit quality during establishment in an organic production system,” *HortScience*, vol. 50, no. 2, pp. 240 – 246, 2015. [Online]. Available: https://journals.ashs.org/hortsci/view/journals/hortsci/50/2/article-p240.xml
46. I. Samaniego, B. Brito, W. Viera, A. Cabrera, W. Llerena, T. Kannangara, R. Vilcacundo, I. Angós, and W. Carrillo, “Influence of the maturity stage on the phytochemical composition and the antioxidant activity of four andean blackberry cultivars (rubus glaucus benth) from ecuador,” *Plants*, vol. 9, no. 8, 2020. [Online]. Available: https://www.mdpi.com/2223-7747/9/8/1027
47. L. Isaza, Y. P. Zuluaga, and M. L. Marulanda, “Morphological, pathogenic and genetic diversity of ¡i¿botrytis cinerea¡/i¿ pers. in blackberry cultivations in colombia,” *Revista Brasileira de Fruticultura*, vol. 41, no. 6, p. e–490, 2019. [Online]. Available: https://doi.org/10.1590/0100-29452019490
48. M. Iza, P. Viteri, M. Hinojosa, A. Martinez, A. Sotomayor, and W. Viera, “Morphological, phenological and pomological differentiation of commercial blackberry (rubus glaucus benth.) cultivars,” *Trends in Horticulture*, vol. 5, p. 38, 07 2022.
49. A. Alvarez, H. Silva-Rojas, S. Leyva-Mir, N. Marbán-Mendoza, and A. Rebollar-Alviter, “Resistance of botrytis cinerea from strawberry (fragaria x ananassa duch.) to fungicides in michoacan mexico resistencia de botrytis cinerea de fresa (fragaria x ananassa duch.) a fungicidas en michoacÁn mÉxico,” *Agrociencia*, vol. 51, pp. 783–798, 10 2017.
50. P. Boeri, L. Piñuel, D. Dalzotto, R. Monasterio, A. Fontana, S. Sharry, D. A. Barrio, and W. Carrillo, “Argentine patagonia barberry chemical composition and evaluation of its antioxidant capacity,” *Journal of*

Food Biochemistry, vol. 44, no. 7, p. e13254, 2020. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/jfbc.13254

51. G. X. Galarza, A. Escuela, A. Panamericana, and Z. Honduras, "Efecto de la acción enzimática en la hidrolización de elagitaninos e incremento de ácido elágico en mora, frambuesa y guayaba," 2017. [Online]. Available: https://bdigital.zamorano.edu/handle/11036/5967
52. T. María Guzmán, K. Cuenca, and E. Tacuri, "Caracterización de la poscosecha de la mora de castilla (rubus glaucus) tratada con 1-metilciclopropeno," *Revista Ciencias Técnicas Agropecuarias*, vol. 27, no. 1, pp. 66–75, 2018.
53. F. Arguello, X. Rojas-Lema, and F. Iza, "Línea base de la calidad de la mora de castilla (rubus glaucus) en su cadena alimentaria (quality baseline of the castilla blackberry (rubus glaucus) in its food chain)," 09 2016.
54. S. Úbeda Jasanada, M. Aznar, and C. Nerín, "Determinación de oligómeros en ácido poliláctico, pla, biopolímero destinado al envase alimentario," *Jornada de Jóvenes Investigadores del I3A*, vol. 6, 05 2018.
55. M. d. L. R., C. ., and S. ., "Almidón modificado: Propiedades y usos como recubrimientos comestibles para la conservación de frutas y hortalizas frescas," *Revista Iberoamericana de Tecnología Postcosecha*, vol. 19, 2018. [Online]. Available: https://www.redalyc.org/articulo.oa?id=81355612003
56. K. Majeed, R. Arjmandi, and A. Hassan, "Mechanical and oxygen barrier properties of ldpe/mmt/mape and ldpe/mmt/eva nanocomposite films: A comparison study," *Journal of Physical Science*, vol. 29, pp. 43–58, 05 2018.
57. M. Riera and I. Campozano, "Ácido poliláctico: una revisión de los métodos de producción y sus aplicaciones," *Publicaciones en Ciencias y Tecnología*, vol. 16, pp. 42–53, 07 2022.
58. S. Kormin, F. Kormin, M. D. H. Beg, and M. B. M. Piah, "Physical and mechanical properties of ldpe incorporated with different starch sources," *IOP Conference Series: Materials Science and Engineering*, vol. 226, no. 1, p. 012157, aug 2017. [Online]. Available: https://dx.doi.org/10.1088/1757-899X/226/1/012157
59. S. Ospina and J. Cartagena, "Modified atmosphere: an alternative for food preservation," *Revista Lasallista de Investigación*, vol. 5, pp. 112–123, 07 2008.
60. S. Bertin and J.-J. Robin, "Study and characterization of virgin and recycled ldpe/pp blends," *European Polymer Journal*, vol. 38, no. 11, pp. 2255–2264, 2002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0014305702001118
61. D. M. Hernández Pachón, S. M. Árdila Panesso, J. S. Díaz Jiménez, M. A. Perilla Gómez, D. D. Cubillos Pedraza, J. C. Serrano Sánchez, M. F. Quesada Pacheco, and N. L. Pulido Ortíz, "Caracterización de agentes causales de enfermedades en el cultivo de mora (Rubus glaucus) en la finca manantial en la vereda sabaneta, municipio de La Vega, Cundinamarca," *Revista Ciencias Agropecuarias (RCA), ISSN-e 2422-3484, Vol. 4, Nº. 1, 2018, págs. 9-17*, vol. 4, no. 1, pp. 9–17, 2018.
62. M. A. Mora-Ramos, F. P. Pardo-Carrasco, and H. Bastidas-López, "Diagnóstico patológico en mora de castilla rubus glaucus bentham (rosales:rosaceae)," *ORINOQUIA*, vol. 24, pp. 27 – 32, 12 2020. [Online]. Available: http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0121-37092020000200027&nrm=iso

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