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Scientific Article

Extension of the shelf-life of 'BRS-Princesa' bananas through refrigerated storage

Prolongamento da oferta de bananas 'BRS-Princesa' armazenadas sob refrigeração

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ABSTRACT - Banana is a climacteric fruit with short post-harvest shelf-life, undergoing significant changes during ripening. Refrigerated storage is considered the most efficient method to preserve the quality of fruit by slowing down their metabolism. Thus, the objective of this work was to evaluate physical and chemical characteristics of 'BRS-Princesa' bananas stored under refrigeration, focusing on determining their post-harvest shelf-life. The fruit were stored in a cold chamber at temperature of 14±1 °C and relative air humidity of 75±1% for 0, 7, 14, 21, and 28 days. They were removed from the cold chamber after each period and kept at 25±1 °C in a climate-controlled environment (CCE) until they presented a fully yellow peel (ripening stage 6). The fruit were evaluated immediately after removal from the cold chamber and when they reached the ripening stage 6. Refrigeration affected all physical and chemical characteristics of the fruit evaluated after removal from the cold chamber. However, when the fruit were fully ripe, pulp yield, soluble solids content, and total soluble sugars presented no significant difference, indicating a similar ripening to the control group. Fruit stored for 21 and 28 days showed chilling injury. 'BRS-Princesa' bananas can be stored at 14 °C for up to 14 days, without losses in fruit appearance and quality, thus extending the time for fruit consumption by 8 days when compared to fruit stored in the CCE (25±1 °C).

Keywords: *Musa* spp. Refrigeration. Supply. Post-harvest. Chilling injury.

RESUMO - A banana é um fruto climatérico de vida pós-colheita curta e que sofre mudanças acentuadas durante seu amadurecimento. O armazenamento refrigerado é considerado a forma mais eficaz de preservar a qualidade dos frutos, diminuindo seu metabolismo. Assim, o trabalho teve como objetivo avaliar as características físico-químicas de bananas 'BRS-Princesa' armazenadas sob refrigeração, visando determinar o período de vida útil pós-colheita. Os frutos foram armazenados em câmara fria, em temperatura de 14±1 ºC e 75±1% UR por períodos de 0, 7,14, 21 ou 28 dias. Após cada período, os frutos foram retirados da câmara fria e mantidos em temperatura ambiente (25±1 ºC) até apresentarem coloração da casca completamente amarela (estádio 6 de maturação). As avaliações foram realizadas logo após a retirada dos frutos da refrigeração e quando os frutos atingiram o estádio 6. A refrigeração afetou todas as variáveis de qualidade físico-química dos frutos avaliados após a retirada da câmara fria. Porém, quando os frutos atingiram o completo amadurecimento, as variáveis rendimento da polpa, sólidos solúveis e açúcares solúveis totais não apresentaram diferença significativa, indicando um amadurecimento semelhante ao controle. Frutos armazenados por 21 e 28 dias apresentaram índices de injúrias por frio. As bananas 'BRS-Princesa' podem ser armazenadas a 14 °C por um período de até 14 dias, sem prejuízo à boa aparência e qualidade dos frutos, com incremento de 8 dias na possibilidade de consumo dos frutos, quando comparados ao controle.

Palavras-chave: *Musa* spp. Refrigeração. Vida útil. Pós-colheita. Dano por frio.

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INTRODUCTION

Brazil is the fourth largest banana-producing country (FAO, 2021), where the state of São Paulo is the largest producing state, followed by Bahia, which together represent 26.6% of the national production (IBGE, 2021). Banana is one of the most profitable tropical fruit crops (KIST et al., 2018). Despite 98% of the production being consumed domestically, banana plantations in Brazil have growth potential to meet international markets (BAPTISTELLA; COELHO; GHOBRIL, 2019). Exports reached 83 Mg in 2022, generating US$ 37 million (COMEXSTAT, 2022).

The production of bananas, especially the variety Maçã, is affected by diseases such as Fusarium Wilt of Banana (Panama disease) caused by the fungus *Fusarium oxysporum* f. sp. *cubense*; severe cases can lead to total production loss (KANNAN et al., 2022). The Brazilian Agricultural Research Corporation (EMBRAPA Cassava and Fruit Production) developed a hybrid Maçã banana, the BRS-Princesa (AAAB), resistant to Black Sigatoka and to Fusarium Wilt of Banana (race 1), as an alternative to minimize this problem (SOARES et al., 2021).

The short post-harvest shelf-life of bananas is another factor that causes losses. Banana is a climacteric fruit and, therefore, undergoes significant changes in physical and chemical characteristics during ripening (NERIS et al., 2018).

Refrigerated storage is used as an alternative to extend the shelf-life and preserve the quality of bananas after harvest; fruit should be stored at minimum temperatures of 13 °C, as they are highly sensitivity to cold (chilling) (BRECHT et al., 2019). Storing bananas at temperatures below 13 °C causes discoloration of the peel surface, subepidermal vascular browning, delayed or abnormal ripening, and sometimes no ripening of fruit due to temperature and exposure time (CHANG et al., 2022). The integrity of the plasma membrane, essential for quality maintenance, is altered or damaged under thermal stress or other stresses during storage (HUANG et al., 2019).

Scientific studies have confirmed variation in cold resistance among banana cultivars. For example, Pacovan bananas stored under 12±1 °C showed efficient maintenance of physical and chemical characteristics for 12 days (BARBOSA et al., 2019); Prata-Anã bananas can be stored at 13.5 °C for 25 days (SANTOS et al., 2018); and Caipira bananas, a variety of Maçã banana, can be stored for up to 28 days at 14 °C (LIMA et al., 2014).

BRS-Princesa is a relatively new banana cultivar on the market, therefore, there is little information about the post-harvest management of its fruit and, mainly, about their refrigerated storage, which is important for efficient marketing, primarily for distant markets. In this context, the objective of this study was to evaluate physical and chemical characteristics of 'BRS-Princesa' bananas stored under refrigeration, focusing on determining their post-harvest shelf-life.

MATERIAL AND METHODS

Harvest and preparation of fruit

Banana fruit of the cultivar BRS-Princesa were obtained from a commercial plantation in Presidente Tancredo Neves, BA, Brazil (13°27'14"S, 39°25'15"W). Thebunches were harvested 87 days after bunch emergence, counted from the fall of the bract that covers the last viable hand. Subsequently, the hands were removed from the bunch stalk and taken to the Post-Harvest Laboratory of the Brazilian Agricultural Research Corporation (EMBRAPA Cassava and Fruit Production), in Cruz das Almas, BA, Brazil.

The hands were subdivided, forming five-finger hands, which were washed in a solution of water with 1% neutral detergent; then, the hands with fruit at ripening stage 1 (completely green peel) were stored in a cold chamber at 14±1 °C and relative air humidity of 75±1% for up to 28 days. The treatments consisted of refrigerated storage periods (0, 7, 14, 21, and 28 days), followed by storage at room temperature (25±1 °C) in a climate-controlled environment (CCE) until the fruit reached full ripeness (ripening stage 6; completely yellow peel). The control treatment was formed by banana hands stored in a CCE at 25±1 °C, i.e., without refrigeration (0 days). The fruit were evaluated immediately after removal from the cold chamber and complete fruit ripening (ripening stage 6).

Experimental design

A completely randomized experimental design was used, with six replications (banana hands). The experimental unit consisted of one five-finger hand per evaluation period.

Characteristics evaluated

The analyses were performed using three randomly chosen fruit from each hand. The variables analyzed were: a) fruit ripening stage, evaluated according to the Von Loesecke ripening scale (PBMH; PIF, 2006) immediately after removal from the cold chamber; b) days to ripening, evaluated in fruit after storage at 25±1 °C in the CCE; c) chilling injury, evaluated by the analysis of darkened and brown spots on the fruit peel; d) weight loss (%), determined by the difference between the initial and final fruit weight, using the formula: *[(initial weight –final weight) / initial weight]* × *100*; e) pulp yield, calculated as the pulp weight to peel weight ratio; f) pulp firmness, determined using a manual penetrometer equipped with an 8 mm diameter tip; g) soluble solids content (SSC), determined using a digital refractometer; h) titratable acidity (TA), determined by titration in a 0.1N NaOH solution; i) SSC to TA ratio; and j) total soluble sugars, determined by acidic hydrolysis and quantified by spectrophotometry (YEMM; WILLIS, 1954).

Chilling injury was evaluated based on the scale proposed by Promyou, Ketsa, and Doorn (2008), where 1 = no chilling injury, 2 = slight injury (1% to 20% of the fruit peel affected), 3 = moderate injury (21% to 50% of the fruit peel affected), 4 = severe injury (51% to 80% of the fruit peel affected); and 5 = very severe injury (81% to 100% of the fruit peel affected). The chilling injury index was calculated using the formula ∑ *(injury level* × *number of fruit at the level) / total number of fruit*.

Statistical analysis

The data obtained was subjected to analysis of variance (ANOVA) by the F test at a 5% probability level, and the effects of the quantitative treatments were adjusted to polynomial regression models, using the statistical program SISVAR (FERREIRA, 2019).

RESULTS AND DISCUSSION

Refrigerated storage affected all physical and chemical characteristics of the bananas in the evaluations conducted immediately after the fruit were removed from the cold chamber. However, the refrigerated storage periods did not have a significant effect on pulp yield, soluble solids content, and total soluble sugars when the fruit were transferred to a climate-controlled environment at 25±1 °C (CCE) and reached the consumption stage (stage 6).

The fruit ripening stage, evaluated immediately after removal from the cold chamber, showed significant linear increases over the refrigerated storage period, indicating that the longer the refrigerated storage period, the riper the fruit (Figure 1A). Bananas stored under refrigeration for 7 days showed a similar ripening stage to freshly harvested fruit (ripening stage 1 – completely green peel). Fruit stored for 14 or 21 days were at the ripening stage 2 (green peel with yellowing parts) when removed from the cold chamber, whereas those stored for 28 days presented a more advanced ripening stage (stage 3, more green peel than yellow) (Figure 1A).

The metabolism of fruit remains active but slow at low temperatures; however, this activity is sufficient to promote fruit ripening over time under refrigeration. This was reflected in the proportional decrease in the time required to reach completely yellow peel (ripening stage 6) when the fruit were transferred to the CCE at room temperature (25±1 °C), simulating marketing conditions (Figure 1B).

Fruit stored for 28 days under refrigeration-riper when removed from the cold chamber at ripening stage 3 (more green peel than yellow)-took less time to reach stage 6 (three days) when compared to the other storage periods (Figure 1B). Biochemical and physiological processes are faster when fruit are exposed to higher temperatures after refrigerated storage (ARAÚJO et al., 2020). Additionally, the high degree of fruit ripening at 28 days also contributed to reducing the storage period at 25 °C.

The use of refrigerated storage periods of 7, 14, 21, and 28 days for 'BRS-Princesa' bananas increased the fruit shelf-life by 3, 8, 14, and 19 days, respectively, compared to the control treatment fruit (12 days). These additional days of fruit quality preservation, compared to the control fruit (12 days), added to the days they were under refrigeration, showed that fruit stored for 7, 14, and 21 days can be kept without refrigeration for 8, 6, and 5 days, respectively, until full ripening (Figure 1B). This is significant from a commercial point of view, as bananas need a few days to be marketed.

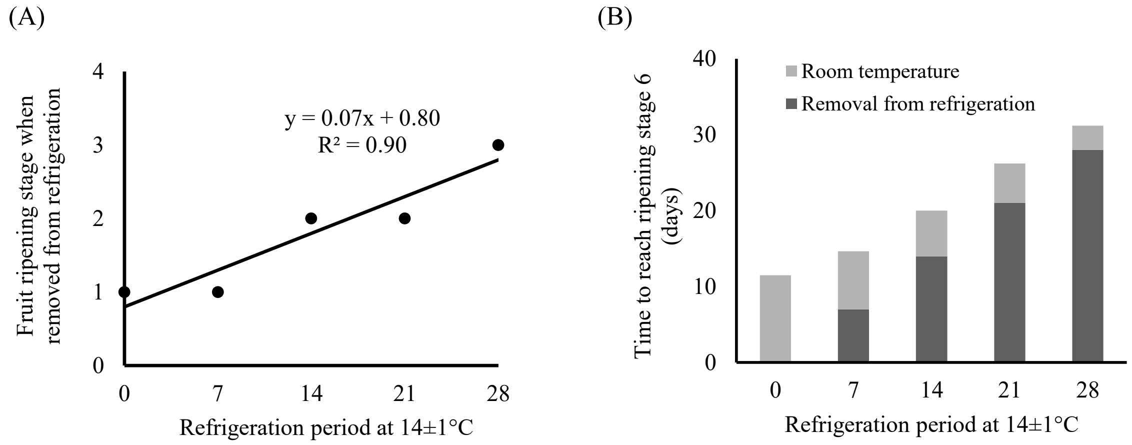


Figure 1. Ripening stage of 'BRS-Princesa' bananas stored at 14±1°C for 0, 7, 14, 21, and 28 days, evaluated immediately after removal from the cold chamber (A) and when they reached stage 6 after transfer to a climate-controlled environment (25±1 °C) (B).

The chilling injury index increased over the storage period. These injuries were noticed in fruit stored under refrigeration for 14, 21, and 28 days immediately after they were removed from the cold chamber. Symptoms were more pronounced after transfer to the CCE until they reached ripening stage 6 (yellow peel) (Figure 2). Fruit showed slight chilling injury symptoms up to 14 days of refrigerated storage (Figure 3) without compromising their appearance. Fruit stored for longer periods (21 and 28 days) showed moderate injury; fruit stored for 28 days showed fungal growth on the peduncle, decreasing their commercial quality. Oliveira et al. (2016) found similar results when evaluating cold tolerance in bananas of the cultivars Nanicão, Caipira, and Maçã, which presented more pronounced chilling injury symptoms after 16 days of refrigerated storage. Chang et al. (2022) found vascular browning in the peel of Cavendish bananas after 19 days of storage at 14.0 °C.

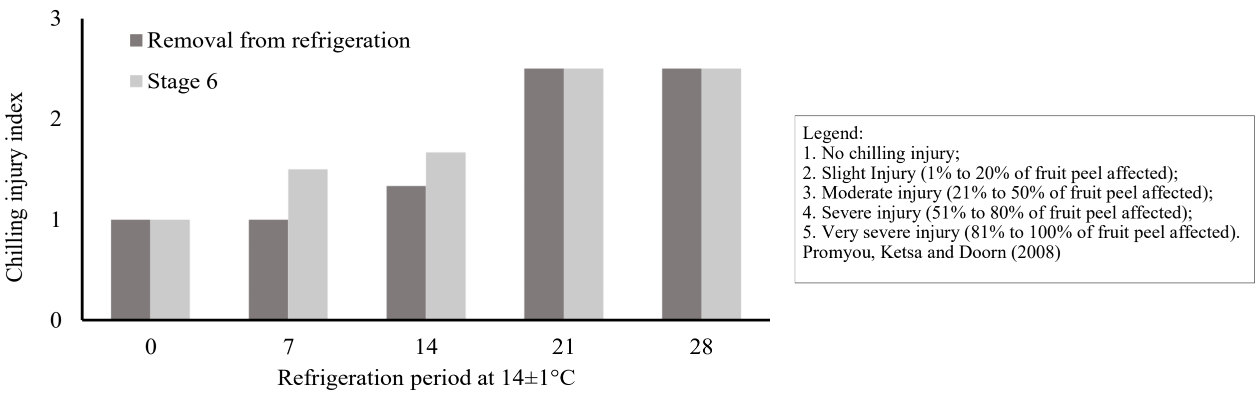


Figure 2. Chilling injury index in 'BRS-Princesa' bananas stored at 14±1°C for 0, 7, 14, 21, and 28 days, evaluated immediately after removal from the cold chamber and when they reached ripening stage 6 after transfer to a climate-controlled environment (25±1 °C).

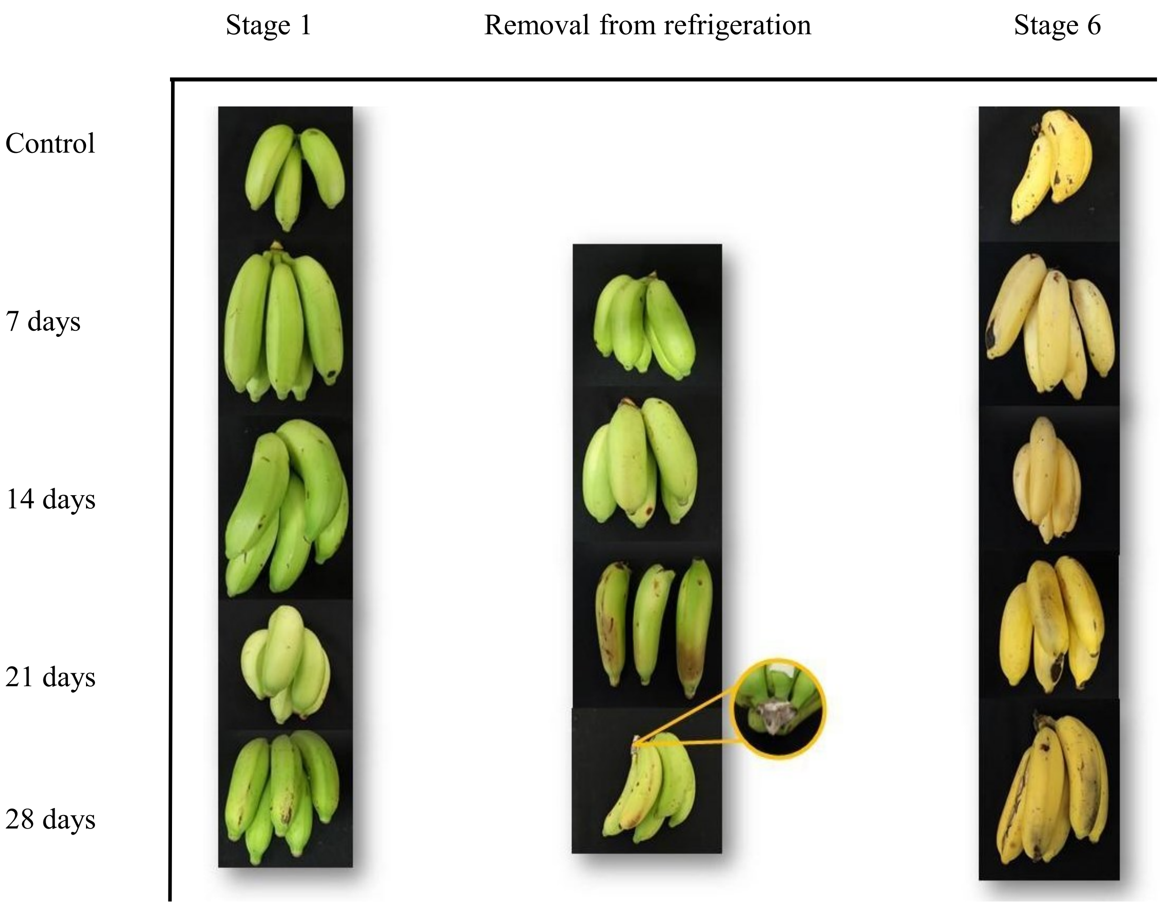


Figure 3. Appearance of 'BRS-Princesa' bananas stored at stage 1 in a climate-controlled environment at 25±1 °C – CCE (control) and at 14±1°C for 0, 7, 14, 21, and 28 days immediately after removal from the cold chamber and when they reached ripening stage 6 after transfer to a CCE.

Weight loss significantly increased over the refrigerated storage, as shown by the evaluations of fruit at ripening stage 6 after transfer to the CCE (25±1 °C) (Figure 4). Fruit stored under refrigeration for 28 days had higher weight loss. The weight loss of fruit stored and ripened without refrigeration (25±1 °C) was 39% higher than the mean of fruit stored at 14±1°C, denoting the efficiency of using low temperatures to prevent significant weight losses. Decreases in temperature contribute to slowing down fruit respiratory activity and the capacity of an environment to absorb moisture, attenuating weight loss due to transpiration (FINGER; VIEIRA, 2023).

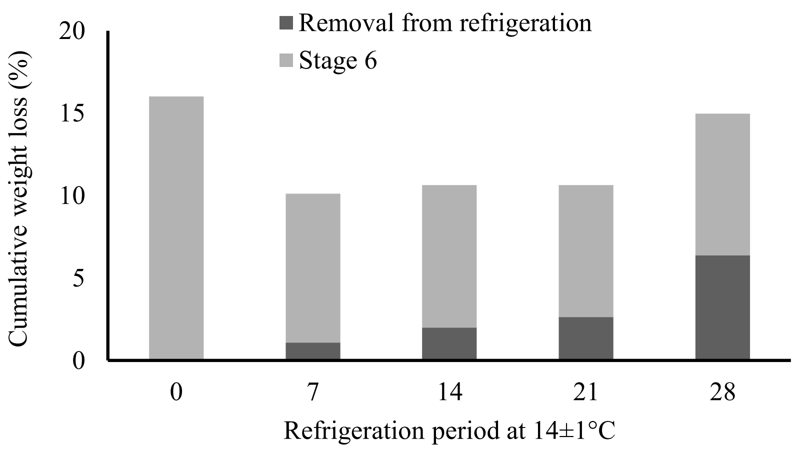


Figure 4. Cumulative weight loss (%) in 'BRS-Princesa' bananas stored at 14±1 °C for 0, 7, 14, 21, and 28 days, assessed immediately after removal from the cold chamber and at ripening stage 6 after transfer to a climate-controlled environment (25±1 °C).

According to Morgado et al. (2022), the advantages of using refrigerated storage include slowing down metabolic processes and reducing dehydration and rotting. The fruit showed signs of wilting at the last evaluation, as perishable products lose weight even when stored under ideal conditions due to respiration and transpiration (SOUZA et al., 2019). Similar results were found by Batista et al. (2021) when evaluating bananas of the cultivar Prata stored for 21 days under similar conditions of those tested in the present study.

The evaluations immediately after removing the fruit from the cold chamber showed that the pulp yield increased linearly over the refrigerated storage period: from 64.5% in the control fruit to 70.8% in the fruit stored for 28 days (Figure 5A). However, the refrigerated storage periods did not show significant difference when the fruit were evaluated at ripening stage 6 (Figure 5B), with a mean of 75.4%. This result is positive, denoting that refrigerated storage does not affect pulp yield after the fruit reach the suitable ripening stage for consumption.

Increases in pulp yield during ripening can be attributed to changes in sugar concentrations in the pulp and peel. A faster increase in sugar contents in the pulp than in the peel results in changes in the osmotic pressure, causing water to be removed from the peel; therefore, the pulp to peel ratio increases (MOHAPATRA et al., 2016).

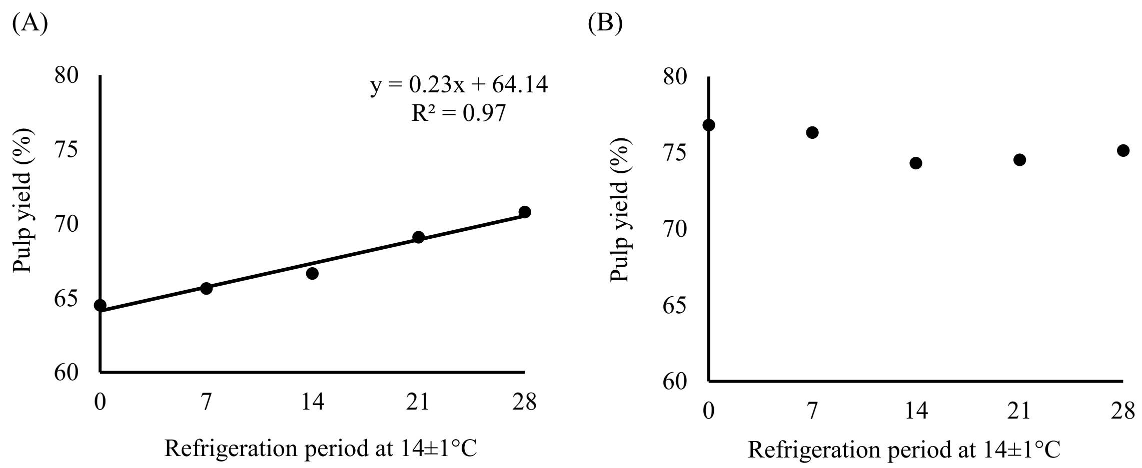


Figure 5. Pulp yield (%) in 'BRS-Princesa' bananas stored at 14±1 °C for 0, 7, 14, 21, and 28 days, assessed immediately after removal from the cold chamber and at ripening stage 6 after transfer to a climate-controlled environment (25±1 °C).

Pulp firmness significantly decreased over the refrigerated storage period, showing a quadratic response according to the regression analysis (Figure 6A). The highest and lowest means were found for fruit stored under refrigeration for 14 and 28 days, respectively (Figure 6A). Fruit at ripening stage 6 had significantly lower pulp firmness compared to the evaluation at the time the fruit were removed from the cold chamber; the refrigerated storage periods presented a significant difference, with a decreasing trend until 14 days of storage and an increasing trend from this period onwards (Figure 6B). Although a significant difference was found when the fruit reached stage 6, the difference between the highest and lowest pulp firmness was of 2.4 N, which is practically imperceptible to consumers.

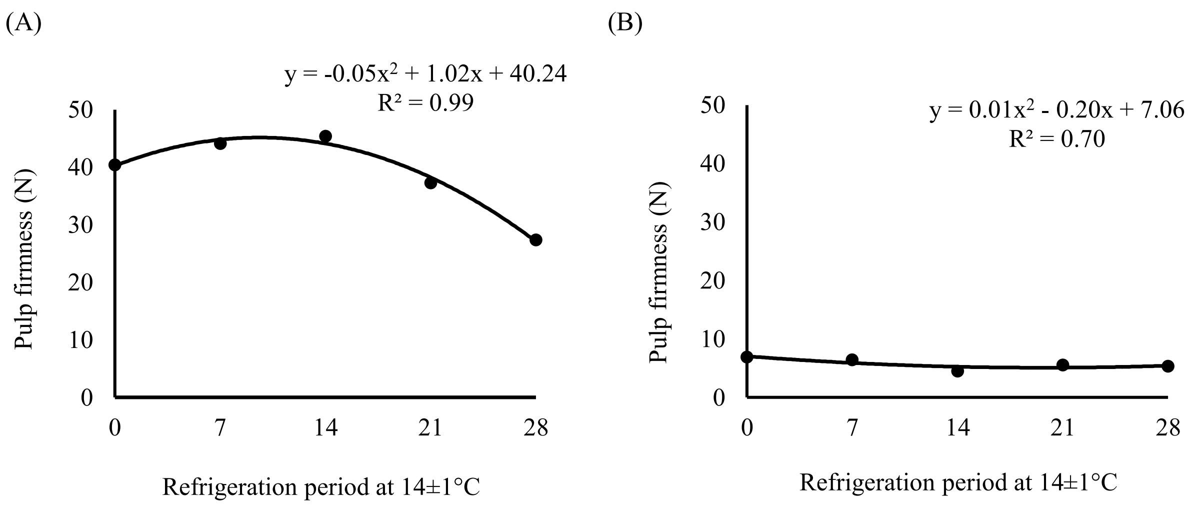
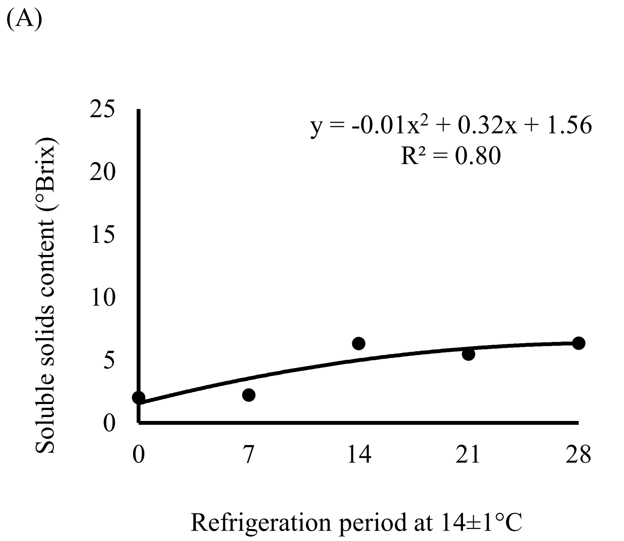


Figure 6. Pulp firmness (N) in 'BRS-Princesa' bananas stored at 14±1 °C for 0, 7, 14, 21, and 28 days, measured immediately after removal from the cold chamber (A) and at ripening stage 6 (B) after transfer to a climate-controlled environment (25±1 °C).

The significant decrease in pulp firmness from the time the fruit were removed from refrigeration until they reached stage 6 is connected to the ripening process. Banana softening is attributed to the degradation of cell wall compounds, reduced starch content, and increased sugar content (YOURYON; SUPAPVANICH, 2017). However, the rate of firmness loss can be slowed by controlling storage conditions, including temperature, humidity, and the presence of gases such as ethylene (GILL et al., 2017).

Soluble solids content (SSC) significantly increased throughout the refrigerated storage period (Figure 7A), but ripe fruit (stage 6) after transfer to the CCE had significantly higher SSC (Figure 7B). However, the refrigerated storage periods did not differ significantly from each other for SSC and total soluble sugars when the fruit reached ripening stage 6. A positive correlation (r = 0.89) was found between SSC and total soluble sugars (Figure 7B), denoting that storage at 14±1 °C did not affect the sweetness of fully ripe fruit suitable for consumption.

The increasing sweetness of fruit during ripening is mainly attributed to increased concentrations of soluble sugars, such as glucose, fructose, and sucrose, due to biochemical changes, including the breakdown of organic acids and the synthesis of volatile compounds, which also contribute to the sweet taste and aroma of ripe fruit (ROCHA; URIBE, 2018).



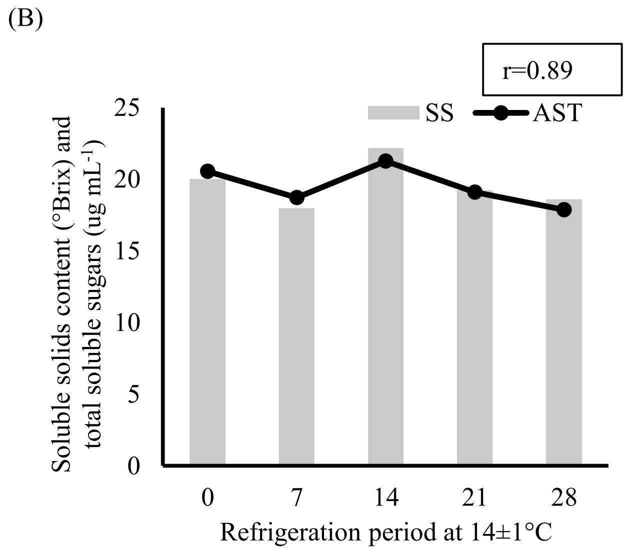
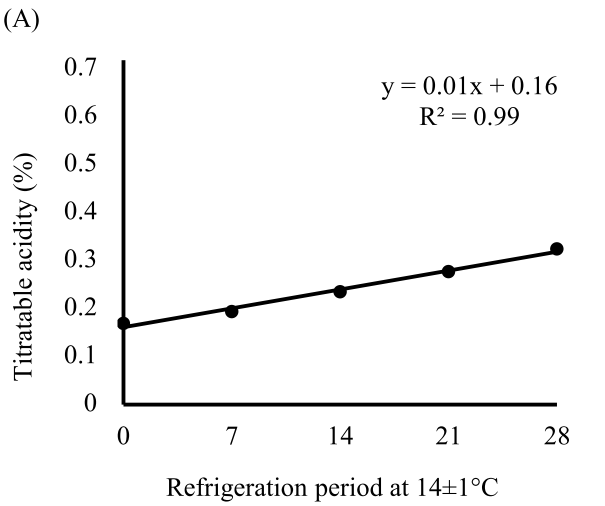


Figure 7. Soluble solids content (SSC; °Brix) in 'BRS-Princesa' bananas stored at 14±1 °C for 0, 7, 14, 21, and 28 days, assessed immediately after removal from the cold chamber (A), and SSC and total soluble sugars (ug mL^{-1}) at ripening stage 6 after transfer to a climate-controlled environment (25±1 °C).

Titratable acidity (TA) increased linearly throughout the refrigerated storage period (Figure 8A), which is due to the progress in the ripening stages when the fruit were still under refrigeration. However, ripe fruit (stage 6) showed a significant decrease in TA for the different refrigerated storage periods (Figure 8B).



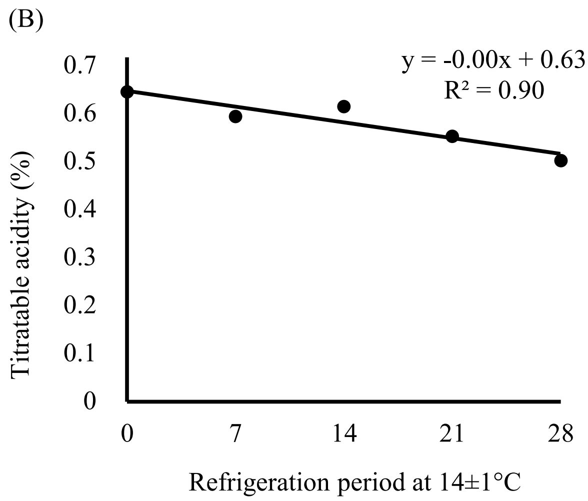


Figure 8. Titratable acidity (% of malic acid) of 'BRS-Princesa' bananas stored at 14±1 °C for 0, 7, 14, 21, and 28 days, assessed immediately after removal from the cold chamber (A), and SSC and total soluble sugars (ug mL^{-1}) at ripening stage 6 after transfer to a climate-controlled environment (25±1 °C).

According to Chandra et al. (2020), TA initially increases as the fruit ripens due to the conversion of starch into soluble sugars and organic acids, as also found in the fruit of the present study over the refrigerated storage period (Figure 8A); however, TA tends to decrease as organic acids are degraded during the respiration process, as they are also respiratory substrates. This trend was observed after the fruit were removed from refrigeration and transferred to the CCE (Figure 8B).

The SSC to TA ratio (SSC/TA) presented significant differences in fruit at the time of removal from refrigeration and in ripe fruit (stage 6) after transfer to the CCE (Figures 9A and 9B). This is mainly due to the TA results. SSC/TA throughout the refrigerated storage period showed a quadratic response, with the highest mean found at 14 days of storage (27.7) (Figure 8A). SSC/TA in ripe fruit (stage 6) showed a quadratic response to the refrigerated storage periods.

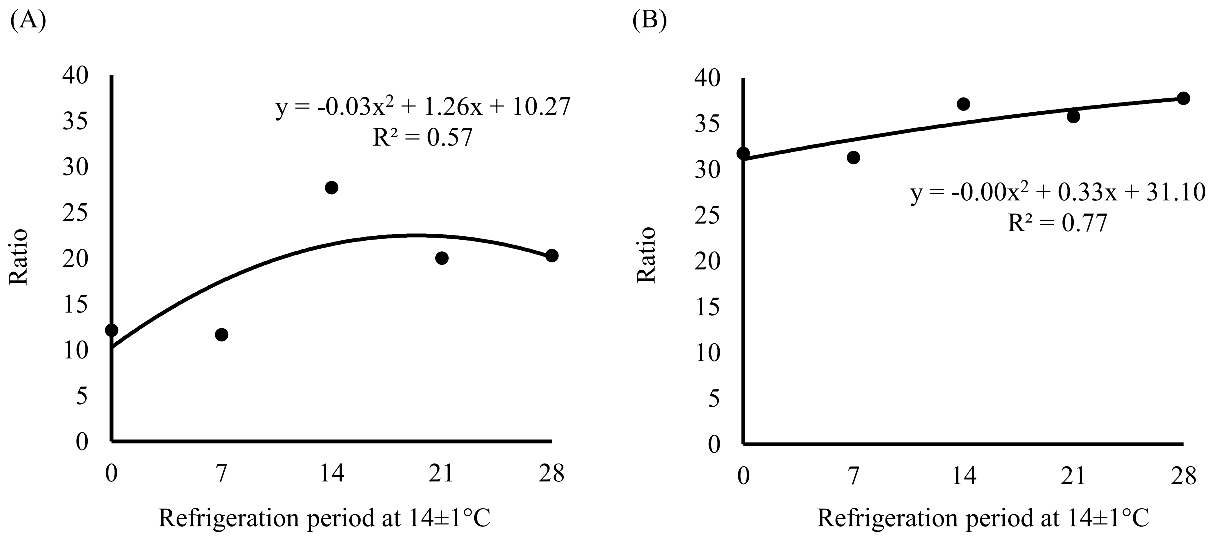


Figure 9. Soluble solids content to titratable acidity ratio in 'BRS-Princesa' bananas stored at 14±1 °C for 0, 7, 14, 21, and 28 days, assessed immediately after removal from the cold chamber (A) and at ripening stage 6 after transfer to a climate-controlled environment (25±1 °C).

Although the fruit stored at 14±1 °C for 21 days had a longer shelf-life and a maturation time within the estimated deadline for marketing, they showed moderate chilling injury symptoms, as well as fruit under refrigeration for 28 days, which makes them unmarketable considering that the appearance of fruit is a determining factor in consumer choice. Fruit stored under refrigeration for 28 days also showed peduncle rot.

The fruit stored at 14±1 °C for 14 days were firmer when removed from refrigeration, making them more resistant to damage, such as bruising, during marketing; they also had a better balance between sweetness and acidity (SSC/AT) both at the time of removal from refrigeration and after transfer to room temperature (25±1 °C). These fruit had a maturation time after removal from refrigeration within the estimated deadline for marketing. Therefore, refrigerated storage at 14±1 °C for 14 days would be the most suitable for bananas of the cultivar BRS-Princesa grown in the Baixo Sul region of Bahia, as it allows growers to better distribute their production to more distant markets.

CONCLUSION

The physicochemical quality of bananas of the cultivar BRS-Princesa is affected by refrigerated storage conditions, especially immediately after removal from the cold chamber. Storage under refrigeration at 14±1 °C for up to 14 days does not negatively impact the physicochemical fruit characteristics, making it the most suitable among the evaluated refrigerated storage periods. Therefore, 'BRS-Princesa' bananas harvested at 87 days after bunch emergence can be stored at 14±1 °C for up to 14 days without compromising appearance and quality, extending the time for fruit consumption by 8 days compared to fruit stored without refrigeration at room temperature (25±1 °C).

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