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Research Article

# Foliar application of boron and ethephon on postharvest ripening and conservation of 'Galaxy' apples

*Aplicação foliar de boro e ethephon sobre a maturação e conservação pós-colheita de maçãs 'Galaxy'*

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## ABSTRACT

Boron (B) and ethephon have been used in preharvest foliar sprays to anticipate the ripening of apples (Malus domestica Borkh.), however there are reports of potential negative effects during the post-harvest conservation of the fruits. In this context, the objective of this study was to evaluate the effects of preharvest foliar application of boron and ethephon on the maturation and conservation capacity of 'Galaxy' apples in refrigerated storage for four months plus seven days of shelf life at 15ºC. The experiment was conducted in a commercial orchard in the municipality of Urupema - SC, Brazil during the 2020/2021 harvest. The experimental design used was of randomized blocks, with four treatments and three replications. The treatments were applied via foliar during preharvest as follows: control (no application); boron 3g L-1 (4 applications); boron 3g L-1 + ethephon 300mg L-1 and ethephon 300mg L-1. The attributes related to quality and conservation of the fruits at harvest were determined in two stages with an interval of ten days, and after storage. Fruit maturation was anticipated by preharvest foliar application of boron and ethephon, without changing the background color and red intensity of the epidermis. There was a reduction in pulp firmness as a function of the treatments after refrigerated storage for four months. Thus, both products can be an alternative for staggering of harvest, but the commercialization of fruits treated and stored in refrigerated storage must be done in advance due to the reduction in pulp firmness.

**KEYWORDS:** Boric acid. Ethylene. apple tree. *Malus domestica* borkh. Flesh firmness.

## RESUMO

O boro (B) e o ethephon têm sido utilizados em pulverizações foliares na pré-colheita para antecipar a maturação de maçãs (*Malus domestica* Borkh.), contudo existem relatos de possíveis efeitos negativos durante a conservação pós-colheita dos frutos. Neste contexto o objetivo do trabalho foi avaliar os efeitos da aplicação foliar de boro e ethephon em pré-colheita sobre a maturação e capacidade de conservação de maçãs 'Galaxy' em armazenamento refrigerado por quatro meses mais sete dias de vida de prateleira a 15 ºC. O experimento foi conduzido em pomar comercial, no município de Urupema - SC, durante a safra 2020/2021. O delineamento experimental utilizado foi o de blocos ao acaso, sendo quatro tratamentos com três repetições. Os tratamentos foram aplicados via foliar em pré-colheita da seguinte forma, controle (sem aplicação); boro 3 g $L^{-1}$ (4 aplicações); boro 3 g $L^{-1}$ + ethephon 300 mg $L^{-1}$ e ethephon 300 mg $L^{-1}$. Foram determinados os atributos relacionados com a qualidade e conservação dos frutos na colheita, sendo que esta foi realizada em duas etapas com intervalo de dez dias, e após o armazenamento. A maturação dos frutos foi antecipada pela aplicação foliar de boro e ethephon em pré-colheita, sem alterar a cor de fundo e a intensidade de cor vermelha da epiderme. Houve redução da firmeza de polpa em função dos tratamentos após o armazenamento refrigerado por quatro meses. Dessa forma, ambos os produtos podem ser alternativa para o escalonamento da colheita, porém a comercialização dos frutos tratados e acondicionados em armazenamento refrigerado deve ser realizada antecipadamente em virtude da redução de firmeza de polpa.

**PALAVRAS-CHAVE:** Ácido bórico. Etileno. Macieira. *Malus domestica* Borkh. Firmeza da polpa.

## INTRODUCTION

The apple production chain has a prominent place in national fruit growing, being a source of income for thousands of families in southern Brazil, with the supply of quality fruits throughout the year, without dependence on fruit imports (BUENO et al. 2021). The quality and storage potential of apples can be influenced by their stage of ripeness at the time of harvest and also by plant management (ARGENTA et al. 2024). As a climacteric fruit, apples have a high respiratory rate during ripening, which is stimulated by ethylene (KLUGE et al. 1997). Apples of the 'Gala' group have a high metabolic rate compared to the Fuji cultivar, and it is recommended to use measures to avoid a very homogeneous ripening and thus allow staggering in harvesting the fruits.

Harvest staggering prevents yield losses due to pre-harvest drop and post-harvest spoilage and is related to the harvest of overripe fruits (ARGENTA & MARTIN 2018). Staggering allows for extending the harvest period, making it possible to optimize the available labor, considering that it is one of the costliest stages and the one that weighs most on the total cost of production, especially due to cost and difficulty of hiring qualified labor. In addition, staggering the harvest period provides greater flexibility in storage and marketing of fruits. According to PETRI et al. (2016), anticipating the harvest by advancing maturation is an excellent opportunity for producers to obtain a better price in the commercialization of their fruits, since during harvesting season there is a considerable increase in supply in the domestic market, causing a reduction in prices, especially in the period from February to April.

A potential way of advance ripening is with the pre-harvest application of ethylene releasing products such as ethephon. Ethephon accelerates ethylene synthesis (SOETHE et al. 2021) and can increase the red color index in fruits and allow for early harvest (LOONEY 2004). MACEDO et al. (2015), found an increase in fruit coloring and higher iodine-starch index, without interference in pulp firmness and soluble solids content of 'Pink Lady' apples submitted to pre-harvest applications of ethephon. However, ethephon can induce other attributes related to ripening, such as reducing pulp firmness and acidity, providing the occurrence of physiological disturbances, reducing the postharvest life of fruits (STEFFENS et al. 2006). SOETHE et al. (2021) report an increase in the SS and ethylene content in 'Baigent' apples with ethephon application.

In addition to ethephon, results have shown that foliar applications of boron can accelerate the ripening of apples in the plant (NACHTIGALL & CZERMAINSKI 2014, BRACKMANN et al. 2016). B is an essential nutrient, which acts in the formation of the cell wall and cell division (DECHEN et al. 1991), cell elongation, metabolism and transport of carbohydrates, organization and functioning of membranes (TANADA 1983). NACHTIGALL & CZERMAINSKI (2014) verified the anticipation of fruit ripening of apple trees submitted to foliar applications of boron, more accentuated in the cultivar 'Gala' from seven to twelve days, while for the cultivar 'Fuji', it was from three to five days, thus anticipating the harvest. BRACKMANN et al. (2016) found greater ethylene synthesis, increased respiratory rate, and reduced pulp firmness in 'Galaxy' apples treated with boron in pre-harvest. No studies were found evaluating the association of boron and ethephon to anticipate the maturation of 'Galaxy' apples.

It is important to highlight that the anticipation of ripening can affect both the quality and the post-harvest conservation capacity of the fruits (NACHTIGALL & CZERMAINSKI 2014, BRACKMANN et al. 2016). Therefore, the objective of this study was to evaluate strategies to anticipate the maturation of 'Galaxy' apples, with foliar application of boron and ethephon, alone or in combination. In addition, to evaluate the postharvest conservation capacity of fruits applied with boron and ethephon.

## MATERIAL AND METHODS

The experiment was conducted in the city of Urupema-SC (28°03'29.47"S 49°54'16.11"W, 1,328m altitude) in a commercial apple orchard (Malus domestica Borkh.), during the 2020/2021 harvest. The climatic data on the harvest is on table 1. The plants were six years old, of the Galaxy cultivar on Marubakaido rootstock, spaced 5 x 2.5 m apart and conducted on the central leader system. The orchard management was done according to technical recommendations for the integrated production of apples. The experimental design was randomized blocks, with four treatments and three replications. Each experimental unit consisted of five plants, distributed along a planting line, of which only the first four were used for the evaluations and one plant considered as a border.

**Table 1.** Precipitation, temperature and relative humidity data from the 2020/21 harvest. Inmet automatic station (A815), São Joaquim/SC.

| Month/Year | Precipitation (mm) | Temperature (°C) | Relative humidity (%) |
|---|---|---|---|
| August/20 | 94.4 | 12.7 | 62.7 |
| September/20 | 131.2 | 14.3 | 78.4 |
| October/20 | 89.2 | 14.8 | 75.0 |
| November/20 | 138.6 | 15.0 | 84.0 |
| December/20 | 151.8 | 16.6 | 82.3 |
| January/21 | 261.2 | 17.1 | 85.7 |
| February/21 | 112.6 | 16.6 | 80.3 |

The treatments consisted of pre-harvest foliar applications of boron and ethephon, as follows: 1) control (no application); 2) Boron 3g $L^{-1}$ (4 applications); 3) Boron 3g $L^{-1}$ + ethephon 300mg $L^{-1}$; 4) ethephon 300mg $L^{-1}$. As a source of ethephon, the product Ethrel® was used, containing 24% of active ingredients, and as a source of boron, the commercial product boric acid, was used, at a 17% concentration. The four applications of boron 3g $L^{-1}$ were done between 40 and 10 days before the expected date for first harvest, and the number of equidistant sprays was spaced between these dates. The other treatments were done 20 days before the scheduled date for first harvest. The products were applied using a Stihl SR-450 motorized backpack atomizer (working pressure of 40 psi). The volume of spray used was 1,000 L $ha^{-1}$.

The harvests were done in two seasons, the first (02/01/2021) anticipated by approximately ten days, to evaluate the anticipation of the physiological maturation of the fruits possibly caused by the application of boron and ethephon, and the second (02/11/2021) at the time of commercial maturation of the fruits of the control treatment, ten days after the first. The prediction of the commercial harvest date was made based on the date of full bloom and considering that the commercial harvest point of 'Gala' apples normally occurs 117 days after full bloom (ARGENTA & MONDARDO 1994). At each harvest, 40 fruits were randomly collected from each experimental unit.

The variables analyzed at each harvest date were pulp firmness, iodine-starch index, soluble solids, titratable acidity, background color and intensity of red color of the epidermis and respiratory rate. 20 fruits from each experimental unit were randomly sampled from each harvest for analysis of each variable, except respiratory rate. The evaluations were performed on the same day of each harvest. On the second harvest, another 20 fruits from each experimental unit were randomly sampled to evaluate the conservation of the fruits in refrigerated storage, which began on the same day, lasting four months at a temperature of 1°C and RH of 94% plus seven days of shelf life at 15ºC.

The analyses were performed as follows: a) Pulp firmness (N): determined with the aid of a portable manual penetrometer, equipped with an 11 mm diameter tip, in two opposite regions, in the equatorial portion of the fruits, after removal of a thin layer of the peel; b) Iodine-starch index: determined by the reaction of starch with a solution with 12g of metallic iodine and 24g of potassium iodide in 1 L of distilled water. After a cut in the equatorial region of the fruits, the iodine solution was applied to the cut surface of the peduncular half of the fruit, the color was compared (reaction of iodine with starch) with the table of photographs developed by STREIF (1984), where the index 01 indicates the maximum starch content (immature fruit), and index 10 represents the fully hydrolyzed starch (predominance of soluble sugars and fully ripe fruit); c) Streif index: expressed by the coefficient S=Firmness (kg/cm²)/Starch regression index (1 – 10).IR(ºBrix); d) Soluble solids (SS) content: by refractometry, through direct reading with an Edutec benchtop digital refractometer model EQQ-9001. The device was calibrated with distilled water and then the juice was distributed over the prism, and the reading was directly in ºBrix; e) Titratable acidity: determined through neutralization titrology with NaOH 0.1 mol $L^{-1}$ up to pH 8.1 expressed in mEq 100 $ml^{-1}$, by means of samples composed of juice containing 10mL, extracted in a food centrifuge; f) Background color and red intensity of the epidermis: determined in terms of hue angle values (hº), using a Delta Color electronic colorimeter, which reads the color on a three-dimensional scale and expresses the result in the h° attribute. The h° (hue angle) defines the basic coloration, with 0° = red, 90° = yellow, and 180° = green. These readings were done, respectively, in areas with smaller (background color) and with greater presence of red color (red side), in the equatorial region of each fruit; g) Respiratory rate: about 1,000 g of fruits were placed in 2,900mL airtight containers and stored for approximately one hour. The respiratory rate was obtained considering the weight of the fruits, density, volume of air inside the container and hermetic closure time and it was determined by quantifying the CO2 production inside the container, through a Felix electronic analyzer, model F-920. The results were expressed in ug $CO_2$ $kg^{-1}$ $h^{-1}$.

To evaluate the postharvest conservation of the fruits, the variables analyzed were pulp browning, farinaceous pulp, incidence of rot, soluble solids, pulp firmness, titratable acidity and respiratory rate. For the variables that were analyzed in the harvests and repeated after storage, the same methodology described above was used. For the others, the following procedure was performed: a) Pulp browning and Farinaceous pulp: evaluated by counting the fruits that presented visual symptoms of pulp browning or farinaceous aspect, expressed as a percentage. b) Incidence of rot: evaluated by counting the fruits that had lesions caused by fungi (>5mm in diameter), expressed as a percentage.

The data was submitted to the Shapiro-Wilk normality test, using the Sisvar software (FERREIRA 2014). When abnormalities were detected, they were transformed using the formula arc.sin(root(x+0.5)/100). Analysis of variance was performed for each trait evaluated, and then the means with significance were submitted to Tukey's test at 5% probability of error. Data that showed a significant difference, a principal component analysis was additionally performed using the Past 4.03 software.

## RESULTS AND DISCUSSION

### After harvest

There was no significant effect of the treatments on the variables background color and intensity of red color of the epidermis (Table 2). Contrary results were obtained by ERNANI et al. (2010) and NACHTIGALL & CZERMAINSKI (2014) who found an increase in the intensity of red with boron application a few weeks before harvest. VARGAS et al. (2019) also did not observe an effect of ethephon on apples coloring, although it was effective in anticipating fruit maturation. Ethylene activates the expression of genes of the anthocyanin biosynthesis pathway, resulting in an increase in color of the fruit epidermis (AWAD & JAGER 2002).

According to the iodine-starch index, maturation was anticipated with the foliar application of boron and ethephon (Table 2). This influence on fruit maturation was more pronounced in the first harvest and in the average of the two harvests, where all treatments differed statistically from the control treatment. NACHTIGALL & CZERMAINSKI (2014) also observed an increase in the iodine-starch index and the anticipation of ripening of 'Gala' and 'Fuji' apples treated in pre-harvest with boron. SÁ et al. (2014) found that foliar application of boric acid (0.3%) at flowering was efficient to increase the starch index in apples of the cultivar 'Imperial Gala'. According to WANG & DILLEY (2001), starch degradation is a direct consequence of the induction by ethylene.

**Table 2.** Epidermis color (red side and background color), iodine-starch index and Streif index in 'Galaxy' apples after harvest as a function of boron and Ethephon treatments during pre-harvest.

| Treatment | Epidermis color[1] | | | | | |
|---|---|---|---|---|---|---|
| | Red side (hº) | | | Background color (hº) | | |
| | 1st harvest | 2nd harvest | Average | 1st harvest | 2nd harvest | Average |
| Control | 22.86 ns | 25.73 ns | 24.30 ns | 58.55 ns | 78.18 ns | 68.37 ns |
| Boron | 24.06 | 26.94 | 25.50 | 63.70 | 71.36 | 67.53 |
| Boron + ethephon | 23.10 | 24.98 | 24.04 | 61.63 | 68.80 | 65.22 |
| Ethephon | 24.00 | 28.58 | 26.09 | 68.43 | 73.78 | 71.11 |
| C.V. (%) | 4.05 | 9.19 | 6.93 | 9.22 | 7.62 | 9.03 |
| | Iodine-starch index[2] (1-10) | | | Streif index | | |
| Control | 3.80 a | 4.80 a | 4.30 a | 0.192 a | 0.153 a | 0.171 a |
| Boron | 5.83 b | 6.30 ab | 6.06 b | 0.105 b | 0.100 b | 0.102 b |
| Boron + ethephon | 6.36 b | 6.43 ab | 6.40 b | 0.097 b | 0.095 b | 0.096 b |
| Ethephon | 6.10 b | 7.63 b | 6.86 b | 0.104 b | 0.077 c | 0.089 c |
| C.V. (%) | 4.44 | 13.21 | 5.2 | 36.0 | 30.8 | 32.9 |

* Average followed by the same letter in the column do not differ statistically by Tukey's test at 5% probability of error. [1] = scale from 0º to 180º, where 0º = red, 90º = yellow and 180º = green. [2] = scale from 1 to 10, where 1 represents the maximum starch content and 10 indicates fully hydrolyzed starch. ns = not significant (p>0.05).

The values of the Streif index show a reduction proportional to the advance of fruit maturation and ripening (Table 2). The results of the Streif index evaluated in this study demonstrated anticipation of maturation with the foliar application of boron and ethephon. In the first harvest, all treatments differed statistically from the control treatment. In the second harvest and in the average, the same behavior was observed. The treatments with boron and the combination of boron and ethephon did not differ from each other in the second harvest. The treatment with ethephon was the one that showed the greatest reduction in the Streif index in the second harvest, thus demonstrating greater anticipation in the maturation of the fruits. According to ALEXANDRE (2001), this index allows a more correct evaluation of the fruit's maturation stage, since these parameters are the ones that vary most drastically during the maturation period.

Titratable acidity did not present statistical difference between the treatments in the first harvest (Table 3). WACLAWOVSKY (2001) also did not verify the effect of ethephon on the titratable acidity in 'Gala' apples. In the second harvest, all treatments differed statistically from the control treatment and, considering the average of the two harvests, the boron treatments and the boron treatment associated with ethephon were more efficient in anticipating maturation in comparison to ethephon. The treatment with ethephon did not present statistical difference in relation to the control treatment and the others in the reduction of titratable acidity.

**Table 3.** Titratable acidity, soluble solids, pulp firmness and respiration rate of 'Galaxy' apples after harvest as a function of boron and Ethephon treatments in preharvest.

| Treatment | Titratable acidity (mEq 100 mL)[1] | | | Soluble solids (º Brix) | | |
|---|---|---|---|---|---|---|
| | 1st harvest | 2nd harvest | Average | 1st harvest | 2nd harvest | Average |
| Control | 5.83 ns | 5.56 a | 5.70 a | 10.60 ns | 10.86 a | 10.73 a |
| Boron | 4.86 | 4.50 b | 4.68 b | 11.48 | 11.40 ab | 11.44 b |
| Boron + ethephon | 5.06 | 4.50 b | 4.78 b | 11.40 | 11.53 bc | 11.46 b |
| Ethephon | 5.30 | 4.63 b | 4.96 ab | 11.26 | 12.13 c | 11.70 b |
| C.V. (%) | 11.44 | 6.85 | 9.01 | 5.25 | 1.93 | 3.77 |
| | Pulp firmness (N) | | | Respiration rate (mL $CO_2$ $kg^{-1}$ $h^{-1}$) | | |
| Control | 75.9 a | 78.4 ns | 77.2 a | 11.17 ns | 6.94 ns | 9.05 ns |
| Boron | 68.6 b | 70.3 | 69.4 b | 12.25 | 7.48 | 9.87 |
| Boron + ethephon | 69.1 b | 69.2 | 69.2 b | 11.56 | 7.61 | 9.58 |
| Ethephon | 70.3 b | 70.0 | 70.1 b | 11.81 | 8.03 | 9.92 |
| C.V. (%) | 1.57 | 5.99 | 3.9 | 4.47 | 7.95 | 9.00 |

* Average followed by the same letter in the column do not differ statistically by Tukey's test at 5% probability of error. ns = not significant (p>0.05).

At the first harvest, the soluble solids (SS) content did not present statistical differences between treatments (Table 3). MACEDO et al. (2015) and MAGRIN et al. (2016) also did not verify the effect of boric acid applied during preharvest on the SS of 'Pink Lady' apples. An increase in SS content was observed in the second harvest with boron and ethephon applications. The treatment with ethephon was the one with the highest SS content but did not differ from the combined treatment of boron and ethephon. Ethephon releases ethylene into the fruit and accelerates its ripening, thus increasing the activity of starch-degrading enzymes, resulting in higher sugar content (LI et al. 2017, PESTEANU 2017), a result also reported by SOETHE et al. (2021). In the average of the two harvests, all treatments differed statistically in relation to control and did not differ from each other. These results corroborate the results found by DRÖSEMEYER et al. (2018) who observed an increase in the SS content of cv. Imperial Gala apples with pre-harvest applications of boric acid. NACHTIGALL & CZERMAINSKI (2014) also found an increase in SS and the anticipation of ripening of 'Gala' apples treated during pre-harvest with boron.

All treatments showed a reduction in pulp firmness when compared to the control treatment at first harvest (Table 3). BRIGHENTI et al. (2017) found that 'Gala' apples treated with ethephon had lower values for pulp firmness, when compared to the control treatment. In the second harvest there were no differences between treatments. According to the results of JOHNSTON et al. (2001) and MAJUMDER & ZHUMMAR (2002), the presence of ethylene is necessary for the activity of enzymes responsible for reducing pulp firmness. Other authors also report reduced pulp firmness with boron or ethephon (WANG & DILLEY 2001, DRÖSEMEYER et al. 2018, BRACKMANN et al. 2016). The applications of boron and ethephon resulted in a reduction in the pulp firmness of the fruits on average of the two harvests in all treatments, which is one of the most important variables for fruit storage. This response indicates a possible reduction in the storage potential of fruits that received foliar application of these products. Boron applications can accelerate fruit metabolism, increasing ethylene production, thus anticipating ripening and causing a reduction in pulp firmness (BRACKMANN et al. 2016). The respiratory rate of the fruits at harvest was not affected by the treatments (Table 3).

**After storage and shelf period**

After four months of refrigerated storage, with the exception of pulp firmness, the physicochemical variables of the fruits did not differ with the applications of boron and ethephon. The postharvest physiological disorders, farinaceous pulp and pulp browning also did not differ (Table 4). There was also no interaction between treatment and days after storage (data not shown). The reduction in pulp firmness was anticipated by treatments with boron or ethephon isolates, being close to the minimum limit for commercialization of 40 N (9 lbs.) for the Gala cultivar and its mutations established by Normative Instruction No. 5/2006 of MAPA, (BRASIL, 2006). Thus, it is clear that fruits treated with these products, stored in cold storage, must be sold in advance. According to PICCHIONI et al. (1995), as boron presents rapid translocation in apple crops, the increase in concentration of this nutrient in the fruits can negatively influence its conservation capacity. The potential effect of ethephon on a given physiological process depends on several factors, including the endogenous concentration of ethylene, the physiological stage of the plant and temperature (CHITARRA & CHITARRA 2005). According to LELIÈVRE et al. (1997), apples of the 'Gala' group, due to their high respiratory rate and high ethylene production, present rapid loss of pulp firmness, reduction of titratable acidity and yellowing of the background color of the epidermis during storage and marketing period. The exogenous application of ethylene can accelerate these processes. Thus, it is evident that when applying boron and/or ethephon with the goal of anticipating the harvest, the area that was sprayed with these products should be harvested before the others, because the delay in harvesting date results in rapid evolution of fruit ripening (KADER 2002), reducing storage capacity.

**Table 4.** Soluble solids (SS) content, titratable acidity, pulp firmness, pulp browning and farinaceous pulp of 'Galaxy' apples after 4 months of refrigerated storage, plus seven days of shelf life at 15ºC, as a function of the treatments with boron and Ethephon in pre-harvest.

| Treatment | SS (ºBrix) | Titratable acidity (mEq 100 mL-¹) | Pulp firmness (N) | Pulp browning (%) | Farinaceous pulp (%) |
|---|---|---|---|---|---|
| Control | 11.83 $^{ns}$ | 3.9 $^{ns}$ | 50.6 a | 0 $^{ns}$ | 0 $^{ns}$ |
| Boron | 11.83 | 4.0 | 45.1 b | 1.07 | 1.07 |
| Boron + ethephon | 11.53 | 3.56 | 47.1 ab | 0 | 2.22 |
| Ethephon | 11.53 | 3.56 | 46.4 b | 0 | 0 |
| C.V. (%) | 4.8 | 3.59 | 2.78 | 43.6 | 73.7 |

* Average followed by the same letter in the column do not differ statistically by Tukey's test at 5% probability of error. ns = not significant (p>0.05).

The incidence of rot did not differ with the applications of boron and ethephon after four months of refrigerated storage (Table 5). Post-harvest rot can be caused by infections in wounds and lesions generated during harvesting and handling of fruits or by quiescent infections, contaminating the fruits while still on the field, but symptoms will develop only after storage. The exogenous application of ethylene can accelerate these symptoms, enhancing the speed of development of infections (ARAÚJO & MEDEIROS 2018), a fact not observed in this study. The incidence of rot is directly correlated with storage time, as four months refrigerated storage is considered a relatively short period for apples, this may explain the low rot rates shown in Table 4, even though the fruits are exposed to boron and ethephon applications during pre-harvest.

**Table 5.** Respiratory rate and incidence of rot on 'Galaxy' apples after 4 months of refrigerated storage, evaluated at the exit of the chamber (SC) and after seven days of shelf life at 15ºC, as a function of treatments with Boron and Ethephon in pre-harvest.

| **Treatment** | **Respiratory rate ($mLCO_2$ $kg^{-1}$ $h^{-1}$)** | | **Rot (%)** | |
|---|---|---|---|---|
| | Chamber's exit | 7 d at 15°C | Chamber's exit | 7 d at 15°C |
| Control | 5.93 $^{ns}$ | 8.37 $^{ns}$ | 1.04 $^{ns}$ | 1.04 $^{ns}$ |
| Boron | 6.05 | 8.98 | 1.04 | 1.04 |
| Boron + ethephon | 5.96 | 9.09 | 1.04 | 1.04 |
| Ethephon | 6.52 | 9.28 | 2.08 | 2.08 |
| C.V. (%) | 7.48 | 6.8 | 64.03 | 64.03 |

ns = not significant ($p>0.05$).

It is estimated that post-harvest losses in apples, during and after storage, reach the value of 153.73 million reais a year in Brazil (OGOSHI et al. 2019). In Santa Catarina, postharvest rot losses of apples under commercial conditions accounted for ≈60% to 80% of the total losses of 'Gala' and 'Fuji' apples during storage, respectively (ARGENTA et al. 2021). In this study, the rot index found was low, showing no evolution after seven days of shelf life.

Respiratory rate did not differ between treatments (Table 5). The rate of deterioration (perishability) of products after harvest is usually proportional to their respiratory rate. A high rate reduces the storage life of products. BRACKMANN et al. (2016) reported higher respiratory rates, as well as a higher incidence of rot in 'Galaxy' apples treated during pre-harvest with boron and stored for eight months in a controlled atmosphere, diverging from the results presented in Table 5. Therefore, it is possible to observe that storage time, year of cultivation, orchard conditions and form of storage can directly influence the respiratory rate and incidence of rot in apples treated with boron during pre-harvest.

## Principal Component Analysis (PCA)

For an integrated visualization of the results, a PCA analysis was done (Figure 1). Major component 1 (CP 1) explains more than 89.0% of variation in results, in which a separation of the control treatment from boron and ethephon can be observed, applied separately or in combination. It is noted that the parameters Streif index, acidity, pulp firmness both at harvest and after storage were correlated with the control treatments, evidencing lower fruit maturation. On the other hand, treatments with boron and ethephon showed a higher correlation with iodine-starch and soluble solids in both crops. These results show that the treatments advanced the maturation of 'Galaxy' apples.

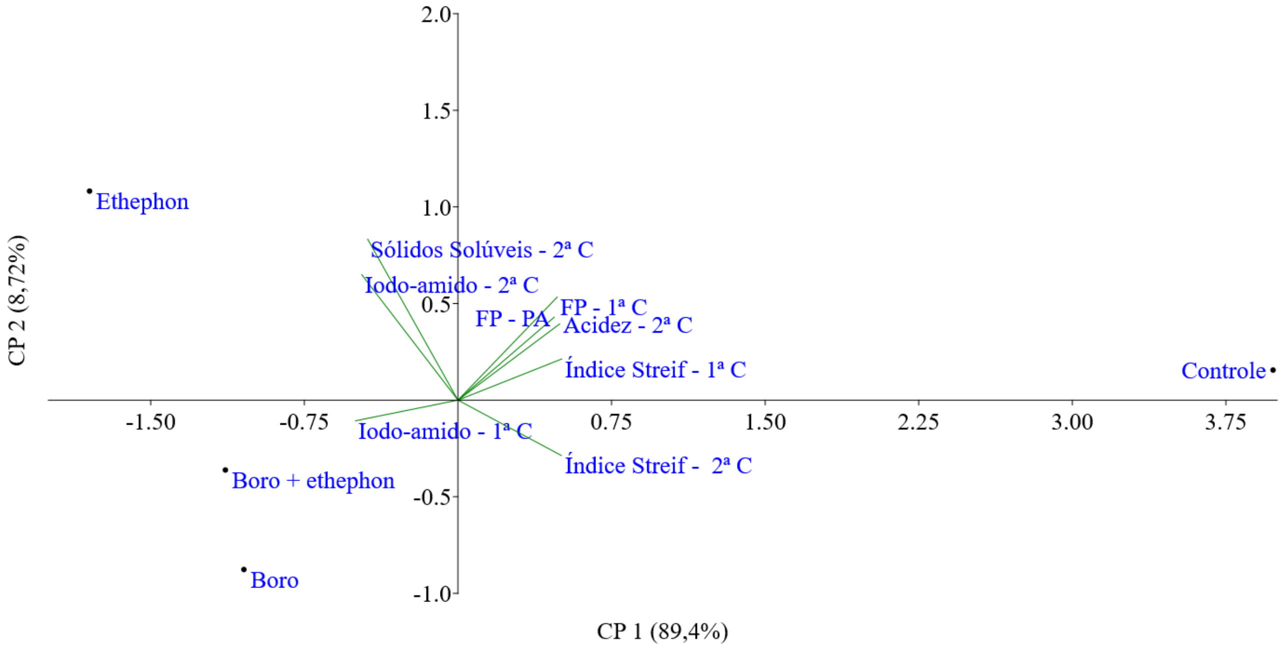


**Figure 1.** Principal components analysis of 'Galaxy' apples after harvest and 4 months of cold storage plus seven days of shelf life at 15ºC as a function of treatments with boron and Ethephon in pre-harvest. 1st C = first harvest; PA = post-storage.

## CONCLUSION

The maturation of 'Galaxy' apple was anticipated by the application of boron and ethephon, evidenced by pulp firmness, iodine-starch index, Streif index and acidity, with no changes in respiratory rate, red color and background color of the epidermis of the fruits, both products being a viable alternative in the management and staggering of harvest in apple orchards. The reduction in pulp firmness was accelerated in the fruits of the second harvest during refrigerated storage for four months due to treatments with boron and ethephon, being close to the minimum commercialization limit, suggesting that the commercialization should be done in advance due to the reduction in pulp firmness.

## AUTHOR CONTRIBUTIONS

Conceptualization, methodology and formal analysis, Anese, RO and Andrade, EDR; software and validation, Anese, RO and Andrade, EDR; investigation, Anese, RO and Andrade, EDR; resources and data curation, Andrade, EDR; writing - preparation of the original draft, Andrade, EDR; writing - review and editing, Anese, RO and Andrade, EDR; visualization, Anese, RO and Andrade, EDR; supervision, Anese, RO and Andrade, EDR; project management, Anese, RO and Andrade, EDR; fundraising, Anese, RO. All authors have read and agreed with the published version of the manuscript.

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## DATA AVAILABILITY STATEMENT

The data can be made available upon request.

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## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

## REFERENCES

ALEXANDRE J. 2001.Colheita da pera ‘Rocha’. In: ALEXANDRE J et al. (Eds.). O Livro da pera ‘Rocha’. Portugal: Associação Nacional de Produtores de Pera ‘Rocha’.

ARAÚJO L & MEDEIROS H A. 2018. Principais doenças e seu controle. In: SEZERINO AA. (Org.). Sistema de produção para a cultura da macieira em Santa Catarina. Florianópolis: Epagri. 136p. (Epagri Sistema de Produção 50).

ARGENTA LC & MONDARDO M. 1994. Maturação na colheita e qualidade de maçãs ‘Gala’ após a armazenagem. Revista Brasileira de Fisiologia Vegetal, São Carlos, 6:2, 135-140.

ARGENTA LC et al. 2021. Characterization and quantification of postharvest losses of apple fruit stored under commercial conditions. HortScience 56: 608-616.

ARGENTA LC et al. 2024. Economic analysis of the harvest date effects on quality and productivity of ‘Fuji Suprema’ apple. Revista Brasileira de Fruticultura 46: e-064.

ARGENTA LC & MARTIN MS. 2018. Manejo das frutas na colheita e após a colheita. In: SEZERINO AA (Org.). Sistema de produção para a cultura da macieira em Santa Catarina. Florianópolis: Epagri. 136p. (Epagri Sistema de Produção 50).

AWAD MA & JAGER A. 2002. Formation of flavonoids, especially anthocyanin and chlorogenic acid in ‘Jonagold’ apple skin: influences of growth regulators and fruit maturity. Scientia Horticulturae, Amsterdam, 93:3-4, 257-266.

BRACKMANN A et al. 2016. Preharvest boron application and its relation with the quality of ‘Galaxy’ apples after harvest and controlled atmosphere storage. Ciência Rural 46: 585-589.

BRASIL. 2006. Ministério da Agricultura, Pecuária e Abastecimento. Instrução Normativa nº 05, de 15 de fevereiro de 2006. Aprovar o Regulamento Técnico de Identidade e Qualidade da Maçã; as Disposições Complementares e a Amostragem, Conformação da Amostra e Análise, conforme os respectivos Anexos I, II e III, desta Instrução Normativa. Diário Oficial da União, Brasília, DF, 16 fev. 2006. Disponível em: https://sistemasweb.agricultura.gov.br/sislegis/action/detalhaAto.do?method=visualizarAtoPortalMapa&chave=805793610. Acesso em: 19 ago. 2024.

BRIGHENTI AF et al. 2017. Plant growth regulators to enhance fruit color of 'Gala' apples. Pesquisa Agropecuária Brasileira 52: 1118-1122.

BUENO MP et al. 2021. Análise da comercialização da cadeia produtiva da maçã brasileira: produção, importação e exportação no período 2015 a 2019. Brazilian Journal of Development 7: 34061-34078.

CHITARRA MIF & CHITARRA A B. 2005. Pós-colheita de frutos e hortaliças*. Lavras: Escola Superior de Agricultura de Lavras - FAEPE.

DECHEN AR et al. 1991. Funções dos micronutrientes nas plantas. In: FERREIRA M E & CRUZ MCP. (Ed.). Micronutrientes na Agricultura. Piracicaba: POTAFOS/CNPq. p.65-97.

DRÖSEMEYER GK et al. 2018. Escalonamento da colheita utilizando ácido bórico como antecipador na maturação em maçãs. Lages: Seminário de Iniciação Científica.

ERNANI PR et al. 2010. Pulverizações com boro em pré-colheita antecipam o amadurecimento de maçãs. In: Congresso Brasileiro de Fruticultura, 21. Natal. Anais... São Paulo: Sociedade Brasileira de Fruticultura.

FERREIRA DF. 2014. Sisvar: A guide for its Bootstrap procedures in multiple comparisons. Ciência e Agrotecnologia 38: 109-112.

JOHNSTON JW et al. 2001. Temperature induces differential softening responses in apple cultivars. Postharvest Biology and Technology 23: 185-196.

KADER AA. 2002. Postharvest technology of horticultural products. 3.d. Los Angeles: University of California, Division of Agriculture and Natural Resources. 535 p. (Publication 3311).

KLUGE RA et al. 1997. Fisiologia e manejo pós-colheita de frutas de clima temperado. Pelotas: Editora UFPEL.

LELIÈVRE JM et al. 1997. Ethylene and fruit ripening. Physiologia Plantarum, Copenhagen, 101: 727-739.

LI F et al. 2017. Ethylene effects on apple fruit cuticular wax composition and content during cold storage. Postharvest Biology and Technology 134: 98-105.

LOONEY N. 2004. Plant growth regulators will still be needed. Good Fruit Grower 55: 14-15.

MACEDO CKB et al. 2015. Antecipação da colheita de maçãs 'Pink Lady' pelo uso de ethephon e óleo mineral. In: Encontro Nacional de Fruticultura de Clima Temperado. Resumos... Fraiburgo: Epagri. p.46.

MAGRIN FP et al. 2016. Aplicação pré-colheita de ácido bórico em maçãs 'Pink Lady' e suas implicações na pós-colheita dos frutos. In: Congresso Brasileiro de Fruticultura. Resumos... São Luís: SBF. 4p.

MAJUMDER K & MAZUMDAR BC. 2002. Changes of pectic substances in developing fruits of cape-gooseberry (*Physalis peruviana* L.) in relation to the enzyme activity and evolution of ethylene. Scientia Horticulturae 96: 91-101.

NACHTIGALL GR & CZERMAINSKI ABC. 2014. Efeito da aplicação de boro via foliar na qualidade e na colheita de frutos de macieira. Bento Gonçalves: Embrapa Uva e Vinho. (Comunicado Técnico 164).

OGOSHI C et al. 2019. Podridões pós-colheita em maçã: perdas econômicas e alternativas de manejo. Brazilian Journal of Development 5: 17093-17101.

PESTEANU A. 2017. Effects of ethephon application on color development of 'Gala Must' apples. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Horticulture 74: 26-32.

PETRI JL et al. 2016. Reguladores de crescimento para frutíferas de clima temperado. Florianópolis: Epagri. 141 p.

PICCHIONI GA et al. 1995. Retention and the kinetics of uptake and export of foliage-applied, labeled boron by apple, pear, prune and sweet cherry leaves. Journal of the American Society for Horticultural Science 120: 28-35.

SÁ AA et al. 2014. Influência de formas de aplicação de boro na qualidade e no rendimento de maçãs (*Malus domestica*). Revista Brasileira de Fruticultura 36: 487-494.

SOETHE C et al. 2021. Maturation of 'Baigent' apples protected by anti-hail nets and sprayed with aminoethoxyvinylglycine and ethephon. Pesquisa Agropecuária Brasileira 56: e02439.

STEFFENS CA et al. 2006. Maturação da maçã 'Gala' com a aplicação pré-colheita de aminoetoxivinilglicina e ethephon. Ciência Rural 36: 434-440.

STREIF J. 1984. Jod-Stärke-Test zur Beurteilung der Fruchtreife bei Äpfeln. Stuttgart: Obst und Garten.

TANADA T. 1983. Localization of boron in membranes. Journal of Plant Nutrition 6: 743-749.

VARGAS MB et al. 2019. Antecipação de colheita e coloração de maçãs 'Cripps Pink' em resposta ao uso de reguladores de crescimento e bioestimulantes. In: Encontro Nacional de Fruticultura de Clima Temperado. Resumos...Fraiburgo: Epagri. p.122.

WACLAWOVSKY AJ. 2001. Controle da maturação de maçãs (*Malus domestica* Borkh.) cv. Gala, com aplicação pré-colheita de aminoetoxivinilglicina (AVG). 134 f. Dissertação (Mestre em Agronomia). Santa Maria: UFSM.

WANG Z & DILLEY DR 2001. Aminoethoxyvinylglycine, combined with ethephon, can enhance red color development without over-ripening apples. HortScience 36: 328-331.