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Original Research Article
**Salicylic acid maintains quality of ‘Chimarrita’
and ‘Maciel’ peaches under cold storage**

ABSTRACT

Aims: The objective of this work was to evaluate the efficiency of postharvest application of salicylic acid on Chimarrita and Maciel peach cultivars under cold storage.

Study design: The experiment was conducted in a completely randomized design with four replications and 15 peaches per experimental unit, following a 4x3 factorial design for each cultivar, 4 treatments and 3 storage periods for both cultivars.

Place and Duration of Study: This work was executed at LabAgro/Fructiculture, Federal University of Pelotas, Rio Grande do Sul state, Brazil, between November 2013 and February 2014.

Methodology: Postharvest application of salicylic acid was performed in both cultivars from the 2013/2014 crop by spraying the fruits with the solution (salicylic acid + distilled water + ethyl alcohol) and then letting them air-dry. The following treatments were used: T1- Peaches without the treatment solution (distilled water + ethyl alcohol (control); T2- Peaches treated with 0.5 mmol.L⁻¹; T3- Peaches treated with 1.0 mmol.L⁻¹; T4- Peaches treated with 1.5 mmol.L⁻¹. The fruits submitted to the treatments were cold-stored at 1.0 ± 0.5° C and 85-90% RH, during 30 days. Physiological weight loss (%), DA index, flesh firmness (N), soluble solids content (°Brix), rot incidence (%) and soluble pectin (g.100g⁻¹), were evaluated after a storage period of 10, 20 and 30 days plus two days for commercial simulation.

Results: *Chimarrita cultivar:* The predict value for physiological weight loss at the stationary point was 3.27%, obtained with 1.33 mmol.L⁻¹ of salicylic acid at day 12. Data regarding rot incidence showed to be adjusted to the regression model (F = 3.90; p = 0.007), with R² of 0.68 e R²adj of 0.64. During the optimization process, the roots of the auxiliary equations were positive and negative in magnitude, indicating the saddle point as the stationary point. Under this condition, 35.4% of rotting was registered for 0.85 mmol.L⁻¹ of salicylic acid, after 23 days. *Maciel cultivar:* The predict value for low mass at this stationary point was 5.18%, reached with 0.56 mmol.L⁻¹ of salicylic acid after 21.19 days. Pulp firmness findings adjusted to the regression model (F = 61.87; p< 0.0001), with R² of 0.89 and R²adj of 0.87. During the optimization process, the roots of the auxiliary equations were positive and negative in magnitude, indicating the saddle point as stationary point, and the predict value was 35.7N for 0.75 mmol.L⁻¹ of salicylic acid in 20 days.

Conclusion: Postharvest application of Salicylic acid at 1.0 mmol.L⁻¹ was efficient in maintaining the quality of the Chimarrita cultivar at 20 plus two days for commercial simulation. As for the Maciel cultivar, a concentration of 0.5 mmol.L⁻¹ of salicylic acid was more efficient for the same storage period.

Keywords: Elicitor, Prunus persica (L.), storage period, quality.

14 1. INTRODUCTION

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16 Peaches are highly perishable fruits and their quality can be affected if proper postharvest
17 handling is not followed [1]. Reported studies have combined others techniques with cold
18 storage in order to increase the shelf life of peaches. One of techniques can be postharvest
19 application of salicylic acid combined with cooling.

20 Salicylic acid, considered as an endogenous plant growth regulator, has been found to
21 generate a wide range of metabolic and physiological responses in plants, affecting growth
22 and development. Salicylic acid, known as a phenol natural and safe compound, exhibits a
23 high potential in controlling postharvest losses [2], like rooting and physiological weight loss.
24 The same has been observed by [3], with positive results. These same authors tested
25 salicylic acid concentrations of 0.35 mmol, 0.7 mmol and 1.0 mmol, reporting good results
26 for pulp firmness at 1.0 mmol of salicylic acid.

27 According to Tareen et al. [4], the use of salicylic acid in peaches proved to be efficient in
28 controlling fruit properties, such as epidermis color, mass loss, firmness and pH.

29 The aim of this study was to evaluate the efficiency of postharvest application of different
30 concentrations of salicylic acid in Chimarrita and Maciel peaches under cold storage.

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33 2. MATERIAL AND METHODS

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35 This study was carried out on Chimarrita and Maciel peaches obtained from the Palma
36 Agricultural Center /Federal University of Pelotas, Capão do Leão, Rio Grande do Sul,
37 Brazil, at latitude 31° 52 ' 00 "S, longitude 52° 21 ' 24" W and an altitude of 13.24 meters.
38 The soil belongs to the Camaquã unit, being moderately deep with medium texture on the
39 horizon A and clay in B, classified as ultisol [5]. The climate region is characterized as
40 temperate and humid with hot summers, "Cfa" according to the Köppen classification. The
41 region has an annual temperature and precipitation average of 17.9° C and 1500 mm,
42 respectively.

43 Postharvest application of salicylic acid performed in both cultivars, 2013/2014, was done by
44 spraying the solution (salicylic acid + distilled water + ethyl alcohol) at the fruits and then
45 leaving them to air dry. Approximately 1.0 ml of the solution was sprayed on both sides of
46 each fruit. In order to promote the solvency of salicylic acid, 5 mL.L⁻¹ of ethyl alcohol was
47 used in the solution.

48 The following treatments were used: T1 (control) - Peaches without the treatment solution
49 (distilled water + ethyl alcohol); T2- Peaches treated with 0.5 mmol.L⁻¹; T3- Peaches treated
50 with 1.0 mmol.L⁻¹; T4- Peaches treated with 1.5 mmol.L⁻¹.

51 Fruits submitted to the treatment were cold-stored at 1.0 ± 0.5° C and 85-90% RH, during 30
52 days. Analyses were undertaken in the following periods: harvest day for lot characterization;
53 after 10 days in cold storage plus 2 days at room temperature (20° C) for commercial
54 simulation (10 + 2); after 20 days in cold storage plus 2 days at room temperature (20 + 2);
55 and after 30 days in refrigerated storage plus 2 days of room temperature (30 + 2).

56 The experiment was conducted in a completely randomized design with four replications and
57 15 peaches per experimental unit, following a 4x3 factorial design for each cultivar, 4
58 treatments and 3 storage periods for both cultivars.

59 This study was executed at LabAgro/Fruticulture and the following variables were analyzed:

60 • **Physiological Weight Loss (PWL)**: PWL was determined by the difference in
61 percentage between the initial mass through the equation: $PWL = (initial\ weight - final\ weight) / initial\ weight \times 100$;
62

63 • **DA index**: obtained through the DA-meter 53500, which gives the index of
64 absorbance difference in wavelengths 670 and 720nm (peak of chlorophyll);

65 • **Flesh Firmness**: Firmness was recorded using a penetrometer expressed in
66 Newtons;

67 • **Rot incidence**: This was analyzed by counting the fruits that presented a lesion
68 diameter greater than 0.5 cm, which is typical of fungus and bacteria. The results were
69 expressed in percentage;

70 • **Soluble solids**: the soluble solids content in °Brix was determined with a digital
71 refractometer.

72 • **Pectin soluble content**: This was evaluated based on [6].

73 Data relating to normality were analyzed by Shapiro Wilk test; heteroscedasticity according
74 to Hartley test and residues independence using graphic analysis.

75 Subsequently, the data were subjected to analysis of variance, F-test ($p \leq 0.05$). Response
76 surface regression was used (PROC RSREG) SAS / STAT 9.1 for Windows (SAS Institute,
77 Cary NC), with linear effects, quadratic and linear interaction of independents variables [7].
78 The model was chosen based on: (a) residue; (b) p value ($p \leq 0.05$); (c) standard **derivation**
79 and (d) R^2 e R^2_{adj} . Afterwards, the polynomial equation was adjusted to dependent variables
80 data.

81 $y = \beta_0 + \sum \beta_{ixi} + \sum \beta_{iixi^2} + \sum \beta_{ijxixj}$, where y is the dependent variable; x_i , x_j are the
82 independent variables that affect the dependent variable y; β_0 is the intercept; β_i is the linear
83 effect; β_{ii} is the quadratic effect and β_{ij} is the interaction between x_i e x_j .

84 For optimization, the canonical rotational analysis added to surface response was used
85 where standard variables (x_1 , dose; x_2 , time) – within the experimental probability – were
86 established in order to obtain the response to each dependent variable studied. The
87 response optimization function consisted in response function version (y_k), from the origin
88 toward the stationary points (x_0). The response function was maximum when all roots
89 achieved negative values and minimum when all roots achieved positive values. If some
90 roots showed positive values and others negative it was characterized as a saddle point [8]
91 [9].

92 Harvest was undertaken in the first week of December, 2013 when fruit characterization was
93 complete, obtaining an average of 1038.67 g.15 fruits⁻¹, DA index of 0.82, soluble solids
94 content of 11.8° Brix and flesh firmness of 18.7 N, for the Chimarrita cultivar.

95 For the Maciel cultivar, the harvest was also carried out in the first week of December 2013
96 when the fruit description was complete, reaching an average of 1613.33 g.15 fruits⁻¹, DA
97 index of 0.67, soluble solids content of 13.93 °Brix and flesh firmness of 39.5 N.

3. RESULTS AND DISCUSSION

3.1 Chimarrita Cultivar

As shown in Figure 1A, physiological weight loss data adjusted to the regression model ($F = 93.63$; $p < 0.0001$) with R^2 0.92 and R^2_{adj} of 0.91. For this variable during the optimization process, roots of the auxiliary equations were positive and negative in their magnitudes, indicating that the stationary point is a saddle point.

The predict value for physiological weight loss at this stationary point was 3.27%, obtained with 1.33 mmol.L^{-1} of salicylic acid after 12 days. [10] Suggest that for Chimarrita peaches, a mass loss limit of 5% can lead to shriveling symptoms, which was not observed in the present study.

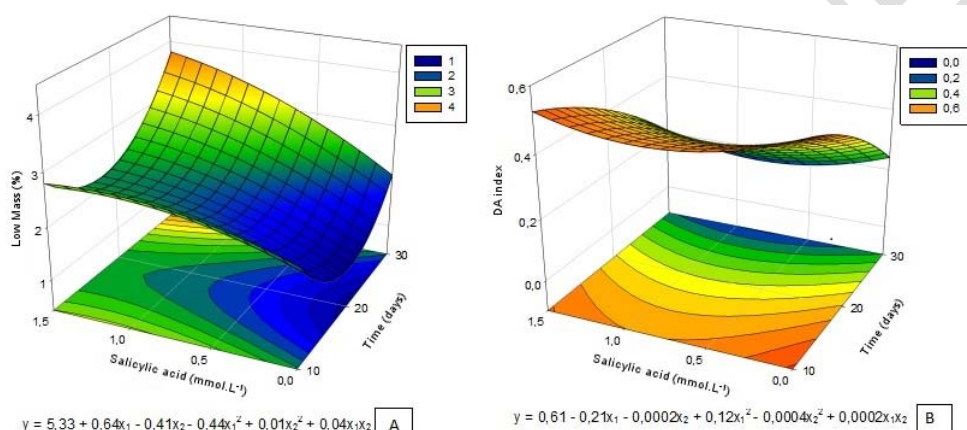


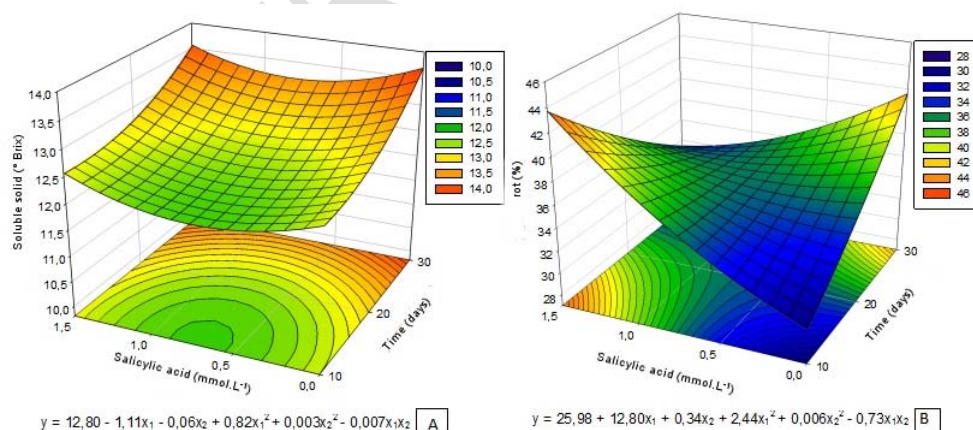
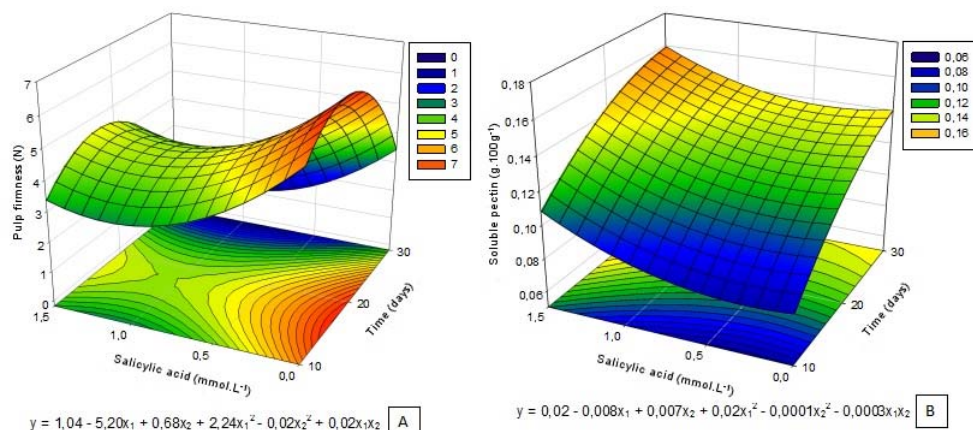
Figure 1: Physiological weight loss (A) and DA index (B) reported in Chimarrita peaches submitted to different concentrations of salicylic acid, after different periods under cold storage, plus 2 days at room temperature for commercial simulation. Pelotas - Brazil.

The results in Figure 1B showed that the DA rate adjusted to the regression model established ($F = 21.90$; $p < 0.0001$), with an R^2 of 0.72 and R^2_{adj} of 0.69. For this variable during the optimization process, roots of the auxiliary equations were positive and negative in their magnitude, indicating that the stationary point is a saddle point, obtaining a predicted DA index value of 0.48 at 0.29 mmol.L^{-1} of salicylic acid, combined with 13.4 days. If compared with lot characterization, DA index decreased considerably. This suggests a possible occurrence of chlorophyll degradation, since the closer it is to zero, the smaller the amount of chlorophyll in the fruit, [11] indicating probable fruit color and ripening evolution.

Firmness results adjusted to the regression model ($F = 11.55$; $p < 0.0001$), with R^2 of 0.77 and R^2_{adj} of 0.74, as shown in Figure 2A. During the optimization process, the roots of the auxiliary equations were positive and negative in their magnitude, indicating the saddle point as the stationary point. At this point, the predict point was 4.6 N in 1.09 mmol.L^{-1} of salicylic acid in 18.7 days. Soluble pectin data adjusted satisfactorily to the regression model ($F = 6.40$; $p = 0.0004$), with R^2 of 0.62 and R^2_{adj} of 0.59 (Figure 2B). During the optimization process, the roots of the auxiliary equations were positive and negative in their magnitude,

131 indicating the saddle point as the stationary point. At this point, 0.10 g.100g^{-1} soluble pectin
 132 was obtained for 0.43 mmol.L^{-1} of acid salicylic for 23.8 days.

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Data regarding rot development showed to be adjusted to regression model ($F = 3.90$; $p = 0.007$), with R^2 of 0.68 e R^2_{adj} of 0.64, as seen in Figure 3B. During the optimization process, roots of the auxiliary equations were positive and negative in their magnitude, indicating the saddle point as the stationary point. Under this condition, 35.4% of rotting was registered for 0.85 mmol.L⁻¹ of salicylic acid, in 23 days. Phytopathological testing was not performed to identify the causal agent of rot, but by its symptomatology, it referred to brown rot. According to [10], *Monilinia fructicola* is set up in the field, thus it is difficult to separate infected fruits from healthy ones, which can explain the large percentage and ranges in rot mean values found in this study.

3.2 Maciel Cultivar

Physiological weight loss adjusted to the regression model ($F = 6.07$; $p = 0.0003$), with R^2 of 0.61 and R^2_{adj} of 0.57 (Figure 4A). During the optimization process, the roots of the auxiliary equations achieved positive values stating that the stationary point is minimum. The predict value for low mass at this stationary point was 5.18%, reached with 0.56 mmol.L⁻¹ of salicylic acid in 21.19 days. Mass loss can be considered low if compared to an experiment carried out with Maciel peaches by [13], where fruits without treatment stored under similar conditions (21 days in cold storage plus 3 days of commercial simulation) showed mean values of 8.1% for harvested peaches. [4] Have also reported that salicylic acid application showed to be effective in reducing mass loss in peaches Flordaking.

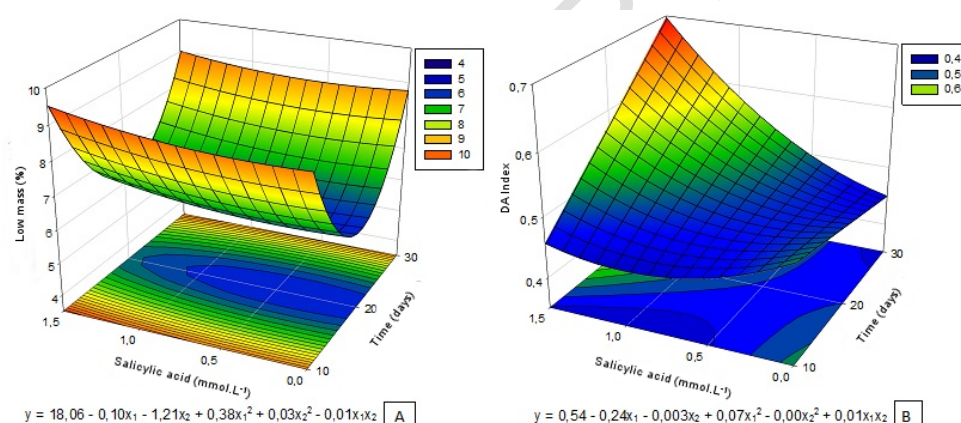
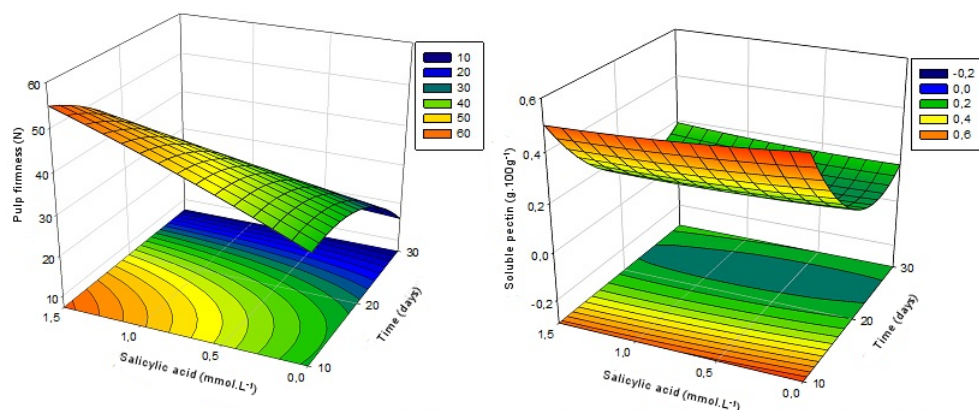


Figure 4: Physiological weight loss (A) and DA index (B) reported in Maciel peaches submitted to different concentrations of salicylic acid, during different cold storage periods, plus 2 days of commercial simulation. Pelotas –Brazil.

DA index behavior was analyzed in Figure 4B, wherein the index decreases during cold storage period; however, the parameter range was low in comparison with harvest day indicating fruit maturity process. DA findings adjusted to the regression model ($F = 7.85$; $p = 0.0004$), with R^2 of 0.68 and R^2_{adj} of 0.65. During the optimization process roots of the auxiliary equations were positive and negative in its magnitudes, indicating the stationary point is a saddle point, and predict value of DA index 0.44 for 0.62 mmol.L⁻¹ of salicylic acid in 14.7 days.

183 Pulp firmness findings adjusted to the regression model ($F = 61.87$; $p < 0.0001$), with R^2 of
 184 0.89 and R^2_{adj} of 0.87 (Figure 5A). During the optimization process, roots of the auxiliary
 185 equations were positive and negative in its magnitudes, indicating the saddle point as
 186 stationary point, and predict value was 35.7N for 0.75 mmol.L⁻¹ of salicylic acid in 20 days.
 187 The results are in agreement with [4] salicylic acid showed to be efficient for maintaining
 188 firmness, if compared to lot at the harvest period.



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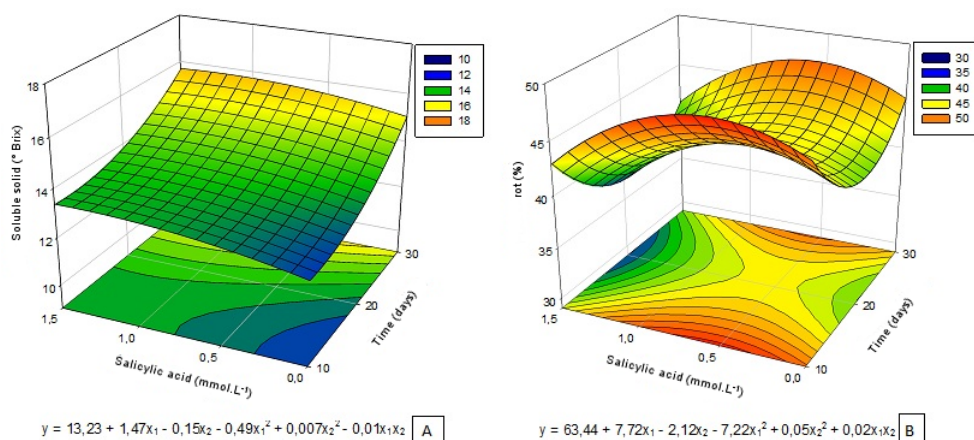
$$y = 24.03 + 23.50x_1 + 1.53x_2 - 1.46x_1^2 - 0.06x_2^2 - 0.69x_1x_2 \quad \text{A}$$

$$y = 1.36 - 0.10x_1 - 0.10x_2 + 0.02x_1^2 + 0.002x_2^2 + 0.003x_1x_2 \quad \text{B}$$

190 **Figure 5: Flesh firmness (A) and soluble pectin (B), reported in Maciel peaches**
 191 **submitted to different salicylic acid concentrations during different cold-storage**
 192 **periods, plus 2 days for commercial simulation. Pelotas - Brazil.**

193 Soluble pectin adjusted to the regression model ($F = 37.67$; $p < 0.0001$), with R^2 of 0.86 and
 194 R^2_{adj} of 0.84 (Figure 5B). During the optimization process, the roots of the auxiliary
 195 equations achieved positive values indicating that the stationary point is minimum. The
 196 predict value for soluble pectin at this stationary point was 0.19 g.100g⁻¹ reached with 0.94
 197 mmol.L⁻¹ of salicylic acid in 22.9 days. According to [14], there is a natural ripening process,
 198 during which pectin solubility occurs, and is deposited in the cell wall, being responsible for
 199 fruit firmness.

200 In a study with Aurora-1 peaches, [14] observed that increase in soluble solids content may
 201 be due to changes in accumulated resources, especially starch, during storage, as shown in
 202 Figure 6A. Soluble content data adjusted to the regression model ($F = 9.95$; $p < 0.0001$), with
 203 R^2 of 0.64 and R^2_{adj} of 0.61. During the optimization process, the roots of the auxiliary
 204 equations were positive and negative in their magnitude, indicating the saddle point as the
 205 stationary point. Soluble contents of 13.3 °Brix for 1.3 mmol.L⁻¹ of salicylic acid in 11.7 days
 206 were reported.



207

208 **Figure 6: Soluble solids content (A) and rot percentage (B) reported in Maciel peaches**
 209 **submitted to different concentrations of salicylic acid, during different cold-storage**
 210 **periods plus 2 days, for commercial simulation. Pelotas - Brazil.**
 211

212 Rot percentage findings adjusted to the regression model ($F = 14.60$; $p < 0.0001$), with R^2 of
 213 0.62 and R^2_{adj} of 0.59 . During the optimization process, the roots of the auxiliary equations
 214 were positive and negative in their magnitude, indicating the saddle point as stationary point.
 215 At this condition, 42.3% rotting was registered for 0.56 mmol.L^{-1} of salicylic acid in 22 days.
 216 This high percentage of brown rot could be attributed to salicylic acid postharvest
 217 application, increasing fruit humidity, promoting rot progress during storage [1].
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220 4. CONCLUSION

221
 222 Salicylic acid at 1.0 mmol.L^{-1} was efficient in maintaining the quality of the Chimarrita cultivar
 223 at 20 days plus two for commercial simulation. However, for the Maciel cultivar, 0.5 mmol.L^{-1}
 224 of salicylic acid was more efficient for the same period.
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