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# Sunburn damage and stem and fruit water potential of apples (*Malus domestica*) "Brasil Gala", "Cripps Pink" and "Granny Smith"

## Daño de sol y potencial hídrico de tallo y tejidos del fruto de manzanas (*Malus domestica*) Brasil Gala, Cripps Pink y Granny Smith

## Danos causados pelo sol e potencial hídrico em tecidos de caule e frutos de maçãs (*Malusdomestica*) 'Brasil Gala', 'Cripps Pink' e 'Granny Smith'

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## Abstract

Fruit discards due to physiological disorders and mechanical damage can exceed 50% of apple production in neotropical climate zones such as Uruguay. These damages become generally visible during ripening and storage, but they depend on factors that occur in the field. Sunburn is a major quality defect in fruit, known to be related to high radiation and temperatures, and, more recently, it has also been related to the water status of tissues in fruit and trees. This study aimed to evaluate the relationship between fruit damage and fruit tissue water status in "Brasil Gala", "Cripps Pink" and "Granny Smith", as well as the effect of treatments to avoid sun damage (50% black net, 20% translucent white net and kaolinite application) on stemwater potential in "Granny Smith". Fruit water potential decreased throughout the growth cycle. The exposed sides of fruits located outside the tree crown showed lower water potential than the non-exposed sides. Only the 50% black net of the sunburn avoidance treatments modified the water potential.

**Keywords**: sun damage, sun scald, fruit quality, abiotic damage, crop protection

## Resumen

Los descartes por desórdenes fisiológicos y daños mecánicos llegan a superar el 50% de la producción de manzana en zonas con clima neotropical como Uruguay. Son daños generalmente visibles durante la maduración y el almacenamiento, pero dependen de factores que suceden en el campo. El quemado de sol se presenta en algunas temporadas como uno de los principales defectos de calidad y ha sido relacionado históricamente con altos valores de radiación y temperatura y más recientemente con el estado hídrico de los tejidos del fruto y del árbol. El presente estudio evaluó la relación del daño por sol con la condición hídrica de tejidos de fruta en Brasil Gala, Cripps Pink y Granny Smith, así como el efecto de los tratamientos para evitar el daño por sol (malla negra 50%, malla blanca translúcida 20% y aplicación de caolinita) sobre el potencial hídrico de tallo en Granny Smith. El potencial hídrico del fruto disminuyó a lo largo del ciclo de crecimiento. En los frutos ubicados en el exterior del árbol, las caras expuestas presentaron valores menores de potencial hídrico de fruto que las caras no expuestas. El efecto sobre el potencial hídrico de los tratamientos para evitar el quemado de sol solo pudo constatarse en el caso de la malla negra 50 %.

**Palabras clave**: daño de sol, escaldado por sol, calidad de fruta, daños abióticos, protección de cultivos

**Resumo**

Os descartes devido a distúrbios fisiológicos e danos mecânicos atingem mais de 50% da produção de maçãs em áreas de clima neotropical, como o Uruguai. Os danos são geralmente visíveis durante a maturação e armazenamento, mas dependem de factores que ocorrem no campo. As queimaduras solares ocorren em algumas épocas como um dos principais defeitos de qualidade e tem sido historicamente relacionada a altos valores de radiação e temperatura e, mais recentemente, ao estado hídrico dos frutos e tecidos das árvores. O presente estudo avaliou a relação dos danos solares com o estado hídrico dos tecidos dos frutos em 'Brasil Gala', 'Cripps Pink' e 'Granny Smith', bem como o efeito dos tratamentos para prevenir danos solares (50% malha preta, 20 % malha branca translúcida e aplicação de caulinita) no potencial hídrico em tecidos de caule em 'Granny Smith'. O potencial hídrico dos frutos diminuiu ao longo do ciclo de crescimento. Nos frutos localizados na parte externa da árvore, as faces expostas apresentaram menores valores de poten-cial hídrico dos frutos do que as faces não expostas. O efeito dos tratamentos para evitar as queimaduras solares no potencial hídrico só pôde ser observado no caso da rede preta de 50 %.

**Palavras-chave**: danos causados pelo sol, escaldadura solar, qualidade da fruta, dano abiótico, proteção de cultivos

## 1. Introduction

Reducing food loss and waste is part of Goal 12.3 of the 2030 Sustainable Development Goals, which calls on nations to halve global food waste per capita[1]. The loss of quality due to physiological disorders in apple production in Uruguay is poorly quantified; the high variability in predisposing climatic factors and the productive and commercial structure create difficulties in systematizing information. According to FAO[1], the most common discarding defects in packing lines are due to physiological disorders and mechanical damage to the fruit. In "Granny Smith", physiological disorders in the field and during cold storage have exceeded values of 50%[2]. This damage is visible during fruit ripening and storage and depends on several preharvest factors. Among them are the high temperatures to which the fruits are subjected, direct radiation, the nutritional status of the plant, and the fruit's water balance, among others, related to climatic conditions and the fruit's position within the tree[3].

In neotropical climate conditions, sun damage is frequent. The climatic variability of the region[4] and its connection with the damage determine significant differences between years, both in magnitude and in the timing of damage development[2]. This physiological disorder is a major cause of fruit quality loss in apples before harvest[2], and the study of management measures for its mitigation is recent[5].

Physiological disorders in apples, and, especially, sun damage, have been related to high radiation and temperature values[6-7] and recently to the water status of the fruit and tree tissues[2][8-9]. The effect of individual factors and their existing interrelationships determine a high degree of complexity in the conditions that trigger physiological disorders. It has also been noted that the effect of climate factors on sunburn appearance depends on fruitsize. Racsko and Schrader[6] report the onset of damage when the fruits reach 45 mm in diameter (7 or 8 weeks after full bloom), and local studies establish the onset of damage at six weeks after full bloom[2].

Taking measures to mitigate predisposing microenvironmental conditions has been a strategy used for controlling disorders in fruit trees. The most common management techniques include installing irrigation systems to reduce water stress, placing shading nets, and applying reflective particle films or sunburn protectants. Protective or shading nets have been used to modify the crop microclimate, whether in reducing fruit exposure to high temperatures or direct sunlight radiation, the effect depends on the type of material, color, and percentage of weft[10]. The mechanisms involved in damage control are not fully described, and the results vary greatly depending on local climate, cultivar, and management[10-11]. As a consequence of microclimate modifications caused by the use of nets, effects have also been reported on the photosynthetic capacity, stomatal conductance[12], potential evaporation[13-14], and water status of plants and fruits[15]. Although this effect on tree physiology is widely reported, studies on the modification of water status and its effects on the development of sun damage are scarce.

Stem water potential at midday is considered a good indicator of water stress in apple trees(16-18) and has been evaluated in net response studies(19). Recent studies examining different irrigation regimes and net types in apple cultivation establish the importance of crop water status on fruit quality(20). Boini and others(18), in line with Severino and others(2), conclude that sun damage is more related to water status than to radiation. On the other hand, the use of nets, whether aiming to reduce sun damage, hail damage or for phytosanitary protection, presents adverse effects on color picking in two-tone cultivars(7) and, depending on the level of shading, it could affect floral induction and the vegetative/reproductive ratio(21).

The link between physiological disorders has been established with stem water potential and fruit water status(18). Increased skin exposure to radiation results in decreased tissue water potential and increased firmness(2)(22). In fruit tissues with sun damage, substances with antioxidant capacity, such as phenols and flavonoids(23), and compatible solutes, such as proline and soluble sugars, which play a central role in osmotic adjustment, preventing turgor reduction, accumulate(2)(24). However, studies on the effect of climate change on fruit and vegetable production have linked an increase in temperature, coupled with water stress, to a reduction in quality in terms of vitamins, antioxidants and minerals(25). This study aims to evaluate the relationship between sun damage and the water condition of fruit tissues in “Brasil Gala”, “Granny Smith” and “Cripps Pink”, as well as to assess the effect of treatments aimed at reducing sun damage on stem water potential in “Granny Smith”.

## 2. Material and methods

The present study was conducted during the 2015/2016 season in a commercial plantation of Brasil Gala/M9, Granny Smith/M7 and Cripps Pink/M9 located in San José, Uruguay (34°38’18” S; 56°40’06” W, 28 masl). The area is within a region of extensive grasslands of the Uruguayan savannah ecoregion, also known as the countryside. It is a regional ecotone between South America’s subtropical and tropical forests and temperate grasslands, currently classified as warm-temperate or neotropical(26). The area has an average daily solar radiation of 577 cal/cm$^2$, with average mean temperatures of 22 °C, and average maximum temperatures of 29 and 39 °C, for December and January, respectively(27). Maximum temperatures during the study cycle included 5 days with maximum temperatures above 35 °C and a peak above 38 °C.

The stem water potential was determined with a pressure chamber (PMS Instrument Corp®, Corvallis, OR, USA), before harvest (150 DAFB) on two healthy leaves per repetition located in the middle third of the tree between 1 and 3 pm. The leaves were covered with aluminum foil and wrapped in a Ziploc polyethylene bag between 1 and 1.5 hours before measurement.

In the case of “Granny Smith”, evaluations were conducted within the context of a sun damage reduction trial, including treatments with nets and the application of sunscreen in a randomized complete block design with three replications. All treatments used monofilament nets with the following characteristics: 20% translucent white net (MB) and 50% black net (MN50). The sunscreen used (PRO) was kaolin (Surround WP®, 50 K/ha), applied five times during the season to keep the fruits covered. All treatments were installed 7 weeks after full bloom in mid-December and maintained until harvest. Sunscreen applications were repeated after 10 mm of precipitation accumulated and/or when the fruit coverage on the exposed side was under 50% (visual assessment). A control treatment (CON) was also included. For the Brasil Gala and Cripps Pink cultivars, 10 randomly selected trees were evaluated per cultivar in commercial plantations.

For the three cultivars, the water potential of the fruit tissue was evaluated during the growth period under the following conditions: (1) exposed green fruit (VE), (2) exposed fruit with red coloration (FR), (3) exposed fruit with incipient sun damage, defined as bronzing according to Racsko and Schrader(6) (FQ), and (4) internal green fruit (VI). Exposed fruits are defined as those located on the periphery of the crown and receive direct radiation, while internal fruits are located in internal areas of the tree and do not receive direct radiation. In each fruit, the external surface was defined as the area of the fruit facing the external side of the tree, and the internal surface as the opposite of the external surface. Five fruits were sampled for each condition to determine tissue water potential $\Psi_F$ using a Wp4c dew point potentiometer (Decagon Devices, USA). Sampling was conducted at approximately 15-day intervals from 68 days after full bloom

(DAFB) until the harvest of each cultivar. Sampling dates at 68, 82, 96 and 111 DAFB were carried out for all three cultivars. Dates at 141 and 153 DAFB were conducted for "Granny Smith" and "Cripps Pink", while an additional evaluation was performed at 168 DAFB for "Cripps Pink".

A 3 $cm^2$ section of epidermis was extracted from each fruit with 1-mm-thick subepidermal tissue, both from the internal and external sides, to determine the water potential (ΨFI and ΨFE, respectively).

### 2.1 Statistical analysis

The analyses were conducted using R version 4.1.0 (2021). For stem and fruit water potential variables, a comparison of medians was performed using non-parametric analyses (Kruskal.test, $p<0.05$). The evolution of fruit water potential under different conditions was analyzed through graphical representation using the geom_smoothggplot procedure, with a CI = 95%.

## 3. Results

The stem water potential exhibited differences among the treatments applied to "Granny Smith" (Figure 1). The lowest values were observed with the 20% translucent white net (MB) (0.83 MPa), showing significant differences compared to sunscreen application (PRO) and the 50% black net (MN50), but not with the control (CON). The 50% black net treatment (MN50) showed values closest to 0, differing from the control and the other two treatments (-0.54 MPa) (Figure 1).

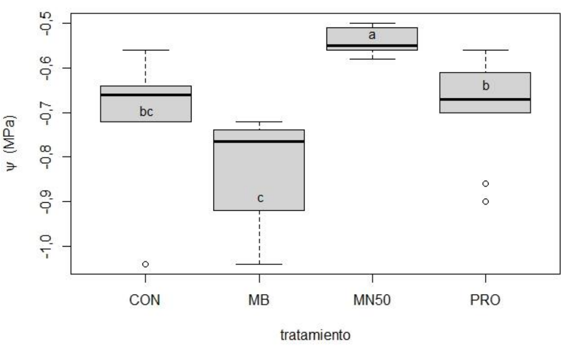


Figure 1. Stem water potential according to field treatment on "Granny Smith". (CON: control, MB: 20% translucent white net, MN50: 50% black net, PRO: sunscreen)

The fruit water potential decreased during the growth cycle in the three evaluated cultivars, Brasil Gala, Granny Smith and Cripps Pink. Cultivars with longer growth cycles reached lower values. "Cripps Pink" maintained its water potential as of 111 DAFB, and "Granny Smith" showed a slight increase in the last assessment (Table 1).

Table 1. Evolution of fruit water potential (MPa) per cultivar

| DDPF | "Brasil Gala" | "Cripps Pink" | "Granny Smith" |
|---|---|---|---|
| 8 | -1.435a | -1.480a | -1.330a |
| 82 | sd | -1.605b | -1.530b |
| 96 | -1.670b | -1.795c | -1.475b |
| 111 | -1.845c | -1.870d | -1.725c |
| 141 | --- | -1.960d | -2.095d |
| 153 | --- | sd | -1.810c |
| 168 | --- | -1.910d | --- |

Different letters within each cultivar indicate differences.

The fruit water potential, collectively evaluated for the three cultivars and the four fruit types (external green, red, sunburned and internal green), was lower on the external side during measurements between 98 and 153 DAFB (Figure 2a).

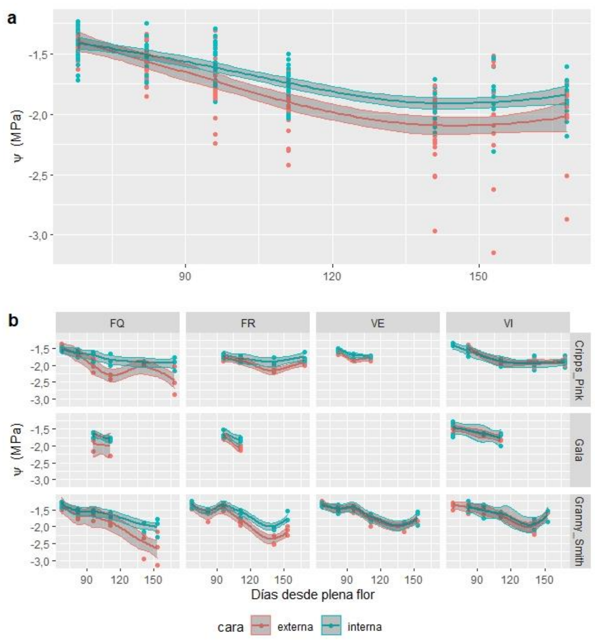


Figure 2. Evolution of fruit water potential on the external and internal sides. a) Average values for "Brasil Gala", "Cripps Pink", and "Granny Smith". b) Values by cultivar (Brasil Gala, Granny Smith, and Cripps Pink) and fruit type (sunburned fruit (FQ), red fruit (FR), healthy fruit, external green (VE), and internal green (VI)). Lines and confidence intervals of 0.95 (indicated in gray) were calculated according to the geom_smooth function (loess method in R)

Green fruits (internal or external) had similar water potential on both sides in all evaluations (dates and cultivars) (Figure 2b). "Cripps Pink" exhibited differences in water potential between the sides of sunburned fruits in the mid and end-of-cycle assessments, 0.50 MPa lower in the damaged area. But there was no difference between the sides in red fruits. "Granny Smith" showed lower water potential on the external side in the last two dates, with average differences between 0.45 MPa and 0.27 MPa in sunburned and red fruits, respectively. "Brasil Gala" showed no differences between sides under any condition (Figure 2b).

## 4. Discussion

Estimating stem water potential at midday in the different treatments presented values between -0.50 and -1.00 MPa (Figure 1). The variation of 0.5 MPa is similar to that presented by the water potential of the fruit tissues and is lower than the values reported by other authors in the fruit[17]. Boini and others[18] consider that -1 MPa does not represent limitations and establish a range between -1.5 and -2 MPa for damage in apple trees. Similarly, a study on the effect of stem water potential related to sunburn in "Cripps Pink" indicates that with water potential values between -1.60, -2.00 and -2.50 MPa it was possible to detect differences in fruit surface temperature, percentage, and severity of sunburn damage[8]. However, under our conditions, values consistently ranged between -0.50 (under shade net, non-stressed) and -1.00 MPa (under conditions of higher stress).

Hail nets have had favorable effects on water balance and leaf pigment contentby modifying microclimatic conditions, partially reducing the effects caused by excessive heat and summer drought[28]. According to Mupambi[10], the impact of the presence of shade net compared to its absence is much greater than the relatively small differences between materials. However, temperature evaluations in under-net situations showed differences between black and white nets. Several authors have demonstrated an increase in air temperature under MB and a reduction in treatments with black net[5][28-31], although these increases in air temperature do not always manifest as higher fruit surface temperatures. The energy intercepted by the nets, not reaching the plant tissues, results in a lower temperature increase. The radiation under the black net showed less energy in the near-infrared compared to the environment under the white nets[5]. This is consistent with the lower water potential of the crop under white netting (Figure 1). The increase in infrared radiation (>740 nm) has a great caloric value[5][32] and could be related to the increases in air temperature recorded in this treatment and the lower water potential of the crop under the white net (Figure 1). The black nets, on the other hand, intercepted an approximate proportion of 0.6 at all wave lengths[5] and similarly reduced the air temperature[5][28-31] and the surface temperature of the fruit[5][12], supporting the results of improved water conditions in the crop observed here.

The water potential of fruit tissues varied depending on the cultivar, damage level, and exposure in accordance with previous studies. The potential decreased with fruit development and was significantly lower in sun-damaged tissues than in healthy unexposed tissues, similar to the findings presented by Torres and others[22]. Also, in line with these authors, no differences were found in the water potential values of external and internal tissues in the early stages of fruit development. This period was 80 days in the cited study and 96 days in our conditions. Several factors could determine when differences in potential between exposed and unexposed surfaces begin. On the one hand, the exposed surface in small fruits is insufficient to absorb solar radiation[6]; on the other hand, the predisposing conditions, air temperature and air vapor deficit, increase as the season progresses[22], as well as irradiance[33]. Both aspects were present in this trial during the first 96 days after full bloom[5]. Previous results indicate that the tissues exposed to the sun have lower water potentials, activating a cascade of responses to abiotic stress, mediated by sugars and ethylene, to cope with environmental stress caused by high irradiation and heat. The consequences include distinctive fruit quality traits such as changes in shape, increased hardness, and elevated sorbitol content[22]. The potential differences between healthy and damaged tissues are consistent with reported findings, with values close to 0.50 MPa (Figure 2b).

## 5. Conclusions

The effect of treatments for sunburn on plant water potential could only be verified in the case of 50% black netting.

Fruit water potential decreased throughout the growth cycle for all cultivars, fruit types, and exposure conditions (FQ, FR, VE, and VI).

Exposed surfaces of the fruits showed lower values of fruit water potential than unexposed surfaces, and the difference between surfaces was not observed in the case of fruits located inside the tree that did not receive direct radiation.

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**Transparency of data**

Available data: The entire data set supporting this study's results was published in the article itself.

**Author contribution statement**

Severino, V.; Arias-Sibillotte, M. and González-Talice, J.: conception, design and writing of the article.

Frins, E., Yuri, J. A. andDogliotti, S.: data analysis and interpretation.

Echeverría, G.: data collection, analysis and interpretation, and writing of the article.

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