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ORIGINAL ARTICLE

Water retention on the surface of apples and sweet cherry leaves and fruits

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Abstract

Surface water retention of leaves and fruits of apple (*Malus domestica* Borkh.) and sweet cherry (*Prunus avium* L.), was evaluated under controlled environmental conditions in order to determine the retention potential at different growth stages. Dipping and spraying, with and without non-ionic surfactant, were used as application systems. Water retention was expressed as the ratio between the weight difference of the organ before and post application and organ weight before application. Leaf water retention by dipping was 62 and 64% for 'Royal Gala' and 'Fuji' apples, respectively, and 37 and 50% by spraying. The surfactant tended to reduce foliar water retention by spraying on both species. An exponential reduction of fruit water retention was observed during their growth. Fruit dipping generated the highest water retention, with values of 50% at the earliest stage. Then, water retention stabilized at 1–2%, when the apples and sweet cherries diameter reached 25 and 15 mm, respectively, despite dipping or spraying. The surfactant tended to increase water retention at early fruit stages and to reduce it with fruit growth. These results can be useful for estimating the potential residue on leaves and fruits in apple and sweet cherry trees, in both the orchard (spraying) and the packing house (dipping).

Keywords: dipping, fruit size, leaf area, spraying, surfactant

Introduction

Foliar application of agrochemicals is used in orchards to control pests and diseases, to correct nutritional deficiencies, to reduce abiotic stress and to manipulate physiological processes (Wang and Liu 2007; Tanou *et al.* 2017). In packing, some fruits are subjected to dipping and drenching with fungicide and nutrient solutions to prevent diseases and physiological disorders (Xin *et al.* 2020).

Foliar application efficiency varies greatly due to the interaction of multiple factors affecting spray deposition and retention of the applied product. Spray deposition corresponds to the amount of solution that reaches the target area (application volume minus drift), while retention represents the amount of solution that remained on the plant (deposition minus runoff and droplet reflection) (Forster *et al.* 2006).

Spray deposition of Surround on adult apple trees reached 60% of the product applied on the leaves and less than 3% on the fruits (Yuri *et al.* 2006). When the spray volume is excessive, the loss can increase due to drift and runoff. In contrast, when the spray volume is very low, it can generate an irregular distribution on the plant (Siegfried *et al.* 2007). To prevent these problems, the amount of water applied must be adjusted by taking into consideration shape, volume, and foliar area of the trees (Duga *et al.* 2015; Musiu *et al.* 2019). Other factors regarding deposition are: orchard characteristics (planting distance, row orientation, ground slope) (Rüegg *et al.* 1999; Siegfried *et al.* 2007), spray system used, application speed and pressure (Vallet and Tinet 2013; Bahrouni *et al.* 2021), and environmental conditions (wind speed, air temperature, relative humidity, rain) (Stover and Greene 2005; Arvidsson *et al.* 2011).

Once the liquid has been deposited on the surface of the target organ, the retention capacity will depend on the physical-chemical properties of the solution (surface tension) and the surface characteristics of the target organs (type, size, presence of roughness, hairiness) (Forster *et al.* 2006; Yao *et al.* 2014).

In some annual and horticultural crops, the addition of a surfactant to the foliar applications improves the wetting of the surface and favors droplet adhesion, since it reduces surface tension and fosters the contact angle change (De Ruiter *et al.* 1990*;* Basu *et al.* 2002).

Estimation of water retention would improve the efficacy of agrochemical applications, since the amount of solution adhered to the different plant organs could be quantified. This would contribute to a more rational use of agrochemicals by reducing their impact on the environment. Some initiatives have tried to predict water retention by mathematical models and computer simulations (Massinon *et al.* 2015; Dorr *et al.* 2016). However, these have not been developed in fruit crops.

In the present study, the water retention dynamic by dipping and spraying, with or without surfactant, was evaluated on leaves and fruits of two apple cultivars and two sweet cherry cultivars at different growth stages, and under controlled environmental conditions with the aim of obtaining reference indicators for product application programs.

Materials and Methods

Leaves and fruits of 'Royal Gala' and 'Fuji' apples (*Malus domestica* Borkh.), and 'Lapins' and 'Sweetheart' sweet cherries (*Prunus avium* L.) were collected from a commercial orchard located in San Clemente, Chile (35°30' S; 71°26' W), during the 2018/2019 growing season.

Healthy leaves from annual shoots in full growth were sampled 40 days after full bloom (DAFB) from apple and 50 DAFB from sweet cherry trees. Fruits of homogeneous size and without damage were picked periodically, from the fruit set until harvest. The samples were stored in a cooler and taken to the laboratory to treat them immediately. Fruit sampling dates were: 'Royal Gala' – 10, 22, 31, 70, 104 and 125 DAFB; 'Fuji' – 15, 27, 36, 75, 109, 130 and 167 DAFB; 'Lapins' and 'Sweetheart' – 8, 23, 35 and 83 DAFB.

Treatments

The leaves were divided into three categories (small, medium and large) according to their area (cm^2), measured with an area meter device LI-3100 (LI-COR, Inc., Lincoln, NE, USA). The fruits were grouped according to the sampling date and diameter (mm). Average leaf area according to category in 'Fuji': small = 18.6 cm^2; medium = 32.7 cm^2; large = 49.5 cm^2, 'Royal Gala': small = 20 cm^2; medium = 32.3 cm^2; large = 52.5 cm^2, 'Lapins': small = = 31.4 cm^2; medium = 54.9 cm^2; large = 78.8 cm^2, 'Sweetheart': small = 41.2 cm^2; medium = 68.2 cm^2; large = 105.2 cm^2.

The treatments consisted of: a) dipping the organs (leaves and fruits) in distilled water; b) dipping in distilled water + 0.1% of non-ionic surfactant (Tween 20®, Sigma); c) distilled water applied with a hand-pumped spray five times at 50 cm of the organ; d) spraying distilled water + 0.1% of surfactant. Each sample was weighed before and after application, leaving them to drain without movement for 5 s with an analytical balance model 100 A-300M (Precisa Gravimetrics AG, Dietikon, Switzerland).

Water retention (R) was expressed as the ratio between the weight difference of the organ before (W_{before}) and post (W_{after}) application and organ weight before application [Equation (1)]:

$$R[\%] = \frac{W_{\text{after}} - W_{\text{before}}}{W_{\text{before}}} \times 100. \qquad \text{(Eq. 1)}$$

Retention was calculated based on the weight of the organs studied, since, in addition to being a simple method, it allows estimating the residual agrochemicals even before their application according to the state of growth of the organ.

To estimate the maximum potential retention of the fruit in several states, fruits of different sizes were subjected to dipping. Also, these values at harvest may be reference indicators for application in postharvest fruit.

The experimental design was totally random, with a sample of 60 leaves per cultivar, 240 fruits for 'Royal Gala', 280 fruits for 'Fuji', 160 fruits for 'Lapins' and 'Sweetheart' each.

Statistical analysis

ANOVA was carried out to evaluate the differences between the treatments and sizes of each cultivar, prior to homogeneity validation (Levene test, $p < 0.05$). When necessary, a transformation of the data was performed. The averages were compared using the Tukey test HSD 95% ($p < 0.05$). The data analysis was carried out using the Statgraphics Centurion XVI software (Warrenton, Virginia, USA). The regression curves were developed using the SigmaPlot 10.0 software (WPcubed GmbH, Germany).

Results and Discussion

Surface water retention on leaves

Water retention in apple leaves depended on cultivar, and the highest values were obtained in 'Fuji'. Regarding the application system, dipping generated a retention average of 62 and 64% for 'Royal Gala' and 'Fuji', respectively (Figs 1A and B), while spraying generated a retention average of 37 and 50% (Figs 1C and D). The added surfactant tended to reduce the retention of sprayed water, mainly on larger leaves from both cultivars. On the other hand, dipping with water and surfactant increased water retention, reaching 86% in 'Fuji' and 68% in 'Royal Gala'.

In sweet cherry leaves, dipping reached an average water retention of 37 and 28% in 'Lapins' and 'Sweetheart', respectively, while it was 36 and 22% with spraying (Fig. 2). The added surfactant reduced water retention by spraying in 'Lapins' (Fig. 2C).

Surface water retention showed a slight tendency to decrease as the leaf size increased, being significant only in 'Royal Gala' and 'Lapins' (Figs 1 and 2). This tendency can be explained by the variation of the exposed surface regarding organ size, morphological characteristics of the leaf surface of each species (trichome density, roughness and epicuticular wax) (Forster *et al.* 2006; Yao *et al.* 2014), as well as changes due to growth (Yu *et al.* 2009).

In apple leaves a reduction of water retention capacity was observed as the leaves aged, which was attributed to reduced hairiness. Thus, leaf wettability would depend on the genotype (Bringe *et al.* 2006; Leca *et al.* 2020). Although a slight decrease in water retention on the leaf surface was observed, as growth increased, the volume of product retained on the surface also increased. A similar response was reported by Picchioni *et al.* (1995).

With similar size, apple leaves almost doubled water retention capacity compared to sweet cherry leaves when dipped in water. Thus, for a 30 cm^2 'Lapins' leaf

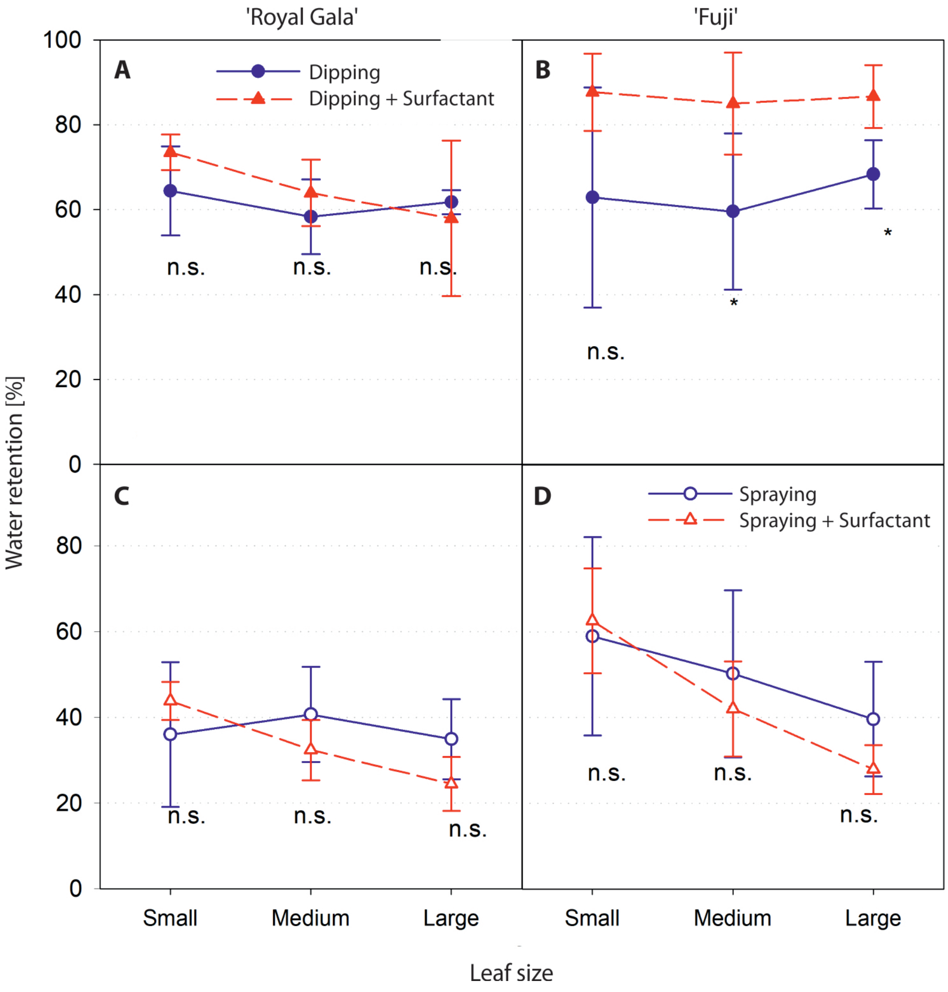

Fig. 1. Water retention, for three leaf sizes, expressed as the ratio between the weight difference of the organ before and post application and organ weight before application; A and C – 'Royal Gala', B and D – 'Fuji' apple leaves treated with (A and B) dipping and (C and D) spraying with and without surfactant. Differences between treatments according to Tukey test ($p < 0.05$). Means ±SD ($n = 5$); n.s. = no significant; *$p < 0.05$; **$p < 0.01$

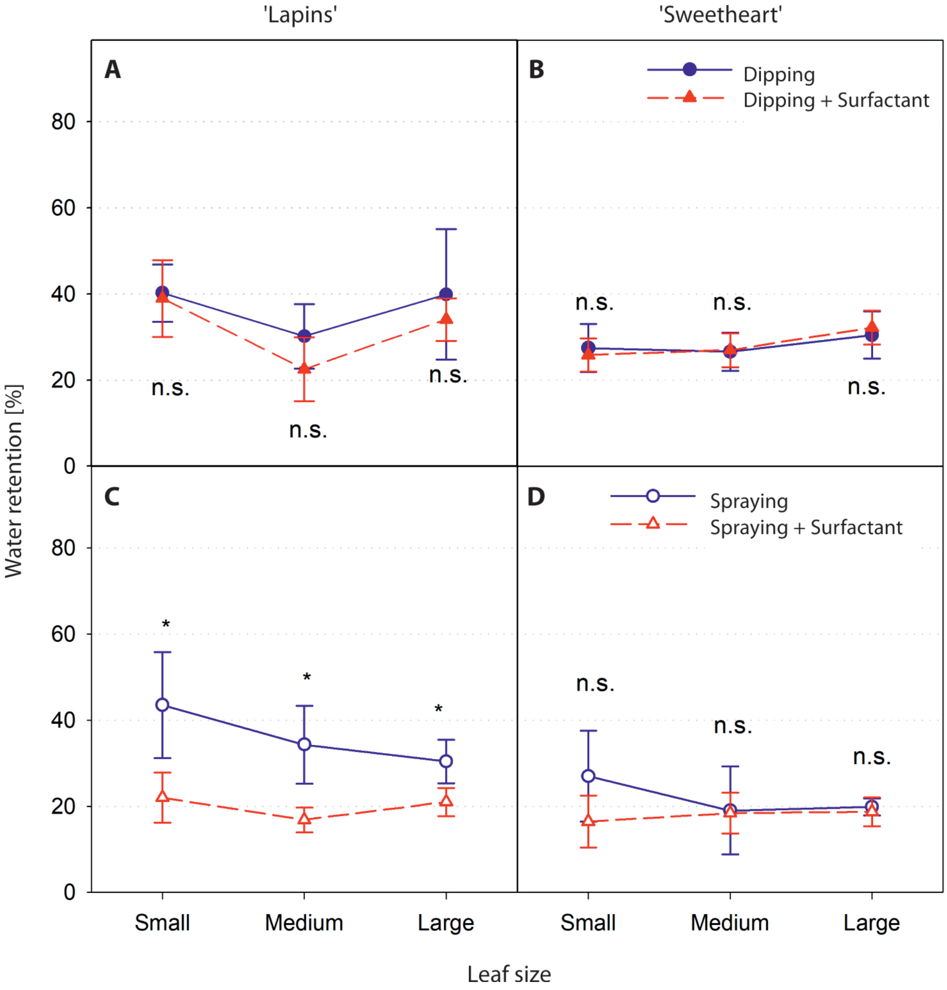

Fig. 2. Water retention, for three leaf sizes, expressed as the ratio between the weight difference of the organ before and post application and organ weight before application; A and C – 'Lapins' and B and D – 'Sweetheart' sweet cherry leaves treated with (A and B) dipping and (C and D) spraying with and without surfactant. Differences between treatments according to Tukey test ($p < 0.05$). Means ±SD ($n = 5$); n.s. = no significant; *$p < 0.05$; **$p < 0.01$

(470 mg fresh weight), the maximum amount of water retained was 190 mg vs. 390 mg retained by 'Royal Gala' leaf (680 mg fresh weight), with similar foliar area. The differences could be explained by the absence of hairiness observed on the sweet cherry leaves.

According to the previous evaluations, it was observed that the shoot growth in apple and sweet cherry trees was fast, reaching a peak 30 and 65 DAFB, respectively, close to the evaluation date in each species, where it was possible to find young and adult leaves at the same time. Variations in water retention must be considered together with the vegetative growth in order to calculate the adequate dosage and volume of foliar applications.

On the other hand, most of the non-ionic surfactants reduced the sprayed droplet size. Compared to applying only water, they generated a smaller mass and kinetic energy on the affected area and also a greater area/volume relation of contact (Yao *et al.* 2014). Non-ionic surfactants, such as polysorbate 20 (Tween 20$^{®}$) with a high hydrophilic content with 16.7 HLB, exerted this effect and showed, in the leaves of different plants, a higher retention than that generated by emulsions with oils, due to a surface tension reduction (Ziani *et al.* 2008). These characteristics improved water distribution on the surface of leaves, creating a thinner but continuous layer, than water without surfactants Tween 20$^{®}$, which generated larger and more distant drops (Fig. 3).

Surface water retention on fruits

In apple fruits, the maximum level of water retention was at the earliest growth stage using dipping with surfactant, with 53 and 42% for 'Royal Gala' and 'Fuji', respectively, while water retention by spraying with surfactant was 15 and 22% (Fig. 4). With fruit diameters over 25 mm, water retention was stabilized, despite the application system, reaching values below 1% for the largest fruits. At the last stage, the solution with

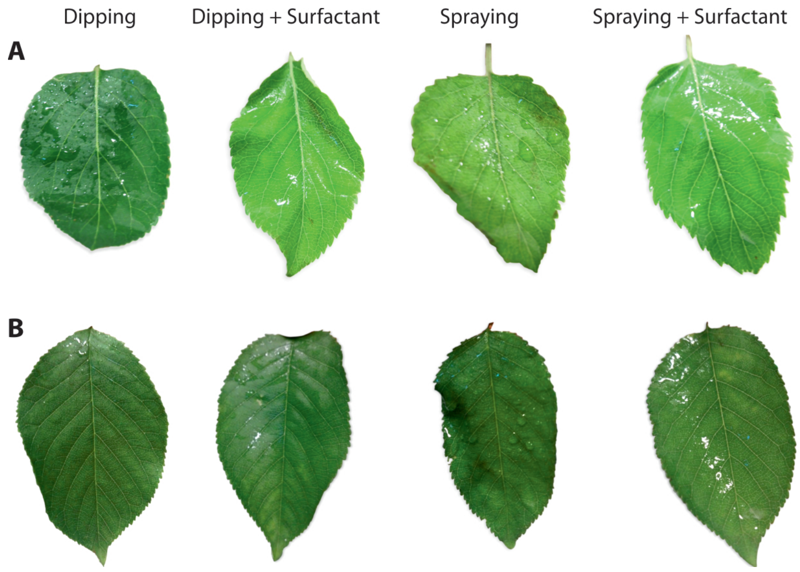

Fig. 3. 'Royal Gala' apple (A) and 'Lapins' sweet cherry leaves (B) after treatment

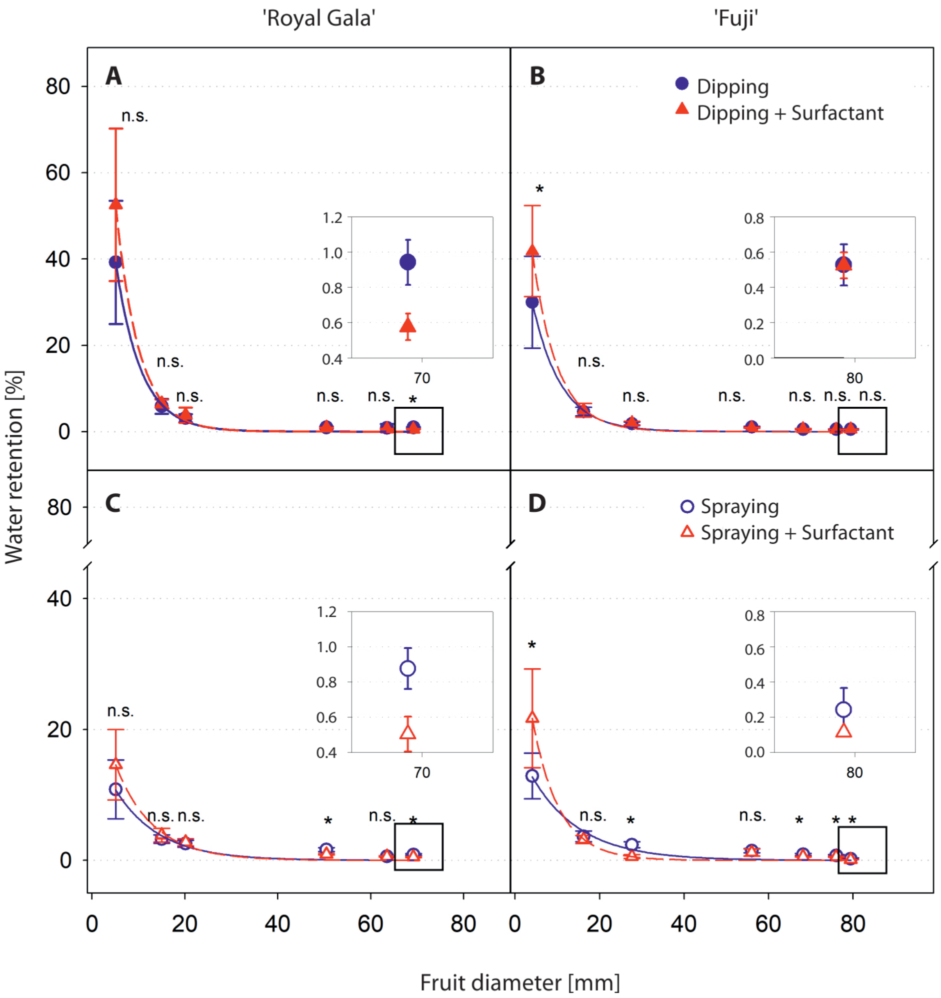

Fig. 4. Fruit water retention as a function of fruit diameter (mm), expressed as the ratio between the weight difference of the organ before and post application and organ weight before application; A and C – 'Royal Gala' and B and D – 'Fuji' apple fruits treated with (A and B) dipping and (C and D) spraying with and without surfactant. Differences between treatments according to Tukey test ($p < 0.05$). Means ±SD ($n = 10$); n.s. = no significant; $*p < 0.05$; $**p < 0.01$

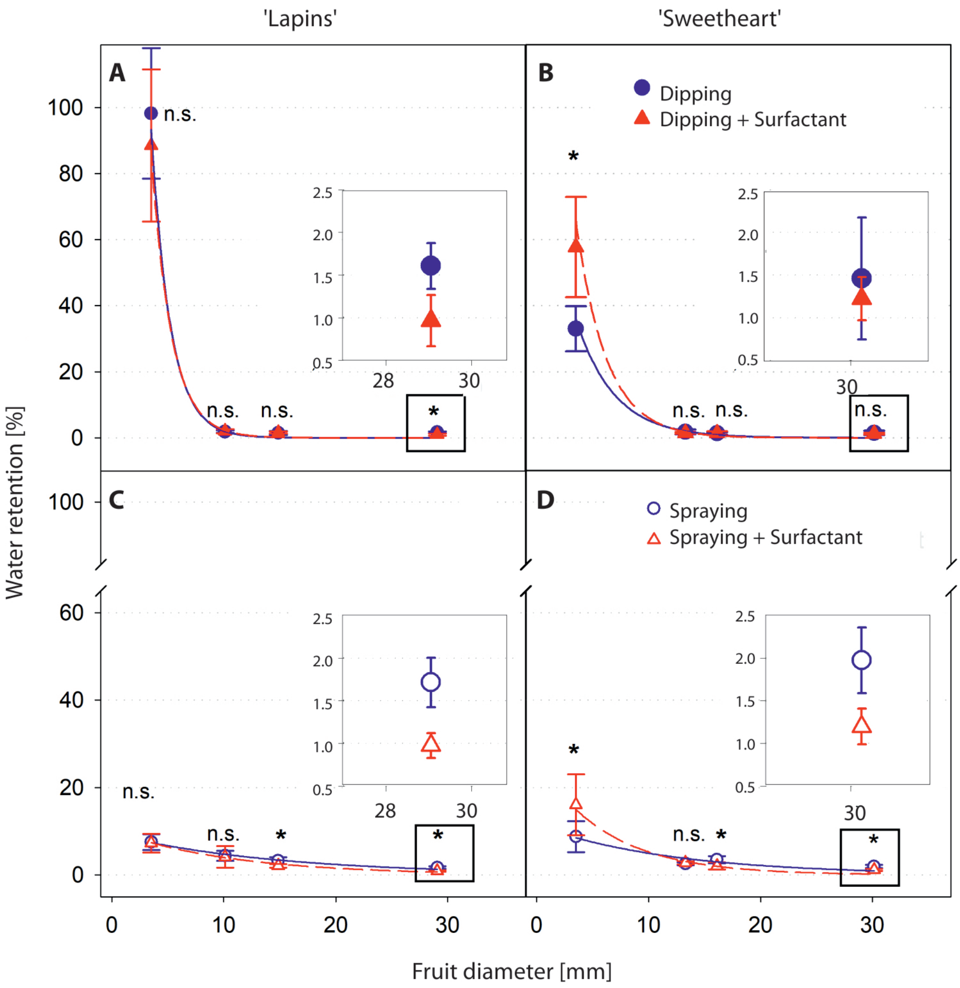

Fig. 5. Fruit water retention as a function of fruit diameter (mm), expressed as the ratio between the weight difference of the organ before and post application and organ weight before application; A and C – 'Lapins' and B and D – 'Sweetheart' sweet cherry, treated with (A and B) dipping and (C and D) spraying with and without surfactant. Differences between treatments according to Tukey test ($p < 0.05$). Means ±SD ($n = 10$); n.s. = no significant; *$p < 0.05$; **$p < 0.01$

surfactant reduced water retention significantly, particularly when it was applied by spraying (Fig. 4).

At the earliest stage of sweet cherries growth, water retention by dipping without surfactant was 98 and 33% for 'Lapins' and 'Sweetheart', respectively, while it reached 8% for both cultivars by spraying (Fig. 5). The effect of the surfactant was only significant for 'Sweetheart', doubling water retention at the earliest stage of fruit growth. With fruit diameters over 15 mm, water retention remained stable, reaching values below 2% until harvest of both cultivars. As with apple fruits, during the last stage, the surfactant reduced water retention significantly and their effect was greater by spraying (Fig. 5).

In both species an exponential reduction of water retention was observed during fruit growth (Figs 4 and 5). This is of particular relevance for planning applications to the fruit when its volume increases, as the penetration of the compound into the fruit will be shallower. The dynamics of water retention in fruit has been insufficiently studied. Peschel *et al.* (2003) noted that, due to the glabrous surface of sweet cherry fruits, they are easier to wet compared to other species, but also have a greater runoff tendency.

The results show that the water retention capacity of the fruits decreased exponentially as their diameter increased, becoming stable from 15 and 25 mm onwards for sweet cherries and apples, respectively (Figs 4 and 5). This dynamic was highly correlated to the changes in fruit surface area to volume ratio, modelled as a spherical body (Fig. 6), which would explain the rapid reduction in the retention capacity of the fruits. This model was made based on the diameter of the fruit, as it is a simple measurement to perform in the field. Also, this variable has a high correlation (over 90%) with the volume of apples (according to previous evaluations). The description of this trend can guide growers in planning fruit-focused sprays,

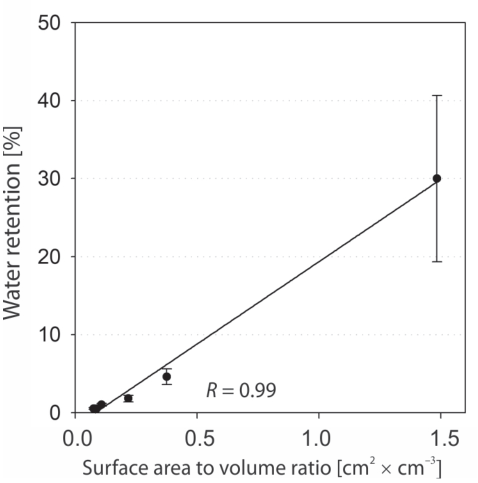

Fig. 6. Relation between area/volume (cm^2 × cm^{-3}) and water retention (%) without surfactants by dipping of 'Fuji' apple fruits

considering the retention potential based on the date and phenological state of the crop.

The high water retention reported at the earliest growth stage of the fruits, particularly through dipping, could have been caused by the presence of the remains of floral elements, which provided additional structures to which the drops could adhere. Therefore, spray applications to the fruits should take into consideration their growth and development to avoid an excess of the product on fruits, especially in species with small fruits such as sweet cherry trees.

On the other hand, the water retention level using surfactant varied depending on the species, organ and growth stage. The differences can be attributed to the morphological characteristics in each condition. Cooper and Hall (1993) found that the use of surfactant in easily wettable organs, without barriers, hampers the impact of the drops, increasing the runoff and reducing water retention. Massinon and Lebeau (2013) reported that in organs which are more difficult to wet, due to the presence of waxes, the addition of surfactants favors solution adhesion, improving water retention. Therefore, the use of surfactant should be done considering surface characteristics of each species to improve the water retention level that ensures the action of the product.

In addition, the Tween 20® surfactant improved the distribution of water on the fruit surface (Fig. 7), similar to that observed on the leaves, with a more uniform wetting, but with less water retention, as a thinner film is formed. This is especially relevant when dosing the products, since less residues would be deposited on the surface of the organs due to greater runoff. Therefore, an adjustment in the amount of product should be considered. Also, a thinner layer of water will dry faster, reducing its absorption potential. However, the advantage of using surfactants is that the spray will be evenly distributed on the skin, this being essential in targeted applications to effectively cover the fruit, such as sunscreens and calcium.

Fig. 7. 'Fuji' apple fruits, (A) 30 mm and (B) 80 mm fruit diameter, and 'Lapins' sweet cherries (C) 30 mm fruit diameter, after treatment

Conclusions

Water retention, expressed in relation to the weight of the wetted fruits and leaves, was affected by the application form, species, cultivar and variations in the size of the target organ. Also, the morphological transformations of the exposed surface throughout growth would affect the retention.

In the leaves, water retention tended to decrease with the growth of the leaf blade. An exponential decrease in retention was observed in the fruits as their size increased. This trend showed a high correlation with the changes that the fruits experience in the relationship between their exposed surface and their volume throughout growth, which could explain the rapid decrease in retention capacity in these organs. After 30 DAFB, when the diameter of the fruits exceeded 15 and 25 mm in sweet cherries and apples, respectively, retention stabilized at 1–2%. Morphological changes in the pericarp of the fruit throughout growth would also influence retention.

In both species, the use of surfactant increased retention in the first stages of fruit growth, since it would facilitate the distribution of the liquid in the hairs arranged on the surface. After the fruits were detached from these structures, the surfactant decreased retention due to an increase in the runoff of the droplets.

The results of this study can be useful in estimating the amount of potential residue on leaves and fruits of apple and sweet cherry trees, in both the orchard (spraying) and the fruit selection and packing process (dipping).

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