

Influence of a Sulphur Dioxide Active Storage System on the Quality of *Ribes rubrum* L. Berries

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The aim of this study was to evaluate the post-harvest changes in the quality of red currants (*Ribes rubrum* L.) cv. 'Rovada' after 60 days of storage under modified atmosphere packaging (MAP) conditions. The storage unit was a pallet, and two treatments were performed. The CO₂-MAP treatment was used as a control, while the SO₂-MAP treatment was CO₂-MAP plus SO₂. The initial gas composition was 15.0 kPa O₂ and 10.0 kPa CO₂ inside all MAPs, while SO₂-generating active sheets were added to pellets in SO₂-MAP treatment. Weight loss, total soluble solid content, titratable acidity, total phenolic and anthocyanin contents, antioxidant activity, microbial count, and visual and sensorial appearance were monitored after 30 and 60 days. The results showed that berries stored with SO₂ maintained the quality parameters for up to 60 days. Exposure to SO₂ was effective in controlling yeast evolution, reducing the population both at 30 and 60 days at one and two orders of magnitude, respectively. Red currants stored under SO₂ MAP obtained better visual quality score compared to CO₂ MAP-treated berries throughout storage.

Active emitters of SO₂, such as those proposed in this study, can be promising solutions to improve the post-harvest storage of red currants and the berries marketability.

INTRODUCTION

Red currants, belonging to the *Ribes* genus of the Saxifragaceae family, are minor crops among berries. They are berry-bearing deciduous shrubs mainly consumed as processed in juices, jams, jellies, syrups, marinades, and wines [Kampuss & Pedersen, 2003; Stępniewska *et al.*, 2016]. Consumption of fresh red currants is largely related to visual appearance, and raceme and stalk freshness are the main quality indices of shelf life. 'Jonkheer van Tets', 'Rondom', 'Rovada', 'Rosetta', 'Rotet', 'Jonifer', 'Laxton no. 1', 'Red Lake', 'Stanza', and 'Laxton's Perfection Red Dutch' are the most common red currant cultivars grown in Europe, where Poland is the most important producer [www.freshplaza.com]. Similar to other berries, red currants (*Ribes rubrum* L.) are important species for the human diet, especially due to the highest capacity to scavenge free radicals [Laczkó-Zöld *et al.*, 2018; Orsavová *et al.*, 2019]. Vitamin C (ascorbic acid) is well known to be the most important free radical scavenger, with average content in fresh berries reported at 41 mg/100 g [Talcott, 2007]. Red currants are also an important source of macro- and microelements (349.90 mg P; 1,876.94 mg K; 8.25 mg Na; 281.08 mg Ca; 1.18 mg Mn; 94.43 mg Mg; 3.73 mg Fe; and 2.41 mg Zn per 100 g of dry weight) [Plessi *et al.*, 1998].

Due to limited fresh market volumes compared to other soft berries, no larger studies on post-harvest techniques have been carried out on *R. rubrum*. Storage temperatures in the range of 0–1°C combined with high values of relative humidity (95%) have been suggested as optimum conditions in a normal atmosphere (NA) to maintain fresh berries for up to 3 weeks, but the evolution of biochemical properties is mainly associated with ripeness at harvest time and the cultivar. Management of the surrounding storage atmosphere (18 to 20% CO₂ + 2% O₂) can extend the storage time [Agar *et al.*, 1997; Roelofs & Waart, 1993], but in some cultivars, high CO₂ concentrations can result in physiological disorders, affecting berry colour and the internal breakdown [Roelofs & Waart, 1993; Thompson, 1998]. Furthermore, some physiological disorders generally manifested by flesh browning and breakdown appear in berries stored with CO₂ above 20%. The modified atmosphere pallet system has been evaluated in the post-harvest storage of berries and other fruits as an alternative preserving technique [Giuggioli *et al.*, 2019; Macnish *et al.*, 2012; Peano *et al.*, 2017] and is commercially available as a logistic solution to reduce fruit loss and optimise space in the warehouses of different fruit companies. The employment of active gas controlled-release pads or ethylene absorbers (C₂H₄) can be positively associated with this technology to improve the success of storage management for different products. Red currants are not ethylene

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producers and are not susceptible to C_2H_4 , but sulphur dioxide (SO_2) release pads could be positively associated with a modified atmosphere strategy to control the decrement of the overall quality and limit the microbial growth in berries [Ahmed *et al.*, 2018; Saito *et al.*, 2020]. Similarly to other berries, red currants are not washed during the supply chain process (harvesting, packing, and transportation); therefore, approved sanitisers, such as chlorine or sodium hypochlorite, cannot be added to control possible microbial contamination. The SO_2 -generating pads have largely been used in the post-harvest process of different fruits, such as table grapes [Ahmed *et al.*, 2018; Carter *et al.*, 2015; Ozkaya *et al.*, 2008; Sortino *et al.*, 2017; Zutahy *et al.*, 2008], blueberries [Rodriguez & Zoffoli, 2016; Saito *et al.*, 2020], fragola [Hakimi *et al.*, 2017], figs [Cantín *et al.*, 2011], raspberries [Spayd *et al.*, 1984], and lemons [Smilnick *et al.*, 1995]. The amount of SO_2 required to be effective is a function of the storage temperature and the time of release of SO_2 of the emmitter used [Rivera *et al.*, 2013]. A critical point that needs to be considered in SO_2 treatment is the maximum absorption by the human body; the daily intake value permitted by the Joint FAO/WHO Expert Committee on Food Additives [JECFA, 2019] is 0–0.7 mg per kg of human body weight.

To improve the knowledge about post-harvest storage of red currants, which has so far been underreported

in literature, the aim of this study was to evaluate the influence of an SO_2 active storage system on the quality of *R. rubrum* berries stored for up to 60 days.

MATERIALS AND METHODS

Fruit source and sample preparation

Red currants (*R. rubrum* cv. Rovada) were harvested in an orchard located at Peveragno (Cuneo, Piedmont, Italy) at the harvesting maturity stage and were free of decay or mechanical or insect injury. The currants were transported directly within 30 min to the Agrifrutta Cooperative warehouse (Peveragno, Cuneo, Piedmont, Italy) for sample preparation and storage. Selected fruits were packed in rigid ventilated polyethylene terephthalate (PET) open baskets containing 0.150 kg of fruit each. Ten PET baskets were placed in a cardboard flat. Eight flats were assembled in a single layer on a 100×120 cm wood pallet base. A total of 20 layers of eight flats each were stacked onto a pallet commercial storage unit (Figure 1).

Pallet treatments and storage conditions

The red currants were sampled in two groups. The first group was palletised in an active modified atmosphere (CO_2 -MAP treatment) and used as a control. The second group was palletised

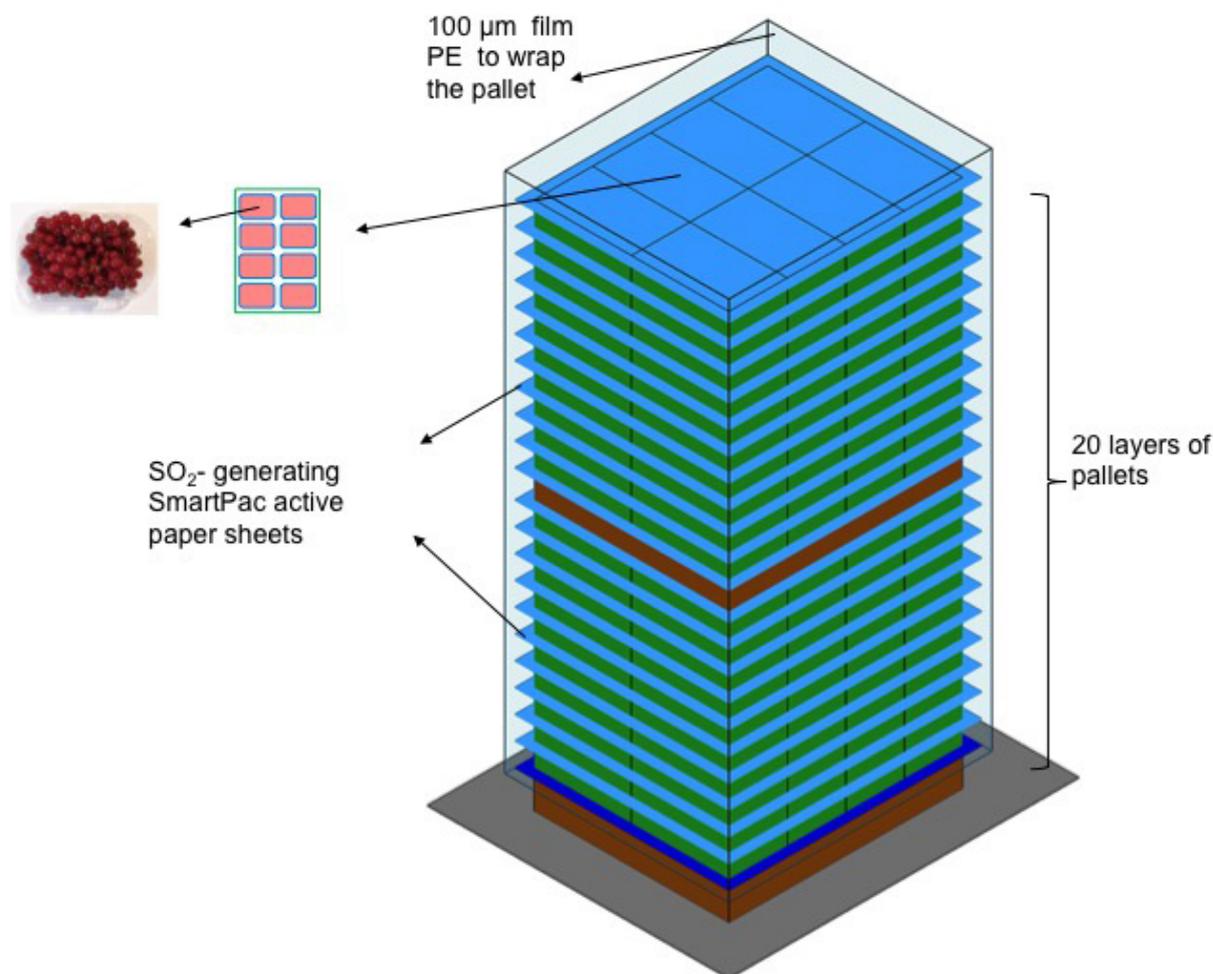


FIGURE 1. Design of the pallet unit used for storage of red currants in SO_2 modified conditions.

with CO₂ + SO₂ (SO₂-MAP treatment). Each pallet was wrapped with a 100 µm thick polyethylene film (PE) (thermally sealed at the base) with values of O₂ (O₂TR) and CO₂ (CO₂TR) transmission rates of 1572 cm³/m²/d/bar and 6111 cm³/m²/d/bar, respectively, measured at 23°C and at 50% relative humidity (RH) with a MultiPerm oxygen and carbon dioxide analyser (Extra Solution s.r.l., Pisa, Italy) according to ASTM F 2622–08 and ASTM F 2476–05 standard guidelines [Briano *et al.*, 2015].

The injection system for CO₂-MAP treatment was operated as reported by Peano *et al.* [2017] to have initial gas values of 15.0 kPa O₂ and 10.0 kPa CO₂. These values were based on previous experimental storage studies on red currants (data not published). The SO₂-generating SmartPac active paper sheets (Serroplast, Bari, Italy) were applied directly to cover each of the total 20 layers stacked onto the storage unit pallet. All samples were stored for 60 days in a cold and dark room at 1 ± 1°C and 90–95% RH. Data were collected at 0 (at the beginning of storage treatment), 30 (middle of the total storage time), and 60 days (long-term storage). For each treatment and storage time, three pallets were considered, sampling 30 random baskets in total. Figure 1 shows the experimental design of the pallet commercial unit.

Pallet atmosphere and SO₂ evaluation

A gas analyser (CheckPoint II, PBI Dansensor, Milan, Italy) was used to measure the relative changes in the carbon dioxide and oxygen concentrations. The gas composition values were measured every 10 days over the trial period and were expressed in kPa. The SO₂ concentration was measured in ppm with dosimeter tubes (Gastec 5DH, Gastec Corporation, Ayase-City, Japan). The results were expressed as an average of three replicates.

Weight loss and quality parameters

Baskets were coded before the treatments. Weight loss (%) was determined using an electronic balance (model SE622, VWR Science Education, Radnor, PA, USA), with a 10⁻² g accuracy. Weight was monitored during the entire storage period and was calculated as the difference between initial (W₀) and final (W_f) basket weights.

$$\text{Weight loss (\%)} = \frac{W_0 - W_f}{W_n} \times 100 \quad (1)$$

The results were expressed as an average of 30 replicates.

After sample blending, the total soluble solids (TSS) were evaluated with a digital refractometer Atago® Pal-1 (Atago Co. Ltd., Tokyo, Japan) and expressed as °Brix. For each quality control, the instrument was calibrated with distilled water. The titratable acidity (TA) was measured using an automatic titrator (Titrino 702, Methrom, Herisav, Switzerland), and determined potentiometrically using 0.1 N NaOH to the end point of 7.0; it was expressed as g of malic acid equivalents per 100 g of berries [Djordjević *et al.*, 2010].

Total anthocyanin content, total phenolic content, and antioxidant capacity

Twenty-five mL of an extraction solvent (500 mL methanol, 23.8 mL deionised water, and 1.4 mL 37% hydrochloric acid)

were added to 10 g of fruit. After 1 h storage in the dark at room temperature, the samples were thoroughly homogenised for 1 min with an Ultra-Turrax homogeniser (IKA, Staufen, Germany) and then centrifuged at 3,000 × g for 15 min. The supernatant obtained by centrifugation was collected, transferred into glass test tubes, and stored at -20°C until analysis. The total phenolic content (TPC) was determined by visible spectrophotometry using the Folin–Ciocalteu reagent according to the method described by Slinkard & Singleton [1977]. Gallic acid was used as a standard and absorbance of reaction mixtures was measured at 765 nm. The results were expressed as mg of gallic acid equivalents per 100 g of fruit fresh weight (mg GAE/100 g fw). The total anthocyanin content (TAC) was quantified according to the pH differential method described by Cheng & Breen [1991]. Anthocyanins were estimated by their absorbance (A) difference at 510 and 700 nm in buffers at pH 1.0 and pH 4.5, where A_{tot} = (A₅₁₅ - A₇₀₀) pH 1.0 - (A₅₁₅ - A₇₀₀) pH 4.5. The results were expressed as mg of cyanidin 3-O-glucoside (C3G) equivalents per 100 g of fruit fw. Antioxidant activity was determined as the ferric reducing antioxidant power (FRAP) following the methods of Pellegrini *et al.* [2003], with some modifications. The absorbance was read at 595 nm 4 min after the addition of appropriately diluted extracts or standard to the FRAP reagent. The results were expressed as mmol Fe²⁺ per 1 kg of fw of red currants. These analyses were performed with a UV-Vis spectrophotometer 1600 (PC VWR International, Milan, Italy).

Microbial count determination

Microbial evaluation was performed considering the count of total yeast, mould, and bacteria. Total yeasts and mould were examined according to the methods reported by the Compendium of Methods for the Microbiological Examination of Foods [Vanderzant & Splittstoesser, 1992]. The same equipment used in a previous work on strawberry was applied [Chiabrando *et al.*, 2018]. All plates were incubated at 30°C for 5 days. Three replicates were analysed, and the microbial counts were expressed as colony-forming units (CFU) per g of berry sample. Total aerobic bacteria (TAB) counts were determined according to ISO 4833–2 [2013]. Three replicates were analysed, and the microbial counts were expressed as colony-forming units (CFU) per g of berry sample.

Sensorial evaluation

Evaluation of the red currant fruits was also determined by means of sensory analysis, involving 10 panellists (five men and five women, 25–60 years old) who were previously trained using commercial berry samples. They received 15 bunches from each sample and provided sample descriptions based on consistency and taste (including sweet, acid, herbaceous, and astringent taste), and total aroma. All attributes were evaluated using a 9-point scale (ranging from ‘very intense’ as ‘9’ to ‘none’ as ‘1’). The taste test was performed 1 h after red currants were taken out of the stored pallet at room temperature (20 ± 1°C).

Visual evaluation

Visual evaluation was performed considering raceme and pedicel desiccation, healthy bunches, and visual quality.

The same panellists as for sensory analysis were recruited. Healthy bunches were defined as the percentage of not damaged fruit. All attributes of freshness of the rachis and pedicels and the visual quality were scored using a 5-point scale. Desiccation scores were 1 = as green as at harvest; 2 = slight browning; 3 = browning but no shrivelling; 4 = browning and some shrivelling; and 5 = dry and brown. Visual quality scores were 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; and 1 = unusable. Scores above 3 were considered unmarketable [Sortino *et al.*, 2017].

Statistical analyses

All pooled data were analysed using SPSS Statistics 24 (2017, IBM, Milan, Italy) for MAC. Analysis of variance (ANOVA) was performed, followed by Tukey's post-hoc test ($p \leq 0.05$), when the differences were significant.

RESULTS AND DISCUSSION

Pallet atmosphere and SO₂ evaluation

MAP technology is well known to be applied as the most easy and convenient tool to extend shelf life and protect berries from external contaminants. The fruit respiration rate, storage temperature, and selectivity of the wrapping film to gas are key factors that contribute to maintaining the required gas composition. Changes in the storage atmosphere composition in the range of 18 to 20% CO₂ and 2% O₂ could be successful in extending the shelf life of *R. rubrum* up to 14 weeks [Thompson, 1998]. As reported in Figure 2, the initial gas composition in the different units of storage was 15.0 kPa O₂ and 10.0 kPa CO₂. A different trend was observed between the two MAP treatments. Considering O₂, a general decrease was observed for each pallet system, even if it was more evident for the berries stored with only CO₂. After 40 days of storage, the O₂ content was under 5.0 kPa, achieving values of 1.5 kPa at the end of storage. Berries stored with SO₂ instead maintained values of 5.6 kPa at the end of storage. The different concentrations of O₂ could be explained by the increase of microbial counts (moulds and bacteria) in red currants stored with the MAP-CO₂ treatments. As a consequence, different levels of CO₂ were recorded among treatments. Up to 30 days, a similar evolution was monitored, then an increase of up to 15.0 kPa (60 days) was achieved for the MAP-CO₂ treatment stored pallets. In blueberries, Smilanick & Henson [1992] reported concentration of SO₂ in 100 ppm at 0°C to control decay diseases. The success of SO₂ treatments is a function of the time of exposure to gas multiplied by the concentration. SO₂-generating SmartPac active sheets were active throughout the entire storage time; furthermore, the gas was recorded for up to 60 days (Figure 3). The highest concentration (20 ppm) was observed after 10 days of storage. Subsequent measurements recorded lower SO₂ concentrations, achieving 0.8 ppm at the end of storage, indicating effective adsorption from the surface of red currants.

Weight loss and quality parameters

The loss of marketable berries along the entire supply chain is registered at around 45% [Temocico *et al.*, 2014].

Weight loss is affected by water loss, which is the major cause of post-harvest deterioration and compromises the visual appearance, chemical content, and flavour of the product [Lufu *et al.*, 2020]. Berry turgidity and raceme and stalk freshness are the main visual quality criteria for the final consumer, and their status is a function of the hydration of fruit tissues. As reported in Figure 4, both MAP treatments were able to limit the weight loss of red currants up to 60 days, and no statistically significant ($p > 0.05$) differences were observed among the different treatments. Both CO₂ and SO₂ gas controlled weight loss to under 5%, which can be considered the limit value for soft berries' marketability [Giuggioli *et al.*, 2019]. Weight loss of the samples analysed in our study was in the range of 0.67–0.73% and 1.00–1.15% after 30 and 60 days of storage, respectively. The maintenance of high humidity around the stored berries thanks to MAP action limited the transpiration activity of red currants, and this is probably due to the proper water transmission rates of the PE film.

The total soluble solid (TSS) contents of fresh and stored red currants are shown in Table 1. The TSS content of fresh berries was in line with data reported by Djordjević *et al.* [2010]. Moreover, similarly to the results reported by Temocico *et al.* [2014], the change in atmospheric composition during storage did not affect the soluble solid content in all samples (Table 1). Storage for up to 60 days caused no significant ($p > 0.05$) decrease in the TSS content, moving from 10.9 °Brix to 10.1 °Brix and 9.7 °Brix for CO₂ and SO₂ MAP treatments, respectively. No significant differences were observed

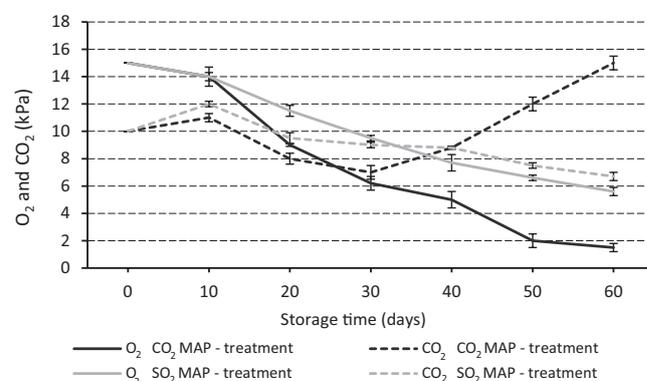


FIGURE 2. Gas evolution (O₂ and CO₂) during red currants 60 days storage.

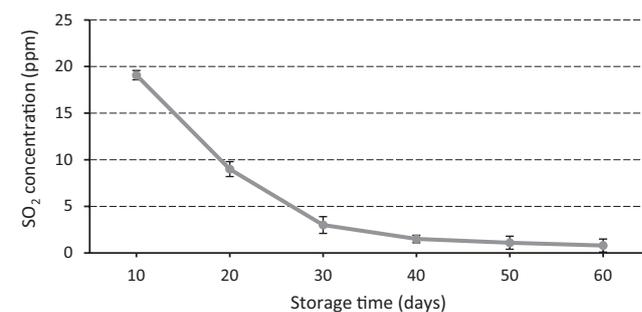


FIGURE 3. SO₂ concentration during red currants 60 days storage under modified atmosphere packaging (MAP) conditions.

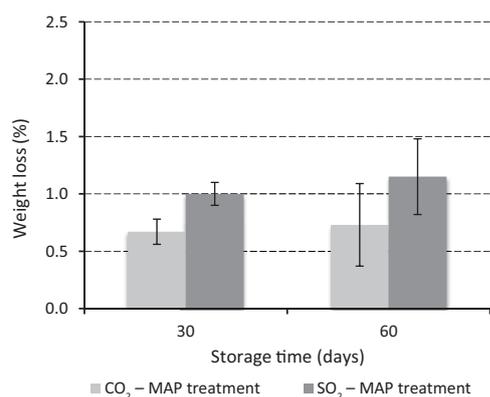


FIGURE 4. Weight loss of red currants during storage under modified atmosphere packaging (MAP) conditions.

among red currant samples exposed to SO₂ and CO₂ at the time, while differences ($p \leq 0.05$) were determined among MAP treatments only after 30 days of storage. Generally, SO₂ and CO₂ treatments, as observed on other fruits, did not affect the total soluble solid content during storage [Cantín *et al.*, 2011, 2012]. The titratable acidity (TA) of red currants ranged from 1.2 to 1.0 g/100 g fw at 60 days of storage, but TA changes during storage and differences between MAP treatments were not significant ($p \leq 0.05$) (Table 1). Generally, losses of total acidity were reported to be accelerated by storage in elevated CO₂ atmospheres [Harb & Streif 2004]; in this case, the concentration of CO₂ achieved in the stored pallet was appropriate for the maintenance of titratable acidity levels to values similar to those at harvest.

Total anthocyanin content, total phenolic content, and antioxidant capacity

The contents of phenolic compounds of fresh and stored red currants are reported in Table 2. The total anthocyanin content (TAC) of fresh fruits of cultivar Rovada was 22.1 mg C3G/100 g fw. This value was in the range of 18–34 mg/100 g fw as suggested by Benvenuti *et al.* [2004] for red currants grown in Italy and was lower than that recorded for cultivars grown in Finland (26.5–104 mg/100 g fw) [Mattila *et al.*, 2016]. Among anthocyanins, red currants are rich in cyanidin glycosides including cyanidin 3-*O*-glucoside, cyanidin 3-*O*-sambusoside, cyanidin 3-*O*-rutinose, cyanidin 3-sophoroside, cyanidin 3-glucosylrutinoside, and cyanidin-3-xylosylrutinoside [Jara-Palacios *et al.*, 2019; Mattila *et al.*, 2016]. No statistically significant ($p > 0.05$) differences were observed over time for each MAP treatment, and between treatments (Table 2). The total phenolic content (TPC) of red currant before storage was 233 mg GAE/100 g fw, which is consistent with values reported in the literature [Laczkó-Zöld *et al.*, 2018]. Similarly to anthocyanins, TPC showed the same evolution among samples over time, and statistically insignificantly lower content was determined in red currants under SO₂ MAP storage. Storage atmospheres enriched in CO₂ could prevent the increase in total antioxidant activity; however, the mechanism of control is still not clear, as no available data have been reported on the effect of SO₂ on evolution of total antioxidant activity in red currants. The initial antioxidant capacity of fresh

TABLE 1. Total soluble solids (TSS) content and titratable acidity (TA) of red currants stored under modified atmosphere packaging (MAP) conditions.

Parameter	Treatment	Storage time (days)		
		0	30	60
TSS (°Brix)	CO ₂ -MAP	10.9 ± 0.5 ^{aA*}	9.5 ± 0.1 ^{aB}	10.1 ± 0.3 ^{aA}
	SO ₂ -MAP	10.9 ± 0.5 ^{aA}	10.8 ± 0.4 ^{aA}	9.7 ± 0.6 ^{aA}
TA (g/100 g)	CO ₂ -MAP	1.2 ± 0.1 ^{aA}	1.0 ± 0.2 ^{aA}	1.0 ± 0.1 ^{aA}
	SO ₂ -MAP	1.2 ± 0.1 ^{aA}	1.1 ± 0.2 ^{aA}	1.0 ± 0.1 ^{aA}

*Mean values with different lowercase letters within a row and capital letters within a column for each parameter measured are significantly different ($p \leq 0.05$).

TABLE 2. Total anthocyanin content (TAC), total phenolic content (TPC), and ferric reducing antioxidant power (FRAP) of red currants stored under modified atmosphere packaging (MAP) conditions.

	Treatment	Storage time (days)		
		0	30	60
TAC (mg C3G/100 g fw)	CO ₂ -MAP	22.1 ± 6.1 ^{a*}	20.5 ± 9.2 ^a	27.4 ± 11 ^a
	SO ₂ -MAP	22.1 ± 6.1 ^a	19.7 ± 1.6 ^a	17.2 ± 4.3 ^a
TPC (mg GAE/100 g fw)	CO ₂ -MAP	233 ± 11 ^a	267 ± 20 ^a	203 ± 21 ^a
	SO ₂ -MAP	233 ± 11 ^a	70 ± 18 ^a	197 ± 20 ^a
FRAP (mmol Fe ²⁺ /kg fw)	CO ₂ -MAP	44.5 ± 1.7 ^a	37.1 ± 0.9 ^b	36.9 ± 1.1 ^b
	SO ₂ -MAP	44.5 ± 1.7 ^a	35.8 ± 1.1 ^b	34.6 ± 1.2 ^b

*Mean values in the row with different letters are significantly different ($p \leq 0.05$); GAE – gallic acid equivalents; C3G – cyanidin 3-*O*-glucoside equivalents; fw – fresh weight.

red currants was 44.5 mmol Fe²⁺/kg fw. It is well known that the total anthocyanin and phenolic contents influence the antioxidant capacity in fruit [Orsavová *et al.*, 2019]. Significant ($p \leq 0.05$) differences were observed for FRAP of stored red currants when compared with fresh berries.

Microbial hazard evaluation

The microbial population is an important factor that influences the quality and safety of fresh fruit [Mostafidi *et al.*, 2020], and can be affected by different pre- and post-harvest sources. Clean pallets and sanitised containers during storage should be available for freshly harvested berries. The maintenance of the high humidity level required in storage makes red currants more susceptible to decay; therefore, sanitisation tools are necessary. MAP is generally considered a good technique to preserve fruits, and CO₂ or other gasses, such as O₃ and SO₂, can minimise contamination due to the sanitiser effect of their molecules [Daeschel & Udompijikul, 2007]. Berries at picking (0 days) showed a microbial count of 13,000, 15,000, and 3,100 CFU/g for yeast, mould, and bacteria, respectively (Table 3). After that time, the two storage treatments showed different effects in terms of controlling

TABLE 3. Microbial counts of red currants stored under modified atmosphere packaging (MAP) conditions.

Microorganism	Treatment	Storage time (days)		
		0	30	60
Yeast (CFU/g)	CO ₂ -MAP	13,000±465 ^{a*}	22,000±1,200 ^a	6,000±115 ^b
	SO ₂ -MAP	13,000±465 ^a	2,800±150 ^b	100±14 ^c
Mould (CFU/g)	CO ₂ -MAP	15,000±330 ^b	17,000±930 ^b	100,000±980 ^a
	SO ₂ -MAP	15,000±330 ^b	400±72 ^c	19,000±1,100 ^a
Bacteria (CFU/g)	CO ₂ -MAP	3,100±124 ^b	2,800±100 ^b	250,000±1,500 ^a
	SO ₂ -MAP	3,100±124 ^a	100±25 ^c	1,500±88 ^b

*Mean values in the row with different letters are significantly different ($p \leq 0.05$).

microbial evolution. SO₂ was effective in controlling yeast evolution, reducing the population both at 30 and 60 days at one and two orders of magnitude, respectively. Less of an effect was observed for the CO₂ treatment but only at 60 days. When berries were exposed to SO₂, its dissolution into a water solution developed three molecular species, namely SO₂ (SO₂×H₂O), bisulphite (HSO₃⁻), and sulphite (SO₃²⁻) [Divol *et al.*, 2012]. The toxic effect against yeast is mainly ascribed to SO₂ because it has no charge; consequently, it should easily pass through the microbial cell membranes. Moreover, the high acidity and the low pH of red currants would be unfavourable to yeast intracellular processes [Divol *et al.*, 2012]. Considering mould, no treatments successfully inhibited them for 60 days when compared to their presence at harvest (0 days). SO₂ samples had 19,000 CFU/g, and CO₂-treated samples had 100,000 CFU/g. The increase in the mould content in the control samples (CO₂ MAP treatment) was probably due to the high humidity in the pallet system because it could not be adsorbed by the SO₂-generating SmartPac active paper sheets. For the same reason, bacterial proliferation was also very high at 60 days of storage for the sample stored

in CO₂-MAP. Exposure to SO₂ deeply reduced the initial bacterial microbial count (3,100 CFU/g); 97% after 30 days and 52% after 60 days.

Sensorial evaluation

Sensorial quality was expressed by the personal preferences of the panellists, and the results are reported in Figure 5. Sensory studies on fresh red currants about the hedonistic overall quality are scarce in the literature, but it is well known that one of the most distinctive attributes of *R. rubrum* is the astringency of fruits, which is mainly affected by flavonol glycosides, derivatives of hydroxycinnamic acids, and various nitrous compounds [Schwarz & Hofmann, 2007a,b]. At harvest (0 days) (Figure 5), red currants ranked a high score in terms of consistency attribute, astringent and acid taste, and total aroma, while the herbaceous and sweet taste were of moderate intensity. A similar profile in terms of sensorial properties among treatments was reported both at 30 (Figure 5A) and 60 days (Figure 5B), indicating that the gas (CO₂ and SO₂) inside the MAP does not differentiate the taste of berries. In fact, after 30 and 60 days the same number

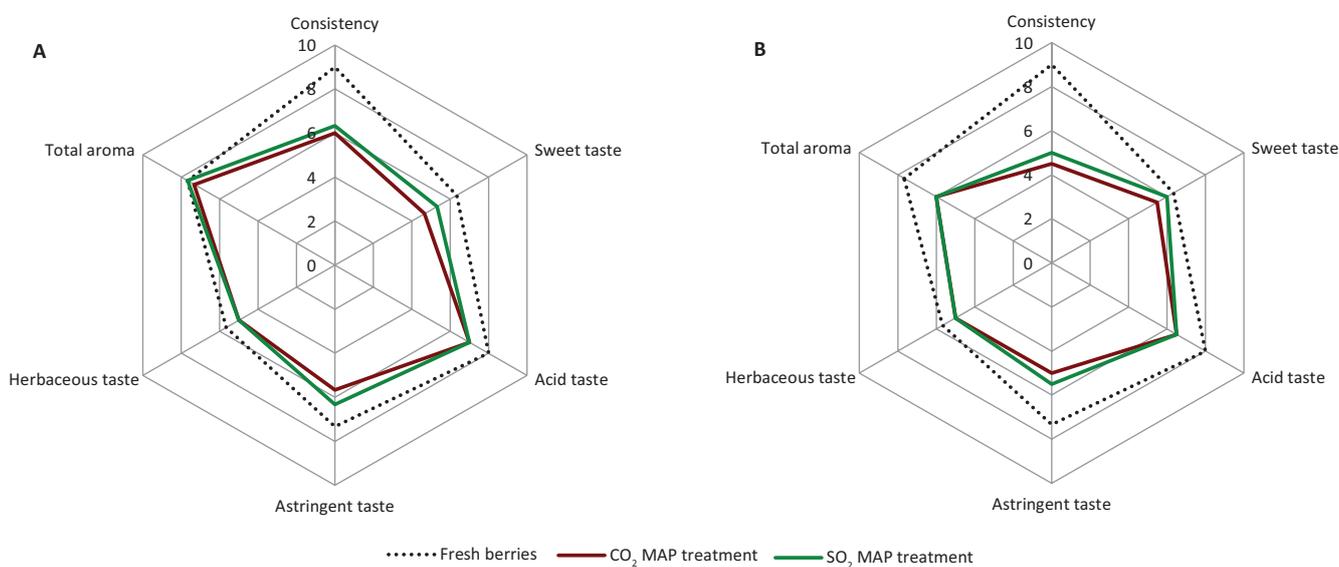


FIGURE 5. Sensory attributes of red currants after 30 days (A) and 60 days (B) of storage under modified atmosphere packaging (MAP) conditions.

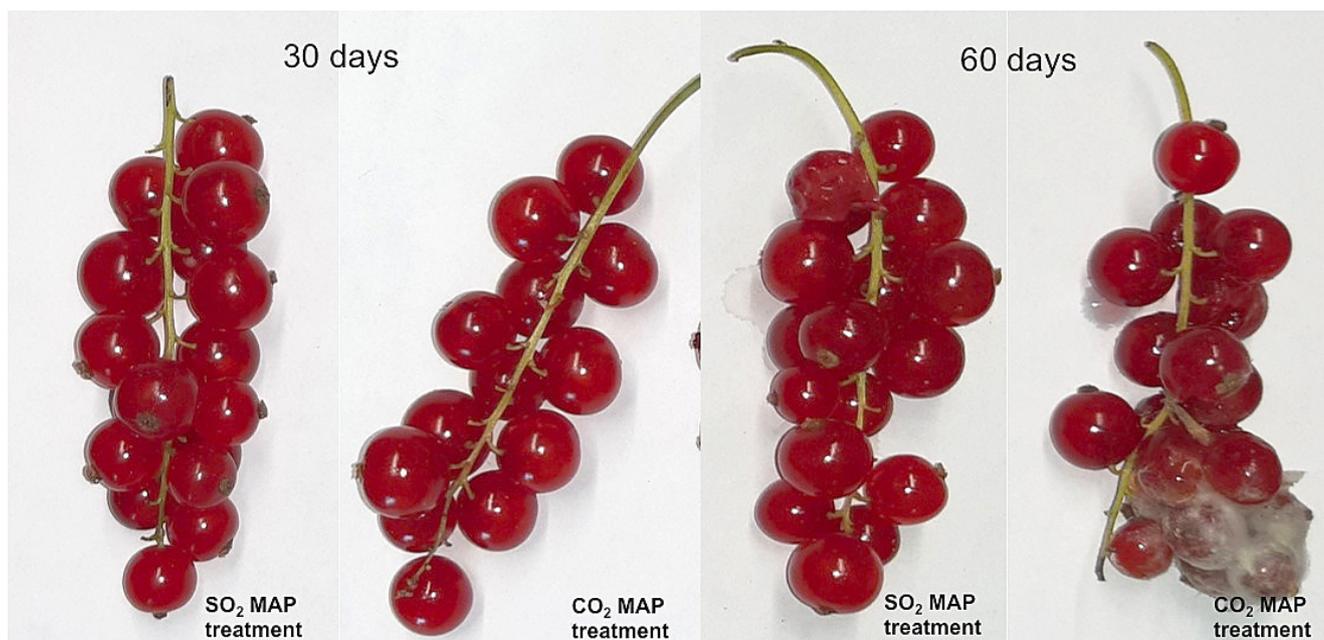


FIGURE 6. Red currants during the storage under modified atmosphere packaging (MAP) conditions.

of points were scored for acid (7.0 and 6.5) and herbaceous notes (5 both after 30 and 60 days), while for the others attributes no more than 0.5 of differences (no significant differences, $p > 0.05$) were scored. After 30 days, berries maintained the highest properties in terms of overall total aroma and acid taste. The perception by panel test decreased at 60 days, while the consistency had already changed (decreasing the score) during the short storage time (30 days). By observing the sensorial profile at the end of storage (60 days), it was possible to determine that astringent and acid notes of taste were the principal hedonistic indicators that influenced the overall acceptability of red currant cv. Rovada samples when stored. Sulphite residues are generally responsible for the decline in the flavour of fruit and affect consumers' willingness to fruit consumption [Shoaei *et al.*, 2019]. However, in this study, there seemed to be no aversion to the red currants; in fact, a similar profile was observed between samples stored in CO_2 and SO_2 MAP.

Visual evaluation

The acceptance of fresh fruits in terms of marketability of the product was preliminary linked to an ideal visual appearance, which is expressed in terms of the absence of defects concerning external and internal parts of fruits, colour, and shape development. In red currants, a high number of berries per raceme, large and uniform fruits throughout the cluster, their complete red coloration, and the maintenance of a green raceme and pedicel are important visual quality criteria for the fresh market. Results of the visual evaluation of berries stored in CO_2 and SO_2 MAP treatments were expressed as raceme and pedicel desiccation, percentage of healthy bunches, and an overall visual quality (Table 4). Generally, the visual evaluation decreased over time, but red currants stored under SO_2 MAP obtained better visual quality score compared to CO_2 MAP treatment berries throughout storage. Figure 6 provides the images of red currants over storage.

TABLE 4. Parameters of visual evaluation of red currants stored under modified atmosphere packaging (MAP) conditions.

Treatment	Storage time (days)	Raceme and pedicel desiccation ¹	Healthy bunches (%)	Visual quality ²
Fresh berries	0	5.0±0.0 ^{a*}	100±0.0 ^a	5.0±0.0 ^a
CO_2 -MAP	30	4.3±0.2 ^b	85±12 ^a	4.0±0.3 ^b
SO_2 -MAP	30	4.5±0.1 ^b	95±5.0 ^a	4.8±0.2 ^a
CO_2 -MAP	60	3.0±0.3 ^c	68±10 ^c	2.0±0.1 ^d
SO_2 -MAP	60	3.3±0.4 ^c	75±8.0 ^b	3.5±0.4 ^c

*Means values in the column with different letters are significantly different ($p \leq 0.05$). ¹Expressed in desiccation scores, were 1 = as green as at harvest; 2 = slight browning; 3 = browning but no shrivelling; 4 = browning and some shrivelling; and 5 = dry and brown. ²Expressed in visual quality scores, were 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; and 1 = unusable.

CONCLUSION

Red currants are an interesting fruit belonging to the berries with a high potential in terms of health properties. The extent of the fresh market, which is still limited compared to those of other soft berries, such as blueberries or raspberries, needs to be supported by advances in post-harvest research. In this study, *R. rubrum* berries were stored at low temperatures under different MAP treatments, and external appearance traits, as well as internal quality properties, were examined for up to 60 days. Exposure to SO_2 gas controlled microbial decay, resulting in a good visual appearance and promising maintenance of the most important sensorial attributes. Active emitters of SO_2 , such as those proposed, can be useful for the storage of red currants in extended storage after harvesting.

Moreover, this technique could also be promising in the transport of red currants. Regardless of the bioactive compounds, future advances will be necessary regarding detailed phenolic composition to analyse and enhance this application.

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