Effects of two sweet cherry cultivars (*Prunus avium* L., cvv. ‘*Ferrovia*’ and ‘*Lapins*’) on the shelf life of an innovative bakery product

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Abstract Sweet cherries are important fruits for human health, but their consumption is quite limited because of their seasonality and short shelf life. Consequently, these fruits are often subjected to technological treatments, but as a result, their consumption may involve significant intake of sugar and calories that tend to enhance many metabolic diseases. Agricultural science has characterized the different cultivars of fresh sweet cherries, but less literature is available about the suitability of different cultivars for industrial applications. The aim of this research was to design a model system to create an innovative bakery product with minimally processed fruits. Moreover, an evaluation of the suitability of two sweet cherry cultivars was performed to determine how to use these cultivars in an innovative bakery product and the effects on their shelf life. The results showed that the ‘*Ferrovia*’ cultivar is more suitable for use as a bakery product filling than ‘*Lapins*’ sweet cherries. During 75 days of storage at room temperature, ‘*Lapins*’ sweet cherries had a_w and moisture values lower than those of ‘*Ferrovia*’. Moreover, samples filled with ‘*Lapins*’ sweet cherries were harder than samples filled with ‘*Ferrovia*’ cherries. The technological processing of the sweet cherries caused a loss in antioxidant capacity that was more pronounced for ‘*Lapins*’ than ‘*Ferrovia*’ cherries (from 13.63 to 0.67 TEAC $\mu\text{mol g}^{-1}$ DW and 11.37–2.70 TEAC $\mu\text{mol g}^{-1}$ DW, respectively). This research highlights the importance of the cultivar for fresh consumption and processing of sweet cherry fruits,

and the results show that if both cultivars are equally ripe, the cherry cultivar that retains a higher flesh firmness is more preferable for use.

Keywords ‘*Ferrovia*’ · ‘*Lapins*’ · Sweet-cherry filling · Shelf life · Polyphenol content · Antioxidant activity

Introduction

Fresh fruit consumption is often lacking, especially in the diets of children. Among fruits, sweet cherries are highly desired by consumers, particularly children. Sweet cherry (*Prunus avium* L.) cultivation is widespread throughout almost the entire world, particularly in the Mediterranean area. Sweet cherries for fresh consumption are one of the most popular spring–summer fruits across temperate regions in Europe, and they are the first fresh fruit of the season (Prvulović et al. 2011). Because of its geographical location, Apulia is the primary Italian region for harvesting and commercializing sweet cherries.

The ‘*Ferrovia*’ cultivar, which ripens between the first and second half of June (medium-late), and the ‘*Lapins*’ cultivar, a self-fertile Canadian variety characterized by late ripening and high productivity (Wang et al. 2015), are the most frequently grown varieties in Apulia. The ‘*Ferrovia*’ cultivar produces a large, heart-shaped fruit with shiny red skin and firm texture and is primarily used for fresh consumption. This cultivar originates from the Bari area (Puglia, Italy), but it has adapted very well to various Mediterranean areas. Its fruit ripens in early June. The fruit flesh is pink and juicy with a strong adherence to the stone. The fruit has a very pleasant flavour and intermediate sweetness (Vavoura et al. 2015).

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The ‘*Lapins*’ cultivar is very productive and self-fertile and has attracted commercial interest because of its large size, high firmness and resistance to fruit cracking from rain. The fruit is susceptible to wind marking, has a mahogany to dark external colour with red flesh when ripe, and matures 7–15 days later than Bing cherries (Çalhan et al. 2014).

This fruit is valued for its high contents of minerals (potassium, phosphorus, calcium, magnesium, manganese, copper, and zinc), vitamins (especially A and C as well as B and PP) and polyphenols, as well as other valuable protective, detoxifying and purifying components (Ferretti et al. 2010). Moreover, people suffering from diabetes mellitus can consume sweet cherries due to their high content of non-glucose sugars. Despite the numerous functional, nutritional and organoleptic properties of sweet cherries, their consumption is quite limited because of the fruit’s seasonality and short shelf life. Therefore, various preservation methods are used to prolong their shelf life and retain their biologically active compounds (Zorić et al. 2016). Almost all sweet cherry production is allocated to the fresh market, but a considerable percentage (15% of EU production) is processed by the food industry. France, Italy and Spain in particular are oriented towards the processing industry for cherries, and the primary uses are canning (cherries in syrup and other products), preparations with alcohol (for the confectionery industry) and sugar preservation (candied fruit, jam, etc.). Nevertheless, excessive consumption of processed fruit products is not recommended since this type of consumption rarely ensures an appropriate intake of the vital micronutrients originally present in fresh fruits because these micronutrients are lost during processing. Moreover, the consumption of processed fruit may involve a significant intake of sugar, which may cause excessive intake of calories and increase the incidences of dental caries, obesity and other metabolic diseases. Consequently, it is necessary to design a product made from minimally treated sweet cherries.

Biscuits are the most common and popular bakery products in the world because of their low moisture content, which prevents microbial spoilage and extends their shelf life, allowing their large-scale production and distribution. These very stable bakery products can be combined with fresh or minimally processed fruits to obtain a complex food that is a suitable snack with higher nutritional and functional value than simple biscuits.

There are few studies in which sweet cherry cultivars have been considered for obtaining minimally processed fruits with high nutritional and quality characteristics. In fact, agricultural science studies have mainly characterized the different varieties or ripening stages of fresh sweet cherries based on their chemical and physical compositions and nutritional and organoleptic features (Díaz-Mula et al.

2002; Taghadomi-Saberi et al. 2013). De Pilli et al. (2014) studied the effect of different ripening stages in ‘*Ferrovia*’ sweet cherries on the shelf life of sponge cake filled with them, but the effects of different varieties of sweet cherries on the quality of processed food have not yet been investigated. It is possible that this lack of information is due to the canning industry idea that the quality of processed food depends exclusively on the technological process, and the raw material is considered to have little relevance.

For these reasons, the aims of this research were to design a model system to create innovative bakery products with minimally processed fruits and to evaluate the suitability of two cultivars of sweet cherries for this use to investigate the effects of the cherry cultivar on shelf life.

Materials and methods

Raw materials

Sweet cherries from the ‘*Ferrovia*’ and ‘*Lapins*’ cultivars were provided by Netti Lucia’s farm (Sammichele di Bari, Italy). Fruits from both cultivars were harvested in June of 2011 at their optimal ripeness stage, i.e., on precisely the 16th of the month for ‘*Ferrovia*’ and on the 24th of the month for ‘*Lapins*’. For each harvest date, an approximately 2 kg sample of fruit was randomly collected.

Chickpea flour, rice flour, sucrose, egg white, vegetable oil, baking powder (E450 disodium diphosphate, E500 sodium hydrogen carbonate, corn starch and flavourings), emulsifier and thickener were purchased from the local market.

Osmo-dehydration treatment

The fresh sweet cherries were cleaned, washed and blanched. The blanching treatment was performed at 900 W for 330 s in a microwave oven (Samsung, mod. EC 116KT, Milan, Italy) by dipping 0.5 kg of sweet cherries into 1 L of distilled water. The cherries were then cooled under running water, drained, destalked, and simultaneously pitted and split in half. The cherry halves were partially osmo-dehydrated by dipping them into an osmotic solution of maltodextrin at 60°Bx (product to solution ratio of 1:4) with continuous stirring (50 rpm) at room temperature for 150 min. After the partial osmo-dehydration treatment, the cherry halves were quickly washed under running water to remove surplus osmotic solution and gently blotted with paper. The partially osmo-dehydrated cherry halves were vacuum packed in plastic bags with a high gas barrier and stored at 4 °C until they could be used as a filling in bakery products.

Sample preparation

In this study, the model bakery product consisted of partially osmo-dehydrated cherry halves inside a biscuit sandwich that was coated all around and between the cherry halves and the biscuits with an edible coating. The function of the edible coating between the components of the model system was to protect the biscuits from excessive water migration from components with a high moisture content, such as the cherry halves, and to simultaneously hold the different components together to prevent the cherry halves from falling out of the biscuit sandwich.

The formula for the biscuits (without filling) was as follows: 28.8% rice flour, 30% sugar, 32% egg white, 3.2% chickpea flour, 4% sunflower oil and 2% baking powder. The biscuits were prepared by blending all the ingredients with a kneading machine (mod. Chef Major Titanium KMP05, KenwoodTM, Woking, UK), and the dough was poured into square metal moulds (with side lengths of 40 mm). The height of the biscuit dough was 3 mm. The samples were baked at 180 °C for 20 min in a convection oven (mod. Hotpoint CP97SE2/HA INOX, AristonTM, Fabriano, Italy). After baking, the biscuits were cooled and removed from the moulds. They were then completely coated with a patented edible coating that consisted of an emulsion of vegetable oil, egg protein, and gelling and humectant agents. The edible coating was brushed onto the samples and then dried at 80 °C for 16 min (8 min for each side). A detailed description of the edible coating ingredients and the preparation method are reported in Italian patent n. 0001413327 (De Pilli et al. 2015). Partially osmo-dehydrated sweet cherry halves (4 grams) were placed between two biscuits. Then, the biscuit sandwiches containing cherry halves were completely coated with the edible coating and dried at 80 °C for 8 min. For each cultivar, 60 biscuit sandwiches were prepared and packed into six plastic bags, i.e., 10 pieces per bag. The plastic bags (15 cm × 20 cm, PET12 - PP/EVOH/PP60) were heat-sealed (Impulse Sealer mod. TIS200, Falc InstrumentsTM, Bergamo, Italy) and stored at room temperature for 75 days. Samples from two bags were collected every 15 days for each cultivar and analysed to evaluate changes in the chemical and mechanical characteristics during storage.

Analyses

All analyses were performed at least three times for each sample type.

Fruit carpological parameters

For each cultivar, 25 fruits were individually weighed, and then, the fruit length, width and thickness were measured with a digital calliper.

pH determination

Forty mL of distilled water was added to 10 mL of fresh juice or partially osmo-dehydrated cherry halves (ratio 1:4 v/v) and homogenized for 1 min. The pH was measured using a pH meter (mod. Meter Basic 20, CrisonTM, Spain) at 25 °C.

Soluble solids contents

The sweet cherry halves and osmotic solution were analysed with a refractometer (mod. WYA 2 s, Irymen SystemTM, USA). All tests were performed at 25 °C.

Water activity

The water activity (a_w) values of fresh sweet cherries, partially osmo-dehydrated cherry halves and biscuits coated with the edible coating were measured with a dew point hygrometer at 25 °C (mod. Aqualab CX-2, Decagon Devices Inc.TM, Washington, USA).

Moisture

The moisture content determination of the partially osmo-dehydrated cherry halves and biscuits coated with edible coating was performed by drying 5 g of sample in an oven (mod. 9000 series ISCOTM, Milan, Italy) at 105 °C until a constant weight was reached (approximately 10 h). The results are expressed as the percentage of the weight difference (AACC 2003).

Mechanical parameters

The breaking strength (N/mm^2) (i.e., the ratio between the maximum force required to cut the sample and the contact surface of the cutting blade) was determined using an Instron 3343 dynamometer (Instron Ltd.TM, High Wycombe, UK) equipped with a load cell of 500 N.

Tests were performed on whole biscuit sandwiches using a cutting blade (thickness of 1 × 55 mm) with a descent speed of 50 mm/min. Merlin Series 9 software recorded the response of the material as it was subjected to this mechanical stress.

Chromatic characteristics

A colorimetric analysis of fresh and treated sweet cherries was performed with a MINOLTA Tristimulus Chromater-2 Reflectance colorimeter (MinoltaTM, Osaka, Japan) equipped with a CR-300 measuring head. Before each analysis, the instrument was standardized on a white tile ($L^* = 93.5$, $a^* = -10.00$, $b^* = 0.8$). For the fresh fruits, measurements were performed on both opposite equatorial sides for each fruit. The colorimetric parameters a^* (redness) and b^* (yellowness) are expressed as the hue angle. The values of the hue angle (H°) were calculated using the following equation: $H^\circ = \arctg(b^*/a^*)$. The hue angle ($^\circ$) represents the colour nuance, and the values are defined as follows: 0° red–purple, 90° yellow, 180° bluish-green, and 270° blue.

Total phenolic content

A phenolic extraction was performed on the fresh and processed sweet cherries by adding 5 g of fruit to 25 mL of a water:methanol (2:8) mixture containing 0.6 mg of NaF (to inactivate the polyphenol oxidase activity and prevent phenolic degradation), followed by homogenization for 1 min and then centrifugation at 5°C and 12,000 g for 10 min. The pellet was discarded, and the supernatant was retained and used as an extract. Each extract (100 μL) was mixed with 1.58 mL of water, 100 μL of Folin–Ciocalteu's reagent and 300 μL of a sodium carbonate solution (200 g L^{-1}). After the samples were allowed to equilibrate for 2 h, the absorbance was read at 725 nm against a blank with a UV/Vis spectrophotometer (PerkinElmer, mod. Lambda 25, Milan, Italy). The total phenolic content was calculated based on calibration curves with gallic acid, and the values are expressed as mg of gallic acid equivalents per gram of dry matter.

Determining the antioxidant capacity

The antioxidant capacity of the fresh and treated sweet cherries was determined by scavenging the radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) (Melicháková et al. 2010). A stock solution was prepared by stirring 24 mg of DPPH in 100 mL of methanol overnight. Trolox (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) purchased from Fluka Chemie GmbH (Buchs, Switzerland) was used as a standard, and methanol was used as the blank. Samples (5 g) of fresh sweet cherries and partially osmo-dehydrated cherry halves were homogenized with 20 mL of antioxidant extraction solution (as prepared by mixing 200 mL of distilled water, 800 mL of methanol and 84 mg of 2 mM NaF) for 5 min and filtered by filter paper with porosity values ranging from 10–20 μm (Whatmann No. 1). In the assay, 0.01 mL of extract, blank (methanol)

or standard (125, 250, 500, 1000, 2000, 2500, and 5000 μM Trolox) was mixed with 0.99 mL of DPPH solution. The absorbance values of the extracts, standards and blank were determined after 5 min at 517 nm with a UV/Vis spectrophotometer (mod. Lambda 25, PerkinElmerTM, Massachusetts, USA). The percentage of the remaining DPPH was proportional to the antioxidant concentration, which was used to calculate the antioxidant capacity of Trolox and is expressed as the micromolar Trolox equivalent antioxidant capacity (TEAC) per gram of dry weight.

Statistical analysis

Factorial analysis of variance (ANOVA) was performed using StatSoft software ver. 6.0 (Statsoft, Oklahoma, USA) to evaluate the effects of different cultivars and storage times on the analytical indexes measured during the storage of the sweet cherry filling. The mean values were compared by Fisher's test.

Results and discussion

Blanching and osmo-dehydration treatments

Blanching and osmo-dehydration treatments were performed on the fresh sweet cherries to preserve their quality and functional properties.

The sweet cherry osmo-dehydration was monitored by continuously measuring the soluble solids contents of the cherries and the osmotic solution until the end of the processing.

Several factors influence the osmotic dehydration process. The most important factors are the osmotic solution concentration and temperature; the solute type used to prepare the osmotic solution; the geometry, size, surface and mass of the material; the product to solution ratio; the contact time between the product and the osmotic solution; and the agitation speed. In this study, the only processing variable considered was the different geometry of the cherry halves from the two cultivars, and the other variables (temperature, speed, osmotic solution concentration, solute type, product and solution ratio and contact time) were constant.

Figure 1 shows the values for the total soluble solids (SSC) of the 'Ferrovía' and 'Lapins' sweet cherries at different times during the osmotic treatments. As expected, a significant dilution of the osmotic solution and partial dehydration of the sweet cherries were observed during the treatment time. Moreover, for a treatment time longer than 150 min, an evident discolouring of the cherries was caused by pigments (anthocyanins) leaching into the

Fig. 1 Total soluble solids (°Bx) values of osmotic solutions for different treatment times and for blanched sweet cherries of the cultivars ‘Ferrovia’ (a) and ‘Lapins’ (b)

osmotic solution, and a loss of consistency without an increase in fruit dehydration was found (data not shown). For these reasons, the treatment time was not extended beyond 150 min.

Before and after the treatment, the a_w , pH and hue angle were determined to evaluate the effect of partial osmo-dehydration of sweet cherries (Table 1). All the samples showed a significant decrease in a_w values after the osmo-dehydration treatment ($p < 0.05$), confirming its

effectiveness. In particular, the a_w values of ‘Lapins’ sweet cherries were less than those of the ‘Ferrovia’ samples. This finding indicates that the ‘Lapins’ cultivar has a greater tendency to dehydrate. By comparing the cherry halves to a hemisphere, some approximate parameters relating to the geometry of the fruits were calculated. The ‘Ferrovia’ cherry halves had an average volume of $4.45 \pm 0.26 \text{ cm}^3$ and a contact surface of $10.38 \pm 0.20 \text{ cm}^2$ in the osmotic solution, while ‘Lapins’ cherry halves had an average volume of $2.63 \pm 0.06 \text{ cm}^3$ and a contact surface of $7.31 \pm 0.05 \text{ cm}^2$ in the osmotic solution. Thus, because the same mass of fruit (500 g) was treated for both cultivars, the ‘Lapins’ cherry halves had a larger exchange surface area than the ‘Ferrovia’ because of their smaller size. In fact, the ‘Lapins’ cherry surface area was 1222.41 cm^2 , and the ‘Ferrovia’ cherry surface area was 1014.22 cm^2 , corresponding to approximately 167 cherry halves for ‘Lapins’ and 97 cherry halves for ‘Ferrovia’. This behaviour could also be explained by considering the microwave blanching previously applied to the fresh cherries. The thermal treatment by microwaves caused internal heating, which produced a higher vapour pressure inside the fruits. This phenomenon could cause the formation of micro-cracks in the cherry skin, which may be more obvious for ‘Lapins’ than ‘Ferrovia’ because ‘Lapins’ cherries have been shown to have a higher susceptibility to cracking in the open field than ‘Ferrovia’ cherries (Charlot et al. 2010). The higher susceptibility to cracking seems to be related to the lower flesh firmness (Yamaguchi et al. 2002).

The pH values of the partially osmo-dehydrated sweet cherries were found to be higher than those of the fresh fruits, probably because of organic acids leaching into the osmotic solution (Table 1). Additionally, both before and after the osmotic dehydration treatment, the pH values of the ‘Lapins’ sweet cherries were greater than those of ‘Ferrovia’ (Table 1). This finding could be attributed to the different organic acid contents of the two different cherry cultivars harvested at the same ripening stage. The change in pH is very important in terms of the chromatic characteristics of sweet cherries since the pH promotes co-

Table 1 Water activity (a_w), pH and hue angle results for fresh and partially osmo-dehydrated sweet cherries from ‘Ferrovia’ and ‘Lapins’ cultivars

Analytical index	‘Ferrovia’		‘Lapins’	
	Fresh fruits	Partially osmo-dehydrated fruits	Fresh fruits	Partially osmo-dehydrated fruits
a_w	1.00 ± 0.001^a	0.98 ± 0.002^b	1.00 ± 0.002^a	0.97 ± 0.002^c
pH	3.69 ± 0.04^a	3.95 ± 0.06^b	3.92 ± 0.02^b	4.23 ± 0.05^c
Hue angle (°)	22.07 ± 0.73^a	59.10 ± 0.96^b	16.89 ± 0.43^c	57.98 ± 1.72^b

*The mean values with the same letters in the same line are not significantly different ($p > 0.05$)

pigmentation reactions in fresh fruits during the ripening stage (Hayaloglu and Demir 2015). In fact, the decrease in chromatic parameters was associated with a weak increase in the pH. The influence of pH on fruit colour is well established in the literature. As the pH increases, the colour of the anthocyanins gradually becomes non-spectral purple, and a progressive loss of colour occurs (Gonçalves et al. 2007; Hayaloglu and Demir 2015). Comparing the hue angle values of both cultivars of fresh sweet cherries shows that the ‘*Ferrovia*’ samples presented higher values for this chromatic parameter than the ‘*Lapins*’ samples. These results indicate that ‘*Ferrovia*’ sweet cherries present a lower red colour intensity than the ‘*Lapins*’ cherries. The hue angle represents the full colour spectrum and ranges from 0° to 360°. When both a^* and b^* have positive values, which was the case for these results, the colour is a combination of red and yellow, and the hue angle values will be between 0° and 90°. When the ratio of b^* to a^* is one, the hue angle is 45°. As a^* decreases and becomes infinitely closer to 0 (i.e., the colour becomes less red), the hue angle increases and becomes infinitely closer to 90°. As the a^* values increase and approach infinity, the colour becomes redder, and the hue angle decreases and becomes infinitely closer to 0°. In contrast, Gonçalves et al. (2007) did not observe a negative correlation between pH and the red colour intensity. After the osmo-dehydration treatment, a significant increase in the hue angle ($p = 0.05$) was observed for both sweet cherry cultivars (Table 1). This finding could be due to more anthocyanins leaching from sweet cherries into the osmotic solution because these compounds are highly water soluble. In fact, the osmotic solution was light purple at the end of the treatment. Chaovanalikit and Wrolstad (2004) observed during canning that approximately half of the anthocyanins and polyphenolics in fruits leached into syrup. It is reasonable to suppose that the loss of red colour in partially osmo-dehydrated sweet cherries could be due to anthocyanins leaching into the osmotic solution. In fact, Gonçalves et al. (2007) affirmed that the hue angle is negatively correlated with the total anthocyanin level.

Water migration during storage

The application of the edible coating to the biscuits resulted in an increase in the moisture and a_w values. Notably, the biscuits showed a moisture content of $1.43\% \pm 0.12$ and a_w of 0.21 ± 0.04 after cooking, and after the edible coating of the biscuits was dried, the moisture content increased to 10% and the a_w increased to 0.6. Moreover, drying caused a decrease in the moisture content and a_w of the partially osmo-dehydrated sweet cherry halves for both cultivars (approximately 80 to 25% moisture content and 0.97 to 0.85 a_w).

Before packaging and during storage of the packaged samples, the a_w values and moisture contents of the separate parts of the sandwich (the biscuits and cherry filling) were periodically determined to investigate the water migration phenomenon between the components with low (biscuits coated with the edible coating) and high (sweet cherry filling) water content.

ANOVA analysis showed the significant effect of the storage time on the moisture content of both the partially osmo-dehydrated sweet cherry halves and biscuits ($p < 0.05$), while the effect of the cultivar was significant only on the moisture content of the sweet cherry halves (Table 2). In particular, a rapid decrease in the sweet cherry moisture content was observed during storage at room temperature for both cultivars, but this decrease was more consistent for the ‘*Lapins*’ cultivar (Fig. 2a). An increase in the moisture content during the first 15 days was observed for the biscuit sandwiches containing both ‘*Ferrovia*’ and ‘*Lapins*’ (Fig. 2b). After the fifteenth day, the moisture content of the biscuits was quite stable for sandwiches containing both cultivars.

Similar behaviour was observed for the a_w values of both the sweet cherry halves and the biscuits in sandwiches containing both cultivars as a function of the storage time (Fig. 2c, d, Table 2). The observed trends in the moisture content and a_w can be explained by moisture migrating between the different components of the sandwiches (biscuits and sweet cherry halves) and the package headspace. The hydration equilibrium and transport of water within food have been widely studied using model systems, such as agar gel and starch mixtures, or simple food products, such as pasta (Rossini et al. 2011; Tavakolipour and Mokhtarian 2016). Moisture transport is more difficult to study in complex foods, such as bakery products, because of their heterogeneous porosity. In these products, different moisture transport mechanisms occur at the microstructural level. For example, translocation and diffusion of liquids occur as a result of capillary action and concentration gradients, vapour in the air diffuses into the pores due to the vapour pressure gradient, and finally, the liquid component diffuses to the surface of the pores (Roca et al. 2006; Romani et al. 2016). The increase in the moisture content and a_w in the biscuits during the first 15 days of storage (Fig. 2b and Fig. 2d) could be due to the migration of water from the sweet cherries to the biscuits. One of the reasons for the lower moisture content of the ‘*Lapins*’ sweet cherry halves compared with those of ‘*Ferrovia*’ may be that the ‘*Lapins*’ cherries are subjected to greater and more rapid dehydration due to their different fruit tissue structures (e.g., the composition of the cell walls and middle lamella and the anatomy of the mesocarp and epicarp). The mechanisms that regulate texture changes during fruit ripening are not yet completely known. Structural

Table 2 Results of the variance analysis of the chemical and mechanical tests on biscuits and partially osmo-dehydrated sweet cherries stored for seventy-five days

Analytical index	Effects	Sum of Squares	Degrees of freedom	Mean square	F	p-level*
Moisture content of sweet cherries	Intercept	8021.91	1	8021.91	9359.91	0.01
	Storage time	311.87	5	62.37	72.77	0.01
	Cultivar	282.53	1	282.53	329.65	0.01
	Storage time * cultivar	70.15	5	14.03	16.37	0.01
	Error	10.28	12	0.86		
Moisture content of biscuit sandwiches	Intercept	3649.74	1	3649.74	6043.83	0.01
	Storage time	83.72	5	16.74	27.73	0.01
	Cultivar	0.01	1	0.01	0.02	0.88**
	Storage time * cultivar	9.91	5	1.98	3.28	0.04
	Error	7.25	12	0.60		
a_w sweet cherries	Intercept	19.20	1	19.20	194,753.36	0.01
	Storage time	0.44	5	0.09	902.15	0.01
	Cultivar	0.01	1	0.01	31.05	0.01
	Storage time * cultivar	0.01	5	0.01	6.17	0.01
	Error	0.01	24	0.01		
a_w biscuit sandwiches	Intercept	16.30	1	16.30	85,600.42	0.01
	Storage time	0.06	5	0.01	66.70	0.01
	Cultivar	0.01	1	0.01	21.07	0.01
	Storage time * cultivar	0.01	5	0.01	0.85	0.53**
	Error	0.01	24	0.01		
Breaking strength	Intercept	38,597.19	1	38,597.19	3460.43	0.01
	Storage time	4420.47	5	884.09	79.26	0.01
	Cultivar	839.55	1	839.55	75.27	0.01
	Storage time * cultivar	319.09	5	63.82	5.72	0.01
	Error	267.69	24	11.15		
Hue angle° sweet cherries	Intercept	88,322.94	1	88,322.94	12,321.32	0.01
	Storage time	1310.21	5	262.04	36.55	0.01
	Cultivar	11.02	1	11.02	1.54	0.23**
	Storage time * cultivar	131.51	5	26.30	3.67	0.01
	Error	172.04	24	7.17		

**Not a significant variable effect ($p > 0.05$)

pectins are a diverse group of heteropolysaccharides containing partially methylated D-galacturonic acid residues with side chain appendages of several neutral polysaccharides. The degree of polymerization/esterification and the proportions of neutral sugar residues/side chains are the principal factors contributing to their microheterogeneity. Pectin-degrading enzymes, such as polygalacturonase, pectin methyl esterase, lyase, and rhamnogalacturonase, are most frequently implicated in fruit tissue softening (Serrano et al. 2005; Prasanna et al. 2007; Sharma et al. 2017). The sweet cherry is considered a non-climacteric fruit, and the mechanisms that regulate its ripening are still

partially unknown. Some authors have hypothesized that the softening of sweet cherries is not dependent on pectin depolymerization but on a different interaction between the polymers in the wall during the ripening stage (Wahib et al. 2017). Vavoura et al. (2015) observed a lower decrease in the fruit firmness of ‘*Ferrovía*’ than ‘*Lapins*’ due to differences in enzymatic activities (primarily glucosidase, galactosidase and fructosidase) of enzymes that are involved in the gradual solubilization of pectins (without depolymerisation) present in the middle lamella between adjacent cell walls (Gerardi et al. 2012). In our case, the pectins present in the middle lamella of ‘*Lapins*’ are likely

Fig. 2 Moisture content and a_w of 'Ferrovia' and 'Lapins' sweet cherries (a, c) and biscuits (b, d) as a function of storage time

more solubilized than those of 'Ferrovia', and fruit tissue with a high permeability could allow substantial water migration during the drying treatment of the edible coating and the subsequent storage phase.

Mechanical and chromatic properties

The primary qualitative characteristics of bakery products are related to their mechanical properties, which influence the crispness and mouthfeel of these types of products. For this reason, the breaking strength of the single components of the biscuit sandwiches was not evaluated, and instead, the whole bakery product was tested.

Figure 3a shows the breaking strength values for the biscuit sandwiches containing both cultivars as a function of storage time. Data from the variance analysis (Table 2) showed that the storage time, cultivar and their interaction had a significant effect on the breaking strength ($p < 0.05$). In particular, sandwiches containing 'Lapins' cherries had a higher breaking strength than the 'Ferrovia' sandwiches from the fifteenth day in storage onward. This finding could be attributed to the higher decrease in moisture content of

the 'Lapins' filling during sample storage (Fig. 2a). Moreover, sandwiches containing both cultivars showed a decrease in breaking strength during the first 15 days of storage, and this decrease was probably caused by water migration from the sweet cherries to the biscuits (Fig. 2). The loss of consistency and, consequently, crispness was more pronounced in the samples containing 'Ferrovia'.

To evaluate the efficacy of the edible coating in protecting fruits from oxidation during storage, the hue angle was determined in partially osmo-dehydrated sweet cherry halves of both cultivars before packaging and during storage. The variance analysis of the hue angle values for the sweet cherries (Table 2) showed that the storage time had a significant effect on this analytical index ($p < 0.05$), while the cultivar did not have a significant effect ($p > 0.05$). Nevertheless, the interaction between the variables resulted in a significant effect on the hue angle ($p < 0.05$). Thus, a significant decrease in the hue angle was observed during storage for both samples (Fig. 3b). This trend could probably be attributed to the progressive oxidation of sweet cherry pigments.

Fig. 3 Breaking strength (N/mm²) results for biscuits filled with sweet cherries of both cultivars (a) and hue angle (°) values of 'Ferrovia' and 'Lapins' sweet cherries (b) as a function of storage time

Phenolic content and antioxidant activity

The persistence of functional characteristics in sweet cherries used as filling in the biscuit sandwiches was evaluated by determining the total polyphenolic content and antioxidant activity of unprocessed and processed cherries. Fresh 'Ferrovia' cherries showed higher total polyphenolic content and lower antioxidant activity than the 'Lapins' cherries (Table 3). Moreover, no significant change in the total polyphenolic content was observed after processing for both cherry cultivars. However, the antioxidant activity markedly decreased after technological treatments of both cultivars, reaching close to zero in 'Lapins' and 2.70 TEAC $\mu\text{mol/g DW}$ in 'Ferrovia'. In addition, a loss of antioxidant activity was observed, not after microwave blanching, but after the partial osmo-dehydration (Table 3). These results are consistent with those of Hayat et al. (2010) on the effect of microwave blanching on the antioxidant activity of citrus mandarin pomace. These authors observed an increase or slight decrease in antioxidant activities after microwave blanching as a function of the power irradiation and treatment time.

The observed discrepancy between the loss of total phenolic content and antioxidant activity in processed sweet cherries could be explained by considering that although the total phenolic content greatly contributes to antioxidant activity, the decrease in antioxidant activity seems to follow the same pattern as anthocyanin reduction (i.e., a decrease in the hue angle) in the treated samples. Kalt et al. (2001) also concluded that anthocyanins could have a greater contribution to antioxidant activity than other phenolic compounds. Huang et al. (2012) found that anthocyanidins and proanthocyanidins may be responsible for the very strong antioxidant activity of blueberries. Turturică et al. (2016) investigated the effect of thermal treatment on the degradation of the polyphenolic compounds in sweet cherry extracts from 70 to 120 °C using fluorescence spectroscopy and spectrophotometric techniques. These authors found that heating sweet cherry extracts resulted in structural changes that led to a significant decrease in fluorescence intensity with increasing temperature. The degradation rate constants were estimated using a fractional conversion kinetic model. The activation energy values revealed the high-temperature dependence of antioxidant activity, followed by anthocyanin content, total polyphenol content, and total flavonoid content. The same results were obtained by Picariello et al. (2017), who stated that the total phenolic and total anthocyanin contents were only slightly reduced by deep thermal treatments during the production of sweet cherry jam.

During storage, total phenolic content did not show a significant change, while an almost total loss of antioxidant capacity was observed for both cultivars (< 1 TEAC mmol/g DW) because of the probable oxidation and degradation of other substances with antioxidant activity. The storage temperature is an important factor that influences the quality of processed fruits and vegetables during storage; this result is more evident when the storage temperature is not controlled and differs from the optimal storage temperature (Sun et al. 2018). A low temperature (approximately 4 °C) can decrease the rates of biological and chemical degradation reactions. Consequently, the osmotic and drying treatments used to dry the edible coating on the biscuit sandwiches may have caused additional degradation of antioxidant compounds that continued during room-temperature storage for 'Ferrovia' (from 2.70 to 0.46 TEAC mmol/g DW), while this degradation ended before storage for 'Lapins'. These results highlight that despite the good resistance of 'Ferrovia' sweet cherries to technological processing effects, the edible coating was not able to protect the compounds with antioxidant activity during storage at room temperature. Moreover, drying the edible coating had a negative effect on preserving the valuable functional compounds in sweet cherries. Therefore, to better retain the functional

Table 3 Polyphenol content and antioxidant activity results for fresh and processed sweet cherries from the ‘Ferrovia’ and ‘Lapins’ cultivars

Analytical index	‘Ferrovia’			‘Lapins’		
	Fresh fruits	Blanched fruits	Partially osmo-dehydrated fruits	Fresh fruits	Blanched fruits	Partially osmo-dehydrated fruits
Polyphenol content (mg gallic acid/g DW)	0.648 ± 0.060 ^{a*}	0.635 ± 0.08 ^a	0.604 ± 0.006 ^a	0.516 ± 0.062 ^b	0.509 ± 0.081 ^b	0.501 ± 0.060 ^b
Antioxidant capacity (TEAC μmol/g DW)	11.370 ± 0.065 ^A	11.450 ± 0.095 ^A	2.7 00 ± 0.228 ^B	13.630 ± 0.068 ^A	14.051 ± 0.072 ^A	0.067 ± 0.064 ^B

*The mean values with the same letters in the same line are not significantly different ($p > 0.05$)

properties of this type of product, the optimized process should provide an edible coating that solidifies upon cooling (for example, using coatings that involve the formation of a gel film) to avoid the need for storage under refrigerated conditions.

Conclusion

This research highlights the effects of different sweet cherry cultivars on the structural and functional properties of biscuits sandwiches, a type of bakery product. The results showed that the ‘Ferrovia’ cultivar has a greater resistance than the ‘Lapins’ cultivar to the technological treatments we applied due to physiological and enzymatic processes occurring inside the fruits.

Finally, when considering cherries from different cultivars that are harvested at the same ripening stage, those with a higher flesh firmness are more suitable because this characteristic makes fruit more resistant to thermal treatment and helps preserve some important sensorial and nutritional properties of cherries.

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