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Influence of weather conditions on the physicochemical characteristics of potato tubers

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ABSTRACT

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Physicochemical properties of the tuber as a commercial product differ according to environmental conditions of the area and the growing season. The knowledge about how weather affects these characteristics, allows estimating the correct selection of the cultivars in order to obtain the highest yields or desired physicochemical qualities. In this sense, the effect of the main meteorological factors on the physicochemical characteristics (size, texture, dry matter, soluble solids, phenols, flavonoids, carotenoids and inhibitor concentration (IC_{50})) of 8 potato cultivars growing in A Limia (North-West Spain) was analysed. The study was conducted during three consecutive years (2014–2016) and the results presented significant differences in the analyzed parameters between years ($P < 0.05$). Spearman's correlations and principal component analysis showed that the tubers of 2014 (with colder weather conditions) had the highest phenol content and the lowest flavonoids and carotenoids content. Therefore, the temperature positively favoured the flavonoid content and carotenoid content (samples from 2016), although the size of potato tubers was considerably smaller.

Keywords: *Solanum tuberosum*; composition; physical characteristics; antioxidant compounds; climatic conditions

Potato, rice, wheat and maize are the main agricultural products for many countries worldwide. During centuries, potato crop was the first source of incomes and the main non-grain basic food in developed countries and, actually, still being the first agricultural product in many developing areas.

Potato tubers are considered a valuable source of energy but also of minerals, vitamins and phytochemicals. The recent increase in consumers' concern for healthy food demands research of physical, chemical and nutritional properties of potatoes. It demonstrated that potato tubers are a significant source of antioxidant compounds in human nutrition, phenolic compounds and carotenoids being the main contributors (Reyes et al. 2004, Lachman and Hamouz 2005, Hamouz et al. 2006). The physicochemical compounds of potato tubers depend on factors such as agricultural practices, agroclimatic factors, type of soil or cultivar and its characteristics can vary considerably. Some factors as altitude, geographical area and temperature during the growing period, showed a strong relationship with the total phenol content in tubers (Hamouz et al. 2010, Zarzecka et al. 2017). Also the temperature during the crop cycle affects total carotenoid content in tubers (Hejtmánková et al. 2013, Lachman et al. 2016, Hamouz et al. 2016). Undoubtedly, nutritional composition of potatos is dependent on climatic

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conditions of the area and cultivar type (Zarzecka and Gugala 2011, Pazderů et al. 2015).

The North West of Spain, mainly A Limia region, is the biggest producing area for rainfed potato in the Iberian Peninsula. More than 250 000 t of these tubers were harvested each year. The main crop cycle is from spring to autumn season when the continental influence of the oceanic climate is more pronounced. Some drought periods and maximum temperatures above 30°C are frequent. As it has already been documented, climatic conditions could have a significant impact on the quality or physicochemical parameters of potatoes and during the response of the vegetative development of the crop. Therefore, this paper studied the influence of the weather during three consecutive growing potato cycles on the physicochemical characteristics of the produced potato tubers. The effect of the meteorological conditions on the size of tubers, texture, dry matter, soluble solids, total phenols, total flavonoids, carotenoids and antioxidant capacity were statistically analysed.

MATERIAL AND METHODS

Studied potato cultivars and weather monitoring. The potato crops were monitored during three years (2014–2016) in field trials planted in the Agricultural Centre of Desenvolvemento Agrogandeiro in A Limia (Ourense – North West Spain). The experiment included the physicochemical analyses of tubers from 8 potato cultivars (Agria, Cazona, Fina, Flamenco, Ganade, Kennebec, Red Scarlett and Yona). Each cultivar was planted in three plots randomly distributed across the experimental field. The meteorological factors were recorded with a portable weather station Onset Hobo Pro Series H08-032-08 and the National Weather Service website.

Determination of physicochemical characters of potato tubers: size, total soluble solid content, texture and dry matter. The size was measured in six tubers per cultivar, using a horizontal calliper intended for the precise measurement of lengths in cm. Total soluble solids were measured as °Brix with a portable refractometer Atago ATC-1E (Barcelona, Spain). The apex and flesh textures of tubers were determined using a penetrometer Bertuzzi-FT 327 (Milan, Italy) fitted with an 8 mm plunger tip and were expressed as kg/cm^2. Dry matter content was measured by the method proposed by AOAC (Ref. 925.10, 1990). 5 g of the sample were introduced into an oven at 103 ± 2°C until constant weight and the results were expressed as percentage.

Analytical methods: freeze-drying, phenols, flavonoids, carotenoids and DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity. Firstly, the tubers were peeled, scratched, frozen at –80°C and freeze-dried at –85°C to obtain a fine powder. The potato extract was obtained, mixing 2 g of potato flour with ethanol 80% and shaking at 70 rpm during 5 h in darkness. Finally, potato extract was centrifuged at 4500 rpm for 10 min.

Folin-Ciocalteu assay described by Singleton and Rossi (1965) was used to determine the total phenol concentration. 1 mL of a diluted potato extract was mixed with 1 mL Folin-Ciocalteu reagent and 4 mL of 7% Na_2CO_3. The final volume was brought to 25 mL with distilled water. The solution was incubated in darkness for 1 h at room temperature, and the absorbance was read at 765 nm in a UV/Vis spectrophotometer (Jenway 6305, Staffordshire, UK). The results were expressed as mg gallic acid per 100 g of fresh weight (FW) of potato.

The flavonoid content was determined using the Dowd method as adapted by Arvouet-Grand et al. (1994). 3 mL of potato extract was mixed with 0.5 mL of $AlCl_3$ solution (5% in methanol) and carried to a final volume of 25 mL with distilled water. The solution was stored 30 min in darkness at room temperature, and the absorbance was measured spectrophotometrically at 425 nm. The results were expressed as mg quercetin per 100 g of fresh weight of potato.

The total carotenoid content was determined following the method of Lachman et al. (2003). Freeze-dried potato (2 g) was mixed with acetone (10 mL), and refrigerated in darkness for 3 days. After, the samples were sonicated for 20 min, filtered through a glass filter and the yellowish cake was washed three times with 5 mL of acetone. The filtrates were carried out to 25 mL and centrifuged at 4500 rpm during 5 min. The absorbance was measured spectrophotometrically at 444 nm and the total carotenoid content was expressed as lutein equivalents following the equation: Total carotenoids = (absorbance × 25/0.259). The results were expressed as mg lutein per 100 g of fresh weight of potato.

DPPH radical-scavenging assay, based on the ability of the antioxidants to block the 2,2-diphenyl-

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1-picrylhydrazyl radical, was used to evaluate the antioxidant activity (Brand-Williams et al. 1995). The potato extract was diluted 1:1 (V/V) with ethanol 80%. 0.3 mL of this dilution was mixed with 2.7 mL of a DPPH solution 6×10^{-5} mol/L and stored during 30 min in darkness. The absorbance was measured at 517 nm against a blank. The antioxidant activity was expressed as the inhibitor concentration (IC_{50}) in mg/mL using ascorbic acid as reference standard.

Statistical analyses. The results were statistically analysed by the method of variance analysis (ANOVA) with detailed evaluation by means of the Bonferroni test at the level of significance $P < 0.05$. A Spearman's rank correlation analysis and principal component analysis were applied to study the relationships among meteorological parameters and physicochemical variables. SPSS 21.0 software package (IBM, Somers, USA) for Windows and Statgraphics Centurion XVI software (Virginia, USA) were used.

RESULTS AND DISCUSSION

Meteorological conditions of the crop cycles. Potato crop cycles were from the middle of May to October (Figure 1). Weather conditions in the three growing potato seasons corresponded with a temperate oceanic climate with summer drought. Some significant differences in mean values of meteorological parameters recorded in each crop cycles according to the Bonferroni test were found. The mean temperature was significantly lower in 2014 (17.0°C) compared to 2016 (18.3°C). The average of the minimum temperature was significantly lower in the 2015 cycle (7.3°C) than in the cycles of the years 2014 (8.5°C) and 2016 (8.4°C).

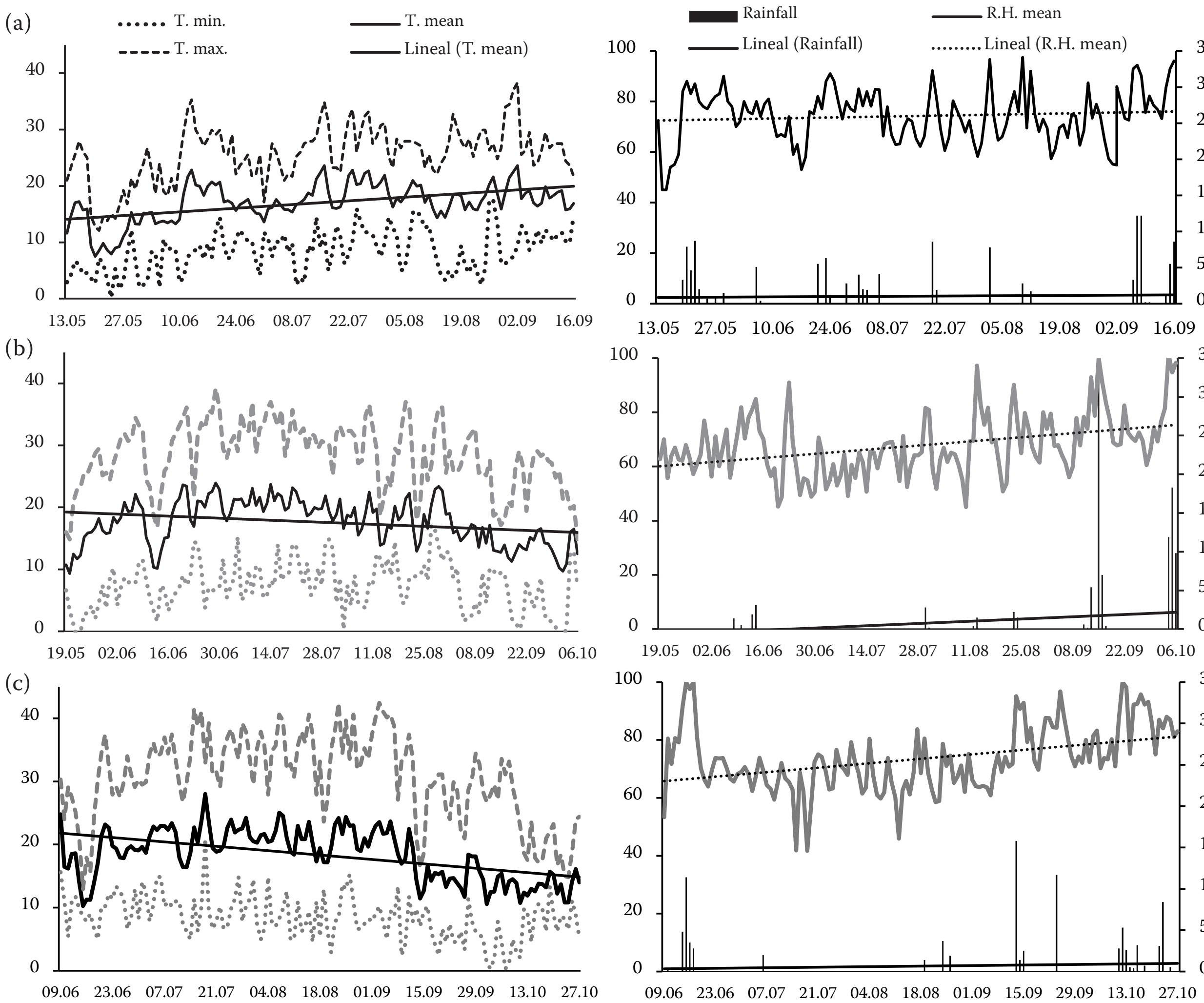

Figure 1. Environmental conditions recorded in (a) 2014; (b) 2015 and (c) 2016 crop cycles. T – temperature; RH – relative humidity

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However, the average of the maximum temperatures showed significant differences in the three years of sampling, with values of 25.6, 28.4 and 30.5°C, in 2014, 2015 and 2016, respectively. The crop cycle of 2015 registered the lowest mean relative humidity (67.7%), significantly different to the cycle of 2014 (74.2%) and 2016 (73.5%). While the cycle of 2016 accumulated the lowest amount of rain (90.7 L/m^2), it did not show significant differences with the other years. The 2016 cycle was the warmest, recording the highest temperatures and the lowest rainfall during the development of potato plants. The 2014 cycle was the coldest, recording the lowest temperatures and the highest accumulated rainfall, principally during the first stages of the crop.

Assessment of physicochemical characteristics of the tubers. The size of tubers showed significant differences in the years sampled ($P < 0.05$) (Table 1). Tubers collected in 2016 had significantly lower mean values, both in width and length. The mean soluble solid content was significantly lower in potatoes of 2015 ($P < 0.05$). Other physicochemical characteristics as a texture of the tubers, dry matter and antioxidant activity did not show significant differences between the three years. The size of the tubers (width and length) showed a significant negative correlation with the mean and maximum temperatures, and significantly positive with the accumulated rainfall (Table 2).

With respect to the quantified chemical components, the phenol concentration was significantly higher in 2014 in comparison with other years, but significantly lower in flavonoids ($P < 0.05$). The carotenoids were significantly higher in 2016 ($P < 0.05$) (Table 1). Spearman's correlation analysis showed negative significant coefficients between the phenol content and the mean and maximum temperatures, and the correlation was positive with the minimum temperature, the relative humidity and the accumulated rainfall (Table 2). In contrast, the concentration of flavonoids was negatively correlated with the minimum temperature, the relative humidity and the accumulated rainfall, and the coefficients were positive with the mean and maximum temperature. The correlation coef-

Table 1. Mean values of the physicochemical variables by potato crop cycle

Physicochemical characteristic	2014	2015	2016
Tuber width (cm)	6.6^a	6.9^a	5.2^b
Tuber length (cm)	8.4^a	9.3^a	6.3^b
Apex texture (kg/cm^2)	8.1	8.4	8.5
Flesh texture (kg/cm^2)	8.2	8.1	7.8
Dry matter (%)	21.8	20.5	20.8
Soluble solids (°Brix)	5.0^a	4.3^b	5.2^a
Total phenols (mg/100 g FW)	38.4^a	25.8^b	24.4^b
Total flavonoids (mg/100 g FW)	0.8^a	1.3^b	1.5^b
Total carotenoids (mg/100 g FW)	0.05^a	0.06^a	0.11^b
Inhibitor concentration (IC_{50}) (mg/mL)	15.8	10.8	14.9

Different letters indicate significant differences between the mean values ($P < 0.05$). FW – fresh weight

Table 2. Spearman's correlation coefficients between the meteorological and physicochemical variables

	Temperature			Relative humidity	Aaccumulated rainfall
	minimum	mean	maximum		
Tuber width	–0.029	–0.671**	–0.671**	–0.029	0.671**
Tuber length	–0.214	–0.479*	–0.479*	–0.214	0.479*
Apex texture	–0.155	0.221	0.221	–0.155	–0.221
Flesh texture	0.029	–0.214	–0.214	0.029	0.214
Dry matter	0.236	–0.14	–0.14	0.236	0.14
Soluble solids	0.328	0.184	0.184	0.328	–0.184
Total phenols	0.442*	–0.487*	–0.487*	0.442*	0.487*
Total flavonoids	–0.450*	0.612**	0.612**	–0.450*	–0.612**
Total carotenoids	–0.295	0.546**	0.546**	–0.295	–0.546**
Inhibitor concentration (IC_{50})	0.339	–0.059	–0.059	0.339	0.059

*$P < 0.05$; **$P < 0.01$

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ficient of the carotenoid content with mean and maximum temperatures was significantly positive, and was negative with the accumulated rainfall (Table 2). Taking into account the physicochemical composition of potato cultivars in each crop cycle, the tendency was similar to the annual averages previously mentioned (Table 3). However, some potato cultivars showed significant differences to this tendency ($P < 0.05$), such as cv. Kennebec (lower soluble solid content in 2014 and higher phenols in 2016), cv. Yona (lower soluble solid content in 2014) and cv. Fina (higher carotenoids in 2015).

Principal component analysis applied to the physicochemical and meteorological parameters significantly related these variables. Five components were extracted, which explained an accumulated variance of 86.8%. This analysis shows

Table 3. Physicochemical characteristics of potato cultivars in each crop cycle

	Year	Agria	Cazona	Fina	Flamenco	Ganade	Kennebec	Red Scarlett	Yona
	2014	7.5	6.2	7.2	5.5	6.7	6.8	6.6	6.7
Tuber width (cm)	2015	7.8	6.3	7.3	6.3	6.2	7.8	6.5	6.7
	2016	5.6	5.8	5.2	5.4	5.1	5.3	5.1	4.2
	2014	9.8	6.2	8.3	8.3	8.1	8.4	9.1	9.1
Tuber length (cm)	2015	10.3	6.2	10.5	10.4	7.3	10.0	10.9	8.8
	2016	7.6	5.3	6.7	7.3	6.0	6.4	6.3	5.2
	2014	9.0	7.6	9.2	7.7	7.9	8.1	6.8	8.7
Apex texture (kg/cm^2)	2015	8.4	7.9	8.8	9.8	6.8	8.6	7.2	9.7
	2016	8.1	8.6	9.6	8.5	8.1	8.2	8.1	9.0
	2014	8.9	9.0	8.6	7.9	7.7	8.1	6.6	8.4
Flesh texture (kg/cm^2)	2015	8.0	8.2	9.3	9.7	6.2	7.6	6.6	9.0
	2016	6.7	8.2	8.5	7.8	7.4	7.5	7.5	8.8
	2014	23.6	23.3	25.4	17.7	24.7	21.7	17.9	20.1
Dry matter (%)	2015	20.1	22.6	21.3	19.0	23.9	19.9	16.8	20.2
	2016	18.3	22.1	22.2	19.0	21.5	21.3	21.5	20.6
	2014	5.1	6.3	6.3	3.3	5.7	4.2	5.0	4.3
Soluble solids (°Brix)	2015	4.7	5.5	4.6	2.6	4.3	4.5	3.9	4.4
	2016	5.6	5.7	5.2	4.8	4.6	5.1	5.8	5.1
	2014	30.8	40.9	49.1	40.6	33.7	19.2	39.9	53.0
Total phenols (mg/100 g FW)	2015	12.8	33.3	20.0	34.9	19.6	19.1	21.7	45.1
	2016	21.0	28.0	24.5	33.7	12.1	24.8	33.5	17.4
	2014	0.8	1.0	0.6	0.8	0.8	0.3	0.8	1.0
Total flavonoids (mg/100 g FW)	2015	1.4	0.9	0.9	2.6	1.1	0.8	0.9	1.7
	2016	1.6	1.2	2.7	1.1	1.1	0.8	1.4	1.7
	2014	0.07	0.04	0.04	0.04	0.07	0.02	0.07	0.06
Total carotenoids (mg/100 g FW)	2015	0.07	0.05	0.08	0.06	0.10	0.03	0.04	0.07
	2016	0.22	0.06	0.08	0.06	0.14	0.08	0.15	0.05
	2014	27.3	8.2	17.3	11.3	13.6	24.3	14.5	9.6
Inhibitor concentration (IC_{50}, mg/mL)	2015	16.1	8.9	15.2	7.1	11.0	10.5	10.7	6.9
	2016	17.6	9.6	12.5	9.8	13.1	11.4	34.3	10.9

FW – fresh weight

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the projection of the variables into the plane composed by the first two principal components that explain 54.0% of the total variance (Figure 2). The potato samples of 2016 were close to the mean and maximum temperatures, the carotenoid and the flavonoid content. On the contrary, the samples of 2014 were located near the accumulated rainfall and the phenol content (Figure 2). The potato cultivars harvested in 2015 were characterized as being the largest coinciding the year that registered the lowest minimum temperatures. Wurr et al. (2001) denoted that particular cool temperatures at the beginning of tuberization resulted in longer tubers. The potato tubers analysed in this study are of short photoperiod and temperate-cold climate, which favours obtaining of larger tubers. Some results published in the last years showed a great influence of the environmental conditions on the characteristics of tubers, especially potato yield and size (Affleck et al. 2008, Pazderů et al. 2015). However, it is important to analyse the changes that different potato cultivars can suffer in their composition, depending on climate, since they can affect their cultivation in some areas.

These results agree with investigations carried out on potatoes grown in regions with relatively low temperatures and more rainfall, which had higher phenolic content (Hamouz et al. 2006, 2010, Reddivari et al. 2007). Reyes et al. (2004) documented that longer days and cooler temperatures in Colorado favoured about 1.4-times higher total phenolic content compared to Texas-grown tubers. In addition, André et al. (2009) found an increase in the phenol content due to drought stress, although they specified the high dependence with the cultivar. As to the carotenoids, some authors highlighted the locality and year with higher average temperatures during the growing season that produced their higher content in tubers (Hejtmánková et al. 2013, Hamouz et al. 2016, Lachman et al. 2016).

The results of this research showed no influence of the meteorological factors on IC_{50} measured in tubers. Nevertheless, the previous studies indicated that the content of total antioxidant compounds could be significantly influenced by location, conditions of growing crop, fertilization and environmental conditions of year (Hamouz et al. 2006). It should be noted that the antioxidant activity is an important property of foods for consumers. This activity, in potato tubers, depends on the phenols, carotenoids or anthocyanins content, among other antioxidants (Lachman and Hamouz 2005, Burlingame et al. 2009). Although years ago, potatoes with coloured flesh were less attractive for consumers, they are currently gaining in importance in terms of health nutrition. They are increasingly sought and recommended as a

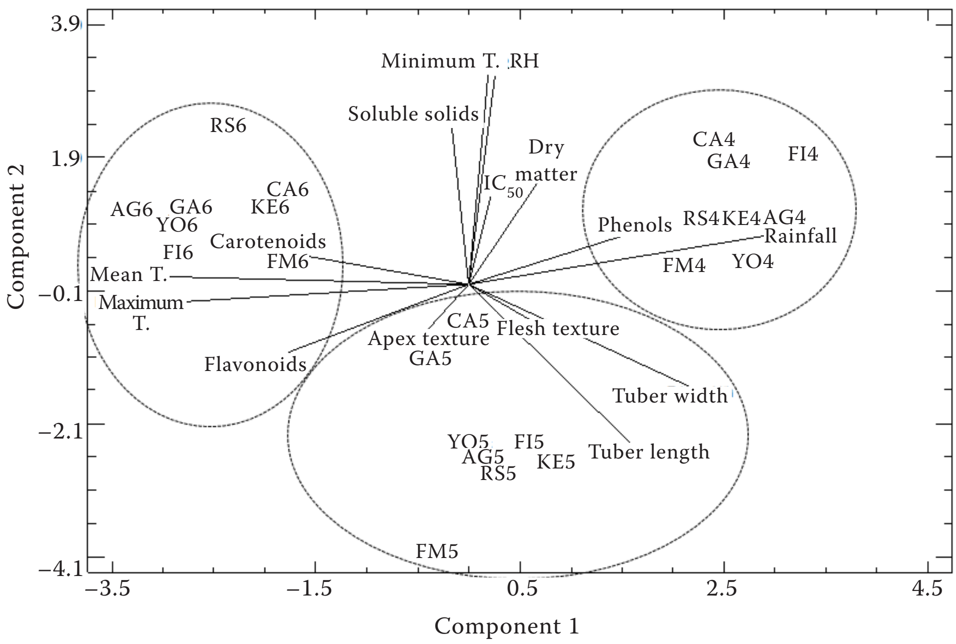

Figure 2. Principal component score plot based on quality and physicochemical variables of potato samples according to the crop year (2014: 4; 2015: 5; 2016: 6). AG – Agria; CA – Cazona; FI – Fina; FM – Flamenco; GA – Ganade; KE – Kennebec; RS – Red Scarlett; YO – Yona; T – temperature; RH – relative humidity; IC_{50} – Inhibitor concentration

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healthier food by their dependence with the antioxidant capacity (Lachman and Hamouz 2005, Pazderů et al. 2015, Seijo-Rodríguez et al. 2018). Planting potato cultivars with coloured flesh (with a higher content of antioxidants) with the aim of diversifying production and increasing the consumers' interest for fresh potatoes could be a good market strategy (Lange and Kawchuk 2014). Hence, it is important to continue the research and characterize each potato cultivar for the physicochemical diversity that it presents.

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