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Effect of boiling on the total phenolic, anthocyanin and carotenoid concentrations of potato tubers from selected cultivars and introgressed breeding lines from native potato species

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ABSTRACT

Potato tubers are considered an important source of bioactive compounds, although the concentrations of different phytochemicals are affected by cooking and other processes. The present study was focused on evaluating the effect of boiling on total phenolic, anthocyanin and carotenoid concentrations of ten promising introgressed breeding lines from native potato species (*Solanum tuberosum* subsp. *andigena* Hawkes and *Solanum stenotomum* Juz. & Bukasov) and three heirloom Spanish *S. tuberosum* L. cultivars (Jesús, Morada and Zamora). In addition, three commercial cultivars (Vitelotte, Kasta and Monalisa) with different flesh color were used as testers. Breeding lines NK-08/349 and NK-08/362 showed high total phenolic (TP) and total anthocyanin concentrations (TA), whereas breeding lines NK-08/286, NK-08/356 and NK-08/370 and the cultivar Morada were characterized by a high carotenoid concentration (TC). In general, purple cultivars and breeding lines (Vitelotte, Morada, Jesus, Kasta, NK-08/349 and NK-08/362) stood out with showed high phenolic and anthocyanin concentrations. The comparative analysis of raw and boiled tubers showed high losses of phenolics, anthocyanins and carotenoids. TP, TA and TC concentrations in boiled tubers were directly correlated with their corresponding concentration in the raw product. In addition, significant correlations ($p \leq 0.05$) between TA and TP concentrations, in both raw and boiled tubers, have been observed. The utilization of peeled and diced tubers, with the subsequent surface increase, seems to be a determinant factor explaining why phytochemical losses were so high.

1. Introduction

Potato is the fourth most important food crop after rice, wheat and maize, and it contains a wide variety of phytochemicals, including carotenoids and phenolic compounds (Brown, 2008; Ezekiel et al., 2013). The regular consumption of phytochemicals may contribute to the prevention of certain chronic diseases associated with oxidative damage (Espín et al., 2007). In particular, native potato germplasm can be considered a great source of nutritional variability in potato breeding programs for increased tuber nutritional value (Burgos et al., 2007).

Phenolic compounds are considered to be bioactive compounds as they have shown beneficial health effects. They are commonly classified into three important groups: phenolic acids, flavonoids and tannins. Substituents on the aromatic ring affect the stability and the radical-quenching ability of the phenolic acids (Rice-Evans et al., 1996). The most abundant phenolic compounds in potato tubers are caffeoyl-esters, and the major phenolic acid is chlorogenic acid, which is bioavailable in humans and constitutes about 80–90% of the total phenolic acids (Brown, 2005). A study of 74 Andean potato landraces revealed a wide variability for total phenolic compounds and antioxidant activity (Andre et al., 2007a).

Anthocyanins are pigments which constitute the main subclass among flavonoids. More than 600 molecular structures have been identified to date as responsible for the red–blue color of many fruits and vegetables. The de-glycosylated forms (aglycones) of anthocyanins are known as anthocyanidins, being malvidin, petunidin, delphinidin and peonidin the most common anthocyanidins found

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in purple-fleshed potatoes, while pelargonidin is in red-fleshed tubers (Kita et al., 2013).

Carotenoids are tetraterpenoids with a long conjugated double bond system and a near bilateral symmetry around the central double bond (Britton, 1995). There are over 750 known carotenoids with their color ranging from pale yellow to deep red (Rodriguez-Amaya, 2001). The carotenoid profiles and concentrations in tubers of *Solanum phureja* Juz. & Bukasov have been correlated with the intensity of yellow flesh color, and zeaxanthin and antheraxanthin were found as the predominant carotenoids in deep yellow-fleshed varieties while violaxanthin, antheraxanthin, lutein and zeaxanthin constituted the main carotenoid profile of yellow potatoes, and violaxanthin, lutein and β-carotene in cream-fleshed potatoes (Burgos et al., 2009).

However, in a recent characterization of 60 potato cultivars, including some native ones, zeaxanthin was not detected in their carotenoid profile suggesting that the storage conditions of tubers may play a modulating role on the carotenogenic pathway and subsequently in the carotenoid composition (Fernandez-Orozco et al., 2013). In addition, data presented by Fernandez-Orozco et al. (2013) suggest a direct correlation between the presence of xanthophyll esters and the ability of tubers to accumulate carotenoid pigments. Cultivated diploid potatoes derived from *Solanum stenotomum* Juz. & Bukasov and *S. phureja* Juz. & Bukasov have been reported to be a relevant source of zeaxanthin and lutein (Brown et al., 1993).

The concentration and stability of bioactive compounds in food can be affected by several factors such as pH, light, oxygen, enzyme activity, ascorbic acid, sugars and cooking techniques, as well as other processing conditions (Palermo et al., 2013; Patras et al., 2010). Therefore, food composition databases should contain information of foods as they are finally consumed. The characterization of potato genotypes in terms of phytochemical concentration has raised an increasing interest over the last two decades.

As noted by Ezekiel et al. (2013), some researchers have focused on the effects of thermal processing on the concentration of different bioactive compounds of potatoes. Some studies have shown significant decreases of total phenolic and antioxidant activity concentrations in cooked tubers when compared to raw ones (Perla et al., 2012; Xu et al., 2009); while other works reported increases following cooking (Blessington et al., 2010; Burgos et al., 2013). Increased total anthocyanin concentrations of tubers after different cooking treatments have been recently published (Lachman et al., 2013). Lemos and Sivaramareddy (2013) have also reported higher total anthocyanin concentrations in French fries when compared to raw potatoes, suggesting that this enrichment can be due to the transfer of the components between the frying medium (oil) and the fried product (potato). According to Burgos et al. (2012), boiling significantly reduces the violaxanthin, antheraxanthin and total carotenoid concentration of yellow-fleshed cultivars, whereas lutein and zeaxanthin concentrations increase in some genotypes after boiling.

The present study aims at analyzing the total concentrations of some selected phytochemicals (total phenolics, anthocyanins and carotenoids) before and after boiling of a set of highly pigmented accessions that supposedly contain high levels of carotenoids and phenolic compounds. The collection included three heirloom Spanish *Solanum tuberosum* L. cultivars with purple flesh color (Morada, Jesus and Zamora) and ten pigmented breeding lines with introgressions of native *Solanum* species (*S. tuberosum* subsp. *andigena* (Juz. & Bukasov) Hawkes and *S. stenotomum* Juz. & Bukasov), using three common cultivars (Vitelotte, Kasta and Monalisa) with different flesh colors as testers, within the context of a potato breeding program specifically addressed to increase the potato tuber nutritional value.

2. Materials and methods

2.1. Plant material

Three commercial cultivars belonging to the species *S. tuberosum* subsp. *tuberosum* were selected as testers on the basis of the contrasting flesh color of tubers: one deep purple (Vitelotte), one medium dark purple (Kasta), and one pale yellow (Monalisa). Three heirloom purple-fleshed Spanish cultivars (Morada, Jesus and Zamora) and ten breeding lines with introgressions from two native *Solanum* species (*S. tuberosum* subsp. *andigena* (Juz. & Bukasov) Hawkes and *S. stenotomum* Juz. & Bukasov), were also selected for the objective of evaluating the effects of boiling on the phytochemical composition of highly pigmented potato tubers (Table 1). Tubers were selected from potato accessions (Potato Germplasm Collection, Neiker-Tecnalia) grown during the year 2011 in a precise field trial in Arkaute (Alava) in the north of Spain (550 m above sea level), with humid climate and annual rainfall of about 800 mm. The soil with a clay loam texture was previously subjected to conventional wheat cropping. After harvesting, mature tubers were stored at 4 °C in a darkened cold room for one month.

2.2. Sample preparations of raw and boiled tubers

A total of 8 raw tubers of each accession were washed and patted dry with paper towels, and subsequently peeled and divided in eight equal parts according to the sampling diagram summarized in Fig. 1. For each tuber, four opposite parts were immediately frozen in liquid nitrogen, kept frozen at −80 °C, and later freeze dried, milled by an automatic mortar grinder (approximately 250 g), and stored at −30 °C until analysis. Samples corresponding to the four remaining parts were placed in a stainless steel pot containing boiling water (2 L) and cooked for approximately 30 min. Boiled tubers were allowed to cool and subsequently frozen in liquid nitrogen and prepared as detailed above for raw tubers.

2.3. Reagents and gallic acid standard

All reagents were prepared using demineralized water (18 MΩ cm at 25 °C) produced with a water purification system (Simplicity 185, Millipore MA, USA). The gallic acid standard was obtained from Sigma–Aldrich Laboratories (Steinheim, Germany) with ≥99% purity according to HPLC analysis by the manufacturer. Folin–Ciocalteu reagent 2 M was also supplied by Sigma–Aldrich Laboratories (Steinheim, Germany). Methanol absolute, sodium

Table 1
Breeding lines with introgressions from two native *Solanum* species (*Solanum tuberosum* subsp. *andigena* (Juz. & Bukasov) Hawkes and *Solanum stenotomum* Juz. & Bukasov).

Clones	Genitor (♂)	Genitor (♀)	Skin/flesh type[a]
NK-08/284	Socco huaccoto (ADG)	Matador (*TBR*)	P/P
NK-08/286	Socco huaccoto (ADG)	Matador (TBR)	Y/Y
NK-08/336	Lutetia (*TBR*)	Puca Quitish (ADG)	P/P
NK-08/348	Morada (*TBR*)	Puca Quitish (ADG)	P/P
NK-08/349	Morada (*TBR*)	Puca Quitish (ADG)	P/YP
NK-08/355	Heidrun (*TBR*)	Puca Quitish (ADG)	P/WP
NK-08/356	Heidrun (*TBR*)	Puca Quitish (ADG)	Y/Y
NK-08/362	Jesus (TBR)	Puca Quitish (ADG)	P/P
NK-08/370	Panda (TBR)	Morada Turuna (STN)	Y/Y
NK-06/130	Jesus (TBR)	N-180 (TBR)	P/P

ADG: *S. tuberosum* subsp. *andigena* (Juz. & Bukasov) Hawkes; TBR: *Solanum tuberosum* L.; STN: *S. stenotomum* Juz. & Bukasov.

[a] Key to skin and flesh types: P = purple; Y = yellow; W = white.