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Influence of the site altitude on strawberry phenolic composition and quality.

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A B S T R A C T

Altitude is associated to general climatic trends, such as temperature reduction, increasing radiation under a cloudless sky, decreasing atmospheric pressure and other environmental changes. Against this background, there is a limited knowledge on the effects of these climatic changes along the altitudinal range on quality characteristics of fruits such as strawberry. Thus, this research aimed to characterize the quality of Elsanta strawberries samples, harvested at altitudes ranging from 900 to 1.500 m above sea level, during two consecutive years (2011 and 2012). Strawberry samples were collected once from the four cultivation sites located at 900 m, 1.100 m, 1.200 m and 1.500 m above sea level in each year, when the yield per pick was the highest. Anthocyanins concentration correlated negatively with the increase of altitude in both years ($R = -0.55$; $p \leq 0{,}01$). Consistently, the strawberry antioxidant potential, measured with an electrochemical method, was lower in fruits grown at higher altitude (36% less when fruits from 900 and 1.500 m asl were compared). Strawberries collected at 1.500 m asl presented an higher average fruit weight, whereas other physico-chemical parameters such as soluble solids and titratable acidity did not change according to the altitude. This research consistently confirm the role of altitude as effective factor on the phenolic synthesis and final accumulation in strawberry fruits, as well as on their antioxidant activity.

1. Introduction

Strawberry (*Fragaria x ananassa* Duch.) is one of the most economically and commercially important berry plants. Strawberry fruits can be consumed fresh or in processed products and, together with other soft fruit species, are known as rich source of fibers, bioactive compounds and phytochemicals (Tulipani et al., 2008). These components are particularly important for human diet especially for their contribution to the reduction of cardiovascular diseases and, more generally, degenerative pathologies (Giampieri et al., 2012). Among phytochemicals, phenolic compounds represent the most important class of secondary compounds (i.e., not directly involved in plant growth), with high biological potential in humans (Häkkinen and Törrönen, 2000).

Phenolic compounds in strawberry were extensively investigated by several authors (Aaby et al., 2005; Aaby et al., 2012; Carbone et al., 2009) and classified as belonging to the main group of flavonoids (anthocyanins, flavanols, flavonols), phenolic acids (hydroxycinnamic acids) and hydrolysable tannins (ellagitannins) (Giampieri et al., 2012). Phenolic compounds in strawberry vary as a function of several factors. Among them, genotype plays a pivotal role in the phenolic content of strawberry fruits (Aaby et al., 2012; Tulipani et al., 2008). In addition, the fruit developmental stage can also drive the synthesis and accumulation of phenolic compounds in strawberry cultivars (Carbone et al., 2009; Kosar et al., 2004). Even the cultivation methods (conventional, organic, biodynamic) were found responsible for some differences in the final accumulation in strawberry fruits of specific phenolic compounds (Asami et al., 2003; D'Evoli et al., 2010; Häkkinen and Törrönen, 2000), even if some concern regarding the methodology applied in these studies were matter of debate (Felsot and Rosen, 2004). Finally, specific agricultural practices, such as cultivation methods, fertilization and mulching techniques, were found able to influence the strawberry phenolic content (Anttonen et al., 2006; Hernanz et al., 2007).

Environmental factors including temperature, light and water availability may influence the level of phytochemicals in strawberry fruits. Wang and Zheng (2001), in an experiment conducted under controlled conditions, showed that strawberry fruits from plants grown in the cool day and cool night temperature had generally lower phenolic acids, flavonols and anthocyanins as compared to strawberries developed at higher day/night temperatures. Experiments conducted under plastic tunnels characterized by different transparency, allowed to evaluate the influence of light (specifically in the UV wavelengths range) on phenolic

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compounds accumulation in strawberries. Fruits were generally UV-unresponsive as for total anthocyanins and total phenols (Ordidge et al., 2010), but showed significant differences for individual phenolics that were reduced in fruits grown under UV-blocking plastic tunnel (Josuttis et al., 2010). As for the effect of water availability on the concentration of health-related compounds in strawberry, an experiment with deficit irrigation showed an enhancement of total phenols in water stressed fruits trigged by a reduced fruit size and weight, followed by an higher proportion of fruit achenes (rich in phenolic compounds) to flesh (Terry et al., 2007).

Altitude of the growing site is a factor that was rarely assessed in relation to its impact on fruit quality and phytochemicals composition. There are several climatic trends generally associated with altitude, such as a reduction of atmospheric temperature, an increasing radiation under cloudless sky, a higher fraction of UV-B radiation and a decreasing total atmospheric pressure (Körner, 2007). It has been postulated that the combined action of these variables could play a role in determining the final phenolic profile of plants. Nevertheless, only few studies tested this specific hypothesis. Crespo et al. (2010) in a study conducted on strawberry cultivated in two sites that differed for soil, climatic condition and elevation above sea level (480 m and 1.060 m), showed that the anthocyanin profile was mainly genetically inherited rather than being affected by production sites. Doumet et al. (2011) compared the major nutritional and nutraceutical components in *Fragaria vesca* grown under the same rural practice and environmental conditions but different altitude. No significant differences were detected with respect to polyphenols, ascorbic acid and radical scavenging activity, whereas sugars and organic acids were found higher at higher altitude. Rieger et al. (2008) observed a decreasing amounts of all anthocyanins with rising altitude in berries of *Vaccinium myrtillus*. Interestingly, the same research outlined an enhancement of ortho-dihydroxylated flavonoids with altitude in *Sambucus nigra* flowers and fruits. These compounds were probably biosynthetically preferred at higher altitude as part of a protective system, being characterized by elevated radical scavenging properties (Rice-Evans et al., 1996). A similar interpretation was given also by Spitaler et al. (2006) when discussing the enhancement of specific phenolic compounds (i.e., caffeic acid) or ratio between 3′,4′-dihydroylated flavonoids to flavonoids without that substitution pattern in *Arnica montana* flowers collected at high altitude. Parameters such altitude and latitude could play an opposite effect on final fruit composition. This was shown by Zheng et al. (2011) on buckthorn berries (*Hippophae rhamnoides* ssp. *Sinensis*), characterized by an increasing concentration of organic acids and a decreasing concentration of sugars with altitude, whereas the opposite was found for latitude. Recently Mikulic-Petkovsek et al. (2014) described the role of the growing location as an important factor affecting bilberry fruit quality. The photosynthetic active radiation (PAR) available at different growing sites appeared as decisive in determining the final phenolic composition and antioxidant potential of bilberries. Altitude was listed among potential factors affecting the final fruit nutritional profiles, but a specific study of its relevance was not considered in the research.

Table 1
General information regarding the cultural conditions at the experimental sites.

	Agronomic descriptors
Plant material	Strawberry cv Elsanta plug plants planted in August 2010
Planting system	Double rows in raised bed. Rows distance: 17 cm; plant spacing on the row: 20 cm. Overall plant density: 8–9 plants per square meter
Yield	Two-year production cycle. Average yield for the first year is 2–2.5 Kg m^{-2} and 1.5–2 Kg m^{-2} for the second year
Harvest period	Begin in the last decade of June at low elevation sites (800–1.000 m asl); end in the last days of July at high elevation sites (1.500–1.700 m asl)
Soil characteristics	Light, sandy soils (especially on slopes), very rich in organic matter (humus from 4–8% to 8–16%) due to former intense land use for livestock raising (Stimpfl et al., 2006)
Mulching	With straw prior to strawberry ripening and harvest
Fertigation and phytosanitary treatments	Made according the Integrated Production System within the GlobalGAP certification process

The present study aimed to investigate the profile of the phenolic compounds as well as the main quality traits of strawberries with respect to the altitudinal variation of their production sites. For the first time research was conducted on strawberries cultivated within the same mountain district, under the same rural practice and soil conditions, in an altitudinal range between 900 and 1.500 m above sea level. In addition, experiments were performed during two consecutive growing seasons in order to keep into account also the year-to-year variation.

2. Material and methods

2.1. Cultivation sites

The two-year trial was conducted in the Martello Valley (municipal district of Martello, 46°33′ N 10°47′ E), located in the northern part of Italy within the mountain Province of Bolzano. The experimental design consisted in four sites in which strawberries were cultivated by professional farmers. Sites were located at the following altitudes: 900 m, 1.100 m, 1.200 m and 1.500 m above sea level. All these sites were south exposed (SE), with the only exception of the 1.200 m site that was north exposed (NE). The experiment was replicated in the same sites for two following years (2011 and 2012) in order to account for the variability related to the season effect. The growing conditions within each sites were uniform. Plug plant plantation was performed at the beginning of August 2010 for all sites and plants were grown on raised beds covered with

Table 2
Climatic characterization of the production district (Martello Valley, municipal district of Martello, 46°33′ N 10°47′ E) at different elevations.

Meteorological parameter	Year	700 m (asl)	1.300 m (asl)	Altitude effect (700–1.300 m)	1.700 m (asl)	Altitude effect (1.300–1.700 m)
T min (May–July)	2011	11.5 °C	8.8 °C	−0.5 °C/100 m	5.9 °C	−0.7 °C/100 m
	2012	12.1 °C	9.8 °C	−0.4 °C/100 m	6.7 °C	−0.7 °C/100 m
T max (May–July)	2011	23.6 °C	19.9 °C	−0.6 °C/100 m	15.8 °C	−1 °C/100 m
	2012	24.2 °C	20.8 °C	−0.6 °C/100 m	16.7 °C	−1 °C/100 m
CR (May–July)	2011	249.7 mm	295.1 mm	+7.5 mm/100 m	314.5 mm	+4.8 mm/100 m
	2012	159.7 mm	197.2 mm	+6.2 mm/100 m	279.6 mm	+20 mm/100 m
DAR (May–July)	2011	246.2 W m^{-2}	nd	nd	210.7 W m^{-2}	−3.5 W m^{-2}/100 m
	2012	256.5 W m^{-2}	nd	nd	225.5 W m^{-2}	−3.1 W m^{-2}/100 m

T min: average minimal temperature; T max: average maximal temperature; CR: cumulated rainfall; DAR: daily average radiation; nd: not determined.