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Quality and chemical composition of ten red raspberry (*Rubus idaeus* L.) genotypes during three harvest seasons

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ABSTRACT

Colour and chemical composition of fruits of 10 red raspberry genotypes grown in Nordic climate during three harvest seasons were studied. The main phenolic compounds in the fruits were ellagitannins and anthocyanins, contributing 57% and 42% to the quantified phenolic compounds, respectively. Cyanidin-3-sophoroside was the most abundant anthocyanin (61%). All quality parameters were significantly affected by genotype. The genotypes could be categorised into three groups. 'Veten' and 'RU984 06038' were characterised by high concentrations of flavonoids, i.e., anthocyanins and quercetin glycosides, and dark red colour. 'Octavia', 'Glen Magna', 'RU004 03067', 'Glen Ample' and 'RU974 07002' were characterised by light colour, high titratable acids and low flavonoid concentrations. 'Malling Hestia', 'RU024 01003' and 'RU004 04095' had high content of dry matter, soluble solids, ascorbic acid and ellagic acid containing compounds, in addition to high hue and chroma values. All quality parameters, except ascorbic acid and lambertianin C, varied significantly between harvest seasons. The lowest seasonal variation in fruit quality was observed in 'RU024 01003' and 'Glen Ample' and the highest 'RU004 03067' and 'Glen Magna'.

1. Introduction

Red raspberry (*Rubus ideaus* L.) is cultivated throughout the world and there has been a growing market and a considerable increase in the production of both raspberry and other small fruits during the last 2 decades (Food and Agriculture Organization of the United Nations, 2013). Red raspberry is a rich source of bioactive compounds with putative health beneficial properties such as phenolic compounds, including anthocyanins and ellagitannins, and nutrients such as minerals, vitamins, carotenoids and organic acids (Beekwilder et al., 2005; Kafkas, Özgen, Özoğul, & Türemiş, 2008; Kalt, Forney, Martin, & Prior, 1999; Liu et al., 2002; Pantelidis, Vasilakakis, Manganaris, & Diamantidis, 2007). Significant influence of genetic and environmental factors on the content of phenolic compounds in raspberry fruits have been reported (Anttonen & Karjalainen, 2005; Kassim et al., 2009). Late season cultivars have been found to be more abundant in anthocyanins, total phenolics, ascorbic acid and ellagic acid than early cultivars (de Ancos, Gonzalez, & Cano, 1999; de Ancos, González, & Cano, 2000; Gonzalez, de Ancos, & Cano, 2003). New strategic breeding programs focusing on selection of crops better adapted to local climatic conditions and with increased content of beneficial compounds for human health have been developed (Alsheikh, Sween, Nes, & Gullord, 2009; Tosun, Ercisli, Karlidag, & Sengul, 2009).

Although, chemical composition of several raspberry genotypes have been reported, detailed information about characteristic traits of genotypes grown in Northern Europe and the effect of harvest season on fruit quality are still scarce (Anttonen & Karjalainen, 2005; Bobinaitė, Viškelis, & Venskutonis, 2012). To our best knowledge, among genotypes investigated in this study, only the phenolic profile of 'Glen Ample' has previously been presented.

The aims of the present study were to determine the phenolic profiles of fruits of red raspberry grown in a Nordic climate and to investigate the effects of genotype and harvest season on fruit quality. Five cultivars and five advanced selections were studied during three harvest seasons. Further objectives were to investigate potential relationships between selected quality parameters and putative health-beneficial compounds in fruits and to evaluate

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the potential of different genotypes for both fresh market and industrial purposes.

2. Materials and methods

2.1. Chemicals

Cyanidin-3-sophoroside was obtained from Polyphenols AS (Sandnes, Norway). Acetone, acetonitrile, L-(+)-ascorbic acid (AA), sodium acetate, sodium carbonate, sodium dihydrogen phosphate dihydrate ($NaH_2PO_4{\cdot}2H_2O$), sodium hydroxide, disodium hydrogen phosphate dihydrate, disodium EDTA, *n*-dodecyltrimethylammonium chloride, methanol and potassium chloride were obtained from Merck KGAa (Darmstadt, Germany). Dehydro-L-(+)-ascorbic acid dimer (DHAA), Tris[2-carboxyethyl]-phosphate, gallic acid, quercetin-3-rhamnosylglucoside (rutin), ellagic acid and Folin–Ciocalteu's phenol reagent were purchased from Sigma Chemical Co. (St. Louis, MO, USA). Metaphosphoric acid was purchased from Sigma–Aldrich Chemie GmbH (Steinheim, Germany). Formic acid was obtained from Fluka (Buchs, Switzerland). All solvents were of HPLC grade and water was of Milli-Q-quality (Millipore Corp., Bedford, MA, USA).

2.2. Plant material

Fruits of floricane fruiting red raspberry (*Rubus idaeus* L.) cultivars 'Glen Ample', 'Glen Magna', 'Malling Hestia', 'Octavia' and 'Veten', and the advanced selections 'RU004 03067', 'RU004 04095', 'RU024 01003', 'RU974 07002' and 'RU984 06038' were grown and harvested at an experimental field at Graminor Njøs, Leikanger in Western Norway (61° 11′ N 06° 51′ E, altitude approx. 45 m a. s. l.) in three seasons (2009–2011) (Table 1 and Supplementary Table 1). In Norway the cultivar 'Veten' has been the preferred cultivar for processing, while 'Glen Ample' is the preferred cultivar for the fresh market. The fields had a moraine loam soil with 4–12.5% clay. The plants were planted in rows on low ridges 3 m apart with a planting distance of 0.5 m which is equivalent to approximately 5700 plants/ha. The ridges were supplied with a black woven plastic mulch with trickle fertigation in a Gjerde growing system (Øydvin, 1986). The genotypes were grown in experimental plots consisting of 10 plants. Berries were harvested 8–12 times at 3–4 days intervals during July–August each year. Berries were frozen at −20 °C within 5 h after harvest. Samples from the different harvests were mixed prior to analyses.

2.3. Dry matter (DM), soluble solids (SS), pH and titratable acids (TA)

Fruits (150 g) thawed for 1 h at 20 °C were homogenised using a food processor (CombiMax 700, Braun GmbH, Kronberg, Germany) prior to analyses. Content of DM was determined by the vacuum drying method (NMKL, 2002). Homogenised berries (10 g) were dried in a vacuum oven (RVT 360, Heraeus GmbH, Hanau, Germany) for 24 h at 70 °C. DM was expressed as g/100 g of fresh weight (FW). SS content (°Brix) was determined using a digital refractometer (RE40, Mettler Toledo, Japan) and expressed as %. The pH was determined at 20 °C with a pH metre (827 pHlab, Metrohm, Switzerland). For determination of TA, homogenised samples (30 g) were further homogenised for 45 s using a Polytron® homogenizer (PT-MR 3100, Kinematica AG, Switzerland) and centrifuged at 39191*g* for 10 min at 4 °C (Avanti J-26 XP, Beckman Coulter, USA). The supernatant (5 ml) was diluted 1:10 with distilled water followed by titration to pH 8.1 with 0.1 M NaOH using an automatic titrator (T50, Mettler Toledo, Switzerland). The content of TA was calculated as citric acid (g/100 g FW). All samples were analysed in duplicates for DM and TA, and triplicates for SS and pH.

2.4. Colour measurements

Randomly selected fruits (about 150 g) were thawed for 45 min at room temperature, then homogenised using a food processor (CombiMax 700, Braun GmbH, Kronberg, Germany). After additional 15 min, colour was measured with a Hunter Lab colour system (LabScan XE, Reston,Virginia, USA). The 1976 CIE $L^*a^*b^*$ system was used for evaluation of colour (illuminant D65, 10° observer, mode (geometry): 0°/45°, and area view 0.5″, port size 0.7″. L^* defines lightness where lower values indicate darker colour (0 = black) and higher values indicate lighter colour (100 = white). Negative a^* values indicate green and positive values red colour, while negative b^* values imply blue and positive values yellow colour. Hue angle (colour shade) was computed as arctan b^*/a^* and chroma (colour saturation) as the square root of $(a^{*2} + b^{*2})$. High values of hue angle indicate more red-orange colour and low values more red-bluish colour. Chroma shows transition from grey (low values) to pure colour (high values). The instrument was calibrated using a standard white ($X = 80.86$, $Y = 85.69$, $Z = 91.51$) and a standard black reflective plate. The samples were analysed in triplicates.

2.5. Total ascorbic acid

Total ascorbic acid content was determined in accordance with the method previously described by Karlsen, Blomhoff, and Gundersen (2005) and modified by Aaby, Wrolstad, Ekeberg, and Skrede (2007). Separation and detection of L-ascorbic acid (AA) was performed on an Agilent 1100 series HPLC system (Agilent Technologies, Waldbronn, Germany) with a monolithic Chromolith Performance RP-18e column fitted with a Chromolith RP-18e guard cartridge, both obtained from Merck KGaH (Darmstadt, Germany).

Table 1
Parentage and origin of the raspberry genotypes.

Genotype	Parentage	Origin[a]	Harvest time compared to 'Glen Ample'
'Glen Ample'	'SCRI 7326E1' x 'SCRI 7412H16'	SCRI, 1994	Middle early
'Glen Magna'	'Meeker' x 'SCRI 7719B11'	SCRI, 1994	Middle early to late[b]
'Malling Hestia'	'EM 3689' x 'Gaia'	East Malling, 2005	Late[c]
'Octavia'	'Glen Ample' x 'EM 5928/114'	East Malling, 2002	Late
'RU004 03067'	'Glen Ample' x 'Julia'	Graminor	Middle early to late
'RU004 04095'	'Qualicum' x 'Glen Ample'	Graminor	Middle early to late
'RU024 01003'	'Julia' x 'RU974 07002'	Graminor	Middle early to late
'RU974 07002'	'N-91–63-1' x 'N-92–68-3'	Graminor	Middle early
'RU984 06038'	'Glen Ample' x 'Qualicum'	Graminor	Middle early
'Veten'	'Asker' x 'Lloyd George'	Njøs, 1961	Middle early

[a] SCRI, Scottish Crop Research Institute, UK; East Malling, East Malling Research Station, UK; Graminor, Graminor Breeding Ltd, Norway.
[b] Harvest time – 1 week after 'Glen Ample'.
[c] Harvest time – 2 weeks after 'Glen Ample'.