



Variation of chemical and sensory profiles of blackcurrant (*Ribes nigrum*) juices produced from different cultivars of European origins

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ABSTRACT

Blackcurrant cultivars originating from different European countries (Finland, Latvia, Lithuania, Poland, and Scotland) but cultivated at the same geographic location and under the same climatic conditions in Finland were investigated. Berries of 21 cultivars were pressed into juices without enzymatic assistance, and the chemical and sensory profiles were studied. The genotype significantly influenced juice yield (47–70% of berry weight), anthocyanin profile (including 42–64% of delphinidins and 32–54% of cyanidins; rutosides vs. glucosides, 3–9:1), and sensory properties of the juice (appearance, flavor, and mouthfeel). The studied cultivars exhibited a large diversity in anthocyanin content in berries (904–4595 µg/g of berries), juices (obtained by pressing pulps, 141–1028 µg/g of juices), and press residues (skins and seeds, 3492–19852 µg/g of residues). Variation of anthocyanins in juices was unrelated to the variation in berries. The perceived color was affected by the anthocyanin contents in juices but not by the anthocyanin levels in berries. These measured compounds did not have a direct association with viscosity, flavor, or aftertaste of the juices.

1. Introduction

Blackcurrant (*Ribes nigrum* L.) is widely cultivated in Europe. The small and aromatic berries of blackcurrant are rich in phytochemicals, such as phenolic compounds, volatile aroma compounds, and polyunsaturated fatty acids. These components may have potential health benefits for the cardiovascular, nervous, ocular, skeletal, skin, and renal systems (Cortez & Gonzalez De Mejia, 2019; Gopalan et al., 2012; Yang & Kortnesniemi, 2015).

Besides being also consumed as fresh, berries of blackcurrant are commonly processed into juice and jam. Juice processing typically includes the use of pectinolytic enzymes, which break down pectin-rich structures, in order to increase the yields of juice and various chemical components (Cortez & Gonzalez De Mejia, 2019). However, the use of enzymes results in significant differences in the sensory quality including flavor and odor characteristics, as well as the chemical composition (Laaksonen et al., 2014, 2020; Laaksonen, Mäkilä, Tahvonnen, Kallio, & Yang, 2013; Marsol-Vall, Laaksonen, & Yang, 2019). In blackcurrants, the phenolic compounds locate dominantly in the berry skin, whereas the majority of sugars and organic fruit acids are in the

pulp (Sandell et al., 2009). The skin fraction of the berry is somewhat mildly flavored as the potentially astringent and bitter compounds are bound by the polysaccharides, while the pulp has a more intense flavor (Sandell et al., 2009).

Aside from the effect of juice processing, the quality of juices varies among blackcurrant genotypes. Extensive studies have reported a large chemical diversity among blackcurrant berries of different cultivars, showing variation in the contents and profiles of sugars, organic acids, volatiles, tannins and other phenolics (Jung, Fastowski, Poplacean, & Engel, 2017; Liu et al., 2018; Mikulic-Petkovsek et al., 2014; Milivojevic et al., 2012; Pagès-Hélary, Dujourdy, & Cayot, 2021; Woznicki et al., 2016; Wu, Gu, Prior, & McKay, 2004). These sensory-active compounds remain in the juices after the pressing process and influence juice quality. Despite of sensory quality being one of the important criteria for blackcurrant selection in food industry, the impact of blackcurrant cultivars on the sensory characteristics of the juice has been seldomly investigated or used as a selection criterium in cultivar breeding processes. Few studies have reported an association between the sensory quality of juices and the genotype of blackcurrants. The juices of forty-six genotypes of *Ribes* species cultivated in United Kingdom were

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evaluated based on forty-seven attributes belonging to appearance, aroma, flavor, after-taste, and mouth feel (Brennan, Hunter, & Muir, 1997). A large genotypic variation was observed in the sensory properties among juices, suggesting the essential role of blackcurrant genotype in determining the sensory quality of juices. However, no clear correlation was found between the sensory characters and the studied anthocyanins or ascorbic acid. Later, the juices of two Scottish cultivars, namely 'Ben Lomond' and 'Ben Alder', were rated according to their sensory profiles. A high rate was given to 'Ben Alder' for purple color, aroma, flavor, and mouthfeel (Brennan, Hunter, & Muir, 2003). Laaksonen et al. (2013) compared the sensory quality of blackcurrant juices of five Finnish genotypes. The juices made of traditional cultivars, namely 'Mortti' and 'Ola', were sweeter, whereas more novel cultivars had higher intense of sourness, bitterness, and astringency. Several cultivar-specific differences in sensory quality, especially taste attributes, were observed in juices made with or without enzymatic processing (Laaksonen et al., 2013). Corrigan, Hedderley, Langford, and Zou (2014) evaluated the sensory profiles of blackcurrant juices made from berries grown in New Zealand. The genotype affected the aroma, flavor, and mouthfeel attributes significantly. Yet, this study did not provide information on the chemical components. Therefore, more sensory studies with blackcurrant cultivars are urgently needed to find suitable cultivars for commercial juice production, and to give advice for breeding programs aiming for improved fruit quality of blackcurrants.

The present study was designed to investigate the diversity in chemical composition and sensory properties of juices pressed from berries of different blackcurrant cultivars. It was a follow-up of our previous research (Tian et al., 2019), where we revealed the chemical composition of the berries of twenty-one blackcurrant cultivars (including some breeding selections) originated from five different European countries but grown at the same location in Finland. In the present study, we pressed juices from the berries without enzymatic assistance, which mechanically separated the berry pulp fraction from the skins and seeds. The primary chemical components in both berries and juices (mainly as anthocyanins) were analyzed with liquid chromatographic method. The juices of twelve blackcurrant cultivars were evaluated by a trained sensory panel using a generic descriptive analysis on juice appearance, flavor, and mouthfeel characteristics. The results of sensory evaluation were linked to the primary chemical components in both juices and berries of blackcurrant. The 'cultivar' and 'country of origin' of blackcurrants, which were shown as important sources of variance in our previous study (Tian et al., 2019), were also hypothesized to be the factors causing significant differences in physical characteristics and sensory quality of juices. Another aim of the study was to produce novel information on non-enzymatic processing to guide the production of alternative pulp products, such as purees and smoothies. Moreover, juice press residues (mostly as skin fraction of blackcurrant), as the major side-streams of juice production, have a great potential in innovative food products (Mäkilä et al., 2014; Reißner et al., 2021; Tian & Yang, 2021). These materials were investigated in this study, mainly focusing on the yields and the contents of major bioactive compounds. Our results provide important guidance in selecting optimal cultivars for high-quality blackcurrant products, which will benefit the breeding programs and the commercial use of blackcurrants. The knowledge regarding distribution of anthocyanins in berries, juices, and juice-pressing residues will promote novel processing and thorough exploitation of blackcurrants, which will enhance sustainability in food industry.

2. Materials and methods

2.1. Plant materials

The berries of blackcurrant cultivars of Finnish, Latvian, Lithuanian, Polish, and Scottish origins were used in this study (Table 1). All plants had been cultivated in southwest Finland (latitude 60°23' N, longitude

Table 1

Blackcurrant cultivars with their country of origin, yields of juice and press residue, and physicochemical characteristics of juice.

Country of origin	Cultivar	Juice yields (%)	Press residue yields (%)	Loss rate (%)	pH	Brix
Average (n = 45)	–	61.9 ± 5.7	27.3 ± 5.2	10.8 ± 2.0		
Finland	Marski	65.4 ± 0.3 ^{de}	23.4 ± 0.1 ^{abc}	11.2 ± 0.3 ^{bcdefg}	3.0 ± 0.0 ^{cdef}	15.3 ± 0.4 ^{def}
Finland	Mikael	67.1 ± 1.1 ^{de}	23.7 ± 1.1 ^{abc}	9.3 ± 0.0 ^{abcd}	3.0 ± 0.0 ^{cdef}	15.5 ± 0.1 ^{def}
Finland	Mortti	62.0 ± 2.9 ^{cde}	28.0 ± 1.9 ^{abcd}	9.9 ± 1.0 ^{abcde}	3.0 ± 0.2 ^{cdef}	16.4 ± 0.2 ^{fgh}
Finland	Venny (green)	63.6 ± 1.3 ^{de}	25.3 ± 0.5 ^{abcd}	11.0 ± 0.8 ^{bcdefg}	3.0 ± 0.1 ^{cde}	17.3 ± 0.4 ^{hi}
Finland	Vilma (green)	62.5 ± 1.2 ^{cde}	25.3 ± 0.1 ^{abcd}	12.2 ± 1.1 ^{bcdefg}	3.1 ± 0.1 ^{ef}	18.1 ± 0.4 ^{ij}
Latvia	Mara	65.3 ± 1.3 ^{de}	20.7 ± 0.3 ^a	14.1 ± 1.0 ^g	2.7 ± 0.0 ^{ab}	14.5 ± 0.1 ^{bcd}
Lithuania	Almiai	65.9 ± 0.6 ^{de}	24.5 ± 1.3 ^{abc}	9.6 ± 0.8 ^{abcde}	3.0 ± 0.0 ^{cdef}	13.0 ± 0.0 ^a
Lithuania	Dainiai	58.3 ± 0.9 ^{bcd}	30.6 ± 1.7 ^{cde}	11.1 ± 0.9 ^{bcdefg}	3.0 ± 0.0 ^{cdef}	16.1 ± 0.1 ^{efg}
Lithuania	Gagatai	67.7 ± 0.1 ^{de}	23.6 ± 0.1 ^{abc}	8.7 ± 0.0 ^{ab}	3.1 ± 0.0 ^{def}	13.4 ± 0.0 ^{ab}
Lithuania	Joniniai	62.3 ± 0.6 ^{cde}	29.0 ± 0.6 ^{abcd}	8.7 ± 0.3 ^{ab}	2.9 ± 0.0 ^{abcde}	15.0 ± 0.0 ^{cde}
Lithuania	Tauriai	58.3 ± 1.4 ^{bcd}	28.6 ± 1.3 ^{abcd}	13.1 ± 0.1 ^{efg}	2.9 ± 0.1 ^{abc}	18.0 ± 0.0 ^{ij}
Poland	Tisel	52.1 ± 3.6 ^{ab}	37.8 ± 3.8 ^{ef}	10.1 ± 0.3 ^{abcdef}	3.0 ± 0.1 ^{cdef}	18.9 ± 0.2 ^j
Scotland, UK	Ben Dorain	66.0 ± 0.0 ^{de}	23.4 ± 0.2 ^{abc}	10.6 ± 0.2 ^{abcdefg}	2.8 ± 0.0 ^{abc}	14.8 ± 0.0 ^{cd}
Scotland, UK	Ben Finlay	46.7 ± 2.7 ^a	40.5 ± 1.1 ^f	12.8 ± 1.6 ^{cdefg}	3.0 ± 0.0 ^{cde}	13.1 ± 0.1 ^a
Scotland, UK	Ben Gairn	59.4 ± 2.7 ^{bcd}	29.5 ± 2.1 ^{bcde}	11.1 ± 2.0 ^{bcdefg}	3.0 ± 0.0 ^{cdef}	16.8 ± 0.2 ^{gh}
Scotland, UK	Ben Hope	63.1 ± 4.3 ^{cde}	26.8 ± 3.1 ^{abcd}	10.0 ± 1.2 ^{abcde}	2.8 ± 0.0 ^{abc}	14.5 ± 0.7 ^{bcd}
Scotland, UK	Ben Starav	60.4 ± 1.8 ^{bcde}	27.0 ± 1.7 ^{abcd}	12.6 ± 0.2 ^{cdefg}	2.9 ± 0.0 ^{bcde}	17.1 ± 0.1 ^{ghi}
Scotland, UK	Ben Tirran	69.5 ± 0.3 ^e	21.4 ± 0.3 ^{ab}	9.1 ± 0.1 ^{abc}	2.8 ± 0.0 ^{abc}	14.8 ± 0.3 ^{cd}
Scotland, UK	Ben Tron	67.1 ± 0.4 ^{de}	25.9 ± 0.5 ^{abcd}	7.0 ± 0.1 ^a	3.0 ± 0.0 ^{cdef}	13.9 ± 0.1 ^{abc}
Scotland, UK	9154-3	53.8 ± 7.6 ^{abc}	33.3 ± 8.0 ^{def}	12.9 ± 0.5 ^{defg}	3.2 ± 0.0 ^f	12.9 ± 0.1 ^a
Scotland, UK	S18/2/23	64.0 ± 1.2 ^{de}	22.2 ± 0.6 ^{abc}	13.8 ± 1.8 ^{fg}	2.7 ± 0.0 ^a	13.3 ± 0.7 ^a

Results are shown as means (± standard deviation) of 2–3 replicates. Statistical differences are based on one way-ANOVA and Tukey's post hoc test ($p < 0.05$); significant differences are shown with different superscript letters a-g.

22°33' E) in the Piikkiö research site of Natural Resources Institute Finland (Luke) since 2009. Detailed cultivating conditions have been described previously (Tian et al., 2019). Blackcurrant berries were harvested in August 2014, at dates defined by an experienced horticulturist based on the color, flavor, and structure of optimally harvest-ripe berries. After harvesting, all samples were stored in -20°C until analysis.

2.2. Chemicals

Reference standard compounds of delphinidin 3-O-glucoside, cyanidin 3-O-glucoside, and cyanidin 3-O-rutinoside were purchased from Extrasynthese (Genay, France). Solvents of LC and MS grade, including acetonitrile, formic acid, hydrochloric acid, and methanol, were purchased from Honeywell Riedel-de Haën Co. (Seelze, Germany).

2.3. Juice preparation

Juices were prepared as described previously (Sandell et al., 2009). Batches of 250 g of each cultivar sample were placed in a 500 mL beaker and gently thawed in a microwave oven with 30% power for 4 min. The thawed berries were pressed with a hydraulic press (Hafico, Germany) through a piece of cheesecloth until the pressure reached to 300 kg/cm². The juice pressing was conducted in 2–3 replicates for each cultivar. The yields of juices (mainly as berry pulp), residues (skins and seeds), and the losses (primarily pulp) were weighed and calculated. From obtained juices, pH values were measured using a WTW pH meter (Weiheim, Germany), and Brix values were determined by a Brix meter from Atago Co. Ltd. (Tokyo, Japan). After the measurements of physical characteristics of the juices, juice replicates from each cultivar were combined and stored at –20 °C until chemical analyses and sensory evaluation.

2.4. Analysis of anthocyanins in berries and juices

Extraction, identification, and quantification of anthocyanins in blackcurrant berries were conducted as reported previously (Tian et al., 2019). Briefly, for berry analyses, 5.0 g of crushed frozen berries were extracted with acidified methanol (methanol/hydrochloric acid, 99:1, v/v) at a solid/solvent ratio of 1:3 (w/v). The extraction was assisted with ultra-sonication (10 min) and centrifuge (4420×g for 10 min). The supernatants from three-time extraction were combined and diluted to a final volume of 50 mL with acidic methanol. For juice analyses, the juice samples of a cultivar were thawed and vortexed. Approximately 5 g of the juice samples was taken and extracted once with 5 mL of the acidified methanol, which was followed by the centrifugation to collect supernatants for the analyses. The extraction of anthocyanins from berries and juices was carried out in triplicates.

The identification of anthocyanins was conducted by using a Waters Acquity Ultra performance liquid chromatography (UPLC) system equipped with 2996 DAD detector, an electrospray ionization interface (ESI) and a Waters Quattro Premier mass spectrometer (Waters Corp., Milford, MA). Mass spectrometric analysis was operated in positive-ion mode. Studied anthocyanins were determined by comparing molecule ions and typical fragment ions with previous literature (Tian et al., 2017). The LC-MS identification has been reported and discussed in detail previously (Tian et al., 2019). A Shimadzu LC-10AT liquid chromatograph system, coupled with an SPD-M20A VP photodiode array (Shimadzu Corp., Kyoto, Japan), was used for quantitative analysis of anthocyanins. All chromatograms were monitored at the wavelength of 520 nm. The identified compounds were quantified by external reference standards (Tian et al., 2019).

2.5. Analysis of free sugars and organic acids in berries

The concentration of free sugars and simple organic acids was studied in the blackcurrant fruits only. The method was described in our previous research (Tian et al., 2019). Approximately 15.0 g of crushed frozen berries (triplicates for each cultivar) were extracted with 4 × 10 mL of Milli-Q water at room temperature, followed by 15 min of ultra-sonication and 15 min of centrifuge (4420×g). The combined supernatants were diluted to 50 mL with Milli-Q water, and later analyzed by using a Shimadzu GC-2010 equipped with flame ionization detector (Shimadzu corp., Kyoto, Japan). Free sugars and simple organic acids were detected as trimethylsilyl (TMS) derivatives and characterized

according to the retention time of external reference standards. The quantification required a mixed internal standard, containing sorbitol (for sugars) and tartaric acid (for acids).

2.6. Sensory evaluation of juices

The sensory characteristics of the juice samples were evaluated using a generic descriptive analysis. A panel was trained according to the ISO 8586 standard for evaluating blackcurrant juice samples of 12 cultivars. The panelists (n = 14) were pre-trained to sensory testing and tastes before the actual training sessions focusing on the blackcurrants. Prior to the study, panelists were informed about the protocols, samples, and their rights as participants to the study, and written consent was obtained from all panelists. Descriptors were selected based on the previous studies (Sandell et al., 2009; Laaksonen, Sandell, & Kallio, 2010; Laaksonen et al., 2013; Laaksonen et al., 2014). Eleven sensory attributes were chosen for the evaluation (Supplementary Table 1). The intensities of the attributes were rated on a continuous graphical scale anchored from each end, from 0 (none) to 10 (very strong), with the help of anchored reference samples. No references were used for total flavor intensity, intensity of aftertaste, or viscosity (mouthfeel). The panelists participated in four different evaluation sessions, in which they were presented with six blind-coded samples (10 mL in a 50 mL glass) each time in randomized orders. The samples of 12 blackcurrant cultivars were randomized between the first two sessions and the latter two sessions. All samples were evaluated in duplicates. The data were collected using Compusense-five software (version 5.6, Compusense, Guelph, Canada).

2.7. Statistical analyses

The concentration of studied compounds (anthocyanins, sugars, and organic acids) was calculated on the basis of fresh weight of berries or juices (FW). The values in tables are expressed as mean ± standard deviation (SD). Statistical differences were calculated based on one way-ANOVA and Tukey's post hoc test (p < 0.05) by IBM SPSS Statistics 24 for Windows (SPSS Inc., NY, United States). Principal component analysis (PCA) with full cross validation was applied by using Unscrambler 10.4 (Camo Process AS, Oslo, Norway) to investigate the correlation among cultivars, chemical components, juice-pressing properties, and sensory properties. PanelCheck (version 1.4.2, Nofima, Tromsø, Norway) was used to evaluate the performance (e.g. repeatability, agreement, and sensitivity) of the sensory panel. None of the assessors showed poor performance, thus all were included in the results.

3. Results and discussion

3.1. Physical characteristics of juices

Table 1 shows the physical characterization of the blackcurrant juices. The studied cultivars had a juice yield of 62% on average. The highest and the lowest juice yield were found in the Scottish cultivars 'Ben Tirran' (70% of fresh weight of berries) and 'Ben Finlay' (47%), respectively. The Polish cultivar 'Tisel' showed the highest Brix degree of 18.9. The juices of most cultivars had a rather similar pH value of ca. 3. The fractions of skins and seeds of berries were obtained as pressing residues, the contents of which ranged from 21% ('Mara') to 41% ('Ben Finlay'). Moreover, our calculation suggested that the applied pressing process caused a loss accounting for 11% of fresh berries on average (Table 1).

For most of the studied cultivars, the variation in the physical characteristics in juice processing was not statistically significant (Table 1). The juice yields of most of the cultivars ranged from 60% to 67% of berry weight. All the cultivars of Finnish origin had quite similar juice yields, which was also observed in our previous research where the cultivars 'Morti', 'Mikael', and 'Marski' showed a juice yield of 64–70%

after pressed with the same procedure as in the present study (Laaksonen et al., 2013). Kowalski and Gonzalez de Mejia (2021) also reported that no significant difference was detected in the juice yields when studying the juices made of ten blackcurrant cultivars grown in United States. In their research, the juices were pressed out using a cheesecloth without hydraulic pressure. This might explain lower juice yields (29–39%) and contents of press residues (mainly including skins and seeds, 26–44%) obtained in this study compared to our results.

3.2. Anthocyanins in berries, juices, and press residues

Altogether 15 anthocyanins were characterized in the fruit extracts of blackcurrants, but no anthocyanins were detected in the berries of two green-fruited cultivars ‘Venny’ and ‘Vilma’. In blackcurrant berries, the total content of identified anthocyanins varied from 904 µg/g FW (Scottish breed S18/2/23) to 4595 µg/g FW (‘Marski’) (Table 2). Supplemental Table 2 shows the concentration of major anthocyanins in the

Table 2
Contents of anthocyanins (µg/g, fresh weight) in the juices, berries, and press residues of blackcurrant cultivars.

Cultivar	Juices (µg/g of juice)						Berries total (µg/g of berries)	Residue (calculated) total ^a (µg/g of residues)
	Delphinidin 3-O-glucoside	Delphinidin 3-O-rutinoside	Cyanidin 3-O-glucoside	Cyanidin 3-O-rutinoside	others	total		
Marski	47.1 ± 3.8 ^c	150.6 ± 4.7 ^e	15.8 ± 1.0 ^c	97.6 ± 2.5 ^{bc}	14.6 ± 1.0 ^{bcd}	325.6 ± 12.4 ^{cd}	4595.0 ± 62.3 ^g	18570.9
Mikael	64.8 ± 2.6 ^{de}	146.7 ± 4.8 ^{de}	49.2 ± 1.5 ^f	218.3 ± 6.9 ^f	20.6 ± 0.5 ^{def}	499.6 ± 15.7 ^{ef}	2464.5 ± 62.9 ^c	8788.2
Mortti	27.0 ± 0.9 ^b	90.1 ± 3.0 ^{bcd}	10.5 ± 1.0 ^{bc}	67.2 ± 2.1 ^{bcd}	9.1 ± 0.3 ^{ab}	203.8 ± 6.5 ^{bc}	2363.6 ± 60.6 ^{bc}	7918.1
Venny (green)	0.1 ± 0.0 ^a	0.2 ± 0.0 ^a	0.1 ± 0.0 ^a	0.1 ± 0.0 ^a	–	0.4 ± 0.0 ^a	–	–
Vilma (green)	0.2 ± 0.0 ^a	0.3 ± 0.0 ^a	0.1 ± 0.0 ^a	0.3 ± 0.0 ^a	–	0.8 ± 0.1 ^a	–	–
Mara	18.3 ± 0.6 ^b	72.5 ± 2.3 ^{bc}	5.4 ± 0.2 ^{ab}	39.2 ± 1.3 ^{ab}	5.7 ± 0.2 ^a	141.1 ± 4.5 ^b	4221.4 ± 89.1 ^{fg}	19852.0
Almiai	59.8 ± 1.0 ^{cd}	258.1 ± 5.5 ^f	29.4 ± 0.5 ^d	216.2 ± 5.7 ^f	30.7 ± 0.4 ^{gh}	594.2 ± 12.9 ^{fg}	2267.5 ± 163.8 ^{bc}	7424.0
Dainiai	94.1 ± 14.4 ^g	350.6 ± 55.5 ^{hij}	50.1 ± 7.5 ^f	351.3 ± 55.4 ^{hi}	41.4 ± 6.5 ^j	887.4 ± 139.4 ^{hi}	2624.1 ± 431.8 ^{cd}	6562.9
Gagatai	70.9 ± 2.0 ^{de}	275.4 ± 7.8 ^{fg}	34.0 ± 1.0 ^d	225.1 ± 6.1 ^f	37.8 ± 1.6 ^{ij}	643.1 ± 18.1 ^g	3596.9 ± 359.5 ^{ef}	13159.2
Joniniai	24.2 ± 3.3 ^b	161.8 ± 19.5 ^e	12.8 ± 1.4 ^c	159.7 ± 18.6 ^e	22.8 ± 2.4 ^{ef}	381.3 ± 45.3 ^{de}	1458.0 ± 148.1 ^{ab}	4094.1
Tauriai	17.7 ± 0.5 ^b	49.7 ± 1.4 ^{ab}	9.7 ± 0.2 ^{bc}	55.6 ± 1.7 ^{bc}	10.3 ± 0.4 ^{abc}	143.0 ± 4.2 ^b	1993.4 ± 94.3 ^{bc}	6612.9
Tisel	111.2 ± 0.4 ⁱ	394.7 ± 1.4 ^{kl}	50.6 ± 0.0 ^{fg}	385.5 ± 1.5 ⁱ	60.6 ± 1.7 ^k	1002.6 ± 3.2 ^{ij}	2169.8 ± 114.4 ^{bc}	4090.4
Ben Dorain	96.5 ± 3.6 ^{gh}	387.8 ± 14.5 ^{ijk}	42.7 ± 1.5 ^e	300.3 ± 11.6 ^g	25.8 ± 0.3 ^{fg}	852.9 ± 31.3 ^h	3825.3 ± 116.0 ^{fg}	13555.5
Ben Finlay	109.7 ± 2.7 ^{hi}	294.3 ± 6.2 ^{feh}	44.9 ± 1.0 ^{ef}	223.9 ± 4.4 ^f	18.5 ± 0.3 ^{de}	691.5 ± 14.2 ^g	2462.9 ± 86.7 ^c	5065.3
Ben Gairn	85.8 ± 10.0 ^{fg}	427.3 ± 53.1 ^{kl}	29.9 ± 3.4 ^d	301.1 ± 36.5 ^{gh}	25.9 ± 3.3 ^{fg}	870.0 ± 106.2 ^{hi}	2735.9 ± 620.2 ^{cde}	7195.1
Ben Hope	61.6 ± 2.7 ^d	241.3 ± 5.7 ^f	33.2 ± 1.2 ^d	213.5 ± 3.1 ^f	16.5 ± 1.6 ^{cd}	566.2 ± 13.7 ^{fg}	4304.6 ± 58.8 ^{fg}	14517.6
Ben Starav	133.7 ± 6.5 ^j	449.2 ± 24.7 ^l	56.9 ± 2.9 ^g	354.3 ± 18.8 ⁱ	33.7 ± 2.7 ^{hi}	1027.8 ± 55.5 ^j	3537.4 ± 323.8 ^{def}	10322.6
Ben Tirran	28.6 ± 0.4 ^b	104.5 ± 1.6 ^{bcdde}	12.1 ± 0.2 ^c	74.6 ± 1.0 ^{bcd}	10.4 ± 0.2 ^{abc}	230.3 ± 3.3 ^{bc}	2763.4 ± 497.1 ^{cde}	12067.2
Ben Tron	76.2 ± 0.6 ^{ef}	333.2 ± 0.9 ^{ghi}	27.8 ± 0.0 ^d	211.7 ± 0.7 ^f	33.5 ± 0.9 ^{hi}	682.4 ± 1.1 ^g	3535.6 ± 451.7 ^{def}	11698.6
9154-3	24.7 ± 3.1 ^b	119.6 ± 15.3 ^{cde}	11.2 ± 1.4 ^{bc}	110.5 ± 14.2 ^{de}	9.5 ± 1.0 ^{ab}	275.6 ± 35.0 ^{bcd}	2105.3 ± 382.7 ^{bc}	5770.2
S18/2/23	30.7 ± 2.3 ^b	64.5 ± 5.2 ^{bc}	13.4 ± 1.1 ^c	51.6 ± 4.2 ^{bc}	5.4 ± 0.7 ^a	165.6 ± 13.5 ^b	904.0 ± 133.6 ^a	3491.7
<i>Averages based on country of origin</i>								
Finland, black	46.3 ± 16.6 ^{BC}	129.1 ± 29.5 ^{BC}	25.2 ± 18.2 ^{BC}	127.7 ± 69.3 ^{BC}	14.8 ± 5.0 ^{AB}	343.0 ± 129.2 ^{BC}	3141.0 ± 1092.7 ^{AB}	11520.1
Finland, green	0.1 ± 0.1 ^A	0.2 ± 0.1 ^A	0.1 ± 0.0 ^A	0.2 ± 0.1 ^A	–	0.6 ± 0.2 ^A	–	–
Latvia	18.3 ± 0.6 ^B	72.5 ± 2.3 ^B	5.4 ± 0.2 ^B	39.2 ± 1.3 ^B	5.7 ± 0.2 ^A	141.1 ± 4.5 ^B	4221.4 ± 89.1 ^A	19852.0
Lithuania	53.3 ± 30.3 ^{BC}	219.1 ± 109.9 ^{BCD}	27.2 ± 15.6 ^{BC}	201.6 ± 102.0 ^C	28.6 ± 11.8 ^B	529.8 ± 266.4 ^{BC}	2388.0 ± 774.8 ^B	7346.4
Poland	111.2 ± 0.4 ^D	394.7 ± 1.4 ^D	50.6 ± 0.0 ^C	385.5 ± 1.5 ^D	60.6 ± 1.7 ^C	1002.6 ± 3.2 ^D	2169.8 ± 114.4 ^B	4090.4
Scotland, UK	71.9 ± 37.3 ^{CD}	269.1 ± 140.5 ^{CD}	30.3 ± 15.5 ^{BC}	204.6 ± 103.0 ^C	19.9 ± 10.1 ^{AB}	595.8 ± 299.6 ^{CD}	2925.4 ± 1049.2 ^{AB}	8982.6

Results are shown as means (± standard deviation) of triplicates. Statistical differences are based on one way-ANOVA and Tukey’s post hoc test (p < 0.05); significant differences are shown with different superscript letters a-l & A-D.

^a Contents in residues (C_{residue}) were calculated based on the mean values of total anthocyanins in berries (C_{berry}) and juice (C_{juice}), the juice yields (juice %), the loss rate (loss %), and press residue yields (press residue %), by the following equation: C_{residue} = $\frac{C_{\text{berry}} - C_{\text{juice}} \times (\text{juice \%} + \text{loss \%})}{\text{press residue \%}}$

fruit extracts of berries. The dominant compounds were identified as 3-O-glycosylated delphinidin and cyanidin with rutinose or glucose as sugar moieties, which altogether accounted for 91% of total anthocyanins on average. Other anthocyanins included arabinose and coumaroylglucosides of delphinidin and cyanidin, as well as the glycosides of other anthocyanidins (pelargonidin, petunidin, peonidin, and malvidin). These minor anthocyanins represented for 6–17% of total content of detected anthocyanins in berries.

The high variability in anthocyanin composition among blackcurrant cultivars has been reported previously (Brennan et al., 1997; Kikas, Rätsep, Kaldmäe, Aluvee, & Libek, 2020; Mattila, Hellström, Karhu, Pihlava, & Veteläinen, 2016; Nour, Stampar, Veberic, & Jakopic, 2013; Rachtan-Janicka, Ponder, & Hallmann, 2021). Kikas et al. (2020) evaluated the fruit quality of 37 blackcurrant cultivars of 11 geographical origins. The anthocyanin contents in the fruits, determined by UHPLC-MS, were in a range of 183–471 mg/100 g FW. Mattila et al. (2016) studied anthocyanin profiles in blackcurrant varieties grown in Finland by using HPLC. The studied 32 varieties had a total content of anthocyanins of 276–670 mg/100 g FW. The lowest contents were found in 'Mikael', which were close to the content determined in the same variety in this study (277 ± 27 vs 246 ± 6 mg/100 g FW). Nevertheless, the results of 'Mortti' and 'Marski' had large deviation from the level found for these varieties in our study ('Mortti': 384 ± 17 vs 236 ± 6 mg/100 g FW, and 'Marski': 304 ± 10 vs 460 ± 6 mg/100 g FW). Since the blackcurrant plants of both studies were cultivated in the same site but harvested in the different years, annual variation in weather conditions may have been responsible for the deviation in anthocyanin contents.

Four major anthocyanins identified from the berry extracts of blackcurrants were also present in the corresponding juices (Table 2). The total content of identified anthocyanins in the juices of black-fruited cultivars was 536 µg/g FW of juices on average. The juices of 'Ben Starav' and 'Tisel' had the highest contents of total anthocyanins (1028 and 1003 µg/g FW, respectively). The lowest contents were found in the samples of 'Mara' (141 µg/g FW), 'Tauriai' (143 µg/g FW), and S18/2/23 (166 µg/g FW). The most abundant anthocyanins in blackcurrant juices were delphinidin 3-O-rutinoside, cyanidin 3-O-rutinoside, delphinidin 3-O-glucoside, and cyanidin 3-O-glucoside, representing for 29–51%, 28–44%, 7–17%, and 3–10% of total anthocyanins, respectively. Other anthocyanins were detected in the juices at minor contents. The overall percentages of delphinidins and cyanidins were generally in accordance with the earlier results, when the juice of 'Mortti' was pressed without the assistance of enzymes (Mäkälä, Laaksonen, Kallio, & Yang, 2017). Kowalski and Gonzalez de Mejia (2021) investigated the freeze-dried blackcurrant juices of Scottish, Canadian, Polish, and Swedish cultivars and reported similar ratios of major anthocyanins (delphinidin 3-O-rutinoside, 50% of total anthocyanins; cyanidin 3-O-rutinoside, 25%; delphinidin 3-O-glucoside, 24%; and cyanidin 3-O-glucoside, 1%).

The content of anthocyanins remaining in the press residues (fractions of skins and seeds) was estimated through calculation (Table 2). Like in berries and juices, clear differences were detected in the anthocyanins of the press residues. The calculated contents in residues ranged from 3492 µg/g (S18/2/23) to 19852 µg/g ('Mara'). High levels of anthocyanins in the press residues may result from the fact that anthocyanins are predominantly located in the skins and a major part of fruit anthocyanins thus remained in the residues as juice was pressed without the use of enzymes (Weber & Larsen, 2017).

3.3. Comparison of anthocyanins among cultivars and countries of origin

PCA models were created to visualize the difference of blackcurrant cultivars in major chemical components. All studied cultivars were compared in the model of Supplemental Fig. 1. Cultivars 'Venny' and 'Vilma' were separated from black-fruited cultivars due to the absence of anthocyanin compounds, which explained the negative correlation

between these two cultivars and anthocyanin contents in the loading plot.

The comparison of nineteen black-fruited cultivars is presented in Fig. 1. Both 'Tisel' and 'Dainiai' had positive correlations with anthocyanin contents in the juices, while showing negative correlations with the anthocyanin contents in the berries (Fig. 1a). On the contrary, the berries of 'Mara', 'Marski', and 'Ben Hope' contained the highest contents of anthocyanins among all studied cultivars, but much lower levels of these compounds were detected in their juices after pressing process. 'Ben Starav' and 'Ben Dorain' were positively correlated to the anthocyanins in both berries and juices along PC-1, indicating high amounts of anthocyanins presenting in these berry and juice samples. In contrast, 'Tauriai', 'Joniniai', and S18/2/23 were low in anthocyanins, showing negative correlations with the anthocyanin contents in berries and juices.

Anthocyanin contents, as shown in the loading plot of Fig. 1a, varied among samples of berries, juices, and press residues. The dominating anthocyanins in each group of the samples were attributed to delphinidin 3-O-glucoside (De-Glu), delphinidin 3-O-rutinoside (De-Rut), cyanidin 3-O-glucoside (Cy-Glu), and cyanidin 3-O-rutinoside (Cy-Rut). It was noticed that the anthocyanin contents in blackcurrant juices correlated negatively to those in berries along PC-1, which suggested that the concentration of anthocyanins in blackcurrant berries was not the key factor influencing their content in their juices when using a non-enzymatic pressing. This is due to the fact that the juice is produced mainly by pressing the pulps of berries. In the blackcurrant berries, the pulps contain lower levels of anthocyanins than the skins. Without adding enzymes to break the cell walls of the berry skins, most of the anthocyanins are retained in the press residues (skins and seeds). Sandell et al. (2009) quantified major anthocyanins in berries and juices of blackcurrants by using HPLC-DAD. After the non-enzymatic pressing, only 15% of delphinidin 3-O-rutinoside, 15% of cyanidin 3-O-rutinoside, and 8% of delphinidin 3-O-glucoside were pressed out from berries into juices (Sandell et al., 2009). In the present study, a strong correlation of anthocyanins in berries and in the pressing residues was also observed (Fig. 1a). This indicated that the contents of anthocyanins in the fruit extracts of blackcurrants were not solid indicators for evaluating anthocyanin contents in the produced juices. And *vice versa*, the pressed juice did not correctly reflect the anthocyanin levels in the blackcurrant berries. The variation in anthocyanin contents (either in juices, berries, or in their skin fractions) among cultivars may be also related to the skin texture of fruits. Segade, Giacosa, Gerbi, and Rolle (2011) investigated skin texture and anthocyanin content in Mencia grape (*Vitis vinifera* L.) and suggested significant negative correlations between skin thickness and anthocyanin extractability, although the correlation coefficient values differed among the samples collected in different vineyards. Yet, similar findings have not been reported in blackcurrants.

Sandell et al. (2009) revealed that both organic acids and sugars located mainly in the pulp of blackcurrants, and thus appeared also in the juice after hydraulic pressing. For the cultivars of the present study, the contents of these compounds in the berry extracts have been reported previously (Tian et al., 2019). The data were re-calculated on the basis of fresh weight and used in the statistical models of Fig. 1 to investigate the relationship among sugars, organic acids, and anthocyanins in the juices that were mainly made of berry pulps. Among all the studied cultivars, no clear correlation was observed between sugars or acids in berries and anthocyanins in juices (Fig. 1b and c). Thus, the levels of free sugars or acids presented in black-fruited blackcurrant berries might not have association with the anthocyanin profiles in juices, even though our results suggested that there was a negative correlation among these compounds when studied in berries only.

The impact of cultivar origins on chemical composition of blackcurrant juices was also investigated by calculating the contents of anthocyanins in juice samples as averages based on the countries of origin (Table 2). Since only one sample of Latvian origin and one sample of Polish origin were included in this study, the comparison was conducted

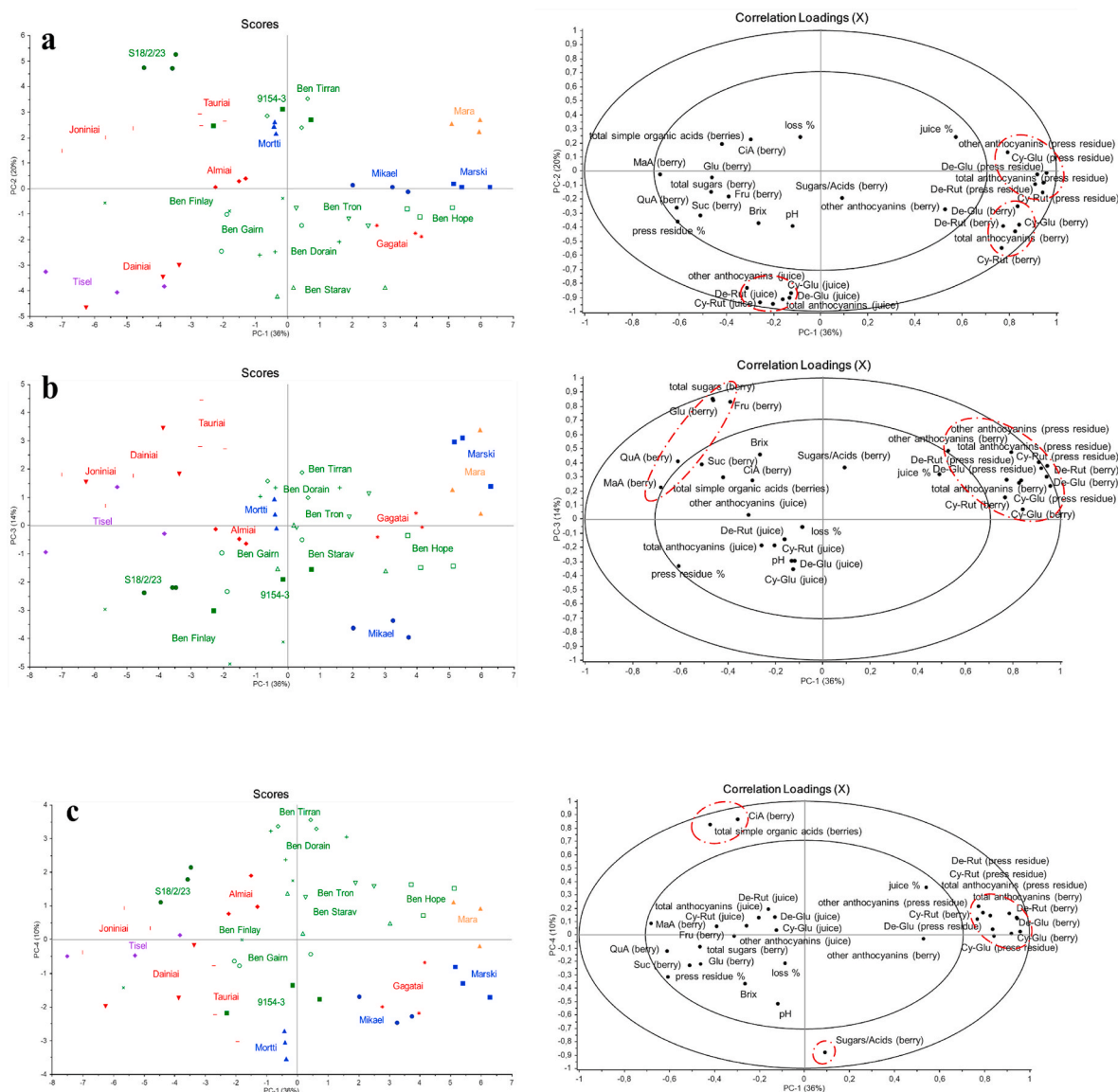


Fig. 1. PCA plots of correlation of cultivars to juice-pressing properties, primary chemical components in berries, and anthocyanins in juices and juice press residues of blackcurrants: a. PC-1/PC-2, b. PC-1/PC-3, c. PC-1/PC-4.

The contents of sugars and organic acids in the berry extracts of blackcurrants have been reported in our previous paper (Tian et al., 2019). These data were re-calculated on the basis of fresh weight and used in the PCA models.

Colors in score plot: cultivars of Scottish origin (green), cultivars of Lithuanian origin (red), cultivars of Latvian origin (orange), cultivars of Polish origin (purple), black-fruited cultivars of Finnish origin (green-fruited cultivars excluded) (blue). Abbreviation used in loading plots: malic acid (MaA), citric acid (CiA), quinic acid (QuA), fructose anomers (Fru), glucose anomers (Glu), sucrose (Suc), delphinidin 3-*O*-glucoside (De-Glu), delphinidin 3-*O*-rutinoside (De-Rut), cyanidin 3-*O*-glucoside (Cy-Glu), cyanidin 3-*O*-rutinoside (Cy-Rut). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

among the cultivars of Scottish, Lithuanian, and Finnish origins. The results suggested that the variation in the total contents of anthocyanins was not statistically significant among these three origins, which again indicated the dominating role of genetic background instead of the country origin. This was in accordance with our previous research, where the contents of these compounds in the berries of the same studied cultivars (calculated on the basis of dry matters of berries) were compared using partial least squares (PLS) regression models. In that study, the key differences among cultivars of Scottish, Lithuanian, and Finnish origins were found only in the contents of phenolic acids (Tian et al., 2019).

3.4. Sensory profiles of blackcurrant juices

The juices of 12 black-fruited blackcurrant cultivars were selected for sensory evaluation. These cultivars of five country origins represented different yields of juices, residues, and losses (Table 1), as well as varying levels of anthocyanins, sugars, and organic acids (Table 2, Tian et al., 2019). All juice samples were evaluated and ranked based on appearance, flavor, and mouthfeel as shown in Table 3. Among all eleven sensory attributes studied, color intensity and viscosity in appearance were the attributes evaluated as the most intense in comparison to others, whereas sweetness had the lowest evaluation values (Table 3). The correlation among sensory attributes was revealed by a PCA model with three validated PCs (Fig. 2). Interestingly, color intensity correlated negatively with viscosity along PC-1, and with

Table 3
Sensory attributes and their intensities (scale 0–10) in the juices of different blackcurrant cultivars.

Cultivar	Appearance		Flavor and mouthfeel								
	Intensity of color	Viscosity, appearance	Sweetness	Sourness	Bitterness	Puckering astringency	Drying astringency	Sharpness	Viscosity, mouthfeel	Total intensity of flavor	Intensity of aftertaste
Marski	6.0 ± 1.6 ^{cde}	8.6 ± 1.4 ^g	2.6 ± 2.2 ^{abc}	4.8 ± 2.0 ^{abc}	5.0 ± 1.7 ^{bc}	3.5 ± 1.5 ^{ab}	4.6 ± 1.6 ^{ab}	3.4 ± 1.7 ^{ab}	6.6 ± 2.2 ^f	6.3 ± 1.5 ^{abc}	5.5 ± 1.9 ^b
Mikael	4.0 ± 1.9 ^{ab}	6.6 ± 1.9 ^{ef}	4.2 ± 2.7 ^c	4.7 ± 1.8 ^{abc}	3.3 ± 1.4 ^a	3.9 ± 2.1 ^{ab}	4.0 ± 1.5 ^{ab}	4.0 ± 1.5 ^{abcde}	5.0 ± 2.7 ^{def}	5.8 ± 1.3 ^{abc}	4.5 ± 1.7 ^{ab}
Mortti	4.1 ± 1.8 ^{ab}	8.3 ± 1.8 ^g	3.8 ± 2.4 ^c	4.2 ± 2.0 ^{ab}	3.7 ± 1.5 ^{ab}	4.0 ± 2.0 ^{ab}	4.3 ± 1.8 ^{ab}	3.5 ± 1.7 ^{abc}	6.8 ± 2.3 ^f	5.8 ± 1.7 ^{abc}	5.0 ± 1.8 ^{ab}
Mara	3.5 ± 1.6 ^a	7.9 ± 1.6 ^{fg}	2.7 ± 2.0 ^{abc}	5.7 ± 2.3 ^{bc}	3.4 ± 1.5 ^{ab}	4.2 ± 2.3 ^{ab}	4.7 ± 1.8 ^{ab}	5.3 ± 1.6 ^e	5.8 ± 1.7 ^{ef}	6.7 ± 1.8 ^{bc}	5.6 ± 2.2 ^b
Almiai	6.6 ± 1.5 ^{def}	4.2 ± 1.7 ^{bcd}	2.8 ± 1.7 ^{abc}	4.3 ± 1.4 ^{ab}	3.4 ± 1.2 ^{ab}	3.0 ± 1.4 ^a	3.8 ± 2.0 ^{ab}	3.7 ± 1.8 ^{abcd}	2.8 ± 1.5 ^{abc}	5.2 ± 1.4 ^{ab}	4.1 ± 1.8 ^{ab}
Gagatai	7.2 ± 1.2 ^{efg}	3.7 ± 1.8 ^{abc}	4.2 ± 2.0 ^c	3.9 ± 1.4 ^a	2.8 ± 1.5 ^a	3.0 ± 1.9 ^a	3.5 ± 1.2 ^a	3.1 ± 1.7 ^a	2.6 ± 1.9 ^{abc}	4.9 ± 1.6 ^a	3.5 ± 2.1 ^a
Tauriai	3.3 ± 1.5 ^a	6.2 ± 1.0 ^{ef}	3.7 ± 2.2 ^{bc}	5.5 ± 1.6 ^{abc}	3.7 ± 1.8 ^{ab}	4.7 ± 1.9 ^{ab}	4.3 ± 1.9 ^{ab}	4.9 ± 1.6 ^{bcdde}	4.2 ± 1.8 ^{bcdde}	6.1 ± 1.7 ^{abc}	4.8 ± 1.8 ^{ab}
Tisel	8.1 ± 0.8 ^g	5.6 ± 1.4 ^{de}	3.5 ± 2.5 ^{abc}	5.4 ± 1.7 ^{abc}	3.9 ± 1.8 ^{abc}	4.0 ± 1.8 ^{ab}	4.1 ± 2.1 ^{ab}	4.9 ± 1.7 ^{bcdde}	4.2 ± 1.9 ^{ede}	6.6 ± 1.7 ^{bc}	5.2 ± 1.9 ^{ab}
Ben Finlay	7.5 ± 1.4 ^{fg}	7.3 ± 0.8 ^{fg}	1.6 ± 1.4 ^a	5.7 ± 2.2 ^{bc}	5.4 ± 1.4 ^c	4.8 ± 1.4 ^b	4.9 ± 1.5 ^{ab}	4.5 ± 1.7 ^{abcde}	5.3 ± 1.7 ^{def}	6.8 ± 1.7 ^c	5.5 ± 1.9 ^b
Ben Hope	5.1 ± 2.3 ^{bcd}	5.2 ± 3.3 ^{cde}	2.9 ± 2.2 ^{abc}	6.1 ± 2.2 ^c	4.3 ± 2.1 ^{abc}	4.8 ± 1.7 ^b	5.3 ± 2.0 ^b	5.0 ± 1.4 ^{cde}	3.8 ± 2.6 ^{abcd}	6.8 ± 1.8 ^{bc}	5.8 ± 1.9 ^b
Ben Tirran	4.8 ± 1.7 ^{abc}	2.4 ± 1.5 ^a	1.7 ± 1.4 ^{ab}	6.4 ± 2.1 ^c	4.1 ± 1.9 ^{abc}	4.7 ± 1.5 ^{ab}	4.7 ± 1.8 ^{ab}	5.2 ± 1.9 ^{de}	2.1 ± 1.7 ^a	7.0 ± 1.4 ^c	5.4 ± 1.9 ^b
Ben Tron	8.1 ± 1.0 ^g	2.9 ± 1.5 ^{ab}	3.1 ± 2.3 ^{abc}	4.9 ± 1.7 ^{abc}	3.1 ± 1.6 ^a	4.3 ± 2.0 ^{ab}	4.6 ± 1.8 ^{ab}	3.6 ± 1.7 ^{abc}	2.2 ± 2.0 ^{ab}	5.6 ± 1.8 ^{abc}	4.4 ± 2.0 ^{ab}
<i>Averages based on country of origin</i>											
Finland	4.7 ± 2.0 ^{AB}	7.8 ± 1.9 ^B	3.5 ± 2.5 ^A	4.6 ± 1.9 ^A	4.0 ± 1.7 ^A	3.8 ± 1.9 ^A	4.3 ± 1.6 ^A	3.7 ± 1.6 ^A	6.1 ± 2.5 ^B	6.0 ± 1.5 ^{AB}	5.0 ± 1.8 ^{AB}
Latvia	3.5 ± 1.6 ^A	7.9 ± 1.6 ^B	2.7 ± 2.0 ^A	5.7 ± 2.3 ^{AB}	3.4 ± 1.5 ^A	4.2 ± 2.3 ^A	4.7 ± 1.8 ^A	5.3 ± 1.6 ^C	5.8 ± 1.7 ^B	6.7 ± 1.8 ^B	5.6 ± 2.2 ^B
Lithuania	5.7 ± 2.2 ^{BC}	4.7 ± 1.9 ^A	3.6 ± 2.1 ^A	4.5 ± 1.6 ^A	3.3 ± 1.5 ^A	3.6 ± 1.9 ^A	3.9 ± 1.7 ^A	3.9 ± 1.8 ^{AB}	3.2 ± 1.9 ^A	5.4 ± 1.6 ^A	4.1 ± 2.0 ^A
Poland	8.1 ± 0.8 ^D	5.6 ± 1.4 ^A	3.5 ± 2.5 ^A	5.4 ± 1.7 ^{AB}	3.9 ± 1.8 ^A	4.0 ± 1.8 ^A	4.1 ± 2.1 ^A	4.9 ± 1.7 ^{BC}	4.2 ± 1.9 ^A	6.6 ± 1.7 ^B	5.2 ± 1.9 ^{AB}
Scotland, UK	6.4 ± 2.2 ^C	4.4 ± 2.8 ^A	2.3 ± 2.0 ^A	5.8 ± 2.1 ^B	4.2 ± 1.9 ^A	4.6 ± 1.7 ^A	4.9 ± 1.8 ^A	4.6 ± 1.7 ^{ABC}	3.3 ± 2.4 ^A	6.5 ± 1.8 ^B	5.3 ± 2.0 ^{AB}

Results are shown as means (± standard deviations) of two replicates evaluated by 14 trained panelists. Attributes are in the order of evaluation from left to right. Statistical differences within each variable are based on one-way ANOVA with Tukey’s HSD test (p < 0.05); significant differences are marked with different superscript letters a-g & A-D.

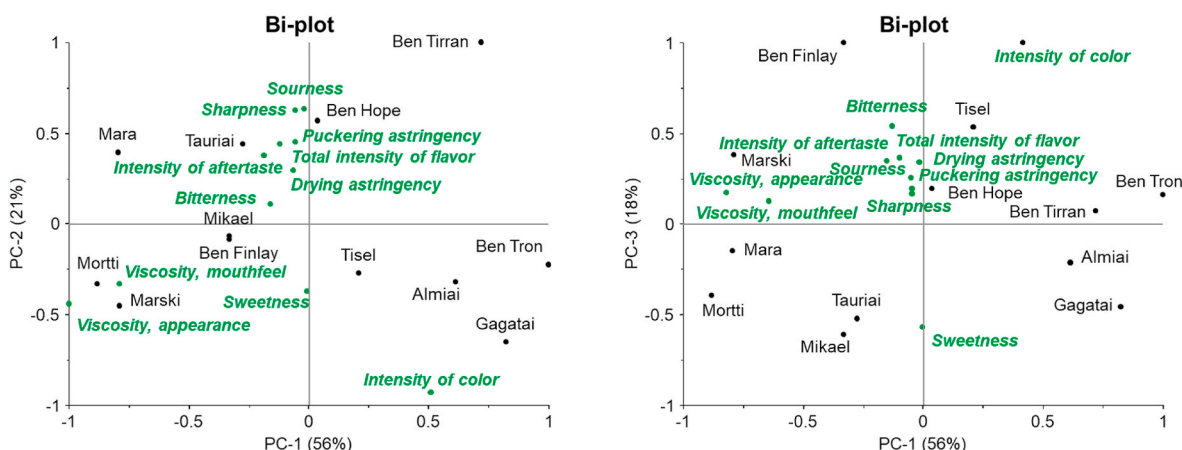


Fig. 2. Consensus PCA bi-plots of the descriptive sensory profile (11 attributes; averaged data from Table 3) for juice samples of 12 blackcurrant cultivars. Colors in plots: juices of blackcurrant cultivars (black), sensorial attributes (green). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

intensities of total flavor and aftertaste along PC-2. In agreement with our previous research (Laaksonen et al., 2012), sweetness had a negative correlation (along PC-3) with other taste attributes studied, such as sourness, sharpness, bitterness, and astringency (puckering and drying). These latter attributes were closely correlated with each other, which

might be responsible for strong flavor and aftertaste in the blackcurrant juices.

Among the studied juices, in the PC-1/PC-2 plots of Fig. 2, ‘Ben Tron’, ‘Gagatai’, and ‘Almiai’ showed high intensity in juice color. ‘Mortti’ and ‘Marski’ were perceived as the most viscose in appearance

and mouthfeel. ‘Mara’, ‘Tauriai’, ‘Ben Tirran’, and ‘Ben Hope’ had strong total flavor, aftertaste, sourness, sharpness, and astringency. It was noticed that, besides the dark color, the juice of ‘Tisel’ also showed a medium level in most of the studied sensory attributes, which explained why this sample was located closely to all attributes in the PCA plots. The plots of PC-1 and PC-3 present the deviation of juices in sweetness. The juice of ‘Gagatai’, ‘Mikael’, ‘Tauriai’, and ‘Mortti’ were sweeter than the juices of other cultivars, whereas ‘Ben Finlay’ had the lowest value in sweetness.

The juice sensory differences among the average values of country origins are presented in Table 3. The comparison among country origins was conducted with the cultivars of Scottish, Lithuanian, and Finnish origins, since only one Latvian and one Polish cultivar were included in this study. Compared to the ones originating from Lithuania and Scotland, the studied Finnish samples had higher viscosity in both appearance and mouthfeel. This may have been due to high levels of pectin in

the Finnish cultivars. The production of blackcurrant juices using pectin-rich cultivars would require the addition of pectinase. Besides the concern on juice yields, juices with high content of pectin are perceived as cloudy, which will likely further influence the consumers’ acceptance to the juice products (Mieszczakowska-Frac, Markowski, Zbrzeźniak, & Plocharski, 2012). The pectin-rich cultivars may have alternative usage in food industry, especially in the production of highly viscose or semi-solid products as jelly and jam (Belkheiri et al., 2021). The samples of Scottish cultivars were slightly more intense in color and sourness than others. Yet, for other studied sensory attributes, significant deviations were not found among these three country origins.

3.5. Interactions between chemical components and sensory attributes

The relationships between sensory attributes and chemical components of blackcurrant samples were also revealed in PCA models. In the

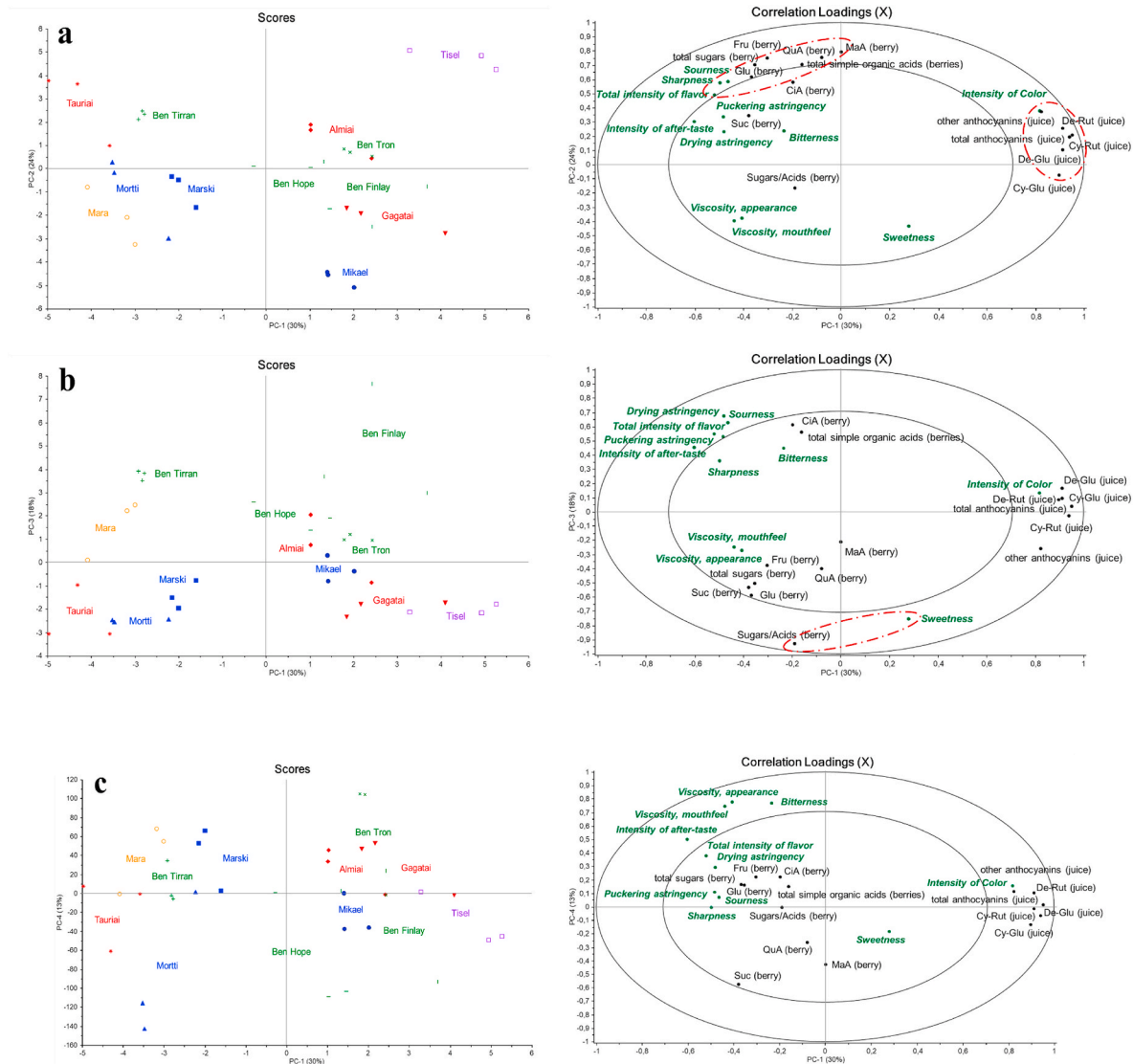


Fig. 3. PCA plots of correlations of sensory attributes to chemical components in juices and berries of blackcurrants: a. PC-1/PC-2, b. PC-1/PC-3, c. PC-1/PC-4. The contents of sugars and organic acids in the berry extracts of blackcurrants have been reported in our previous paper (Tian et al., 2019). These data were re-calculated on the basis of fresh weight and used in the PCA models. Colors in score plot: cultivars of Scottish origin (green), cultivars of Lithuanian origin (red), cultivars of Latvian origin (orange), cultivars of Polish origin (purple), black-fruited cultivars of Finnish origin (green-fruited cultivars excluded) (blue). Abbreviation used in loading plots: malic acid (MaA), citric acid (CiA), quinic acid (QuA), fructose anomers (Fru), glucose anomers (Glu), sucrose (Suc), delphinidin 3-O-glucoside (De-Glu), delphinidin 3-O-rutinoside (De-Rut), cyanidin 3-O-glucoside (Cy-Glu), cyanidin 3-O-rutinoside (Cy-Rut). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

loading plot of [Supplemental Fig. 2](#), the visually assessed color intensities of the juices were strongly associated with the concentrations of anthocyanins in juices. Nevertheless, the color intensities correlated negatively to the anthocyanin contents in berries (and press residues). For example, the juices of 'Mara' and 'Marski' were significantly lower in color intensity than that of 'Tisel', despite of higher anthocyanin contents detected in their berries. This negative correlation verified our findings based on anthocyanin measurements that the color of blackcurrant juices cannot be reliably predicted using the anthocyanin content in the whole berries.

Aside from the color, anthocyanin levels in berries did not show clear associations with other sensorial properties of the juices. As shown in [Fig. 3](#), the content of each identified anthocyanin correlated negatively with the sensorially assessed attributes of flavor and mouthfeel of the juices. The plots of [Fig. 3a](#) showed that the total intensity of flavor, as well as taste sharpness and sourness, in blackcurrant juices had strong correlation with total contents of sugars and organic acids in whole berries, especially with glucose (Glu), fructose (Fru), malic acid (MaA), and quinic acid (QuA). This may have contributed to the observed high intensity of sourness and sharpness in the juice of 'Ben Tirran'. The PC-3 of the model ([Fig. 3b](#)) suggested that the sweetness of juices was strongly associated with the ratio of sugars and organic acids, as found in 'Mortti'. The sugars/acids ratio in berries had a negative correlation with both mouth-drying and puckering astringency of juice. The high intensities of flavor and aftertaste in the juices of 'Mara' and 'Ben Tirran' might have been related to the low ratio of sugars and acids.

The relationship between chemical constituents and sensory properties of blackcurrant juices has been observed in some previous studies, which focus only on certain cultivars of Finnish origin ([Laaksonen et al., 2012, 2014; Laaksonen et al., 2013; Laaksonen, Salminen, Mäkilä, Kallio, & Yang, 2015; Marsol-Vall, Kortensniemi, Karhu, Kallio, & Yang, 2018](#)). Monoterpene hydrocarbons and oxygenated monoterpenes were the major volatiles contributing to the odor of juices ([Marsol-Vall et al., 2018](#)). Sugars and organic acids were responsible for sweetness and sourness of juices ([Laaksonen et al., 2012](#)). Mouth-drying astringency was attributed to the content of glycosylated flavonols, and hydroxycinnamic acids were considered as puckering astringent ([Laaksonen et al., 2013](#)). High levels of proanthocyanidins, primarily as prodelphinidins, led to strong intensity of both mouth-drying and puckering astringency ([Laaksonen et al., 2015](#)). Yet, this relationship is not always consistent, due to the large diversity of phenolic compounds and the presence of other components in blackcurrants ([Mattila et al., 2016; Tian et al., 2019; Vagiri et al., 2013; Yang et al., 2019](#)). In the present study, we did not investigate whether the astringency taste of the juice samples was ascribed to the presence of these compounds. It was due to the fact that the contents of these minor phenolics commonly remain at low levels in juices when using non-enzyme aided pressing approach ([Laaksonen et al., 2013; Sandell et al., 2009](#)). Moreover, as shown in [Table 3](#), the juice of 'Ben Hope' was perceived as the most astringent sample, whereas the juice of 'Gagatai' was the least astringent one. Yet, according to our previous results ([Tian et al., 2019](#)), both cultivars contained similar contents of hydroxycinnamic acids, flavonol glycosides, and flavan-3-ols in their berries (82 vs 83 mg/100 g dry matters). Thus, these phenolic compounds might have not been the only reason causing the unpleasant flavor of the studied juice samples. Also, no clear correlation was found between the viscosity of juices and the studied sugars and organic acids. The viscosity in appearance and mouthfeel might be related to the high contents of pectin in juices ([Laaksonen et al., 2013](#)), since no pectinolytic enzymes were applied in the juice pressing process of this study. Moreover, for pectin-rich cultivars, the non-enzymatically pressed juices are expected to be both viscous and astringent. This is due to the fact that the polysaccharides in berries are commonly bound with phenolic compounds ([Andersen & Markham, 2005](#)). Nevertheless, in our study, PCA models did not show any clear correlation between these two sensorial attributes among all studied juices. The juice of 'Marski' was the most viscous sample but was

perceived as moderately astringent only ([Table 3](#)). Thus, pectin might not be responsible for astringent taste of juices.

The selection of blackcurrant cultivars is important to commercial juice production, since the chemical composition of berries is highly influenced by genetic background, in addition to environmental factors, which will further lead to a large shift in sensorial property of juices. As noticed in our study, after over five-year cultivation in the same geographical location and under the same climatic conditions, the genotype of blackcurrant still exhibited a large diversity in the chemical composition of the berries as well as the yield and sensory quality of the juices. By the comparison among Scottish, Lithuanian, and Finnish cultivars, it could be concluded that the variation was mainly unrelated to the origins of countries; instead, cultivars *per se* had a strong effect on fruit and juice quality attributes. The present study also emphasized that the compositional diversity in berry pulps and different responses to juice processing caused considerable variability in sensory properties of juices. The impact of environment on chemical composition of blackcurrants was not investigated in this research. Yet, our previous study on the same blackcurrant cultivars suggested the berries harvested in year 2014 and 2015 had a clear variation in contents of sugars, organic acids, and phenolic compounds. This may be related to the changes in temperature and precipitation during the fruit development ([Tian et al., 2019](#)).

Moreover, in this study, the juice samples were made by a non-enzymatic process of berry pulp pressing. For the cultivars that had the highest and the lowest juice yields, their juices were perceived as similarly strong in total flavor and were both high in sourness, bitterness, and astringency. The application of pectinase in juice pressing is known to promote juice yields by degrading pectin, but it also enhances the unpleasant flavors by releasing certain phenolics from skin fraction into juice ([Laaksonen et al., 2013](#)). Therefore, for the juice producing industry, it is challenging to maintain sensory properties of juice when increasing juice yields.

4. Conclusion

As a summary, the investigations on juice yields, chemical composition, and sensory profiles of juices made from different blackcurrant cultivars were conducted to offer novel information on how genotype affects the juice properties. The anthocyanin profiles of juices were influenced by the cultivar. Yet, the impact of genotype on anthocyanin profile varied between the juices and the whole berries, since anthocyanins were distributed differently in berry pulps and skins. Therefore, the chemical composition of berries may not provide a reliable prediction of the sensory quality of juices, due to the effects of genotypes and juice processing. The color intensity of juices should be evaluated by using the anthocyanin content of juices, and not that of whole berries. The sugar content in berries did not predict the perceived sweetness of juice, whereas the content of organic acids predicted the acidic and sharp taste sensations. Both sugar and acid contents in berries were associated with the total intensity of flavor in blackcurrant juice samples. Moreover, our investigation suggested the importance of studying the quality of end products (e.g., juices or pulps) and not only that of whole berries, when selecting breeding lines or cultivars for commercial use. The results on cultivar-specific sensory attributes will provide important reference for the breeding and the quality assessment of blackcurrants, to meet the quality standards of food industry.

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CRedit authorship contribution statement

Ye Tian: Methodology, Formal analysis, Investigation, Funding acquisition, (personal grant), Writing – original draft, Writing – review & editing. **Saila Karhu:** Conceptualization, Resources, Funding acquisition, Writing – review & editing. **Mika Virtanen:** Methodology, Investigation. **Kaisa M. Linderborg:** Conceptualization, Writing – review & editing. **Baoru Yang:** Conceptualization, Funding acquisition, Resources, Supervision, Writing – review & editing. **Oskar Laaksonen:** Conceptualization, Formal analysis, Writing – original draft, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

Data will be made available on request.

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Appendix B. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.lwt.2022.114353>.

Appendix A. Abbreviation used

Abbreviations used in the article are

malic acid (MaA)
citric acid (CiA)
quinic acid (QuA)
fructose anomers (Fru)
glucose anomers (Glu)
sucrose (Suc)
delphinidin 3-O-glucoside (De-Glu)
delphinidin 3-O-rutinoside (De-Rut)
cyanidin 3-O-glucoside (Cy-Glu)
cyanidin 3-O-rutinoside (Cy-Rut)

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