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BLACKCURRANT GENOTYPES, FATTY ACID PROFILE

RESEARCH ARTICLE

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Evaluation of seed content and fatty acid profile in blackcurrant (*Ribes nigrum* L.) genotypes

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ABSTRACT

Twenty-two blackcurrant genotypes, 'Karri', 'Almo', 'Ats', 'Elo', 'Varmas', 'Mairi', 'Asker', 'Pilėnai', 'Vyčiai', 'Ben Alder', 'Ben Nevis', 'Ben Lomond', 'Ben Sarek', 'Intercontinental', 'Titania', 'Öjebyn', 'Ļentjai', 'Pamyati Vavilova', 'Zagadka', 10B, 1-96-16, and 2-96-51, were evaluated in two subsequent years. The aim of the research was to compare berry weight, seed content in the berries, and fatty acid profile in the seeds. The composition of fatty acids was identified and quantified using gas chromatography.

Blackcurrant berry weight varied between 1.0 and 1.7 g, depending on the genotype, being the highest in genotypes 'Mairi', 'Karri', 'Intercontinental', and 'Ļentjai'. Seed content in berries ranged from 2.2% to 4.6% and was the highest in 'Karri' and 'Elo'. Oil content correlated positively with the proportion of seeds per fresh weight of berries. Therefore, the highest seed content correlated with the highest oil content per fresh weight of berries in 'Karri' and 'Elo', 1.2% and 1.3%, respectively. On average over two years, the total oil content in the seeds ranged from 24.4% to 31.2%, showing the highest levels in 'Ben Nevis', 'Pamyati Vavilova', and 'Asker'. The most abundant fatty acid identified in blackcurrant seeds was linoleic acid, ranging from 40.1% to 48.6%, followed by α-linolenic acid, from 11.7% to 16.5%, oleic acid, from 10.3% to 16.4%, and γ-linolenic acid, from 10.9% to 15.6%.

Introduction

A European Commission document (2023) titled 'Upgrading the EU's policy toolbox for nutrition leadership' highlights the necessity of utilizing renewable resources (Dekeyser and Rampa 2023). Plant-based biomass, such as berry pomace, represents renewable resources of biological origin. This biomass, rich in bioactive substances, is produced in substantial quantities during juice production. Berry seed oils constitute a noteworthy group of plant oils with favourable nutritional characteristics, including a beneficial fatty acid (FA) profile, oxidative stability, and positive health effects. These oils are suitable for human consumption and, as such, may have potential applications in the food industry (Sławińska et al. 2023). Furthermore, previous studies have demonstrated that the composition of fruit pomace seed oil remains stable even after long-term frozen storage, making pomace a valuable raw material for oil extraction (Radocaj et al. 2014). Plant-derived FAs are of considerable dietary and cosmetic significance due to their high content of polyunsaturated FAs (PUFAs) as well as saturated and monounsaturated FAs (MUFAs). These FAs exhibit variation in the cis–trans isomerism, chain length, and the position of the first double bond. Nutritionally, FAs can be categorized into essential and non-essential types. While humans and animals lack the enzymatic capacity to synthesize essential FAs (EFAs) such as linoleic acid (LA; C18:2 n-6), α-linolenic acid (ALA; C18:3 n-3), and γ-linolenic acid (GLA; C18:3) from oleic acid (OA; C18:1 n-9) due to the absence of required desaturases, higher plants are capable of synthesizing LA, ALA, and GLA. Given their crucial role in human health, EFAs must be obtained through diet. EFAs are essential for cellular growth and brain function (Chauhan et al. 2023) and have therapeutic effects in preventing and managing diseases such as arthritis, cardiovascular and inflammatory diseases, cancer, and hyperlipidemia (Kuhnt et al. 2012; Omachi et al. 2024).

Omega-3 (n-3) and omega-6 (n-6) FAs serve as precursors for eicosanoids, lipid-based signalling molecules vital for innate immune responses (Sheppe and Edelmann 2021). The optimal ratio of n-6 to n-3 FAs (ranging from 2.5:1 to 4:1) is important in human nutrition. However, contemporary diets often contain an excess of n-6 FAs and a deficiency in n-3 FAs, disrupting this balance. In European countries, the n-6 to n-3 ratio is approximately 20:1, while in the United States, it reaches as high as 30:1. Therefore, it is essential to ensure a sufficient intake of n-3 FAs, while limiting the consumption of oils rich in n-6 FAs (Michalak and Kiełtyka-Dadasiewicz 2018).

Several studies have demonstrated that oils derived from fruit seeds play a significant role in health promotion by slowing the aging process and reducing stress (Beattie et al. 2005; Pieszka et al. 2013; Michalak and Kiełtyka-Dadasiewicz 2018). However, the mean intake of fruits and berries in Nordic and Baltic countries is between 100 and 200 grams per day (Rosell and Fadnes 2024), which is below the recommended level for sufficient consumption. For instance, in Estonia, the recommended daily intake of fruits and berries is at least 240 grams, as outlined by the National Institute of Health Development (Tervise Arengu Instituut 2025).

Additionally, fruit seed oils could be incorporated into cosmetic formulations due to their beneficial effects on the skin. For example, the sea buckthorn seed oil has shown the ability to improve skin hydration, protect against transdermal water loss, facilitate the transport of other oil components through the skin, and allow them to reach different layers of the epidermis. Furthermore, its radical-scavenging activity helps to protect the skin from oxidative damage and slow the aging process, thus making it a common ingredient in anti-wrinkle and anti-aging cosmetic products (Sławińska et al. 2023). Hendawy et al. (2021) found that the consumption of raspberry seed oil, which has an optimal n-6 to n-3 FA ratio (2–3:1), improved hepatic enzyme activities, reduced glucose levels, and mitigated insulin resistance by improving inflammatory and oxidative stress markers. Similarly, Pieszka et al. (2015a, 2015b) reported low n-6/n-3 ratios in chokeberry and blackcurrant seed oils, 1.45 and 2.61, respectively, and Konopka et al. (2023) claimed the recommended n-6/n-3 FA ratio (below 4–5:1) for seed oils of blackberry, blackcurrant, blueberry, raspberry, and strawberry. In addition, the inclusion of strawberry seed oil in the diet normalized lipid metabolism and affected metabolite formation in the distal intestine of Wistar rats (Hendawy et al. 2021). Interestingly, the evaluation of 16 rowanberry genotypes showed considerable variation in the n-6/n-3 ratio within *Sorbus aucuparia*, ranging from 6.70 to 25.19 (Sarv et al. 2024). Šavikin et al. (2013) reported that various *Ribes* species are recognized as potential sources of high-value FAs, particularly ALA, GLA (18:3 n-6), and stearidonic acid (SDA).

Blackcurrant (*Ribes nigrum* L.) is one of the most appreciated berry crops for fresh consumption and processing after strawberry cultivated in Estonia. Blackcurrant has also high importance in many other countries, such as Scotland, Sweden, Lithuania, Latvia, and Russia, as a number of valuable cultivars have been bred in these countries. Fruit weight and nutritional value of the blackcurrant fruit depend primarily on the genotype but also on the temperatures during fruit ripening (Kahu et al. 2009; Kaldmäe et al. 2013; Kikas et al. 2017). The value of blackcurrant fruits, buds, and leaves has been demonstrated (Tabart et al. 2006), but the trend of using fruit seeds has increased. More precise data on their nutritional composition would allow for a better understanding of their role in diet as well as their potential health benefits. This, in turn, could have a significant impact on environmental sustainability by reducing waste and promoting resource efficiency. During juice production, a huge amount of valuable residues remain, including seeds, which contain approximately 20% oil that is rich in PUFAs (Wójciak et al. 2022) and tocopherols (Šavikin et al. 2013; Pieszka et al. 2015a; Pieszka et al. 2015b; Basegmez et al. 2017). In addition to GLA (18:3 n-6), blackcurrant oil contains significant amounts of other nutritionally important FAs, such as ALA and SDA (18:4 n-3) (Yang et al. 2011; Šavikin et al. 2013). Furthermore, the oil has a beneficial n-6/n-3 ratio of 3–4:1 (Wójciak et al. 2022). The study of Gustinelli et al. (2018) showed that the seed oil of blackcurrant possessed stronger antioxidant activity as well as a higher content of vitamin E and carotenoids than the seed oils of cloudberry and bilberry. Although several studies have reported data on the FA composition of blackcurrants, significant variability exists, influenced by the climatic conditions and place of growth but particularly by the parents of the berries in the pedigree due to their genetic predisposition (Goffman and Galletti 2001; Ruiz del Castillo et al. 2002; Šavikin et al. 2013; Flores and Ruiz del Castillo 2016). For instance, the content of GLA in blackcurrant seed oils has varied from 11% to 24%, depending on the cultivar (Ruiz del Castillo and Dobson 2002; Jurgoński et al. 2018). The earlier study of Šavikin (2013) revealed that cluster analysis based on the seed oil FA profiles could be a good method for distinguishing the origin of blackcurrant genotypes. Detailed data on the chemical composition of blackcurrant genotypes would allow for a better understanding of their role in nutrition as well as their potential health benefits. Therefore, the aim of our study was to compare the seed content and FA composition of 22 blackcurrant genotypes cultivated in Estonia.

Materials and methods

Plant material for experiments

The research was carried out at the Polli Horticultural Research Centre (58° 7′ N, 25° 32′ E) of the Estonian University of Life Sciences. The soil type in the trial area was a sandy loam, containing 1.6% humus, and the preceding crop was cereal (rye and barley). The genotypes ‘Karri’, ‘Almo’, ‘Ats’, ‘Elo’, ‘Varmas’, ‘Mairi’, ‘Asker’, ‘Pilėnai’, ‘Vyčiai’, ‘Ben Alder’, ‘Ben Nevis’, ‘Ben Lomond’, ‘Ben Sarek’, 'Intercontinental', 'Titania', 'Öjebyn', 'Ļentjai', 'Pamyati Vavilova', 'Zagadka', 10B, 1-96-16, and 2-96-51 were chosen for evaluation. Berry samples (500 g) of the 22 genotypes were hand-picked in the middle of the harvest season in two consecutive years from a test plot established six to seven years earlier. The lineage of the genotypes selected for the study is shown in the pedigree Table 1. The genotypes included in the study originated from six countries: Estonia (10 genotypes), Scotland (4), Sweden (3), Russia (2), Belarus (1), and Lithuania (2).

The average berry weight was determined by weighing 20 fruits per sample. The seeds were separated from 100 g of berries by sieving and, thereafter, the seed percentage in fruit was calculated.

Seed oil extraction

The seed oil content was analysed using AOAC Method 948.22. The oil was extracted from the sample using petroleum ether as a solvent in a Soxhlet apparatus for 12 hours. After extraction, the residues were dried in an oven at 105 °C until they reached a constant weight. The oil content was expressed as a percentage of the dry weight, either per seed or per fruit.

Determination of fatty acids

For determining the FA composition, berries were crushed in water (1:1), and seeds were separated from pulp by washing and sieving. FAs of seeds were extracted and methylated by a one-step procedure using toluene as a solvent (Sukhija and Palmquist 1988). Methyl heptadecanoate (C17:0) was used as an internal standard. FA methyl esters were quantified by gas chromatography using an Agilent 6890A gas chromatograph (Agilent Technologies Inc., USA) equipped with an autosampler, under the following conditions: a 100 m × 0.25 mm CP7420 capillary column with a 0.25 µm film thickness. Helium was used as the carrier gas. The initial oven temperature was 70 °C, which was held for 1 min, and then it was increased to 100 °C at a rate of 5 °C/min and held for 2 min. The oven temperature was increased to 165 °C at a rate of 10 °C/min and held for 55 min. Then the oven temperature was increased to 180 °C at a rate of 2 °C/min and held for 20 min. Further, it was increased to 225 °C at a rate of 5 °C/min and held for 20 min. Finally, the oven temperature was increased to 240 °C at a rate of 5 °C/min and held for 5 min. The injector and detector were at 250 °C. A constant carrier gas pressure was 23 psi. The identification of common FAs was accomplished by comparing sample

Table 1. Pedigree of 22 blackcurrant genotypes

Genotype	Pedigree	Country
10B	Öjebyn × Kantata 50	Estonia
1-96-16	Elo × Öjebyn	Estonia
2-96-51	Pamyati Vavilova × Ļentjai	Estonia
Almo	Kantata 50 × Öjebyn	Estonia
Asker	Pamyati Vavilova × Öjebyn	Estonia
Ats	Öjebyn × Varmas	Estonia
Ben Alder	Ben More × Ben Lomond	Scotland
Ben Lomond	(Brödtorp × Janslunda) × (Consort × Magnus)	Scotland
Ben Nevis	(Brödtorp × Janslunda) × (Consort × Magnus)	Scotland
Ben Sarek	Seedling (Goliath × Öjebyn) free pollination	Scotland
Elo	Öjebyn × Kantata 50	Estonia
Intercontinental	Ri74020-11 × Titania	Sweden
Karri	Mulgi must × Kantata 50	Estonia
Ļentjai	Brödtorp × Minaj Shmyriov	Russia
Mairi	Öjebyn × Kantata 50	Estonia
Pamyati Vavilova	Paulinka × Belorusskaya Sladkaya	Belarus
Pilėnai	Minaj Shmyriov × Öjebyn	Lithuania
Zagadka	Niina × Sopernik	Russia
Titania	Altaiskaya dessertnaya × (Consort × Kajaanin Musta)	Sweden
Varmas	Albos × Uus must	Estonia
Vyčiai	Minaj Shmyriov free pollination	Lithuania
Öjebyn	unknown	Sweden

peak retention times with FA methyl ester standard mixtures (Supelco 37 Component FAME Mix, Nu-Chek Prep GLC 603, 408, using Agilent Technologies ChemStation software). Results for all FAs were expressed as g/100 g of the total FA or g/100 g sample.

Statistical analysis

Statistical analysis was performed using Statistica 13.0 (StatSoft Inc., USA). Correlation analysis was used in order to determine relationships among analysed and measured traits in the 22 blackcurrant genotypes ($p < 0.05$, $N = 22$). A single-linkage Euclidean distance cluster analysis (Sibson 1973) was performed for individual FAs (percentage of the total FAs in seeds) of the 22 blackcurrant genotypes. Average fruit weight (g), seeds per fruit (%), and FAs per fruit and in seeds (%) in tables are presented as mean ± standard deviation.

Results and discussion

Blackcurrant berry weight and seed content

In the current study, the variations in berry weight and seed content were observed across different blackcurrant (*Ribes nigrum* L.) genotypes. The berry weight varied between 1.0 and 1.7 g, being the highest in the genotype 'Mairi' (1.7 g), followed by the similar weight of 'Karri' (1.6 g), 'Intercontinental' (1.6 g), and 'Ļentjai' (1.6 g) (Table 2). These values were consistent with earlier experiments (Libek and Kikas 2002; Kaldmäe et al. 2013; Kikas et al. 2017), where similar fruit weight results were obtained for the same genotypes, 'Mairi', 'Karri', 'Intercontinental', and 'Ļentjai', ranging from 1.3–1.6 g, 1.4–1.8 g, 1.5–1.8 g, and 1.7 g, respectively, in different studies.

In this study, the seed content in the fruit of the 22 genotypes ranged from 2.2% to 4.6%, being the highest in the genotypes 'Karri' and 'Elo', 4.6 % and 4.5 %, respectively (Table 2). The highest seed content in 'Karri' and 'Elo' corresponded to their highest oil concentration per fruit, 1.2 % and 1.3 %, respectively (Table 2). It should be mentioned that the cultivars 'Mairi', 'Karri', and 'Elo' have the genotype 'Kantata 50' in their pedigree (Table 1), which may contribute to similarities in fruit quality among them. In addition to the genotypes 'Karri' and 'Elo', the local breeding line 1-96-16, whose parents include 'Elo', had a high seed content (> 4.0%), while oil concentration per fruit was the third highest (1.1%) (Table 2). Interestingly, in the previous study of Šavikin et al. (2013), conducted in Serbia, the seed contents of 'Ben Lomond', 'Ben Nevis', 'Titania', and 'Öjebyn', as well as the respective oil contents in the seeds, were lower than in our trials.

On average over two years, the total oil content in the seeds of the 22 genotypes ranged from 24.4% to 31.2%, showing the highest levels in 'Ben Nevis', 'Pamyati Vavilova', and 'Asker' with 31.2%, 31.2%, and 31.1%, respectively.

Table 2. Average fruit weight, seeds per fruit, and fatty acid content per fruit and in seeds of 22 blackcurrant genotypes (Polli, Estonia)

Cultivar	Fruit weight (g)	Seeds per fruit (%)	Oil content per fruit (%)	Oil content in seeds (%)
10B	$1.4 \pm 0.28^{a–f}$	$3.1 \pm 0.27^{f–i}$	$0.9 \pm 0.02^{e–h}$	$27.4 \pm 2.83^{d–g}$
1-96-16	1.1 ± 0.07^{gh}	4.1 ± 0.01^{bc}	1.1 ± 0.18^{bc}	$26.7 \pm 4.36^{e–h}$
2-96-51	$1.2 \pm 0.07^{e–h}$	2.5 ± 0.04^{jk}	$0.7 \pm 0.01^{g–j}$	30.3 ± 1.03^{abc}
Almo	$1.2 \pm 0.00^{d–h}$	$3.2 \pm 0.19^{e–h}$	$0.9 \pm 0.18^{d–g}$	$28.7 \pm 3.86^{a–e}$
Asker	$1.2 \pm 0.07^{e–h}$	3.2 ± 0.08^{efg}	1.0 ± 0.06^{cde}	31.1 ± 2.53^{a}
Ats	$1.5 \pm 0.14^{a–d}$	2.2 ± 0.38^{k}	0.6 ± 0.11^{jk}	$27.6 \pm 0.11^{b–g}$
Ben Alder	1.0 ± 0.07^{h}	$3.1 \pm 0.20^{f–i}$	$0.8 \pm 0.00^{f–i}$	25.6 ± 1.43^{fgh}
Ben Lomond	$1.3 \pm 0.28^{b–g}$	4.0 ± 0.56^{cd}	1.1 ± 0.04^{bc}	$28.3 \pm 2.83^{b–f}$
Ben Nevis	$1.3 \pm 0.28^{b–g}$	3.7 ± 0.20^{cde}	1.1 ± 0.05^{ab}	31.2 ± 3.09^{a}
Ben Sarek	$1.5 \pm 0.07^{a–e}$	$2.9 \pm 0.55^{g–j}$	$0.7 \pm 0.06^{h–k}$	25.2 ± 2.71^{h}
Elo	$1.3 \pm 0.07^{c–h}$	4.5 ± 0.73^{ab}	1.2 ± 0.01^{ab}	$27.6 \pm 4.23^{c–g}$
Intercontinental	1.6 ± 0.07^{abc}	2.2 ± 0.76^{k}	0.6 ± 0.13^{k}	$26.6 \pm 3.12^{e–h}$
Karri	1.6 ± 0.14^{ab}	4.6 ± 0.46^{a}	1.3 ± 0.09^{a}	$28.4 \pm 4.70^{a–e}$
Ļentjai	1.6 ± 0.21^{abc}	$2.9 \pm 0.36^{g–j}$	$0.9 \pm 0.03^{e–h}$	$29.8 \pm 2.55^{a–d}$
Mairi	1.7 ± 0.35^{a}	2.6 ± 0.14^{jk}	$0.8 \pm 0.12^{g–j}$	$30.0 \pm 2.97^{a–d}$
Pamyati Vavilova	1.1 ± 0.14^{fgh}	$3.1 \pm 0.07^{f–i}$	$1.0 \pm 0.04^{c–f}$	31.2 ± 1.99^{a}
Pilėnai	$1.3 \pm 0.00^{b–g}$	$2.7 \pm 0.23^{h–k}$	$0.8 \pm 0.06^{f–i}$	30.4 ± 0.52^{ab}
Zagadka	$1.2 \pm 0.00^{d–h}$	3.6 ± 0.17^{def}	$0.9 \pm 0.04^{e–h}$	24.4 ± 2.29^{h}
Titania	$1.3 \pm 0.21^{c–h}$	2.6 ± 0.11^{ijk}	$0.7 \pm 0.03^{h–k}$	$27.6 \pm 2.24^{c–g}$
Varmas	$1.4 \pm 0.07^{a–g}$	2.3 ± 0.23^{k}	0.7 ± 0.07^{ijk}	$28.7 \pm 0.19^{a–e}$
Vyčiai	$1.5 \pm 0.14^{a–d}$	3.2 ± 0.35^{fgh}	$0.9 \pm 0.03^{d–g}$	$28.9 \pm 2.29^{a–e}$
Öjebyn	1.1 ± 0.07^{gh}	4.0 ± 0.29^{bcd}	1.1 ± 0.09^{bcd}	$27.0 \pm 4.07^{e–h}$

Different letters in columns mark significant differences at $p \leq 0.05$

The genotype 'Mairi', in addition to the largest fruit weight, had quite a high concentration of oil in the seeds (30.0 %). However, the proportion of seeds in the fruit of 'Mairi' was relatively small compared to the corresponding value of the other genotypes studied.

The genotypes 'Mairi', 2-96-51, 'Pilėnai', 'Asker', 'Ben Nevis', and 'Pamyati Vavilova' possessed the oil content of > 30% in seeds, with the values of 30.0%, 30.3%, 30.4%, 31.1%, 31.2%, and 31.2%, respectively. The content of the seeds tended to be higher in fruits with a smaller weight (e.g. 'Asker', 'Ben Lomond', 'Ben Nevis', 'Pamyati Vavilova', and 'Pilėnai'), but this was not the case for every tested genotype. The variation in seed content is noteworthy as seed proportion can influence textural qualities and processing possibilities of the fruits as well as be related to the content of bioactive components in seeds.

Fatty acid content in blackcurrant seeds

In terms of FA composition, the most predominant FAs identified in blackcurrant seeds were LA, ranging from 40.1% to 48.6%, followed by ALA, from 11.7% to 16.5%, OA, from 10.3% to 16.4%, and GLA, from 10.9% to 15.6% (Table 3). The content of SDA ranged from 2.2% to 3.6%. The content of SDA was high in 'Ben Alder' (3.2%) and 'Pamyati Vavilova' (3.6%). The genotype 'Karri' possessed the highest LA content (48.1% of the total FAs), but the other identified FAs in this cultivar remained below the calculated average of the 22 tested genotypes. Three cultivars, 'Ben Sarek', 'Ļentjai', and 'Pamyati Vavilova', had contents of five FAs that were higher than the average of the tested genotypes. The results regarding the major FAs in the blackcurrant seeds correspond to the findings of other researchers (Ruiz del Castillo et al. 2002; Šavikin et al. 2013; Flores and Ruiz del Castillo 2016). Ruiz del Castillo et al. (2002) found the contents of FAs in the following order: LA (42.3%–53.3%) > GLA (11.6%–24.6%) > ALA (10.0%–19.2%) > OA (6.6%–11.9%) > PA (palmitic acid) (5.6%–7.3%) > SDA (2.4%–4.3%) from the total FAs on average over 36 different genotypes. In their study, LA was found to be the major component, at a level of up to 50% of the total FAs.

Correlation analysis

A strong positive correlation (r = 0.95) was found between the oil content in fruits and the proportion of seeds per fresh weight of berries (Table 4). The content of oil in fruits depends more on the proportion of seeds in the fruits than on the fruit weight/size. Some genotypes can have large fruits and small seeds or vice versa. High correlation is showing that the cultivars with higher seed to pulp ratio have greater oil concentration that can influence their nutritional value and suitability for oil extraction.

Table 5 shows the content of nutritionally important FAs in blackcurrant seeds. The n-6/n-3 ratio of all the examined currant varieties was below 4, which falls within the recommended range of 1:1 to 5:1 for maintaining a healthy balance. A balanced n-6/n-3 ratio is crucial for optimal physiological

Table 3. Average percentage of nutritionally significant FAs of the total FAs in the seeds of 22 blackcurrant genotypes (Polli, Estonia)

Genotype	LA C18:2 n-6	ALA C18:3 n-3	OA C18:1 c-9	GLA C18:3 n-6	PA C16:0	SA C18:4 n-3
10B	46.4 ± 0.71^{cde}	14.0 ± 1.73$^{b–f}$	13.8 ± 0.24$^{c–g}$	12.3 ± 0.77$^{f–i}$	6.4 ± 0.33$^{b–g}$	2.4 ± 0.05^{ijk}
1-96-16	45.0 ± 0.65^{efg}	13.9 ± 1.74$^{b–f}$	16.4 ± 0.01^{a}	11.2 ± 1.04^{hi}	6.3 ± 0.21$^{c–h}$	2.3 ± 0.09^{jkl}
2-96-51	43.3 ± 1.80^{hi}	14.7 ± 1.58$^{a–d}$	12.7 ± 1.77$^{f–i}$	14.1 ± 2.22$^{a–f}$	6.3 ± 0.14$^{c–h}$	2.9 ± 0.09^{c}
Almo	45.3 ± 0.33$^{d–g}$	12.9 ± 0.85$^{d–h}$	14.9 ± 0.75$^{a–e}$	13.4 ± 0.33$^{b–g}$	6.0 ± 0.51^{ghi}	2.6 ± 0.17$^{e–i}$
Asker	45.0 ± 1.33^{efg}	12.3 ± 1.27^{fgh}	15.0 ± 0.51$^{a–d}$	13.6 ± 1.09$^{b–g}$	6.3 ± 0.30$^{d–h}$	2.4 ± 0.02^{ijk}
Ats	45.6 ± 0.36$^{d–g}$	11.9 ± 1.64^{gh}	12.9 ± 0.16$^{f–i}$	14.9 ± 2.23^{ab}	6.6 ± 0.56$^{a–e}$	2.5 ± 0.19^{hij}
Ben Alder	44.3 ± 0.54^{gh}	16.5 ± 1.91^{a}	10.3 ± 1.1^{j}	13.9 ± 2.41$^{a–f}$	6.7 ± 0.25$^{a–d}$	3.2 ± 0.30^{b}
Ben Lomond	44.4 ± 2.32^{gh}	15.5 ± 3.06^{ab}	11.8 ± 0.95^{ij}	12.6 ± 3.06$^{e–i}$	6.8 ± 0.83^{ab}	2.7 ± 0.27$^{c–h}$
Ben Nevis	46.6 ± 1.03^{bcd}	15.5 ± 2.17^{ab}	11.9 ± 0.32^{hij}	10.9 ± 1.89^{i}	6.5 ± 0.69$^{a–f}$	2.5 ± 0.25$^{f–i}$
Ben Sarek	45.4 ± 0.03$^{d–g}$	14.2 ± 2.45$^{b–e}$	11.3 ± 0.29^{ij}	14.5 ± 2.72$^{a–d}$	6.5 ± 0.34$^{a–e}$	2.8 ± 0.30$^{c–g}$
Elo	45.6 ± 1.64$^{d–g}$	12.9 ± 1.68$^{d–h}$	15.7 ± 0.03^{ab}	12.0 ± 1.56^{ghi}	6.2 ± 0.74$^{e–h}$	2.2 ± 0.11^{l}
Intercontinental	42.4 ± 0.16^{i}	13.7 ± 2.91$^{c–f}$	15.0 ± 1.70$^{a–d}$	13.5 ± 2.71$^{b–g}$	6.3 ± 0.51$^{c–h}$	2.8 ± 0.13^{cd}
Karri	48.1 ± 0.15^{a}	13.5 ± 0.66$^{c–g}$	13.1 ± 0.43$^{e–i}$	12.3 ± 1.12$^{f–i}$	6.0 ± 0.35$^{f–i}$	2.2 ± 0.22^{kl}
Ļentjai	45.3 ± 1.27$^{d–g}$	14.4 ± 2.41$^{b–e}$	11.8 ± 1.03^{ij}	13.8 ± 2.25$^{a–g}$	6.9 ± 0.24^{a}	2.7 ± 0.02$^{c–h}$
Mairi	44.3 ± 0.09^{gh}	12.7 ± 1.12$^{e–h}$	15.1 ± 0.46$^{a–d}$	14.3 ± 0.69$^{a–e}$	5.6 ± 0.15^{i}	2.6 ± 0.02$^{d–i}$
Pamyati Vavilova	40.1 ± 0.98^{j}	15.1 ± 1.92^{abc}	13.7 ± 0.16$^{d–g}$	15.5 ± 1.38^{a}	6.4 ± 0.38$^{b–g}$	3.6 ± 0.01^{a}
Pilėnai	44.8 ± 1.99^{fg}	14.0 ± 1.70$^{b–f}$	14.3 ± 2.62$^{b–f}$	12.7 ± 1.99$^{d–i}$	6.6 ± 0.02$^{a–e}$	2.5 ± 0.16^{hij}
Zagadka	43.1 ± 0.80^{hi}	15.6 ± 2.20^{ab}	12.0 ± 0.17$^{g–j}$	14.6 ± 1.53^{abc}	6.9 ± 0.25^{a}	2.8 ± 0.11^{cde}
Titania	45.9 ± 1.16$^{c–f}$	13.3 ± 1.20$^{d–h}$	14.2 ± 0.98$^{b–f}$	12.5 ± 1.02$^{e–i}$	6.8 ± 0.20^{abc}	2.5 ± 0.05$^{g–j}$
Varmas	42.7 ± 0.36^{i}	11.7 ± 1.22^{h}	15.5 ± 0.04^{abc}	15.6 ± 0.91^{a}	6.2 ± 0.02$^{e–h}$	2.8 ± 0.10$^{c–f}$
Vyčiai	47.9 ± 0.85^{ab}	14.6 ± 1.33^{bcd}	10.5 ± 0.64^{j}	13.0±0.96$^{c–h}$	6.5 ± 0.21$^{a–f}$	2.6 ± 0.13$^{e–i}$
Öjebyn	47.1 ± 1.20^{abc}	14.0 ± 0.78$^{b–f}$	14.4 ± 0.58$^{b–f}$	11.5 ± 0.38^{hi}	5.9 ± 0.40^{hi}	2.2 ± 0.09^{kl}

Different letters in columns mark significant differences at $p \leq 0.05$

Table 4. Correlation coefficients among the analysed and measured traits in 22 blackcurrant genotypes (Polli, Estonia)

Variable	Mean	SD	Fruit weight (g)	Seeds per fruit (%)	Oil content per fruit (%)	Oil content in seeds (%)
Fruit weight (g)	1.3	0.2	1.00	–0.26	–0.22	0.11
Seeds per fruit (%)	3.2	0.7	–0.26	1.00	0.95*	–0.14
Oil content per fruit (%)	0.9	0.2	–0.22	0.95	1.00	0.17
Oil content in seeds (%)	28.3	2.0	0.11	–0.14	0.17	1.00

* Correlation is significant at $p < 0.05$

Table 5. The amount of saturated (SFA), polyunsaturated (PUFA), and monounsaturated (MUFA) FAs in the seeds of 22 blackcurrant genotypes (Polli, Estonia)

Genotype	SFA (%)	MUFA (%)	PUFA (%)	n-6	n-3	n-6/n-3	18n-6/18n-3
10B	8.2	15.7	75.4	59.0	16.4	3.6	0.9
1-96-16	8.5	18.2	72.6	56.4	16.2	3.5	0.8
2-96-51	8.7	14.7	75.3	57.7	17.6	3.3	1.0
Almo	8.1	16.8	74.4	58.9	15.5	3.8	1.0
Asker	8.4	17.0	73.6	58.9	14.7	4.0	1.1
Ats	8.8	14.8	75.2	60.7	14.5	4.2	1.3
Ben Alder	8.8	12.1	78.1	58.5	19.6	3.0	0.9
Ben Lomond	9.5	13.8	75.5	57.3	18.2	3.2	0.8
Ben Nevis	9.0	13.8	75.8	57.8	18.0	3.2	0.7
Ben Sarek	8.9	13.2	77.2	60.2	17.0	3.6	1.1
Elo	8.1	17.7	72.8	57.7	15.1	3.9	0.9
Intercontinental	8.8	16.9	72.7	56.2	16.5	3.5	1.0
Karri	8.1	15.0	76.4	60.7	15.7	3.9	0.9
Ļentjai	9.0	13.6	76.5	59.4	17.2	3.5	1.0
Mairi	8.1	17.0	74.2	58.9	15.3	3.9	1.1
Pamyati Vavilova	8.8	15.7	74.5	55.8	18.7	3.0	1.0
Pilėnai	8.6	16.3	74.3	57.8	16.5	3.5	0.9
Zagadka	9.1	13.8	76.4	58.0	18.4	3.2	1.0
Titania	8.8	16.1	74.4	58.6	15.8	3.7	1.0
Varmas	8.7	17.5	73.0	58.5	14.5	4.1	1.3
Vyčiai	8.1	12.5	78.5	61.3	17.2	3.6	0.9
Öjebyn	8.0	16.3	75.0	58.8	16.2	3.6	0.8

processes. Western diets are known to contain excessive amounts of n-6 FAs, which have been linked to pro-inflammatory effects. A favourable n-6/n-3 ratio suggests that an increased consumption of foods rich in blackcurrant seeds could help to reduce inflammatory responses, including those associated with cardiovascular diseases and metabolic disorders. Developing novel food products from juice production pomace could provide a concentrated source of n-3 FAs, potentially increasing n-3 intake and having a benefit for human health.

Cluster analysis linked close together the genotypes according to the parents in the pedigree (Fig. 1). The shortest linkage (distance ≤ 1.9) and a common shoulder of a cluster was between the genotypes that had 'Öjebyn' or 'Kantata 50' or both in their pedigree: 10B, 'Titania', 'Pilėnai', 'Öjebyn', 'Almo', 'Asker', 'Mairi', 1-96-16, and 'Elo'. According to the previous study of Šavikin et al. (2013), cluster analysis based on the seed oil FA profiles is a convenient method for distinguishing the origin of blackcurrant seeds. In their study, all *Ribes nigrum* L. genotypes were categorized in one cluster at a low linkage distance. However, in the current study, the genotype 'Pamyati Vavilova' was distinguished from the other genotypes due to its lowest concentration of LA and highest concentrations of GLA and SA. These differences are influenced by the pedigree of the only genotype studied, originating from Belarus, which has no common parents with the other genotypes.

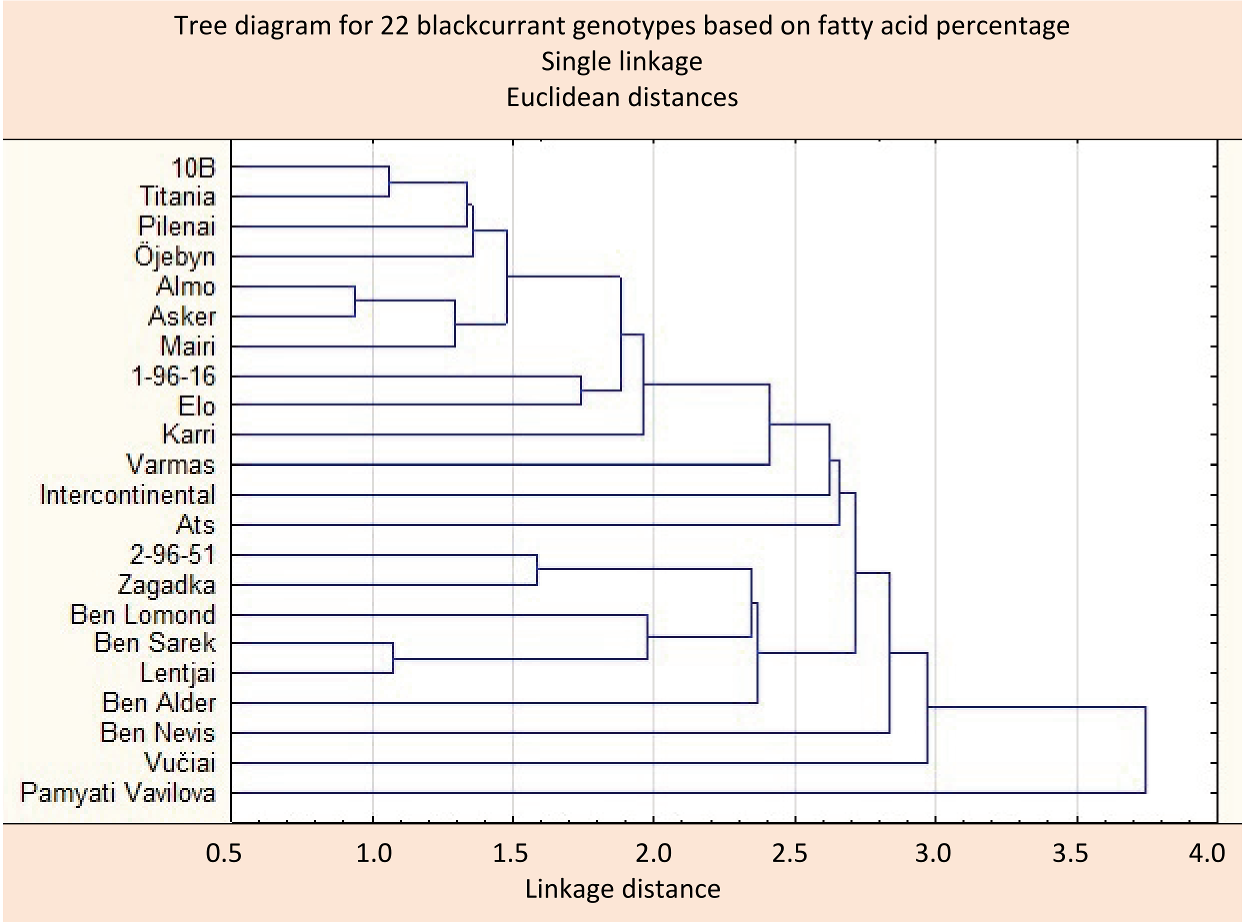

Fig. 1. A diagram based on the Euclidean distances between 22 blackcurrant genotypes evaluated according to the percentage of individual FAs from total FAs in the seeds of *Ribes nigrum* L.

Conclusions

Based on the current work, it can be concluded that the seed content of the studied blackcurrants varied by genotype by 2.2%–4.6%, being the highest in the genotypes 'Karri' and 'Elo'. The highest seed content in these genotypes was in correlation with their highest oil concentration per fruit. It was demonstrated that the oil content in berries depended more on the proportion of seeds in the berries than on the weight/size of the berries. Seed content is an important factor in cultivar selection and breeding programmes. Understanding the genetic basis for the variation of seed content can help to develop blackcurrant varieties oriented to specific market demands.

Based on the percentage of individual FAs from the total FAs in the blackcurrant seeds, the cluster analysis linked close together the genotypes that had 'Öjebyn' or 'Kantata 50' or both in the pedigree. Three cultivars, 'Ben Sarek', 'Ļentjai', and 'Pamyati Vavilova', had five FAs higher than the average of the tested genotypes. Blackcurrant seeds are a valuable source of unsaturated FAs, mainly α-linolenic acid, oleic acid, and γ-linolenic acid. A balanced ratio of n-6/n-3 FAs (< 4) makes blackcurrant seeds valuable from a nutritional point of view. Cluster analysis based on the seed oil FA profiles is a convenient method for distinguishing the origin of seeds.

More information about the composition of blackcurrant (*Ribes nigrum* L.) berries can provide additional opportunities for the utilization of juice production by-products to develop novel foods and cosmetic products or in animal nutrition. This, in turn, can have a significant impact on environmental sustainability by reducing food production waste and promoting resource usage efficiency.

Data availability statement

All research data are contained within the article and can be shared upon request from the authors.

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Musta sõstra (*Ribes nigrum* L.) genotüüpide seemnete sisalduse ja rasvhapete profiili hindamine

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Kahel järjestikusel aastal uuriti kokku 22 musta sõstra genotüüpi: 'Karri', 'Almo', 'Ats', 'Elo', 'Varmas', 'Mairi', 'Asker', 'Pilėnai', 'Vyčiai', 'Ben Alder', 'Ben Nevis', 'Ben Lomond', 'Ben Sarek', 'Intercontinental', 'Titania', 'Öjebyn', 'Ļentjai', 'Pamyati Vavilova', 'Zagadka', 10B, 1-96-16 ja 2-96-51. Uurimistöö eesmärk oli võrrelda marjade massi, seemnete sisaldust marjades ning seemnetes sisalduvate rasvhapete profiili. Rasvhapete koostist määrati ja kvantifitseeriti gaasikromatograafiga.

Musta sõstra marjade mass varieerus genotüübist sõltuvalt 1,0–1,7 g vahemikus, olles suurim genotüüpide 'Mairi', 'Karri', 'Intercontinental' ja 'Ļentjai' korral. Seemnete sisaldus marjades jäi 2,2%–4,6% vahemikku, olles suurim genotüüpide 'Karri' ja 'Elo' puhul. Õlisisaldus korreleerus positiivselt seemnete sisaldusega marjade märgkaalu kohta, olles suurim genotüüpide 'Karri' ja 'Elo' korral – vastavalt 1,2% ja 1,3%. Kahe aasta keskmine õlisisaldus seemnetes varieerus 24,4%–31,2% vahemikus, olles suurim genotüüpide 'Ben Nevis', 'Pamyati Vavilova' ja 'Asker' puhul. Rasvhapetest leidus musta sõstra seemnetes kõige rohkem linoolhapet (LA, 40,1%–48,6%), millele järgnesid α-linoleenhape (ALA, 11,7%–16,5%), oleiinhape (OA, 10,3%–16,4%) ja γ-linoleenhape (GLA, 10,9%–15,6%).