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Characterization of Six Cold-Pressed Berry Seed Oils and Their Seed Meals

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Featured Application: Nutraceuticals and skin care agents.

Abstract: When producing fruit juices, the pomace, containing the seeds, is left as a byproduct. In this study, cold-pressed blackcurrant, raspberry, blackberry, blueberry, strawberry, and sea buckthorn seed oils and their seed meals were characterized to explore possible commercial applications. The fatty acid (FA) composition, sterol content, tocopherol content, total polyphenolic content (TP), color, ferric reducing antioxidant power (FRAP), and free-radical scavenging capacity (DPPH assay) were determined. The levels of TP ranged from 8.9 to 19.3 mg GAE/100 g of oil with the highest TP content observed in blackcurrant oil. Concerning the antioxidative activity, sea buckthorn oil and blackberry oil performed best, both exhibiting high FRAP and DPPH scavenging activities. The fatty acid profiles of all oils showed that the main polyunsaturated fatty acids were linoleic acid (C18:2) and α-linolenic acid (C18:3). When studying the sterol and tocopherol content, the highest total amount of sterols (4500 mg/kg) as well as the highest total amount of tocopherols (1036 mg/kg) were observed in blackberry oil. It can be concluded that the cold-pressed berry seed oils examined in this study exhibit interesting characteristics for further commercialization. Moreover, the seed meal is a valuable byproduct that contains high amounts of polyphenols and has a high level of antioxidant activity.

Keywords: cold-pressed berry seed oil; fatty acid profile; minor compounds; antioxidants

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1. Introduction

Berries contain several essential micronutrients, dietary fibers, and polyphenolic components, such as ellagitannins, resveratrol, and anthocyanins, the latter giving them their distinctive red color. Berries are grown primarily for consumption as such or for processing into juices [1], cordials, and jams. The byproducts, seeds, and pomace can also be used in food [2] or in cosmetics [3]. The processing steps for the berries are as follows: pressing to obtain the juice, drying the pomace, and sieving out the seeds. There are different options to obtain the seed oil: cold pressing and solvent extraction with hexane or with supercritical carbon dioxide. The seed meal remaining after oil extraction could be used in cosmetic applications, e.g., scrubs, although it is generally seen as a low-value waste product.

Berry seed oils are utilized in food and cosmetic applications because they contain polyunsaturated fatty acids (PUFAs) [4] and other bioactive components, such as antioxidants and vitamins that potentially are beneficial for human health. Antioxidants slow down or to stop damage to cellular DNA, proteins, and lipids caused by reactive oxygen species [5]. As for all food or cosmetic ingredients, the safety of the oils' use must be guaranteed. It is known that allergic reactions to berry seed oils do not often occur [6]. Toxic compounds are rarely found in berry seed oils, except for those originating from

biocides used to protect the plants during its growing process. Oxidative stability is a very important factor concerning the potential use of berry seed oils in food and cosmetic applications. The oxidative stability of an oil depends on the fatty acid composition and the concentration of minor compounds such as tocopherols and polyphenols. For example, strawberry, blackberry, and blackcurrant seed oils are prone to oxidation due to their high content of linoleic acid, an unsaturated fatty acid with two double bonds. Because of their anti-inflammatory activity, berry seed oils are used in cosmetics and pharmaceutical products. The use of berry seed oils for the prevention of skin lesions such as rash, gingivitis, and eczema has been patented [7]. Dairy products and fruit juices are marketed for their high concentration in omega-3 fatty acids, originating from berry seed oils [8]. Moreover, claims on the presence of bioactive substances and effects on human health are used for marketing dietary supplements containing oil from black currant seeds and sea buckthorn seeds. Berry seed oils are considered specialty oils due to their nutraceutical effects. Thus, to provide guidelines for innovative applications, the chemical and physical properties of different berry seed oils were investigated.

2. Materials and Methods

2.1. Chemicals and Raw Materials

Methanol (MeOH), Na_2CO_3, $FeCl_3.6H_2O$, $FeSO_4.7H_2O$, and $NaC_2H_3O_2.3H_2O$ were purchased from Chem-Lab (Zedelgem, Belgium). Folin–Ciocalteu reagent, gallic acid, catecheic acid, 2,4,6-tripyridyls-triazine, and 2,2-diphenyl-1-picrylhydrazyl were purchased from Sigma-Aldrich (Hoeilaart, Belgium).

Raw materials were obtained from SVZ Rijkevorsel NV (Rijkevorsel, Belgium), a fruit and vegetables processing company. All raw materials originated from pomace after commercial fruit puree production, where they are considered a waste stream.

2.2. Cold Pressing of Berry Seed Oil

Seeds were cold pressed using a screw extruder (IBG Momforts Oekotec, DD85G, Mönchengladbach, Germany). Temperatures remained under 50 °C during pressing. Solid impurities were removed from the oil by sedimentation followed by filtration (IBG Momforts Oekotec, D112, Mönchengladbach, Germany, 40 μm pore size).

2.3. Extraction of Polyphenols from Berry Seed Oil

Three milliliters of MeOH were used to extract 1 g of cold-pressed oil by vortexing at ambient temperature. After 5 min of centrifugation at 2880 g (IEC Centra CL3R, Thermo Scientific, Breda, The Netherlands), the MeOH extracts were collected. Afterwards, the oil residues were extracted two times more with 3 mL MeOH. All MeOH extracts were combined and were brought to a total volume of 10 mL by adding extra MeOH. These 10 mL solutions were stored at 4 °C under a nitrogen atmosphere.

2.4. Extraction of Polyphenols from Seed Meal

Half a gram of seed meal was extracted with 10 mL of the solvent mixture MeOH:aceton:water ratio 7:7:6 in a 15 mL falcon tube for one hour at 50 °C. To improve the extraction yield, the tubes were mixed every 5 min using a vortex apparatus. Subsequently, the extracts were centrifuged and filtered through a 0.22 μm filter and stored at −20 °C until further use.

2.5. Total Phenolic Content (Folin–Ciocalteu)

The Folin–Ciocalteu method was used to measure the total phenolic content of the oil extracts. Folin–Ciocalteu reagent (100 μL) was added to the sample (20 μL sample and 1.58 mL distilled water). This solution was mixed for 5 min. Subsequently, 300 μL of 7.5% Na_2CO_3 was added, the solution was mixed and incubated at 40 °C for 30 min. A spectrophotometer (Spectroquant Prove 300, Millipore, Hoeilaart, Belgium) was used to measure the absorbance of the test solutions at 750 nm. Gallic acid (0–200 mg/mL) was

used as a standard to construct the calibration curve. The results are expressed as mg of gallic acid equivalents (mg GAE/100 g).

2.6. Radical Scavenging Activity (DPPH Assay)

The DPPH (1,1-diphenyl-2-picrylhydrazyl) assay [9] was used to determine the radical scavenging activity of all oil samples. One mL methanolic solution of DPPH was added to a mixture of 200 µL extract and 800 µL 0.1 M Tris-HCl (pH 7.4). The mixture was shaken vigorously and was left to stand at room temperature for 30 min in the dark. The absorbance was measured at 517 nm in a spectrophotometer (Spectroquant Prove 300, Millipore, Hoeilaart, Belgium). The antioxidant activity was expressed as IC50. Inhibition ratio of DPPH (%) was determined according to the following formula:

$$\text{inhibition ratio} = (A1 - A2) \times 100/A1$$

where A1 is the absorbance of the blank addition (methanol instead of sample) and A2 is the absorbance of the sample solution. Inhibition ratios were plotted against the sample concentrations and the IC50 value was calculated from the regression curve.

2.7. Antioxidant Activity (FRAP Assay)

Ferric reducing antioxidant power assay of the cold-pressed oil was carried out according to the method of Benzi and Stain with some modifications [10]. The TPTZ (2,4,6-tripyridyls-triazine) reagent consisted of 300 mM acetate buffer pH 3.6, 10 mM TPTZ, and 20 mM $FeCl_3.6H_2O$ solution. FRAP reagent (675 µL) was mixed with the sample (75 µL), and the absorbance was measured at 595 nm after 15 min. Since seed oil does not dissolve in the aqueous FRAP reagent, the oils were extracted 3 times with methanol, and the pooled methanol extracts underwent the FRAP assay. The results were calculated from the calibration curve and expressed in µM equivalent $FeSO_4.7H_2O$.

2.8. Fatty Acid Composition

The fatty acid composition of the oils samples was determined by gas chromatography with an MS detector (Trace 1300, Thermo Scientific, Interscience, Louvain-la-Neuve, Belgium) using a capillary RTx-2330 column (30 m × 0.25 mm, film thickness 0.20 µm) equipped with a PTV injector (inlet temperature 250 °C, split flow 10:1) under a temperature gradient (70 °C for 2 min; ramp to 180 °C at 13.5 °C/min; 180 °C for 5 min; ramp to 240 °C at 6 °C/min). A constant helium flow of 1 mL/min was applied as a carrier gas. The MS transfer line was set at 250 °C, the ion source at 280 °C and the electron ionization was used.

Samples for GC-MS analysis were prepared by adding 0.020 g of oil and 0.02 g of tetradecane (internal standard) to a test tube and diluting this to 2.000 g with n-heptane. A total of 2 mL of 2 M KOH in methanol was added, after which the sample was vortexed for 5 min. The sample for injection was produced by taking 0.100 g of the upper layer and diluting it to 1.000 g with n-heptane. A calibration curve was constructed using a fatty acid methyl ester standard mix. Analysis results were evaluated using Chromeleon 7.3.2 software.

2.9. Sterol and Tocopherol Content and Composition

The procedure mentioned by Hussain et al. [11] was used to determine tocopherol and sterol content and composition. Gas chromatography was performed on a Trace 1300 system (Thermo Scientific, Interscience, Louvain-la-Neuve, Belgium) equipped with a capillary MXT-5 column (30 m × 0.53 mm, film thickness 0.25 µm) and a split-splitless injection system (350 °C). Flame ionization detection was utilized at 380 °C (constant flow, hydrogen 35 mL/min, air 350 mL/min, nitrogen 40 mL/min) and the following temperature gradient was applied: 50 °C for 1 min, ramp to 180 °C at 10 °C/min; ramp to 230 °C at 3 °C/min; ramp to 380 °C at 15 °C/min; 380 °C for 10 min. The carrier gas was helium (constant flow, 1.5 mL/min). A 10 m% sample solution was prepared in n-heptane. Of this solution, 0.1 g

was mixed with 0.1 g of a 0.1 m% internal standard solution (tetradecane in n-heptane) and was diluted to 1 g with n-heptane. A calibration was performed using tocopherol and sterol standards. To analyze the resulting chromatograms, Chromeleon 6.8 software was used.

2.10. Color Measurement

A UV-VIS spectrophotometer (Spectroquant Prove 300, Millipore, Hoeilaart, Belgium) equipped for color measurements was used. The completely melted oil with no visible sediments or solids was filled in cuvettes with an optical path length of 1 cm. The CIELab coordinates, L* (lightness), a* (red–green), and b* (yellow–blue) of all samples were automatically calculated from the raw spectral data by the software.

3. Results and Discussion

3.1. Color Parameters

Color is an important characteristic to determine the visual acceptance of an oil. The color of oils depends on the wavelength of transmitted visible light and is mainly influenced by two groups of pigments, namely, carotenoids and chlorophylls [12], which are exclusively synthesized in plants. Carotenoids are red pigments and precursors of vitamin A and have antioxidant activity [13]. Chlorophylls yield a green color, and, contrarily to carotenoids, they accelerate oil oxidation in the presence of oxygen and light [14]. However, chlorophylls can act as antioxidants in the absence of light.

Table 1 shows the calculated color parameters for the different berry seed oils. The tested oils differed in their colors. Blackcurrant and blackberry oils were the darkest oils and were very similar in color. Raspberry seed oil and sea buckthorn oil had the highest yellowness. However, based on the a* values obtained, raspberry oil belonged to the yellow-green part of the spectrum and sea buckthorn to the reddish-yellow part of the spectrum. Blueberry and strawberry oils belonged to the same region of the spectrum (reddish yellow) as the blackcurrant and blackberry oils but were more yellowish and brighter.

Table 1. CieLab color measurements in berry seeds oils. The L* value describes the brightness of the color, with values ranging between 0 (dark) and 100 (light); negative a* values stand for green colors, while positive a* values stand for red colors; negative b* values represent blue colors, and positive b* values represent yellow colors.

Oil Source	L* Value	a* Value	b* Value
Blackcurrant oil 1	4.97 ± 0.06	5.43 ± 0.02	21.59 ± 0.17
Blackcurrant oil 2	9.76 ± 0.02	4.21 ± 0.03	32.31 ± 0.17
Raspberry oil 1	87.56 ± 0.02	−4.56 ± 0.01	113.85 ± 0.22
Raspberry oil 2	88.82 ± 0.01	−6.00 ± 0.02	76.92 ±0.14
Blackberry oil 1	6.86 ± 0.01	5.11 ± 0.01	24.81 ± 0.06
Blackberry oil 2	5.61 ± 0.02	4.93 ± 0.01	22.9 ± 0.05
Blueberry oil 1	42.79 ± 0.01	5.7 ± 0.02	78.16 ± 0.22
Blueberry oil 2	44.49 ± 0.02	6.81 ± 0.02	83.78 ± 14
Strawberry oil 1	53.10 ± 0.07	8.06 ± 0.02	93.58 ± 0.4
Strawberry oil 2	60.79 ± 0.08	7.86 ± 0.01	102.48 ± 0.17
Sea buckthorn oil 1	69.25 ± 0.05	46.48 ± 0.11	125.41 ± 0.5
Sea buckthorn oil 2	57.86 ±0.02	40.99 ±0.14	108.87 ± 0.4

Key: Data are reported as mean values ± standard deviation of triplicates. Color measurement parameters: D65/2°.

3.2. Total Polyphenols (TP) Content

Polyphenols are present in different varieties of plants [15] where they fulfil functions related to growth, protection against pathogens and diseases, and reproduction [16]. Different types of polyphenols possess different structural and physicochemical properties. Moreover, they exhibit different stability and reactivity in response to factors such as pH, temperature, oxygen, and light [17]. Phenolic compounds provide stability to edible

oils [18]. The type of oil crop as well as the breeding and harvest conditions determine which types of phenolic compounds are present in the oil [19].

In this study, the levels of polyphenolic compounds were determined in different oil samples. Most of the polyphenols remained in the seed meals, and only a small amount was transferred into the oil (Figure 1). The total polyphenol content of the cold-pressed seed oils ranged from 8.9 to 19.3 mg GAE per 100 g of oil. These levels were higher than the ones described for cold-pressed palm oil (3.12–7.18 mg TP/100 g) and extra virgin olive oil [19]. The TP values were highest for the blackcurrant oils, and the lowest TP amounts were found in the raspberry seed oils. The TP content found in the press cake were 10- to 100-fold higher than those in the seed oils and ranged from 312 to 5500 mg GAE/100 g press cake. Thus, 10% of the polyphenols from seeds were transferred to the oil. This can be explained by the hydrophilic properties of most of the polyphenols.

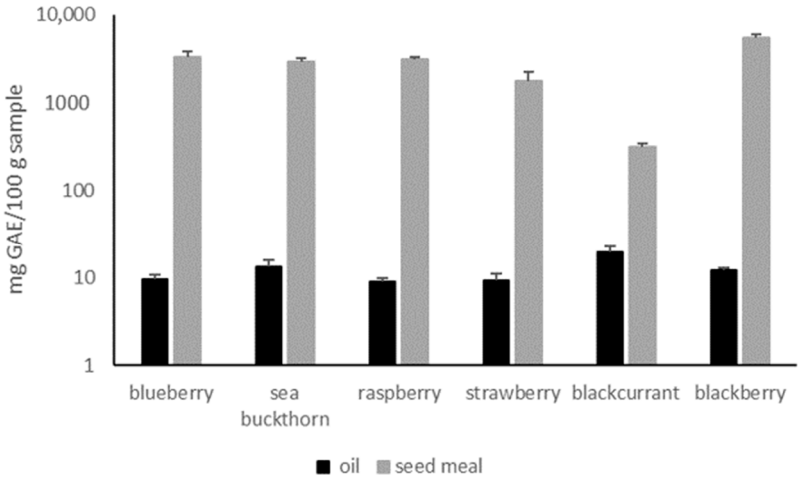

Figure 1. Content of total polyphenols in different cold-pressed berry seed oils and their respective seed meals. Results are mean values ± standard deviation of triplicates.

3.3. Antioxidant Activity

Antioxidants promote human health because they lower the risk of aging-related diseases, e.g., heart diseases and cancer [20,21]. Conventional oil extraction and processing techniques involve heating. Since a lot of bioactive compounds are thermally instable, they are broken down due to the heating. Because no heating is involved when cold pressing is used, berry seed oils produced in this manner contain higher amounts of natural antioxidants. The antioxidant capacity of oils is connected to the concentration of phenolic compounds [22,23]. The ferric reducing antioxidant power (FRAP) method was used to determine the antioxidative activity of the cold-pressed seed oils. In the FRAP assay, ferric ions (Fe^{3+}) are reduced to ferrous ions (Fe^{2+}), which leads to a change in color. The intensity of the color depends on the reducing potential of the compounds present in the oil samples. FRAP values of the cold-pressed oils are shown in Figure 2. In the present study, the highest FRAP activity was detected in one of the sea buckthorn oils. Blackberry and blackcurrant oils exhibited high FRAP activity with FRAP values over 900 µmol Fe^{2+}/100 g oil. These observations are in accordance with results mentioned in literature [24]. Strawberry seed oil had the lowest FRAP value. Like the TP content, the FRAP activity was 10–100 times higher in extracts from the seed meals.

Another antioxidant parameter is the IC50 value which is used to quantify the free radical scavenging activity. The IC50 value is defined as the extract concentration required for 50% inhibition of DPPH radicals under the given experimental conditions. Although all oil samples exhibited the capacity to react with and quench free DPPH in a dose-dependent way, a clear difference in the DPPH-scavenging capacity can be observed (see Table 2). Blackberry seed oil extracts exhibited the strongest DPPH-scavenging activity, followed by sea buckthorn, raspberry, blueberry, blackcurrant, and strawberry oil extracts.

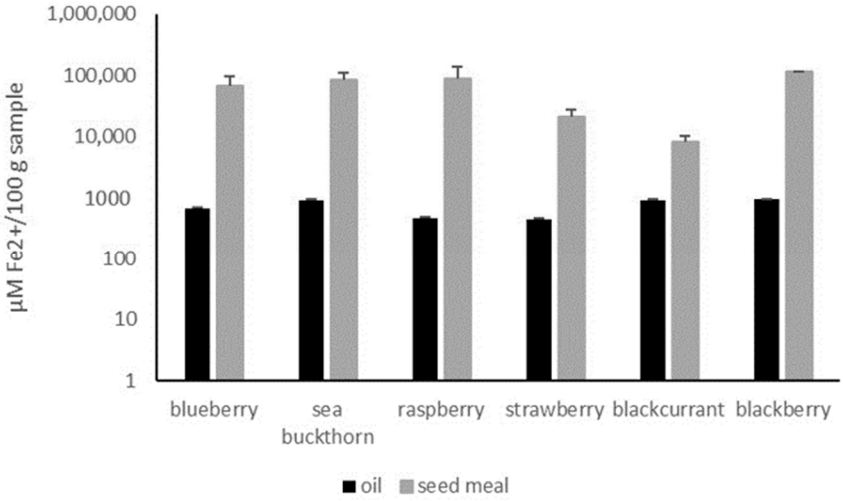

Figure 2. Antioxidant activity (FRAP) in different cold-pressed berry seed oils and their respective seed meals. Results are mean values ± standard deviation of triplicates.

Table 2. The DPPH scavenging capacity of different cold-pressed berry seed oils.

	DPPH (IC_{50} Dose Expressed as mg Oil Equiv/mL)
Blackcurrant oil 1	59.0 ± 1.4
Blackcurrant oil 2	23.7 ± 3.6
Raspberry oil 1	32.4 ± 2.6
Raspberry oil 2	41.1 ± 2.0
Blackberry oil 1	16.2 ± 0.9
Blackberry oil 2	14.6 ± 1.1
Blueberry oil 1	48.2 ± 1.7
Blueberry oil 2	48.8 ± 1.7
Strawberry oil 1	91.8 ± 5.2
Strawberry oil 2	75.0 ± 5.8
Sea buckthorn oil 1	23.5 ± 2.6
Sea buckthorn oil 2	32.7 ± 3.6

The results are expressed as mean values ± standard deviation of triplicate analyses.

3.4. Fatty Acid Composition

Omega-3 oils exhibit positive effects on human health, such as its anticancer, anti-inflammatory, and cardioprotective activity [25,26]. The European Scientific Committee on Food states that 0.5% of the total daily energy intake should be derived from omega-3 polyunsaturated fatty acids and 2% of the total daily energy intake should be derived from omega-6 polyunsaturated fatty acids [27]. From a dermatological point of view, PUFA can complement structures of the intercellular cement of the stratum corneum due to their chemical affinity [28–30].

Thus, the fatty acid composition of the oils was analyzed (Table 3). In agreement with Dobson et al. [31], linoleic acid (LA) was the major fatty acid followed by α-linolenic acid (ALA) and γ-linolenic acid (GLA). Strawberry oil exhibited the highest total PUFA content (77–81%). Sea buckthorn, blueberry, strawberry, and raspberry oils contained the highest concentration of ALA, while ALA concentrations in blackberry and blackcurrant oils were significantly lower. The total PUFA content in raspberry seed oil was 10% lower than reported by Oomah [32], mainly due to a lower content of LA. Blackberry oil contained the lowest amount of PUFA (approximately 67%). The highest concentrations of saturated fatty acids (SFA) were measured in blackberry and sea buckthorn oil (approximately 10%), whereas raspberry oils contained the lowest amount of SFA. The highest and lowest concentrations of monounsaturated fatty acids were detected in blueberry oils and blackcurrant

oils, respectively. γ-linolenic acid was only detected in blackcurrant oils. Overall, the results of the analyses are in accordance with the results presented by Teng et al. [33].

Table 3. Fatty acid composition of cold-pressed seed oils.

	Fatty Acid (g/100 g Oil)									
	C14:0	**C16:0**	**C16:1**	**C18:0**	**C18:1**	**C18:2**	**C18:3ω3**	**C18:3ω6**	**C20:0**	**C20:1**
Blackberry 1	<0.1	5.3	0.1	3.7	19.5	49.4	17.4	N.D.	1.1	0.4
Blackberry 2	<0.1	4	<0.1	3.1	19.1	51.0	16.6	N.D.	1.0	0.4
Raspberry 1	<0.1	3.2	0.1	1.4	14.9	43.6	29.6	<0.1	0.6	0.1
Raspberry 2	<0.1	3.1	0.1	1.3	15.6	45.6	29.2	<0.1	0.5	0.1
Blueberry 1	0.4	7.3	0.4	2.0	21.2	37.9	24.3	<0.1	2.0	0.2
Blueberry 2	<0.1	4.2	0.1	1.2	20.8	42.9	30.3	<0.1	2.0	0.2
Strawberry 1	<0.1	3.4	0.2	1.4	15.7	38.9	36.3	<0.1	0.9	0.3
Strawberry 2	<0.1	4	N.D.	1.0	16.0	46.0	35.0	N.D.	N.D.	N.D.
Blackcurrant 1	<0.1	5.5	<0.1	1.6	14.4	47.7	13.2	15.8	0.2	1.1
Blackcurrant 2	<0.1	6	<0.1	1.6	15.1	45.2	11.8	15.9	0.2	1.1
Sea buckthorn 1	<0.1	7.1	0.5	2.8	22.9	35.4	29.8	<0.1	0.5	0.2
Sea buckthorn 2	N.D.	7.7	N.D.	2.1	15.4	38.9	36.3	N.D.	N.D.	N.D.

N.D. = not detected

3.5. Sterol and Tocopherol Contents

In most vegetable oils, sterols are the principal components of unsaponifiable substances. The main sterols of vegetable oils are β-sitosterol, campesterol, stigmasterol, and brassicasterol [34]. The phytosterol content in the berry seed oils from the present study is shown in Table 4. The highest values of total phytosterols, exceeding 4500 mg/kg, were determined in blueberry oils, while the lowest amounts were detected in the raspberry oils. In most oils, β-sitosterol was the predominant phytosterol, the highest amount of which was found in blueberry oils (4300 mg/kg). Blueberry oils also contained the highest amounts of campesterol, but no brassicasterol was detected in these oils. The highest amount of brassicasterol was detected in one of the sea buckthorn oils.

Table 4. Sterol content of oils from blackcurrant, raspberry, blackberry, blueberry, strawberry, and sea buckthorn seed oils (mg/kg).

	Sterols (mg/kg)			
Plant Species	**Brassicasterol**	**Campesterol**	**Stigmasterol**	**β-Sitosterol**
Blackcurrant 1	172.4	<0.1	<0.1	272.9
Blackcurrant 2	102.5	<0.1	<0.1	210.0
Raspberry 1	115.1	<0.1	<0.1	194.0
Raspberry 2	137.7	<0.1	<0.1	182.2
Blackberry 1	46.8	<0.1	<0.1	243.8
Blackberry 2	71.4	<0.1	<0.1	481
Blueberry 1	<0.1	200	34	4300
Blueberry 2	<0.1	190	18	4200
Strawberry 1	1.3	<0.1	<0.1	474
Strawberry 1	42	<0.1	<0.1	347
Sea Buckthorn 1	465.7	<0.1	0	584.3
Sea Buckthorn 2	120.5	23.2	17.9	633.4

From Table 5, it can be seen that except for in blueberry oil, α- and δ-tocopherol are predominantly present in all oils. Blackberry oils contained the highest total amount of tocopherols (1036 mg/kg) as well as the highest amount of δ-tocopherol (555.2 and 957.9 mg/kg). A different pattern was observed for the tocopherol profile in blueberry seed oil, where the concentration of β-tocopherol was the highest (46.6–57.4 mg/kg) compared to the α, δ, and γ isomers. Blackcurrant and sea buckthorn seed oils showed comparable levels of α- and γ-tocopherol.

Table 5. Tocopherol contents (mg/kg oil) in seed oils from different berry sources.

	Tocopherols (mg/kg Oil)			
Plant Species	α	β	γ	δ
Blackcurrant 1	239.6	35.2	14.0	239.7
Blackcurrant 2	335.1	34.5	12.2	239.9
Raspberry 1	123.5	41.3	5.5	207.3
Raspberry 2	133.7	32.0	7.3	210.9
Blackberry 1	57.1	22.6	6.5	555.2
Blackberry 2	37.1	64.6	7.5	957.9
Blueberry 1	<0.5	46.6	<0.5	37.3
Blueberry 2	<0.5	57.4	<0.5	36.1
Strawberry 1	55.0	57.5	4.9	87.8
Strawberry 1	53.9	34.2	6.1	137.4
Sea Buckthorn 1	275.4	20.0	17.9	256.6
Sea Buckthorn 2	393	3	15	306

3.6. Correlations between Parameters and Statistical Analysis

When plotting different parameters against each other, it can be seen that an increase in the total polyphenols (TP) content causes the FRAP value to increase (see Figure 3). The latter was confirmed by an ANOVA analysis of all data using TP, total amount of mono-unsaturated fatty acids (MUFA), total amount of polyunsaturated fatty acids (PUFA), total amount of sterols, and total amount of tocopherols as factors. From Table 6, it can be seen that TP has a significant positive influence on FRAP. The latter is as expected since the antioxidant activity of edible oils has been ascribed to the presence of phenolic compounds [23].

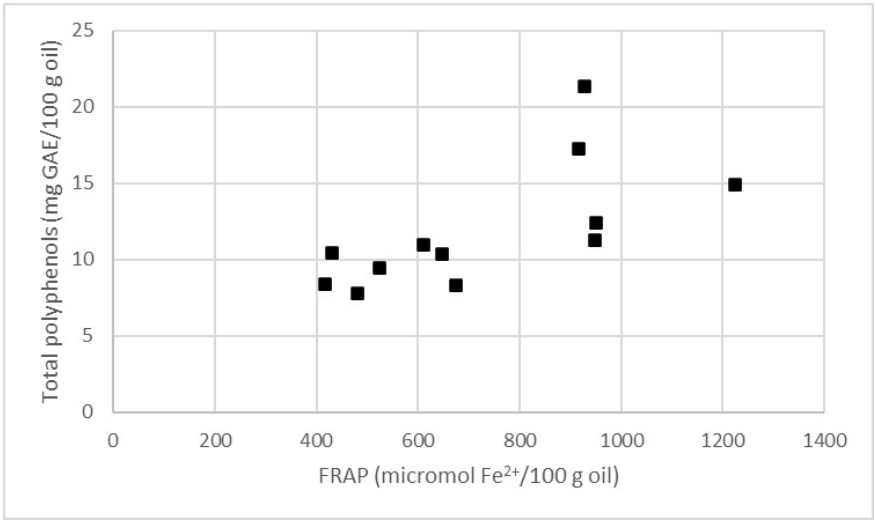

Figure 3. Total polyphenol content plotted against the FRAP value for all cold-pressed berry seed oil samples. Results are mean values of triplicates.

Table 6. ANOVA table for FRAP value (p-value < 0.05 indicates that a term is significant).

Source	Sum of Squares	df	Mean Square	F-Value	p-Value
Model	632,499	5	126,500	7.570	0.0143
TP	189,778	1	189,778	11.356	0.0150
MUFA	12,424	1	12,424	0.743	0.4217
PUFA	13,664	1	13,664	0.818	0.4007
Sterols	89	1	89	0.005	0.9443
Tocopherols	192	1	192	0.011	0.9182
Residual	100,269	6	16,712		
Cor. total	732,769	11			

When following the same approach for DPPH, it can be observed that the presence of tocopherols has a negative influence on the DPPH value (see Figure 4). The latter was once again confirmed by an ANOVA analysis using TP, PUFA, total amount of sterols, and total amount of tocopherols as factors (see Table 7). This result is unexpected since tocopherols are known for their radical scavenging activity [35], although recent publications also mention that tocopherols can also act as prooxidants [36].

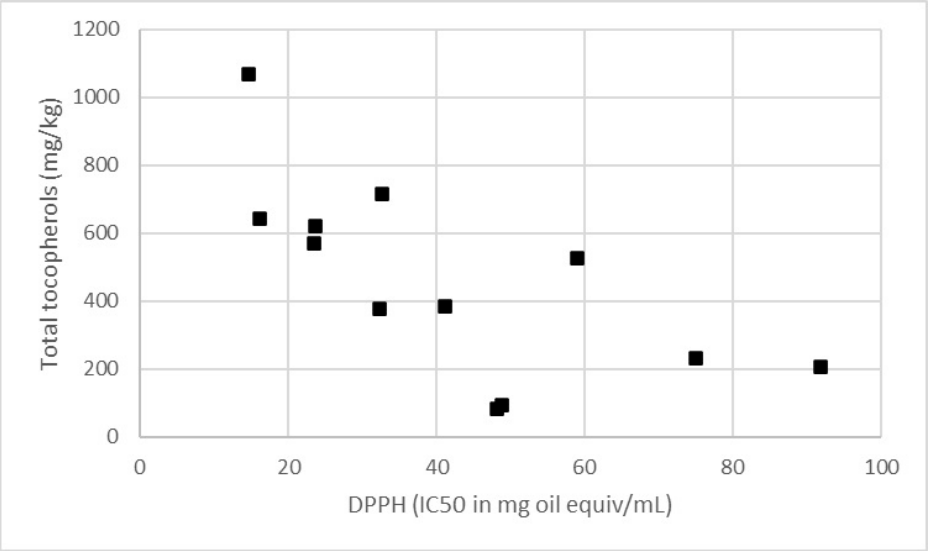

Figure 4. Total tocopherol content plotted against the DPPH value for all cold-pressed berry seed oil samples. Results are mean values of triplicates.

Table 7. ANOVA table for DPPH value (p-value < 0.05 indicates that a term is significant).

Source	Sum of Squares	df	Mean Square	F-Value	p-Value
Model	4787	4	1197	5.865	0.0215
TP	668	1	668	3.275	0.1133
PUFA	342	1	342	1.674	0.2368
Sterols	251	1	251	1.228	0.3044
Tocopherols	1349	1	1349	6.610	0.0370
Residual	1428	7	204		
Cor. total	6215	11			

4. Conclusions

Based on the results (see Section 3 'Results and Discussion'), the potential for commercial exploitation of berry seed oil as a byproduct in the production of juices, cordials, and jams appears to be excellent. The constituents of berry seed oils, especially omega-3 fatty acids and tocopherols, suggest that they are good nutraceuticals. This offers opportunities for the marketing of these oils as dietary supplements. The seed meal is a valuable byproduct that contains high amounts of polyphenols and has high antioxidant activity.

In the future, these byproducts can be exploited as food additives or supplements providing high-value microconstituents, which may be economically attractive for consumers.

From a dermatological point of view, lipid components for cosmetic applications are divided into two classes: those containing biologically active substances and those that only form an occlusive layer on the skin surface. Due to their chemical affinity, PUFA can complement structures of the intercellular cement of the stratum corneum. It would be interesting to study the anti-inflammatory as well as the UV-protecting properties of the oils.

Finally, there is still a lack of information on the impact of different oil extraction technologies on its yield and quality. In practice, this information is needed for business representatives when looking towards further commercial applications.

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