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Chemical composition, phenolics, and firmness of small black fruits

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Summary

Black fruits either cultivated as chokeberry (*Aronia melanocarpa* (Michx) Elliot), highbush blueberry 'Duke' (*Vaccinium corymbosum* L.), lowbush blueberry 'Putte' (*Vaccinium corymbosum* × *Vaccinium angustifolium*), and blue honeysuckle (*Lonicera caerulea* L.), or collected in the wild as bilberry (*Vaccinium myrtillus* L.), elderberry (*Sambucus nigra* L.), and wild blackberry (*Rubus* sp. L.) were assayed for nutritionally valuable components and phenolic composition. On fresh weight basis, lowest acidity was found for elderberry (0.83 g citric acid/100 g) and the highest for honeysuckle 2.86 g citric acid/100 g. Soluble solids content ranged from 16.0% (chokeberry) to 7.4% (blackberry). Honeysuckle berries showed the highest content of L-ascorbic acid (47 mg/100 g), while bilberries the lowest (7 mg/100 g). The berries also showed a disparate firmness ranging from 86 G/mm (bilberry) to 498 G/mm (chokeberry). Regarding total phenol, chokeberry and bilberry were predominant amounting 672.4 mg/100 g and 639.7 mg/100 g, respectively. Moreover, bilberry had the highest amount of anthocyanins (619.6 mg/100 g) and flavonoids (630.2 mg/100 g). The highest concentration of flavonols was observed for lowbush blueberry 'Putte' (35.2 mg/100 g), whereas, phenolic acids for chokeberry (121.9 mg/100 g). In contrast, the lowest total phenol was recorded for blackberry (137.8 mg/100 g) due to the low level of anthocyanins (129.4 mg/100 g), flavonols (5.1 mg/100 g), and phenolic acids (3.3 mg/100 g). Cyanidin 3-glucoside was the only anthocyanin occurring in the all species. The presence of chlorogenic acid and quercetin 3-glucoside was detected in the all berries except for blackberries. The 2-year study comparing black fruits of seven species out of different genera demonstrates their high nutritional value and health-promoting potential.

Introduction

The consumption of fruits plays an important role in the maintenance of health and in disease prevention, such as inflammation, cardiovascular disease, cancer and aging-related disorders (ZHENG and WANG, 2003; TURAL and KOCA, 2008; YILMAZ et al., 2009). Small fruits constitute a good source of natural antioxidant substances. Particularly, phenols contribute substantially to the antioxidant status of many fruit species having potential health benefits (PANTELIDIS et al., 2007). Fruits, especially black and red berries are very rich sources of these compounds (WU et al, 2004). Moreover, majority of fruits provide enjoyable eating experience. Three essential components of fruit sensory quality are flavour, sweetness (correlated with soluble solids content), and acidity (KAFKAS et al., 2007). Firmness contributing to fruit texture and imparting mechanical resistance under transport and handling manipulations is also in demand as it relates to good quality of fresh fruit.

The targeted berries in this project comprise: chokeberry (*Aronia melanocarpa* (Michx) Elliot) highbush blueberry (*Vaccinium corymbosum* L.), lowbush blueberry (*Vaccinium corymbosum* × *Vaccinium angustifolium*), bilberry (*Vaccinium myrtillus* L.), blue honeysuckle (*Lonicera caerulea* L.), elderberry (*Sambucus nigra* L.), and wild

blackberry (*Rubus* sp. L.).

Chokeberry (black chokeberry) is a species with lower cultivation requirements within *Rosaceae* family and is an indigenous species to eastern North America (JEPPSSON, 2000a). Native Americans used chokeberries both as a food and a natural remedy for cold treatment. Today, chokeberries are also cultivated in Eastern Europe (BENVENUTI et al., 2004). The dark violet berries of 10 mm diameter develop in corymbs. Chokeberry is grown mainly for juice production because berries are astringent and therefore not favoured as 'table fruits'. However, compared with other fruits chokeberries are most abundant in anthocyanins (ZHENG and WANG, 2003) and used as food colorants, and a source of valuable phytonutrients (SLIMESTAD et al., 2005).

Blueberries belong to the genus *Vaccinium*, a widespread genus with over 200 species of evergreen and deciduous woody plants varying in size from dwarf shrubs to trees. Blueberries include several closely related small fruit species. The main species are the North-American highbush blueberry (*Vaccinium corymbosum* L.) and lowbush blueberry (*Vaccinium angustifolium* L.) together with the native European blueberry, also called bilberry (*Vaccinium myrtillus* L.). In Northern Europe, bilberry is one of the most important wild berries. Blueberries are rich in anthocyanins and valued due to their suggested positive effects on night vision (RIIHINEN et al., 2008).

Blue honeysuckle (honeyberry, haskap, haskappu) is widely cultivated in Russia, China, and Japan, and has recently been introduced into the USA (CHAOVANALIKIT et al., 2004). The species is not very popular in Europe however, the climatic conditions are propitious for its cultivation. The plants are frost-resistant and they do not get frozen even when the temperature drops below -40°C, whereas expanded flowers do not get injured down to -8°C (KAWECKI et al., 1997). An early bearing (before strawberries) is another advantage. Moreover, the bushes and fruit are rarely infested by pests or pathogens, thus the species is well suited for organic cultivation (BORS, 2008). The fruits are elongated of elliptic, or cylindrical shape covered with an abrading wax bloom. One berry weight varies from 0.65 to 1.45 g. The flesh of fruit is dark-purple, aromatic, juicy, sweet and sour (resembles that of bilberry) (KAWECKI, 1996). Honeysuckle berries are used in a wide range of products including juice, wine, pastries, jams, dairy products and are eaten fresh (BORS, 2008).

Elderberry belonging to *Sambucaceae* family, also dubbed black or common elder, is a widespread species that grows on sunlight-exposed locations in most parts of Europe, Asia, North Africa, and the USA. The fruit develop in umbels. The berries are dark purple or black, each of a diameter up to 6 mm (VEBERIC et al., 2009). The berries ripening in late summer have been used for generations as a remedy for colds and influenza, and herpes. The high anthocyanin content makes them useful in processing of jelly or jams and concentrated juice is suitable as a natural colorant of other foods as candies and wine (KAACK et al., 2005).

Blackberry (bramble) (genus *Rubus* L., subgenera *Eubatus* Focke). The genus *Rubus* is a member of the rose family (*Rosaceae*). Wild raspberries occur on five continents, but are most abundant in the Northern Hemisphere. The temperate and subtropical region of eastern Asia is recognized as the centre of origin where the most

diversity exists. More than 200 species have been identified, but only a few are important commercially. These include the European and the North American red raspberry (*Rubus idaeus* ssp.) and the black raspberry (*Rubus occidentalis* L.) of the eastern USA (PRITTS, 2009). In Poland, 63 species of blackberries occur in the wild but only a few of them have nutritional and healing properties (BONENBERG, 1988). Because the species easily cross between themselves and with red raspberry thus have been used by plant breeders to improve cold hardiness and resistance to diseases, and insects for red raspberry and blackberry cultivars (PRITTS, 2009).

Materials and methods

Plant material

The berries compared in this study were collected in summer of 2007 and 2008 at fully ripe stage. Highbush blueberries 'Duke' were obtained from a commercial plantation near Szczecin, lowbush blueberries 'Putte' (*Vaccinium corymbosum* × *Vaccinium angustifolium*), blue honeysuckle berries 'Brazowa', and chokeberries originated from the Experimental Station at Rajkowo near Szczecin. The bilberries were collected in a coniferous forest near Sulechów (~190 km south from Szczecin) and blackberries were picked in a coniferous/deciduous forest near Szczecin.

Methods

The measurements of fruit size, weight, and firmness as well as soluble solids, titratable acidity and L-ascorbic acid content were performed on fresh berries instantaneously after the harvest.

Fruit mass was measured with RADWAG WPX 4500 electronic scales (0.01 g accuracy). Fruit diameter and firmness was measured with a non-destructive computerized device FirmTech 2 (BioWorks, USA). The firmness for 100 randomly selected berries from each replicate was expressed as a gram-force causing fruit surface to bend 1mm. Further, the acidity was determined by titration of a water extract of berry homogenate with 0.1 N NaOH to an end point of pH 8.1 (measured with an Orion 720 A pH meter; Orion Research Incorporated, USA). Titratable acidity was determined by potentiometric method using pH-meter Orion 720 A, USA, and expressed as equivalents of citric acid per 100 g. Soluble solids content was determined with a digital refractometer PAL-1 (Atago, Japan). L-ascorbic acid content was measured with a RQflex 10 rquantometer (Merck) and expressed as mg per 100 g fruit juice.

Phenolics composition of blueberries was determined in fruit samples that were kept frozen (-32°C) in polyethylene bags (250-300 g) until analyzed. The 2 g aliquots of fruit (after thawing) were extracted three times with ~8 mL of 80% MeOH acidified with a glacial acetic acid (1 mL of 100% acetic acid per 1 L 80% MeOH) in an ultrasonic bath for 15 min. The samples were filtered and transferred to the flasks and made up to the final volume 25 mL. Further, the extracts were centrifuged twice at 12,000 g and 20 µL of supernatants were injected into the HPLC system. The HPLC apparatus consisted of a Merck-Hitachi L-7455 diode array detector (DAD) and quaternary pump L-7100 equipped with D-7000 HSM Multisolvant Delivery System (Merck-Hitachi, Tokyo, Japan). The separation was performed on a Cadenza CD C18 (75 mm x 4.6 mm, 5 µm) column (Imtakt, Japan). Column oven temperature was set at 20 °C. The mobile phase was composed of solvent A (4.5% formic acid, pH 2.2) and solvent B (acetonitrile). The program began with a linear gradient from 0% B to 21% B (0-30 min), followed by washing and reconditioning the column. The flow rate was 1 mL min⁻¹ and the runs were monitored at the following wavelengths: phenolic acids at 320 nm, flavonol glycosides (quercetin and kaempferol derivatives) and luteolin at 360 nm, and anthocyanin glycosides at 520 nm. The Photo Diode

Array spectra were measured over the wavelength range 200-600 nm in steps of 2 nm. Retention times and spectra were compared to those of pure standards within 200-600 nm. Standards of anthocyanidin glycosides were obtained from Polyphenols Laboratories (Norway), while, flavonols, phenolic acids, and luteolin from Extrasynthese (France).

The results obtained were subjected to statistical analysis using Statistica 7.1 (Statsoft, Poland). The values were evaluated by the Duncan test and the differences at P<0.05 were considered significant.

Results and discussion

Anthocyanins. For the all berries compared in this study, anthocyanins constituted a dominating group accounting for 64.9% (lowbush blueberry) – 93.9% (wild blackberry) of total phenols (Tab. 1). Cyanidin-3-glucoside was detected in the all species exhibiting predominant participation in honeysuckle berries (69.2%) and wild blackberries (75.5%). Whereas, cyanidin-3-galactoside was the main anthocyanin in chokeberry fruit (56.4%). Regarding berries of *Vaccinium* genus, a predominant anthocyanin was delphinidin-3-galactoside in highbush and lowbush blueberries (24.7 and 26.1%, respectively), and delphinidin-3-glucoside in bilberries (21.8%). On the other hand, cyanidin-3-rutinoside occurred only in honeysuckle berries (1.3%), cyanidin-3-sambubioside in elderberry (43.9%), while malvidin-3-xylosylrutinoside was determined exclusively in black-berry fruits (10.9%).

Quantitatively (Tab. 1, 2) bilberry, chokeberry, and elderberry were richest in anthocyanins (619.6, 529.3, and 465.1 mg/100 g, respectively). The lowest content of anthocyanins was found for blackberry (129.4 mg/100 g), honeysuckle and lowbush blueberry (162.2 and 168.2 mg/100 g). The anthocyanin content is related to berry size and skin-to-pulp ratio as for highbush blueberries the pigments are located mainly in the skins. High anthocyanins content confirm reports of JAKOBEK et al. (2007a) for chokeberry (4341 mg/kg⁻¹), DEINEKA et al. (2005) for elderberry (0.42-0.86 g/100 g), and GIOVANELLI and BURATTI (2009) for bilberries (330-344 mg/100 g). Whereas, data obtained by PLESSI et al. (2007) corroborate low anthocyanin content in blackberries (0.066-0.130 g/100 g).

Anthocyanins impart the color to the plants or plant products in which they occur. They play a definite role in the attraction of animals for pollination and seed dispersal. Despite their functions in plants, anthocyanins were effective in reversing age-related deficit in neural and behavioral parameters; reveal anti-tumor activity and antioxidant activity scavenging reactive oxygen species, and inhibiting lipoprotein oxidation and platelet aggregation (reviewed by KONG et al., 2003).

Flavonols. The participation of flavonols in total phenol ranged from 1.7% in bilberry to 13.6% in lowbush blueberry (Tab. 1). For the tested berries six derivatives of quercetin and two glycosides of kaempferol were identified. Quercetin-3-glucoside was the most ubiquitous flavonol and its presence was detected in the all species but wild blackberry. Kaempferol-3-rutinoside was found in elderberry, bilberry, highbush blueberry and lowbush blueberry. On the other hand, quercetin-3-vicianoside and quercetin-3-robinobioside occurred only in chokeberry, whereas kaempferol-3glucoside was detected exclusively in elderberry.

In the literature, there is a great divergence over flavonol content in fruits indicating a profound influence of cultivar factors, geographical and climate conditions, and analytical procedures employed. In this study, significantly higher flavonol content was recorded for lowbush blueberry (>35 mg/100 g) followed by elderberry (>28 mg/100 g), and highbush blueberry (>26 mg/100 g) (Tab. 2). Definitely lowest flavonol content was found for wild blackberry (>5.1 mg/100 g). RIIHINEN et al. (2008) determined a sum of myricetin and quercetin

Tab. 1: Phenol pattern of selected berries – mean for 2007-2008

Phenol (mg/100 g)	Chokeberry (<i>Aronia melanocarpa</i>)	Elderberry (<i>Sambucus nigra</i>)	Bilberry (<i>V. myrtillus</i>) 'Duke' (<i>V. corymbosum</i>)	Highbush blueberry	Lowbush blueberry 'Putte' (<i>V. corymbosum</i> x <i>V. angustifolium</i>)	Honeysuckle 'Brazowa' (<i>Lonicera caerulea</i>)	Blackberry (<i>Rubus</i> sp.)
Delphinidin 3-galactoside	-	-	126.85	92.62	26.1	-	-
Delphinidin 3-glucoside	-	-	139.68	5.44	6.6	-	-
Delphinidin 3-arabinoside	-	-	67.64	49.51	8.2	-	-
Cyanidin 3-arabinoside	116.39	-	37.22	4.32	2.4	-	-
Cyanidin 3-galactoside	379.36	-	50.55	13.68	6.7	-	-
Cyanidin 3-glucoside	7.11	225.26	40.14	7.19	1.6	69.2	75.5
Cyanidin 3,5-diglucoside	-	14.39	-	-	-	4.9	-
Cyanidin 3-xyloside	26.40	-	-	-	-	-	3.9
Cyanidin 3-rutinoside	-	-	-	-	-	1.3	-
Cyanidin 3-sambubioside	-	225.45	-	-	-	-	-
Petunidin 3-galactoside	-	-	14.70	16.26	3.8	-	-
Petunidin 3-arabinoside	-	-	47.89	3.28	1.7	-	-
Petunidin 3-glucoside	-	-	34.09	8.55	1.4	-	-
Peonidin 3-galactoside	-	-	46.54	36.86	3.8	-	-
Peonidin 3-glucoside	-	-	11.57	21.13	1.4	3.7	-
Peonidin 3-arabinoside	-	-	-	0.38	0.2	-	-
Malvidin 3-galactoside	-	-	-	0.68	0.4	-	-
Malvidin 3-glucoside	-	-	2.69	1.18	0.2	-	3.6
Malvidin 3-arabinoside	-	-	-	10.57	0.4	-	-
Malvidin 3-xylosylglucoside	-	-	-	-	-	-	10.9
Chlorogenic acid	65.42	14.69	9.48	76.72	21.5	9.5	-
3,5-Dicaffeoylquinic acid	-	-	-	-	-	2.4	-
Neochlorogenic acid	56.51	5.30	-	-	-	0.4	-
p-Coumaric acid	-	-	-	-	-	-	0.9
Ellagic acid derivatives	-	-	-	-	-	-	1.5
Quercetin 3-galactoside	8.31	-	5.68	19.16	9.2	-	-
Quercetin 3-glucoside	4.03	2.30	1.17	3.85	2.5	1.6	-
Quercetin 3-ramnoside	-	-	3.36	1.51	0.8	-	-
Quercetin 3-vicianoside	2.36	-	-	-	-	-	-
Quercetin 3-robinobioside	1.03	-	-	-	-	-	-
Quercetin-3-rutinoside	5.51	21.95	-	-	-	2.8	-
Kaempferol 3-rutinoside	-	1.47	0.41	2.05	2.92	-	-
Kaempferol 3-glucoside	-	1.04	-	-	-	-	-
Flavonol unidentified	-	-	-	-	-	2.9	3.7
Luteolin-7-O-glucoside	-	-	-	-	-	1.3	-

as 562 $\mu\text{g g}^{-1}$ in the peels of 'Northblue' (*Vaccinium corymbosum* × *Vaccinium angustifolium*), whereas no flavonols were detected in berry pulps. Also, for elderberry there are reports indicating higher sum of quercetins 51.94-73.43 mg/100 g (VEBERIC et al., 2009) or 29-60 mg/100 g (KAACK and AUSTED, 1998). For highbush blueberries grown organically in New Jersey (USA) WANG et al. (2008) obtained flavonols scope 75.4-197.2 $\mu\text{g/g}^{-1}$, while conventionally cultivated plants had 83.2-119.6 $\mu\text{g/g}^{-1}$. MI et al. (2004) for blackberries obtained 102.0-160.2 mg flavonols per kg responding to the values for bilberry and honeysuckle estimated in this study.

Phenolic acids. Qualitatively, among phenolic acids, chlorogenic acid was most widely distributed in the berries, except for blackberry (Tab. 1). For highbush and lowbush blueberries the participation of chlorogenic acid surpassed 20% of total phenol. Neochlorogenic acid was detected in chokeberry, elderberry, and honeysuckle. The

presence of 3,5-dicaffeoylquinic acid was specific for honeysuckle berries, whereas p-coumaric acid and ellagic acid derivatives occurred only in blackberries. The berries showed different quantities of phenolic acids (Tab. 1, 2). Chokeberries had the highest amount of phenol acids (>120 mg/100 g) followed by highbush blueberry (76.72 mg/100 g) and lowbush blueberry (55.60 mg/100 g). The smallest amount of phenolic acids was found for blackberries (3.31 mg/100 g). Regarding phenolic acids, the greatest divergence was observed between chokeberry (121.93 mg/100 g) and bilberry (9.48 mg/100 g) both having similar level of total polyphenol. ZHENG and WANG (2003) measured much higher values as a sum of caffeic acid derivative and caffeic acid (2617.5 $\mu\text{g/g}$ fresh weight) for chokeberries, however, chlorogenic acid was not detected. RIIHINEN et al. (2008) for highbush blueberry obtained higher value of hydroxycinnamic acids in berry pulp 923 $\mu\text{g/g}$ compared with the data found in this study (76.7 mg/100 g). Further, MERTZ et al. (2007)

Tab. 2: Phenolic composition of selected berries - mean of 2007-2008

Species	Phenolic compounds (mg/100 g)					
	Anthocyanins	Flavonols	Luteolin-7-O- α glucoside	Total flavonoids	Phenolic acids	Total phenol
Chokeberry	529.3 d	21.2 cd	-	556.0 e	121.9 f	672.4 e
Honeysuckle 'Brazowa'	162.2 a	15.0 bc	2.6	177.2 ab	25.1 c	204.9 b
Highbush blueberry 'Duke'	271.6 b	26.6 de	-	298.2 c	76.7 e	374.9 c
Lowbush blueberry 'Putte'	168.2 a	35.2 f	-	203.4 b	55.6 d	259.0 b
Bilberry	619.6 e	10.6 ab	-	630.2 f	9.5 ab	639.7 e
Elderberry	465.1 c	28.5 e	-	493.6 d	20.0 bc	513.6 d
Blackberry	129.4 a	5.1 a	-	134.5 a	3.3 a	137.8 a

report a sum of conjugated forms of hydroxycinnamic acids ranging from 6.74 mg/100 g dry matter (*Rubus adenotrichus*) to 12.7 mg/100 g (*Rubus glaucus*).

The differences in the content of identified compounds summing up for total phenol and phenolic acids are in turn reflected in the level of total flavonoids calculated for the species (Tab. 2).

Flavons. Luteolin 7-O-glucoside (2.60 mg/100 g) was the only flavon identified in this study. Its presence was detected only in honeysuckle berries amounting 1.3 mg/100 g (Tab. 1, 2). In our previous study (SKUPIEN et al., 2007), the berries of honeysuckle 'Zielona' showed 9.40 mg/100 g luteolin-7-O-glucoside.

Total phenols. The berries varied among themselves significantly in total phenol (Tab. 1, 2). Chokeberries (>670 mg/100 g) and bilberries (>630 mg/100 g) were predominant, followed by elderberry (>510 mg/100 g). The lowest content of phenolics was determined in wild blackberries (>130 mg/100 g). JAKOBEK et al. (2007b) obtained higher amount of total phenol for chokeberry (7194 mg/kg) and DAWIDOWICZ et al. (2006) for elderberry (62.16-73.07 g/100 g). GIOVANELLI and BURATTI (2009) observed similar values (577-614 mg/100 g) for bilberries. On the other hand, PLESSI et al. (2007)

reported much higher phenolics content for cultivated blackberries (0.402-0.556 g/100 g) similar to the content obtained in this study for elderberries.

Soluble solids. The great variability was found between the berries regarding soluble solids content (SSC) (Tab. 3). Chokeberries showed the highest SSC 16.0%, whereas blackberry the lowest 6.7%. Similar results for chokeberries were obtained by JEPSSON (2000a) 16.3-17.8%, for blueberries (13.4-14.9%) and bilberries (15.1-15.6%) by GIOVANELLI and BURATTI (2009), for elderberry wild population (7.1-17.5%) by KAACK et al. (2005), and for green-ripe maturation stages of blackberries (7.00-11.11%) by TOSUN et al. (2008).

Acidity. Total acid content in the berries was also differentiated (Tab. 3). Lower records were observed for elderberries, lowbush and highbush blueberries (0.83-0.92 g citric acid/100 g). Whereas, highest acidity showed blackberries (2.20 g citric acid/100 g) and honeysuckle berries 2.89 g citric acid/100 g). TOSUN et al. (2008) for ripe blackberries determined twice as much of citric acid content (5.78 g citric acid/100 g). On the other hand, data obtained by ARUS and KASK (2007) corroborate findings for honeysuckle berries (1.6-2.9% organic acids). Also, titratable acidity found for highbush

Tab. 3: Soluble solids, titratable acidity, and vitamin C content in selected berries (mean for 2007-2008)

Species	Soluble solids (%)	Titratable acidity (g citric acid/100 g)	Vitamin C (mg/100 g)
Chokeberry (<i>Aronia melanocarpa</i>)	16.0 d	1.42 b	31 a
Honeysuckle 'Brazowa' (<i>Lonicera caerulea</i>)	10.1 b	2.86 c	47 c
Highbush blueberry 'Duke' (<i>Vaccinium corymbosum</i>)	14.2 cd	0.92 a	34 a
Lowbush blueberry 'Putte' (<i>V. corymbosum</i> x <i>V. angustifolium</i>)	12.5 bc	0.88 a	27 b
Bilberry (<i>Vaccinium myrtillus</i>)	13.0 c	1.44 b	7 a
Elderberry (<i>Sambucus nigra</i>)	13.8 cd	0.83 a	15 a
Blackberry (<i>Rubus</i> sp.)	7.4 a	2.34 c	11 a

blueberries (1.15-1.47 g citric acid/100 g) and for bilberries (1.00-1.18 g citric acid/100 g) by GIOVANELLI and BURATTI (2009) are in accordance to the results for *Vaccinium* berries estimated in this study (0.88-1.44 g citric acid/100 g).

Vitamin C. L-ascorbic acid content determined for the species in berry juice ranged from 47 mg/100 g (honeysuckle) to 7 mg/100 g (bilberry) (Tab. 3). For honeysuckle cultivars grown in South Estonia ARUS and KASK (2007) report higher values 66-77 mg/100 g. NOORMETS et al. (2006) estimated the range 6.2-14.3 mg/100 g for vitamin C in *Vaccinium myrtillus*, *Vaccinium corymbosum* x *Vaccinium angustifolium* and *Vaccinium angustifolium*. Whereas, SINELLI et al. (2008) found lower values for *Vaccinium corymbosum* 0.05-8.00 mg/100 g. For elderberry KAACK and AUSTED (1998) obtained 6-25 mg/100 g. However, the content of 31 mg/100 g recorded for chokeberry was high compared to the data obtained by BENVENUTI et al. (2004) 13.1 mg/100 g. Cultivars of blackberry studied by PANTELIDIS et al. (2007) and BENVENUTI et al. (2004) showed similar level of ascorbic acid respectively 14.3-17.5 mg/100 g and 12.4-13.1 mg/100 g.

Firmness. Comparing physical properties of berries imparting mechanical resistance as well as transport and storage suitability it can be said that chokeberries (498 G/mm) surpassed other tested fruits (Tab. 4). In our previous study (SKUPIEŃ et al., 2008), control chokeberries also showed high firmness (309-570 G/mm). Lowbush and highbush blueberries demonstrated medium rates of firmness (364 and 251 G/mm, respectively). The lowest firmness was measured for bilberries (86 G/mm) indicating softness of these perishable fruits. The damage of fruit skin is detrimental because it affects the appearance negatively that is especially important for fruits produced for fresh market purpose. Further, cracking and damage of skin exposes fruits to oxygen causing browning of anthocyanins and pathogen attack (JEPSSON, 2000b).

Fruit size and weight. Chokeberry and highbush blueberry were characterized by the biggest fruits (17.8 and 15.8 mm, respectively) (Tab. 4). However, the highest mass of a single fruit was observed for wild blackberry (1.23 g), honeysuckle (1.15 g) and highbush blueberry (1.04 g). The elderberries were the smallest (5.7 mm) and of lowest

one-fruit weight (0.19 g). JEPSSON (2000b) measured higher fruit weight for 8 genotypes of chokeberry varying from 1.22 g (in 1995) to 1.96 g (in 1996) (after recalculation). For honeysuckle (OCHMIAN et al., 2008) berry weight varied from 0.75 to 1.28 g depending on genotype and seasonal variation. GIOVANELLI and BURATTI (2009) observed 0.80-1.60 g (after recalculation) for highbush blueberry and 0.28-0.29 g for bilberry.

Conclusions

Black fruits differ in size, some of them are cultivated species and others grow in the wild. The berries are palatable and rich in phenolic compounds however their properties may vary considerably. Among the berries analyzed in this finding the highest ratio for soluble solids: titratable acidity was found for elderberry and highbush blueberry 'Duke', whereas for blue honeysuckle berries 'Brazowa' and wild blackberries soluble solids:titratable acidity ratio was ~5-fold lower. The highest L-ascorbic acid content showed honeysuckle berries while the lowest level was found for bilberries. Chokeberry fruits were characterized by highest firmness and the bilberries were the softest. Regarding total phenol, chokeberries and bilberries were predominant, and the highest flavonoid and anthocyanin content was found in bilberries. On the other hand, lowbush blueberries 'Putte' demonstrated the highest flavonol content, whereas chokeberries had the highest amount of phenolic acids. Significantly lower values of total phenol and phenolic acids were recorded for wild blackberries.

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Tab. 4: Physical properties of selected berries (mean of 2007-2008)

Species	Fruit firmness (G/mm)	Fruit diameter (mm)	Weight of one fruit (g)
Chokeberry (<i>Aronia melanocarpa</i>)	498 e	17.8 e	0,80 b
Honeysuckle 'Brazowa' (<i>Lonicera caerulea</i>)	116 a	10.7 b	1.15 c
Highbush blueberry 'Duke' (<i>Vaccinium corymbosum</i>)	351 cd	15,8 d	1.04 c
Lowbush blueberry 'Putte' (<i>V. corymbosum</i> x <i>V. angustifolium</i>)	364 d	13.2 c	0.77 b
Bilberry (<i>Vaccinium myrtillus</i>)	86 a	14.3 c	0.79 b
Elderberry (<i>Sambucus nigra</i>)	289 c	5.74 a	0.19 a
Blackberry (<i>Rubus</i> sp.)	223 b	13.5 bc	1.23 c

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