Agronomy Research **16**(2), 454–463, 2018
https://doi.org/10.15159/AR.18.039

Research on the mineral composition of cultivated and wild blueberries and cranberries

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Abstract. European cranberry (*Vaccinium oxycoccos* L.) and European bilberry (*Vaccinium myrtillus* L.) are among the most popular wild-harvested fruits in Latvia, traditionally used in folk-medicine and food. The commercial cultivation of American cranberry (*Vaccinium macrocarpon* Ait.) and highbush blueberry (*Vaccinium corymbosum* L.) was successfully started during last 20 years. With a berry production increase due to considerable hectarage of plantings and growing consumer interest in health-improving foods cultivated blueberries and cranberries have found a place in a daily intake as an excellent source of phenolic and nutritive compounds, vitamins and minerals. As the chemical composition of *Vaccinium spp*. has an important implication on human health, detailed information on the nutritional content of berries are of special importance. The aim of this study was to compare the contents of twelve biologically essential elements (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B) in berries of four *Vaccinium* species: cultivated and wild blueberries (*Vaccinium corymbosum* and *Vaccinium myrtillus*) and cranberries (*Vaccinium macrocarpon* and *Vaccinium oxycoccus*). Together 136 (leaf and berry) samples were collected from 7 main cranberry and blueberry producing sites and 17 native woodland areas and bogs in Latvia. A comparison of wild and cultivated species showed similar concentrations for the macroelements K, Ca and S in cranberry and N, P in blueberry fruits. While statistically significant differences were found for N, P and Mg in case of cranberries and Ca, K, Mg and S for blueberries. The research revealed statistically significant differences of most micronutrients in cultivated and wild berries. Plant leaf and fruit analysis revealed the organ-specific distribution of mineral elements in all species studied. In most of the cases, leaf analysis supported concentration differences in fruits.

Key words: *Vaccinium myrtillus, Vaccinium corymbosum*, *Vaccinium oxycoccus*, *Vaccinium macrocarpon*, mineral composition of fruits.

INTRODUCTION

American cranberry (*Vaccinium macrocarpon* A.) and highbush blueberry (*Vaccinium corymbosum* L.) are perennial flowering plants from the family *Ericaceae* of the genus *Vaccinium*, commercial cranberry and blueberry varieties, in general, are indigenous to eastern and central North America including the eastern territories of Canada (Trehane, 2004). Commercial production of Vaccinium species in the United States of America has existed since the latter part of the eighteenth century (Eck, 1990). While European bilberry (*Vaccinium murtillus* L.) and European cranberry (*Vaccinium* *oxycoccos* L.) is one of the most popular wild-harvested fruits in many North countries, traditionally used as healthy food as well as in folk medicine. Headaches, fever, eye problems, diarrhea and other problems have all apparently been eased or cured by various vacciniums. Unfortunately, there are wide fluctuations in yield from year to year depending on several factors. The yield of wild berries are often reduced by insufficient water in summer, winter damage and competition from other plant species (Karlsons & Osvalde, 2017).

Many species of *Vaccinum* have a long history of being used for medical purposes. Recent advances in nutrition science have shown that diet has a potential effect on human health and development, dietary guidance is persistent in recommending greater consumption of fruit and vegetables to promote health (Blumberg et al., 2016; Istek & Gurbuz, 2017). Increased consumption of fruits and vegetables can replace foods high in saturated fats, sugar and salt and thus improve the intake of most micronutrients and dietary fiber (Ekholm et al., 2007). Cranberry and blueberry fruits are rich sources of bioactive compounds, such as phenolics, organic acids, anthocyanins, proanthocyanidins, flavonol glycosides, vitamin C, carbohydrates as well as dietary fiber and minerals (Reed, 2002; Nile & Park, 2014; Liu et al., 2015; Michalska & Lysiak, 2015; Szajdak & Inisheva, 2016).

Bioactive compounds from blueberries and cranberries are widely reported to demonstrate a number of health advantages including: inhibition of development and progression of cancer and cardiovascular diseases, antimicrobial activities and prevention of urinary tract infections, tooth and gum disease, stomach ulcers, obesity, diabetes, aging, reduction of cholesterol and biofilm formation (Dugoua et al., 2008; Mckay & Blumberg, 2008; Hwang et al., 2014; Koupy et al., 2015; Shi et al., 2017; Dróżdż et al., 2018).

Vaccinium berries are also valued for their fresh taste as well as their potential for being processed. Today, an increasing demand for healthy ingredients by the food industry and changed consumer consciousness provide great opportunities for further progress of cranberry and blueberry production. The cultivation of American cranberries and blueberries in Latvia is comparatively recent – while the first experimental plantations were established in the middle of 1980's, commercial cultivation of these berries started in last 20 years (Osvalde & Karlsons, 2010). In general, about 98% of global production of cranberries and 85% of blueberries comes from the United States of America and Canada alone (FAOSTAT). However, with more than 125 ha of commercial plantings, Latvia is the sixth major cranberry producing country (10 top countries in cranberry production, 2018). In 2018, there was an estimated 280 ha of highbush blueberries planted in Latvia with increasing annual hectarage.

While the content of anthocyanins and other phenolic compounds, as well as the role of different species of *Vacciniums* in health promotion is quite often determined and compared, the concentration of essential mineral elements, which are also the important components of fruits, was rarely reported (Dróżdż et al., 2018). It should be noted, that many external factors as growth environment (soil, geographical conditions), cultivation and fertilization practices are widely diverse in different cranberry and blueberry production and wild harvesting countries and could contribute to the mineral composition of fruits.

A survey was carried out to compare the contents of twelve biologically essential elements (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B) in berries and leaves of four *Vaccinium* species: cultivated and wild blueberries and cranberries. Plant tissue (leaf) and berry analysis were used to evaluate the content of analyzed nutrients.

MATERIALS AND METHODS

Together 136 (leaf and berry) samples of four *Vaccinium* species: cultivated and wild blueberries – Highbush blueberry, (*Vaccinium corymbosum*) and European bilberry, (*Vaccinium murtillus*) and cranberries (American cranberry, (*Vaccinium macrocarpon*) and European cranberry, (*Vaccinium oxycoccus*) were collected from 7 main cranberry and blueberry producing sites (Gaujienas, Talsu, Krāslavas, Babītes, Beverīnas, Smiltenes and Varakļānu district) and 17 native woodland areas and bogs (Jelgavas, Saldus, Mārupes, Ķekavas, Olaines, Līvānu, Salaspils, Tukuma, Jūrmalas, Jaunpiebalgas, Valkas, Jaunpils district) in Latvia.

Berry and leaf materials were collected at each site as a composite sample from locations representative of the planting or woodland area in berry harvest time (July – August for blueberries, September for cranberries. For each composite sample approximately 500 g of berries and 200 g of leaves were collected.

The leaf and berry material was oven-dried at 60 °C to a constant weight and finely ground using a laboratory mill. Then the samples were dry-ashed in concentrated HNO_3 vapors and re-dissolved in HCl solution (HCl – distilled water mixture 3:100) (Rinkis et al., 1987). Concentrations of 12 biogenous elements (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B) were determined in all berry and leaf samples. The levels of Ca, Mg, Fe, Cu, Zn, and Mn were estimated by atomic absorption spectrophotometer (Perkin Elmer AAnalyst 700, acetylene-air flame) (Page et al., 1982) those of N, P, Mo, B by colorimetry, S by turbidimetry, and K by a flame photometer (Jenwey PFP7, air propane-butane flame). Mineral concentrations in plant tissue for macronutrients were expressed as mass percent (%), and for micronutrients as mg kg^{-1} of dry weight, while macro- and microelements in berries were expressed as mg 100 g^{-1} of fresh weight. The contribution of 100 g of fresh berries to the Recommended Dietary Allowance (RDA) for adults per day was calculated. All chemical analyses were done in the Laboratory of plant mineral nutrition of the Institute of Biology, University of Latvia. The levels of statistical significance were determined with MS Excel 2016. Standard errors (SE) were calculated in order to reflect the mean results of chemical analysis of leaves and berries. T-test 'Two-Sample Assuming Unequal Variances' ($p < 0.05$) was used to compare the mean element concentrations of fruits and leaves of four *Vaccinium* species. To assess differences between the chemical compositions of wild and cultivated cranberry and blueberry leaves and berries, the principal component analysis (PCA) was done using PC-ORD Version 6 (McCune & Mefford, 1999).

RESULTS AND DISCUSSION

The relationship between food and health becomes increasingly significant as consumers now demand healthy, tasty and natural foods that have been grown in uncontaminated environments. Mean macro- and micronutrient concentrations in berry and leaf samples, as well as concentration range, are shown in Table 1 to Table 3. In general, our research revealed statistically significant differences for majority analyzed mineral elements between studied species in fruits and leaves.

Table 1. Mineral element concentrations in *Vaccinium spp*. leaf samples

Element	*V. oxycoccos*	*V. macrocarpon*	*V. myrtillus*	*V. corymbosum*
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
	Macroelements (% dry weight)			
N	0.81 ± 0.048a[1]	0.65 ± 0.017a	1.08 ± 0.051a	1.64 ± 0.064b
P	0.07 ± 0.005a	0.12 ± 0.011b	0.12 ± 0.006a	0.13 ± 0.005a
K	0.35 ± 0.014a	0.54 ± 0.029b	0.77 ± 0.031a	0.43 ± 0.041b
Ca	0.75 ± 0.039a	0.89 ± 0.055a	0.84 ± 0.046a	0.74 ± 0.049a
Mg	0.12 ± 0.01a	0.22 ± 0.01b	0.32 ± 0.029a	0.28 ± 0.016a
S	0.09 ± 0.004a	0.10 ± 0.007a	0.15 ± 0.005a	0.14 ± 0.019a
	Microelements (mg kg^{-1} dry weight)			
Fe	95.18 ± 21.0a	71.31 ± 7.71b	81.87 ± 6.76a	102.45 ± 4.23b
Mn	1,531.76 ± 158.9a	298.00 ± 71.2b	814.40 ± 146.42a	288.36 ± 26.82b
Zn	36.94 ± 1.7a	26.44 ± 1.2b	18.60 ± 0.96a	9.59 ± 0.19b
Cu	4.88 ± 0.42a	9.06 ± 1.6b	4.97 ± 0.24a	3.97 ± 1.50a
Mo	0.28 ± 0.02a	0.41 ± 0.05b	0.23 ± 0.01a	0.36 ± 0.08b
B	23.94 ± 1.34a	39.13 ± 2.8b	22.73 ± 1.21a	23.73 ± 2.11a

[1]Means with different letters separately for cranberries *(V. oxycoccos* and *V. macrocarpon*) and for blueberries (*V. myrtillus* and *V. corymbosum)* in a row were significantly different (t-Test, $p < 0.05$).

Table 2. Mineral element concentration mg·100 g^{-1} in wild and cultivated cranberry fresh fruit

Element	*V. oxycoccos*		*V. macrocarpon*	
	Range	Mean ± SE	Range	Mean ± SE
	Macroelements (mg 100 g^{-1} fresh weight)			
N	14.9–81.8	54.9 ± 6.1a[1]	9.6–62.4	42.1 ± 3.7b
P	5.0–8.7	6.12 ± 0.26a	6.0–10.8	8.59 ± 0.32b
K	50.8–89.3	67.19 ± 2.86a	52.8–88.8	72.51 ± 2.06a
Ca	8.7–17.4	12.74 ± 0.63a	7.2–13.2	10.19 ± 0.50a
Mg	7.4–9.4	8.09 ± 0.16a	4.8–8.4	6.61 ± 0.22b
S	5.0–1 7.4	8.14 ± 1.10a	4.8–13.2	7.85 ± 0.52a
	Microelements (mg·100 g^{-1} fresh weight)			
Fe	0.12–1.02	0.31 ± 0.05a	0.22–3.88	0.72 ± 0.20b
Mn	0.97–4.19	2.59 ± 0.20a	0.058–0.51	0.19 ± 0.04b
Zn	0.11–0.18	0.15 ± 0.005a	0.04–1.18	0.16 ± 0.06a
Cu	0.04–0.08	0.06 ± 0.002a	0.03–0.07	0.049 ± 0.003a
Mo	0.002–0.006	0.003 ± 0.0003a	0.0002–0.007	0.004 ± 0.0004a
B	0.03–0.16	0.09 ± 0.009a	0.03–0.11	0.065 ± 0.005b

[1]Means with different letters in a row were significantly different (t-Test, $p < 0.05$).

In leaves, significant differences were stated for P, Mg, and all microelements in cranberries and N, K, Fe, Mn, Zn and Mo in blueberries. Thus supporting previous research on cranberries (Karlsons et al., 2009) and partly results gained by Pormale et al. (2010) on blueberries.

As a nitrogen is one of the controlling elements for American cranberry nutrition and adequate fertilization, in general, is used to maintain renewal growth, crop production, and flower bud development for the next crop (DeMoranville, 1997).

However, surprisingly similar (or even higher in wild cranberries) N concentrations were found between wild and cultivated cranberry leaf samples. It should be stressed that wild cranberry growing medium – sphagnum peat is especially N poor (Osvalde et al., 2010). It is evident, based on the present results, that wild cranberry has the ability to improve nitrogen uptake in suboptimal nutritional conditions.

Table 3. Mineral element concentration mg 100 g^{-1} in bilberry and cultivated blueberry fresh fruit

Element	*V. myrtillus*		*V. corymbosum*	
	Range	Mean ± SE	Range	Mean ± SE
	Macroelements (mg 100 g^{-1} fresh weight)			
N	67.5–150.0	91.4 ± 6.9a[1]	74.4–103.1	93.0 ± 6.6a
P	12.2–36.4	19.3 ± 2.2a	6.8–20.3	16.5 ± 3.3a
K	60.0–180.5	110.8 ± 8.9a	66.2–98.0	81.6 ± 6.6b
Ca	12.3–51.6	21.8 ± 3.7a	6.6–15.2	9.1 ± 0.7b
Mg	6.3–28.5	12.45 ± 2.0a	4.5–10.1	6.10 ± 0.5b
S	12.0–30.3	16.7 ± 1.1a	10.1–25.4	20.7 ± 3.5b
	Microelements (mg 100 g^{-1} fresh weight)			
Fe	0.23–0.68	0.38 ± 0.04a	0.25–0.59	0.47 ± 0.02a
Mn	0.23–4.35	1.72 ± 0.3a	0.14–1.52	0.57 ± 0.11b
Zn	0.09–0.30	0.15 ± 0.02a	0.08–0.12	0.10 ± 0.003b
Cu	0.047–0.14	0.072 ± 0.008a	0.01–0.09	0.026 ± 0.01b
Mo	0.001–0.005	0.002 ± 0.0003a	0.003–0.012	0.008 ± 0.002b
B	0.08–0.12	0.095 ± 0.004a	0.07–0.15	0.095 ± 0.007a

[1]Means with different letters in a row were significantly different (t-Test, $p < 0.05$).

Our research revealed a considerably higher content of Mn in *V. oxycoccus* leaves (1,531.8 mg kg^{-1}) in comparison to American cranberry leaves (298.0 mg kg^{-1}). In like manner, Mn concentration in bilberries was 814.4 mg kg^{-1} while in cultivated – 288.4 mg kg^{-1}. Such phenomenon could be explained by the different pH of the growing substrate and genetic differences between species. As reported previously, fertilization practice usually elevates substrata pH in cranberry and blueberry plantations (Osvalde et al., 2010). While significantly lower pH consequentially promotes the availability of Mn in natural high bogs. Fruit Mn contents of all analyzed *Vaccinium* species supported these differences.

It should be noted, that numerous conditions, like plant variety, growing conditions, harvesting, maturity stage can affect the chemical composition of fruit. Besides, the methods of sample preparation and methodology of chemical analyses also influence the obtained results. Thereby it can be complicated to compare and interpret the results obtained by different researchers.

A comparison of wild and cultivated species showed similar concentrations for the macroelements K, Ca and S in cranberry and N, P in blueberry fruits. While statistically significant differences ($p < 0.05$) were found for N, P and Mg in case of cranberries and Ca, K, Mg and S for blueberries. The obtained data indicated that nitrogen and potassium were the major mineral constituents in all analyzed species. The richest source of Ca, Mg (on average, 21.8 and 12.5 mg 100 g^{-1} FW) in this study was cultivated blueberry, while highest P (19.3 and 16.5 mg 100 g^{-1} FW) contents were found in both blueberry species.

The highest mean concentration of Fe (0.72 mg 100 g^{-1} fresh fruit) was found in the American cranberry, while the highest Mn and B (on average 2.59 and 0.09 mg 100 g^{-1} fresh fruit, respectively) concentrations were found in the European cranberry.

Overall, there are scarce comparable data in the literature which show the detailed mineral content of wild cranberries and wild blueberries. In general, our observations on wild and cultivated blueberries mineral content support studies made by Dróżdż et al. (2018) in Poland, Miljkovič et al. (2018) in Serbia and Pormale et al. (2010) in Latvia. Dróżdż et al. (2018) showed that the average Cu concentrations in wild and cultivated berries were similar while in our research Cu content in *V. myrtillus* was more than three times higher (0.072 to compare with 0.026 mg 100 g^{-1}) despite the fact that in leaves concentrations were similar. Comparable results of Cu concentration in *V. myrtillus* (0.60 mg 100 g^{-1}) berries show research made by Stanoeva et al. (2017) in Macedonia. In the present research, relatively high level of Mn was found in the studied wild blueberries and cranberries (2.59 and 1.72 mg 100 g^{-1}). Similar Mn levels were reported for bilberries consumed in Latvia (1.88 mg 100 g^{-1} FW) (Skesters et al., 2014) and higher in berries from Finland – 2.56 mg 100 g^{-1} (Ekholm et al., 2007). While the content of Mn in wild cranberry was similar in Finland (2.37 mg 100 g^{-1}) and previously determined by Karlsons et al. (2009) in Latvia.

The nutritional value of studied fruits as a dietary source of minerals is related to the contribution it makes to the Recommended Dietary Allowance (RDA). Our research shows that berries of both wild species (*V. oxycoccos* and *V. myrtillus*) are excellent sources of Mn (112.5% and 74.6% from recommended daily dose, accordingly) in human nutrition (Table 4). Also, wild berries could be qualified as a valuable source of macroelement P and microelements Cu and B. While cultivated berries provide more Fe and Mo. It should be stressed that cultivated cranberries and blueberries had significantly higher concentrations of Mo in their leaves and fruits, apparently due to use of Mo containing fertilizers. Therefore 100 g of cultivated cranberry and blueberry fruits could provide 8.9–18.1% Mo of RDA.

Table 4. The contribution of 100 g of fresh berries to the Recommended Dietary Allowance (RDA) for adults per day

Element	RDA*, mg	% of RDA supplied by 100 g fresh berries			
		V. oxycoccus	*V. macrocarpon*	*V. myrtillus*	*V. corymbosum*
P	700	7.8	6.0	13.1	13.3
K	2,500	2.7	2.9	4.4	3.3
Ca	1,000	1.3	1.0	2.2	0.9
Mg	420	1.9	1.6	3.0	1.5
S	850	1.0	0.9	2.0	2.4
Fe	8	3.8	9.0	4.8	5.9
Mn	2.3	112.5	8.3	74.6	24.8
Zn	11	1.4	1.5	1.4	0.9
Cu	0.9	7.1	5.4	8.0	2.9
Mo	0.045	7.3	8.9	4.4	18.1
B	1.5	6.0	4.3	6.4	6.4

* USDA National nutrient database for standard reference, (2017).

In general, the PCA of the chemical composition of cranberry leaves and berries demonstrated a good structure of the sampling points in the ordination space according to cranberry species. The first two components explained 55.15% and 48.53% of the total variance for leaves and berries, respectively (Fig. 1. A, B). The most important factors for the Axis 1 of the cranberry leaf PCA were Mn, K and Mg with eigenvector values ranging from 0.820 (Mn) to 0.793 (Mg), for the Axis 2 – Ca, N and S, with eigenvector values ranging from 0.720 (Ca) to 0.603 (S). The highest eigenvector value for the PCA of the berry results was also characteristics for Mn (0.889). In general, the samples of wild cranberry leaves were markedly located on the right side in the ordination space in the direction of N, Zn, Mn, and Fe, but the cultivated cranberries – mainly on the left side in the direction of K, Mg, Ca, B, Mo. The pronounced differences in the chemical composition were also clearly demonstrated for berries of wild and cultivated cranberries. The samples of wild berries were mainly located on the left side in the ordination space in the direction of such nutrients as Mn, Mg, N, and B, cultivated – on the right side in the direction of P and K.

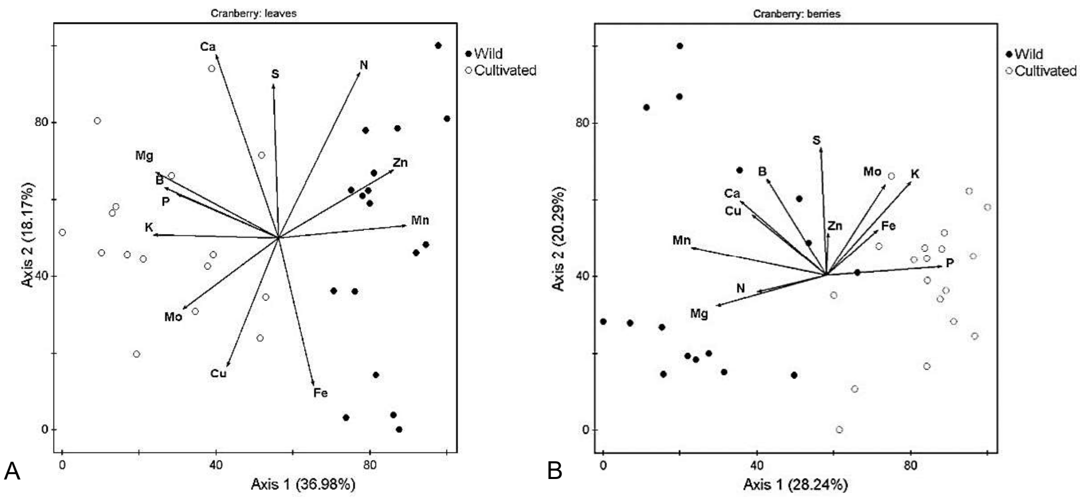

Figure 1. Principal component analysis (PCA) of the chemical composition of wild and cultivated cranberry leaves (A) and berries (B) in Latvia.

The PCA of the chemical results of wild and cultivated blueberry leaves and berries also confirmed the differences in the nutrient concentrations between species. The first two components of the PCA explained 55.74% and 70.04% of the total variance for leaves and berries, respectively (Fig. 2. A, B). In both PCA, the leaf and berry samples of cultivated blueberries were located on the side of the positive of the Axis 2, while the individual sampling sites of bilberry on the opposite side in the ordination space. There were two nutrient groups which mainly affected site distribution for leaf samples of cultivated blueberries: N and Fe, as well as Mo, S, and Cu with eigenvector values from 0.678 (Fe) to 0.785 (S). Generally, these differences could be largely attributed to peculiarities of management practices in blueberry cultivation. The distribution of bilberry leaves in the ordination space was mainly determined by Mn, Zn, and K, with eigenvector values in the range between 0.579 (Mn) and 0.811 (K).

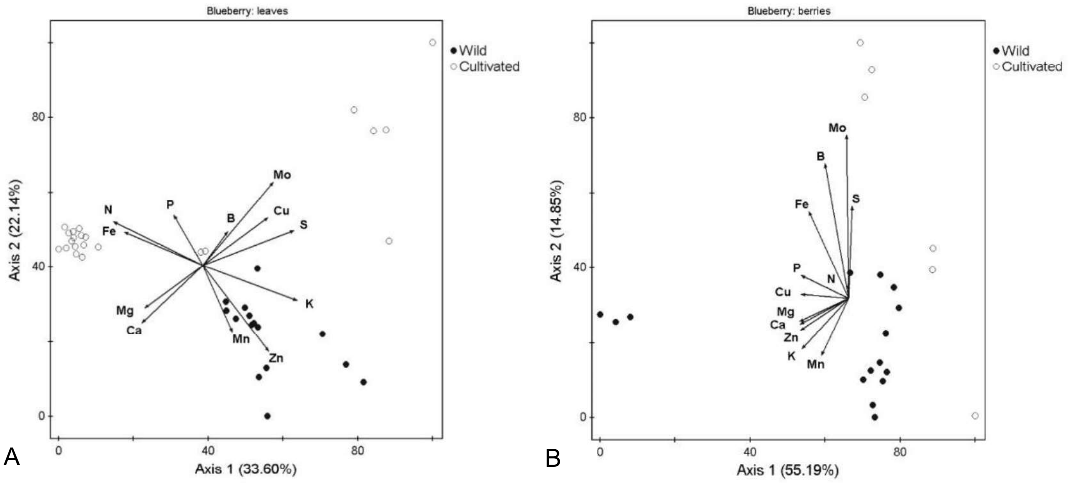

Figure 2. Principal component analysis (PCA) of the chemical composition of bilberry and cultivated blueberry leaves (A) and berries (B) in Latvia.

The results of the PCA for blueberry berries (Fig. 2. B) revealed that the most important elements for the 1st axis, which explained 55.19% of the total variance, were P, K, Ca, Mg, Zn and Cu with eigenvector values ranging from 0.930 to 0.979. The most important factors for the Axis 2 were Mo and B with eigenvector values 0.826 and 0.681, respectively. The PCA results showed a tendency that cultivated berries had higher concentrations of Mo, while the samples of bilberry berries were located in the direction of Mn. Although the most of the wild berry samples were located on the right side of the ordination space, three sites were on the opposite site, thus manifesting also a relatively wide variance of the wild berry chemical composition. Admittedly, the part of samples was located in the center of ordination space revealing certain similarity in the chemical composition of wild and cultivated blueberries.

CONCLUSION

As a conclusion, our study reveals, that studied species differ in their elemental composition. In general, cultivated blueberry and cranberry fruits had a higher content of Fe, Mo while wild berry fruits showed higher levels of Ca, Mg and especially Mn. All berries studied could be qualified as a good source of microelements: excellent source of Mn and valuable source of Fe, Cu, Mo, and B in human nutrition.

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