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Comparison of berry quality in highbush blueberry cultivars grown according to conventional and organic methods

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Abstract: This research was conducted in the Laboratory Orchard at the Department of Horticulture, West Pomeranian University of Technology in Szczecin and at a certified production farm specializing in the cultivation of highbush blueberry located in Szczecin. The effect of cultivation conditions—organic plantation in organic peat substrate (pH 3.46) and conventional plantation in mineral substrate (pH 5.32)—on the berry quality of four highbush blueberry cultivars (firmness, size, chemical composition including content of organic compounds and polyphenols) was examined. Blueberry bushes were planted at a spacing of 2.3 × 1.2 m. Bushes were planted on organic and conventional plantations, and the substrates differed in terms of mineral content. Specific environmental conditions and soil conditions (optimum pH of the substrate) resulted in larger berries on the organic plantations, and the total yield contained big berries (diameter, >12 mm; mean, 83.4%) with lower polyphenol content (287 mg 100 g^{-1}). The berries of the Elliott cultivar, regardless of how the crops were grown, were the largest, characterized by the lowest content of SS (15.3%) and the highest acidity (0.98 g 100 g^{-1}). They were also the most likely to shed. The Duke cultivar was most susceptible to mechanical damage (101 G mm) and was characterized by the lowest berry firmness (162 and 363 G mm) and polyphenol content (organic, 185 mg; conventional, 228 mg 100 g^{-1}).

Key words: Chemical composition, farming methods, firmness, phenolic, substrate, *Vaccinium*

1. Introduction

In recent years, there has been increasing interest in blueberries, which have a positive effect on health. Attention is also focused on production methods that cause the lowest possible negative impact on the environment. As a result, there is a demand for an organic system of farming, food production, and processing. In Europe this is reflected in the enlargement of the area of land cultivated organically and an increase in the number of farms. Organic production is defined by European Union Council Regulation (EEC) no. 2092/91. The main goal of organic agriculture is to obtain nutritious food in conjunction with the maintenance of sustainable soil fertility without the use of synthetic fertilizers and pesticides. Organic fertilizers and natural methods of plant protection are commonly used (plant extracts). Applying organic fertilizers only may affect the quantity and the quality of yield of successive crops. Rembiałkowska et al. (2006) reported that organic agriculture causes plants to significantly change the synthesis route of biologically active compounds to allow them to independently combat pests and diseases. One of the most important groups of compounds produced as secondary metabolites in the fight against pests and diseases are polyphenols. Generally, organic food, especially fruits and vegetables, is perceived to be more nutritious, better tasting, and environmentally friendlier, as compared to conventionally grown crops (Saba and Messina, 2003).

There are many publications that describe differences in the quality of agricultural products depending on the method of cultivation. Research confirms the fact that fruits and vegetables from organic production may contain more polyphenols as well as other compounds of an antioxidant character, such as vitamin C (Caris-Veyrat et al., 2004). Wang et al. (2008) found a higher content of polyphenols in blueberry fruits from organic farming and Wojdyło et al. (2013) found the same result in the organically farmed fruits of black and red currant. Research conducted by You et al. (2011) shows subtle differences in bioactive phytochemicals between the organically and conventionally grown berries. Asami et al. (2003) showed that maize grown organically contained more ascorbic acid and significantly more polyphenols than traditionally grown maize. Controversy remains regarding whether

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or not organic foods have a nutritional advantage when compared to their conventionally produced counterparts (Riahi et al., 2009). However, some claim they do, and some doubt that there is any difference between the two cultivation methods (Bourn and Prescott, 2002; Brandt and Mφlgaard, 2001; Magkos et al., 2003). Weibel et al. (2000) showed that the quality of organic apples was similar to fruit grown with the use of synthetic fertilizers and pesticides, and they found no significant difference in vitamin C content. Similar findings emerged in a study of the fruit of several cultivars of raspberry (Skupień et al., 2011). Wild blueberry (bilberry) has a significant therapeutic benefit (Pandır and Kara, 2013).

Highbush blueberry is characterized by a very specific growing habitat and soil requirements. Peat acidic soils are the best (pH 3.5–4.0) for blueberries, since the bushes have similar conditions in the wild. Light sandy soil can also be suitable for cultivation. It is important for the substrate to have stable moisture content, because the roots are sensitive to both excess and deficiency of water (Moore, 1993). The bushes are generated from species of the genus *Vaccinium*, which grow in soils with low levels of nutrients. As a result, the fertilizer requirements of blueberries, as compared to other fruit plants, are relatively low (Pormale et al., 2009).

The aim of this study was to assess the impact of organic and conventional farming on the highbush blueberry including size of the berry, firmness, and chemical composition including polyphenol compounds.

2. Materials and methods

The studies were carried out in the Laboratory of Orcharding at the Department of Horticulture, West Pomeranian University of Technology in Szczecin and at a certified production farm specializing in the cultivation of the highbush blueberry located in Szczecin. The research station is located in the Szczecińska lowland. In this area there are numerous hills of 40–60 m a.s.l., the remnants of the frontal moraine. This affects the distribution of rainfall intensity, the number of sunlight hours, temperature, and wind speed. The climate of this area is also significantly affected by the presence of big water basins (Szczecin Lagoon, Dąbie Lake, the Odra River), which provide additional moisture in the period of plant vegetation. The plantation is located in a flat area surrounded by forests (Figure 1). The organic plantation covers 40 ha of land near a peat mine surrounded by pine forests. The natural substrate is acidic peat with a thickness of 150–200 cm. The conventional plantation (60 ha) is located on the edge of a forest, and the substrate is mineral soil with a particle size of light sand. Blueberry bushes were planted at a spacing of 1.2–2.3 m in 2003. Bushes were from 150 cm high (Duke: conventional plantation) to 240 cm (Brigitta: organic plantation). The research focused on four cultivars: Sunrise, Brigitta, Duke, and Elliott.

Physical features of the berry (size, firmness, puncture of the skin, removal of the berry from the pedicel), soluble solids, and titratable acidity were measured in fresh berries immediately after harvest. Phenolic composition and mineral composition samples were determined in berry samples that were kept frozen (–32 °C) in polyethylene bags (500 g) until analysis. Fruits were harvested by hand 3–4 times depending on the season. For measurements, fruits of the designated areas were collected during the period of maximum yield (second to third yield collection).

The estimation of mineral content was carried out in accordance with the Polish standard (PN). After mineralization, total nitrogen content was determined with the Kjeldahl method. The content of K and Ca was measured with atomic emission spectrometry, whereas Mg was assessed by flame atomic absorption spectroscopy using SAA Solar. Phosphorus content was determined

Figure 1. View of the plantations: A - organic; B - conventional.

with the Barton method at wavelength 470 nm, whereas sulfur content was determined by turbidimetric method at wavelength 490 nm, employing a spectrophotometer (Marcel s 330 PRO).

The berry weight was measured with RADWAG WPX 4500 electronic scales (0.01 g accuracy). Firmness and puncture resistance of the berry skin was measured with a FirmTech2 apparatus (BioWorks, USA) on 50 randomly selected berries from three replicates and was expressed as a gram-force causing the berry surface to bend 1 mm. Punctures were made using a stamp with a diameter of 3 mm. The removal of the berry from the pedicel was measured by a portable Kirschenzipper device (UP GmbH). Soluble solids content was determined with a digital refractometer PAL-1 (Atago, Japan). Titratable acidity was determined by titration of a water extract of chokeberry homogenate with 0.1 N NaOH to an end point of pH 8.1 (measured with a multimeter Elmetron CX-732), according to PN-90/A-75101/04. For the HPLC analyses, 2 g aliquots of berries were extracted three times with approximately 8 mL of 80% MeOH acidified with a glacial acetic acid (1 mL of 100% acetic acid L-1 80% MeOH) in an ultrasonic bath for 15 min. The samples were filtered, transferred to flasks, and the final volume was made up to 25 mL. Then, 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 a D-7000 HSM Multisolvent delivery system (Merck-Hitachi, Tokyo, Japan). The separation was performed on a Cadenza CD C18 (75 × 4.6 mm, 5 µm) column (Imtakt, Japan). Column oven temperature was set at 30 °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 glycoside (quercetin and kaempferol) derivatives 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. All samples were measured three times. Results are presented as a percentage of total content of each identified phenolic compound. Standards of anthocyanidin glycosides were obtained from Polyphenols Laboratories (Norway), and standards for phenolic acids and flavonols were from Extrasynthese (France).

In order to determine the significance of differences, a two-factor analysis of variance was carried out followed by the assessment of the significance of differences using Tukey's test. Statistical analyses were performed using Statistica software.

3. Results and discussion

The substrates where the bushes were planted (organic and conventional) differed in terms of mineral content, pH, and humus content (Table 1). The organic plantation was established on a peat bog resulting from a degraded bog forest. The plantation is surrounded by a pine forest (*Pinus sylvestris*) with a touch of downy birch (*Betula pubescens*). This location is ideal for growing highbush blueberry. The mineral content in the soil also meets the requirements of this species (Table 1). This allowed the cultivation of blueberries by organic standards—without fertilization and chemical protection. The conventional plantation was established on agricultural wasteland that was subject to natural acidification while it was set aside. The soil is classified as light loamy sand (13%–15% floatable; pH 5.32), which does not comply with the requirements of the highbush blueberry. Therefore, the water used for watering the bushes was acidified with sulfuric acid to a pH of 4.0–4.2. Conventionally farmed fruit was fertilized with synthetic water-soluble nitrogen at a dose of 50 kg N. The organic plantation was not fertilized. The soil at both the organic and conventional plantations was richer in minerals than the soil at the plantations where Wach (2004) conducted research.

Organic fruit production methods certainly burden the environment less, but they often have a negative impact on the quality of the fruit, especially the size and degree of contamination by pathogens. These opinions in relation to the highbush blueberry have not been confirmed. The current study showed that the berries of all cultivars harvested from organically grown shrubs were larger (Table 2). The mean volume of 100 berries was 423 cm^3 and in conventionally grown berries, 246 cm^3. In the total yield from organic plantations the share of large berries (diameter >12 mm) ranged from 63.2% (Duke) to 91.6% (Elliott). Large berries harvested from conventional

Table 1. The content of macro- and micronutrients of the soil, in which highbush blueberry plants were grown.

	Content (mg 100 g^{-1})				
pH	P	K	Ca	Mg	N-NO$_3$
Organic: organic soil					
3.46	6.7	6.2	43	6.9	7.7
Conventional: mineral soil					
5.32	3.3	13.9	175	13.0	3.2

Table 2. The size and proportion of highbush blueberries in total yield depending on the method of cultivation.

Cultivar (B)	Farming methods (A)	Volume of 100 berries (cm^3)	Percentage of berry (%)		Weight of 100 berries (g)	
			Diameter		Diameter	
			<12 mm	>12 mm	<12 mm	>12 mm
Sunrise	Organic	385	11.4	88.6	84.2	247
Brigitta		440	9.7	90.3	85.4	346
Duke		420	36.8	63.2	98.3	262
Elliott		445	8.4	91.6	82.5	315
Mean		423	16.6	83.4	87.6	293
Sunrise	Conventional	210	76.1	23.9	63.4	138
Brigitta		200	47.6	52.4	86.2	155
Duke		265	59.5	40.5	61.6	171
Elliott		310	16.1	83.9	68.0	164
Mean		246	49.8	50.2	69.8	157
Sunrise	Mean	298	43.8	56.3	73.8	193
Brigitta		320	28.7	71.4	85.8	251
Duke		343	48.2	51.9	80.0	217
Elliott		378	12.3	87.8	75.3	240
LSD$_{0.05}$		A 24; B 27; A × B 42	-	-	A 17.2; B 19.1; A × B 22.8	A 33; B 41; A × B 55

plantations were less numerous; in the case of the Sunrise cultivar, only 23.9%, whereas the Elliott cultivar produced 83.9% large fruit. The highbush blueberry is an example of a species that can be successfully grown organically. The described plantation soil and habitat are very similar to the natural habitat of species of the genus *Vaccinium*. The thickness of the soil, up to 2 m, provides optimal conditions for root growth, and the pH of 3.46 is ideal for this species. In addition, the level of minerals meets the needs of the bushes. The substrate at the conventional plantation is far from optimal, especially the pH, which is 5.32 despite constant watering with acidulated water. This is clearly reflected in the quality of the berry. In addition to the influence of the method of cultivation, there were significant differences in berry size among cultivars. At the organic plantation berry size was similar, and the volume of 100 berries ranged from 385 cm^3 (Sunrise) to 445 cm^3 (Elliott). The Brigitta shrubs responded most to changes in growing conditions; the volume of 100 berries was only 200 cm^3 and the weight of 100 large berries (diameter >12 mm) was 155 g.

Method of cultivation also impacted the content of the extract and organic acids in berries (Table 3). Berries harvested at the conventional plantation had more extract (mean 16.3%) and organic acids (0.76 g 100^{-1}). The lowest level of soluble solids was observed in the Duke and Elliott cultivars (15.2% and 15.3%), and Elliott cultivar berries contained more organic acids (averaging 0.98 g). The berries of the Sunrise cultivar were characterized by the lowest acidity, especially the ones grown organically (0.49 g 100^{-1}).

Highbush blueberries are collected entirely by hand in Poland due to the very high price of the berries and a desire to maintain high quality. Therefore, it is important that the berry does not have a tendency to fall prematurely, especially if the date of harvest is moved. During the harvest berries are also vulnerable to mechanical damage. During the study, these parameters were determined. There was no effect of the cultivation method on the force required to detach the berry from the stem, or on the susceptibility of the berry to damage (Table 3). However, there was a significant difference among cultivars in those characteristics. The berries of the Sunrise and Brigitta cultivars required the greatest force to detach from the stems, while the berries of the Brigitta and Elliott cultivars were the least susceptible to damage. They were also characterized by the greatest firmness, both in the axis of height and diameter. The Duke cultivar berries were

Table 3. Chemical and physical parameters of the highbush blueberries in total yield depending on the method of cultivation.

Cultivar (B)	Farming methods (A)	Soluble solids (%)	Titratable acidity (g 100 mL^{-1})	Peel the berry from the pedicel (g)	Puncture axis diameter (G mm)	Firmness (G mm)	
						Axis diameter	Axis height
Sunrise	Organic	16.5	0.49	147	112	176	411
Brigitta		16.4	0.71	133	138	204	452
Duke		14.7	0.64	117	96	158	351
Elliott		15.2	0.93	89	166	182	428
Mean		15.7	0.69	122	128	180	411
Sunrise	Conventional	17.2	0.56	156	134	213	480
Brigitta		16.9	0.76	125	157	245	513
Duke		15.6	0.68	104	105	166	374
Elliott		15.4	1.02	97	182	238	486
Mean		16.3	0.76	121	145	216	463
Sunrise	Mean	16.9	0.53	152	123	195	446
Brigitta		16.7	0.74	129	148	225	483
Duke		15.2	0.66	111	101	162	363
Elliott		15.3	0.98	93	174	210	457
LSD$_{0.05}$		A 0.3; B 0.5; A × B 0.8	A 0.6; B 0.9; A × B 1.1	A 26; B 32; A × B 39	A 22; B 29; A × B 34	A 28; B 32; A × B 41	A 33; B 37; A × B 44

the least firm. In addition, berries grown conventionally were characterized by greater firmness. The impact was undoubtedly caused by the size of the berries, which is significantly negatively correlated with firmness (–0.86**). The berries of the tested cultivars were characterized by a lower firmness compared to berries of the Sierra (440) and Patriot cultivars (512 G mm) (Ochmian et al., 2009a, 2009b, 2010).

Polyphenols are resynthesized products that protect against ultraviolet radiation and pathogens (Hodges et al., 2004). Their content depends on the cultivar (Mikkonen et al., 2001) and the degree of ripeness of the fruit (Wang and Jiao, 2001). Foods rich in bioactive substances, which have a positive influence on the human body, are increasingly appreciated by consumers. They improve health by strengthening the body, soothing upset stomachs and indigestion (Manach et al., 2004), and preventing cardiovascular disease by effectively preventing the oxidation of LDL (Borowska, 2003). They are also characterized by the ability to quench free radical activity (Espín et al., 2000), in particular through the polyphenol compounds contained in dark berries (Ehlenfeldt and Prior, 2001; Zheng and Wang, 2003). A linear relationship was observed between total phenolics and FRAP values for blueberries (Koca and Karadeniz, 2009). Anthocyanin compounds are mainly concentrated in the skin of berries (Ribera et al., 2010).

On the basis of measurements, most cultivars of berries from organic plantations were characterized by a higher content of polyphenol compounds (Figure 2); the average was 288 mg 100 g^{-1}, while the conventional berry contained 260 mg 100 g^{-1}. The largest difference occurred in the Brigitta cultivar; the organic berry contained 325 mg 100 g^{-1} of polyphenols, while the conventional berry contained 260 mg 100 g^{-1}. Only the conventional Duke cultivar berries were richer in polyphenols (227 mg 100 g^{-1}) when compared to the organic berries (204 mg 100 g^{-1}). These levels are higher than those in other fruits or vegetables (Karadeniz et al., 2005). Of all the identified polyphenols, anthocyanins constituted the largest group, and levels were significantly higher in organic berries (approximately 208 mg 100 g^{-1}; Table 4). Among the anthocyanins, delphinidins were mostly marked, especially the delphinidin-3-galactoside in organic berries. Great differences were found in the content of delphinidin-3-glucoside and delphinidin-3-galactoside among cultivars. In the Sunrise cultivar berry, regardless of the method of cultivation, there was up to 30 times more delphinidin 3-glucoside than in the Duke and Elliott cultivars. The berries of the studied cultivars also contained a lot of

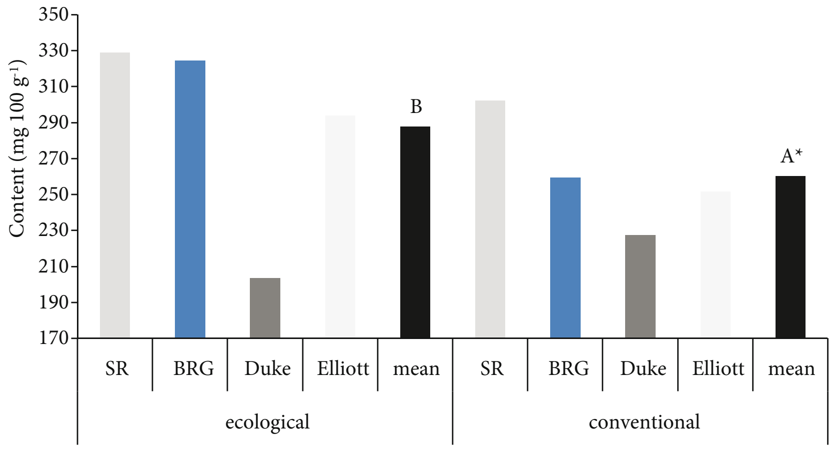

Figure 2. The total content of polyphenols in berries of highbush blueberry cultivars, by farming method. *Means with the same letter do not differ significantly at α = 0.05.

Table 4. The content of anthocyanin compounds in the blueberry cultivars tested, according to the method of cultivation (mg 100 g^{-1}).

Farming method (A)	Organic					Conventional				
Cultivar (B)	Sunrise	Brigitta	Duke	Elliott	Mean	Sunrise	Brigitta	Duke	Elliott	Mean
Anthocyanins										
Del-3-gal	56.7	73.4	73.4	69.6	68.3	48.2	46.6	60.4	55.7	52.7
Del-3-glu	33.81	11.79	3.02	1.20	12.46	31.11	14.74	1.09	1.32	12.07
Del-3-ara	37.46	42.46	8.10	40.06	32.02	30.71	34.61	36.07	32.86	33.56
Cya-3-gal	12.93	9.96	3.86	11.27	9.51	15.51	8.29	8.64	10.14	10.65
Cya-3-glu	6.18	7.09	6.38	5.21	6.22	5.62	4.43	4.06	4.69	4.70
Cya-3-ara	4.79	3.18	5.68	3.44	4.27	4.31	3.21	2.58	3.10	3.30
Pet-3-gal	10.19	14.77	9.86	10.59	11.35	9.27	9.42	12.62	9.54	10.21
Pet-3-glu	8.35	9.05	5.02	6.67	7.27	7.52	3.09	7.34	6.01	5.99
Pet-3-ara	19.89	6.69	6.61	1.25	8.61	21.08	8.44	1.29	1.13	7.99
Peo-3-gal	7.48	31.91	8.00	19.38	16.69	6.58	21.22	9.62	17.05	13.62
Peo-3-glu	12.42	16.87	3.02	9.54	10.46	11.18	15.86	6.30	8.58	10.48
Peo-3-ara	0.36	0.09	1.59	0.21	0.56	0.32	1.08	0.23	0.19	0.46
Mal-3-gal	16.20	0.12	0.67	0.18	4.29	14.58	2.23	0.09	0.16	4.27
Mal-3-glu	0.73	0.10	2.76	0.17	0.94	0.66	1.71	0.85	0.15	0.84
Mal-3-ara	12.26	11.03	18.63	16.90	14.71	11.04	5.99	13.34	15.21	11.40
Total anthocyanins LSD$_{0.05}$ A 17; B 21	240	239	157	196	208	218	181	165	166	183

chlorogenic acid, and there was no effect on its contents due to cultivation method (Table 5). The lowest amounts were found in the Duke cultivar berries (35.9, organic; 45.1 mg 100 g^{-1}, conventional). In the organic berries of the Elliott cultivar, chlorogenic acid remained at 82.2 mg 100 g^{-1}. In the organic and conventional berries flavonoids were also at similar levels. Among the most marked flavonoids, quercitin-3-glucoside was most present in the organic berries of the Brigitta cultivar (22.10 mg 100 g^{-1}). By far, the lowest level of flavonoids was contained in the organic berry of the Duke cultivar (10.6 mg 100 g^{-1}). The values were lower than in other studies of this cultivar (Ochmian et al., 2009b).

In conclusion, mineral content and pH of the soil as well as the location of plantations allowed the cultivation of blueberry according to organic standards—without

Table 5. The content of chlorogenic acid and flavonol compounds in the blueberry cultivars tested, according to the method of cultivation (mg 100 g^{-1}).

Farming method (A)	Organic					Conventional				
Cultivar (B)	Sunrise	Brigitta	Duke	Elliott	Mean	Sunrise	Brigitta	Duke	Elliott	Mean
Chlorogenic acid										
$LSD_{0.05}$ A 9.3; B 9.8	72.0	58.1	35.9	82.2	62.1	67.7	62.7	45.1	71.5	61.8
Flavonols										
Que-3-gal	3.50	2.75	1.13	0.99	2.09	3.19	2.58	2.45	0.89	2.28
Que-3-glu	10.71	22.10	7.57	6.26	11.66	9.64	10.00	13.43	5.63	9.68
Que-3-ram	0.89	1.35	0.84	2.92	1.50	1.25	0.49	0.30	2.63	1.17
Kae-3-rut	1.69	1.28	1.06	5.49	2.38	2.37	2.82	1.05	4.94	2.80
Total flavonols $LSD_{0.05}$ A 3.6; B 4.2	16.8	27.5	10.6	15.7	17.7	16.4	15.9	17.2	14.1	15.9

fertilization and chemical protection. The berries of the organic plantation were larger, and there were more large berries (diameter >12 mm) in the total yield in comparison to the conventionally grown berries. The berries of the Elliott cultivar, regardless of the method of cultivation showed the highest volume, contained the least extract and organic acids, and were most susceptible to shedding. The berries of the Duke cultivar, regardless of the method of cultivation, were most susceptible to damage and were characterized by the lowest firmness of berry and polyphenol content. Highbush blueberry organic farming affected polyphenol compounds in the berries, producing higher content, with the exception of the Duke cultivar. Anthocyanins accounted for over 70% of all identified polyphenol compounds in highbush blueberries. The most important factor for the success of highbush blueberry cultivation is optimal habitat conditions that allow production of organic berries. Despite the absence of fertilization and chemical protection berry quality may be better.

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