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BLUEBERRY(*VACCINIUM CORYMBOSUM*) BREEDING PROGRAMME IN THE MAIN CULTIVATING COUNTRIES

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Abstract

Cutivated blueberies (Vaccinium corymbosum) are known as some of the most important berries for health support, being highly valued for fresh consumption, having sizes two to four times larger than those of wild blueberries (Vaccinium myrtillus), and the nutrient content exceeds those of black blueberry or wild blueberry in the spontaneous flora. This species prefers temperate climate and precipitation more than 700 mm annually. Over the last one hundred years, the geographical area cultivated with the blueberry is widely expanded. European countries have gradually become interested about North American blueberry. The highbush breeding programme began in 1908. The main objectives of the breeding programme are: increased adaptability on low acid soils (pH to 6), extending the harvest season, improving the quality parameters of the fruits (weight, firmness, dry pedicelar scar, high sugar content, thick pruin layer). As a research methodology, it is used the selection of germplasm genitors, the directed hybridization, the production of biological material for nurseries, the evaluation of hybrids and of new selections. As a results of blueberry breeding programme, in the last decade, in the world over 342 blueberry cultivars were registered.

Key words*: breeding programme, highbush, blueberry.*

THE IMPORTANCE OF BLUEBERRY CROP

Blueberry, *Vaccinium* sp., is native to North America, especially Canada, the Eastern and Southern United States, and is represented by about 150-450 species in 30 subgenera (Luby et al., 1991), spread between the 45 ° and 71 ° parallels in North America, Europe and Asia, where it grows in mountainous areas and on acid soils (Bîstrova A. et al., 1968).

The Genus *Vaccinium* L. is a common and widespread dwarf shurb of the *Ericales* order, family *Ericaceae*, Subfamily *Vaccinioideae.* Blueberries are ranked under the family *Ericaceae*, subfamily *Vacciniaceae*, genus *Vaccinium*, and subgenus *Cyanococcus* which are most commonly growing in acid and infertile soil conditions (Ștefănescu et al., 2019). Commercially important species are found in the subgenera C*yancoccus*, *Vitis-Idaea* and *Myrtillus*. The highbush blueberry is derived from two main species, *Vaccinium australe* and *Vaccinium corymbosum* (Vander K., 1988). The breederes made numerous crosses within the subgenus *Cyancoccus* including the tetraploid *V. corymbosum* x the tetraploid *V. angustifolium* (Luby et al., 1991), most of the cultivated *Vaccinium* species belong to the section *Cyanococcus* subgenus (Table 1).

According to Romanian Pomology, vol. VII, published in 1968, the most important blueberry species are the following: *Vaccinium corymbosum* L., synonym *Vaccinium australe* Small. Highbush blueberry is widespread along the Atlantic coast from Florida to Maine, West and South of Michigan. It is a 1-4 m tall plant, which grows in the form of a bush with large fruits (up to 2 cm in diameter). *Vaccinium myrtillus* L. - black blueberry - is widespread in Europe and North Asia.

In Romania it is spread from the region of high hills to the alpine area, occupying large areas in spruce forests, brown soils, podzolic or primary podzols and beech forests on primary podzols, preferring acid soils. *Vaccinium uleginosum* L. (Bog bilberry, northern bilberry, western blueberry) - the wild bilberry - is spread to Europe, Asia and America. In our country it can be found in the Alpine and subalpine

region, through forests, bushes, meadows, on poor soils. *Vaccinium lamarckii* Camp., synonyms *V. angustifolium* Ait., *V. angustifolioum* var. *laevifolium*, *V. pennysilvanicum* Lam. var *angustifolium* (lowbush blueberry) - the American dwarf blueberry - is widespread in North America in a large area from northeast Maine to West Virginia, south Wisconsin and Minnesota west. The selections from *V. lamarckii* Camp. are used in genetic improvement of highbush blueberry.

Table 1. Taxonomy and spread of blueberry species

Genus	Species	Ploidy	Spreading area
Cyanococcus	*V. angustifolium* Ait. (Lowbush blueberry)	4x	N-E North America
	V. ashei Reade. (Rabbiteye blueberry)	6x	S-E North America
	V. boreale Hall & Aald (Northern blueberry)	2x	N-E North America
	V. constablaei Gray (Hillside blueberry)	6x	S-E North America
	V. corymbosum L. (Highbush blueberry)	2x	S-E North America
	V. corymbosum L. (Highbush blueberry)	4x	E North America
	V. darrowii Camp (Darrow's blueberry)	2x	S-E North America
	V. fuscatum Ait. (Black highbush)	2x	Florida
	V. myrtilloides Michx. (Velvetleaf huckleberry)	2x	Central North America
	V. pallidum Ait. (Blue ridge blueberry)	2x, 4x	Mid- Atlantic North America
	V. tenellum Ait. (Small black blueberry)	2x	S-E North America
	V. elliottii Chapm. (Elliott's blueberry)	2x	S-E North America
	*V. hirsutum (*Hairy blueberry)	4x	S-E North America
	V. myrsinites L. (Shiny blueberry)	4x	S-E North America
	V. simulatum Small (Upland highbush blueberry)	4x	S-E North America
Oxycoccus	*V. macrocarpon* Ait. (Large cranberry)	2x	North America
	V. oxycoccos L. (Cranberry, Mossberry)	2x, 4x, 5x, 6x	Circumboreal
	V. erythrocarpum	2x	S-E North America and E. Asia
	V. microcarpum (Small Cranberry)	2x	Circumboreal
Vitis-Idaea	*V. vitis-idaea* L.	2x	Circumboreal
Myrtillus	*V. myrtillus* L.	2x	Circumboreal
	V. deliciosum (Cascade bilberry)	4x	N.W. North America
	V. cespitosum	2x	North America
	V. membranaceum (Mountain bilberry)	4x	W. North America
	V. ovalifolium (Oval-leaved bilberry)	2x	Circumboreal
	V. parvifolium (Red bilberry)	2x	N.W. North America
	V. scoparium (Grouseberry)	2x	N.W. North America
Pyxothamnus	*V. consanguinem (Costa Rican blueberry)*	2x	S. Mexico and Central America
	V. ovatum (California Huckelberry)	2x	N.W. North America
Bracteata	*V. bracteatum (Sea bilberry)*	2x	E. Asia, China and Japan
Vaccinium	*V. uligiosum* L. (Bog bilberry)	2x, 4x, 6x	Circumboreal

Source: from Ballington (1990), Luby et al. (1999), Suda (2003), Hancock et al. (2008) cited by Guo-Qing Song and James F. Hancock (2011)

The Order *Ericales,* Subfamily *Vaccinoidae* includes many species of berries whose fruits have benefits for health. Highbush blueberry (*Vaccinium corymbosum*) is known as one of the most important berries for fresh consumption, being two to four times larger than wild blueberry (*Vaccinium myrtillus*) and its nutrient content exceeds that of black

blueberry or wild blueberry from spontaneous flora (Botez, 1984). Anthocyanins found in the blue epidermis fruits with strong antioxidant, anti-inflammatory, antibacterial effect, blueberries with a high antioxidant capacity. Nutritional value of fruits indicates that blueberries are a high source of minerals (Ca, K, Na, Mg, Zn, Fe), vitamins (A, C, B1, B2), but also protein (Table 2).

Table 2. Nutritional values per 100 g of fruit *Vaccinum myrtyllus*

Principles	Nutritional values	% RDA
Energy	57 Kcal	3%
Carbohydrates	14.49 g	11%
Protein	0.74 g	1%
Total fat	0.33 g	1%
Cholesterol	0 mg	0%
Fiber	2.4 g	6%
Vitamins		
Folaţi	6 µg	1.5%
Niacină	0.418 mg	2.5%
Pantothenic acid	0.124 mg	2.5%
Pyridoxine	0.052 mg	4%
Riboflavin	0.041 mg	3%
Vitamin A	54 IU	2%
Vitamin C	9.7 mg	1.5%
Vitamin E	0.57 mg	4%
Vitamin K	19.3 µg	13%
Electrolites		
Sodium	1 mg	0%
Potassium	77 mg	3%
Minerals		
Calcium	6 mg	0.5%
Iron	0.28 mg	3.5%
Magnesium	6 mg	1.5%
Manganese	0.336 mg	14%
Zinc	0.16 mg	1.5%
Micro-nutrients		
α-carotene	0 µg	-
ß-carotene	32 µg	-
Lutein-zeaxanthin	80 µg	-

Asănică A., 2015

Consumption of blueberry fruits keeps the brain healthy, because the vitamins and minerals found in the composition of these fruits nourish nerve cells, thus prolonging life. Blueberries are also called "vegetal insulin" because they can be consumed by diabetics. Many factors, including genetics, growing conditions, fruit ripening and other variables affect the nutritional levels of the fruit (Frith 1993; Gary 2004; Kuepper 2004; Hedrick 1925). The blueberry fruit content is about 83% water, 0.7% protein, 0.5% fat, 0.5% ash and 15.3% carbohydrates (Hancock et al., 2003). In processed form, blueberries are consumed as jam, marmalade, syrup, liqueur, juice, compote, frozen fruit (Ghena, 2003). The beneficial properties of blueberry were discovered already by the North American Indians, who consumed blueberry tea for body weight control. Thus, shoots and leaves of blueberry have a high content of substances, such as: thiamine, arbutin, hyminic acid, palmitic acid and can be used for medicinal purposes, to treat diseases of the stomach, small intestine, but also in the treatment of diabetes (Hedrick, 1925; Frith, 1993; Gary, 2004; Kuepper, 2004). The leaves can be used to prepare tinctures and teas and help improve visual acuity, preventing the evolution of ophthalmic diseases (Botez, 1984). First breeders performed numerous crosses within the subgenus *Cyancoccus* including the tetraploid *V. corymbosum* x the tetraploid *V. angustifolium* (Luby et al., 1991). The genetic gain plays an essential role in increasing blueberry production (Gallardo et al., 2018).

Highbush blueberry (*Vaccinium corymbosum*) together with the other commercial berry species are classified as the second most econo-

mically important berry after strawberry in the U.S., the U.S. is the world biggest blueberry producer.

Over time, it was difficult to estimate worldwide area harvested, production or consumption of *Vaccinium corymbosum*, but according to data reported in 2018 by FAOSTAT, currently the world area harvested with blueberry is 109,270 ha. Of the continents, the largest blueberry growing are America (86,718 hectares) and Europe (20,718 hectares). Asia and Africa have registered only 96 and 18 ha. In 2018, the area harvested by major blueberry growing countries is as follows: Canada (40,998 ha), USA (36,098 ha), Poland (8,089 ha), Germany (3,040 ha), France (2,393 ha), Netherlands (934 ha), Russian Federation (634 ha), Romania (183 ha, Table 3). Worldwide production of blueberry increased in recent years. In the world the largest producer of blueberries (in thousand tons) is the United States - 255,050 in 2018 followed by Canada - 164,205, Spain - 43,516 (FAOSTAT, 2018, Table 4). In Europe, important productions are obtained also by: Poland - 25,301, Germany - 12,764, Netherlands - 10,257, France - 9,127, Russian Federation - 3,300, Italy - 1,675, Romania - 684 and Switzerland - 353.

Table 3. Area harvested of blueberry in the world and in major growing countries

World/ country	Area harvested/year (ha)										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
World	74.912	72.711	76.455	82.346	83.593	87.567	94.520	104.754	103.832	103.239	109.270
America	58.651	61.048	62.945	69.069	69.133	72.305	78.483	90.857	86.271	82.990	86.718
Europe	14.933	10.352	12.124	11.872	12.795	13.456	14.339	12.128	14.995	18.224	20.407
Asia	100	100	100	110	114	90	89	105	103	97	96
Africa	11	12	13	15	15	15	16	17	18	18	18
Canada	34.109	34.848	34.277	38.493	36.929	37.569	40.443	49.977	42.570	41.569	40.998
USA	24.480	26.010	28.530	29.660	30.919	32.796	34.297	36.349	37.555	33.953	36.098
Spain	477	499	522	547	572	975	1.760	1.803	2.260	3.260	3.722
Poland	2.256	2.366	2.167	2.404	3.126	3.223	3.470	3.230	5.039	7.070	8.089
Germany	1.406	1.426	1.429	1.434	1.835	2.031	2.083	2.479	2.714	2.844	3.040
France	2.800	2.800	2.640	2.455	2.458	2.421	2.489	2.484	2.440	2.440	2.393
Netherlands	419	526	535	584	586	574	639	737	777	832	934
Russian Federation	500	500	500	500	500	500	500	500	607	529	634
Romania	808	741	735	636	544	480	546	150	128	132	183
Italy	173	171	172	172	172	173	172	173	172	172	171
Switzerland	39	42	46	55	66	73	73	76	83	93	85

FAOSTAT, 2008-2018

Table 4. Production of blueberry in the world and in major growing countries

World/ country	Production/year (thousand tons)										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
World	314.895	339.517	327.866	363.776	403.624	434.520	546.384	555.721	641.518	606.206	682.790
America	253.926	273.398	273.565	312.348	345.931	367.937	467.178	473.270	551.122	497.848	554.311
Europe	55.087	60.163	47.970	45.232	50.647	58.876	71.923	74.877	79.840	99.872	119.570
Asia	600	700	800	600	700	600	600	700	693	663	662
Africa	50	54	59	65	68	68	70	75	78	81	78
Canada	95.516	102.753	83.550	104.294	126.012	109.550	183.649	193.469	232.798	173.641	164.205
USA	158.260	169.050	188.926	201.030	212.168	246.559	262.498	254.012	269.257	235.206	255.050
Spain	6.374	6.535	6.696	6.858	7.019	11.912	21.060	21.060	24.945	35.355	45.516

FAOSTAT, 2008-2018

OBJECTIVES OF PERSPECTIVE FOR BLUBERYY BREEDING

The breeding of new cultivars will continue to play a major role in the growth of the blueberry market worldwide. In the last years, breeding programmes have obtained new cultivars that have supported the spread of blueberry into new growing areas, such as low-chill regions and the southern hemisphere (Gallardo et al., 2018). Other desirable objectives for blueberry breeding include tolerance to the high soil pH (with pH up to 6), chilling requirement, cold

hardiness, early bloom, ripening interval, frost tolerance for expand the harvest season to cover regions where the production is low (Hancock et al., 2008), for obtaining mechanized harvestable plants to reduce one of the technological branch costs, fruit quality parameters improvement (high weight, crisp texture, good flavour, firm texture, dry stem scar, thick pruin layer, an optimal sugar-to acid ratio, light blue color) and the disease resistance.

RESULTS AND DISCUSSIONS

The first *Vaccinium corymbosum* plantations were established in New Jersey (1910), and soon expanded (Hancock, 2006a) to North Carolina (1920) and Michigan (1930). In the early 1900s, Dr. Frederick V. Coville showed interest in blueberry breeding, obtaining the first hybrid in 1908. His first cultivar was named 'Brook' in New Hampshire (USA). He studied the species' requirements for soil pH, the need for cold, developed some cutting methods and improving it. In his research, he collaborated with Elizabeth White, breeding numerous hybrid combinations, which resulted in over 30 selections, which later became varieties, many of them still cultivated today: 'Bluecrop', 'Weymouth', 'Blueray', 'Rubel', 'Berkeley','Coville', 'Jersey' cv.

European breeding of *Vaccinium corymbosum* began after 1920 for the first time in Netherlands. In the next years, other countries (Poland, Germany etc.) became interested by that new species. In Germany, in 1929 Dr. Hermann of the Landsberg Plant Breeding Institute (now Gorzów Wlkp.) has made great progress in blueberry breeding and cultivation. Through his research activity, as well as collaboration with other researchers, from the breeding of numerous hybrids resulted the next cultivars: 'Blauweiss - Goldtraube', 'Blauweiss - Zukertraube', 'Heerma', 'Rekord', 'Ama' and 'Gretha'. After 1980, areas harvested with highbush blueberry have increased, mainly concentrating in Germany, Poland, Spain, Romania, Italy (Strik and Yarborough, 2005).

The most important globally representative units for breeding activity are Florida Foundation Seed Producers, Mountain Blue Orchards, Fall Creek Farm and Nursery, Costa Exchange Limited, University of Georgia Research Foundation, The New Zealand Institute for Plant and Food Research, Driscoll Strawberry Associates, Prunus Persica, Berry Blue, Next Progeny, Planasa - Inovation in Plant Varieties, Research Institute for Fruit Growing, Pitești-Mărăcineni etc. (Table 5).

Part of work of some the main centers of breeding is as follows:

Fall Creek Farm and Nursery, activity began in 1978, gradually developing, with the help of a large team, dedicated to innovation in production and customer service. The breeding process carried out here was complemented by the evaluation and selection of genotypes in different areas around the world. The main objectives of the breeding programme are those related to fruit quality (size, attractiveness, shelf life) and adaptability to different areas of cultivation (high and low altitudes, climate with low and high temperatures). Over the time, the breeding process increasead resulting many varieties (Table 6).

Table 5. The main Breeding Centers

No.	Breeding Center	No. of cultivars
1	Florida Foundation Seed Producers. Inc.	49
2	Mountain Blue Orchards Pty. Ltd.	27
3	Fall Creek Farm and Nursery. Inc.	50
4	Costa Exchange Limited	23
5	University of Georgia Research Foundation. Inc.	22
6	The New Zealand Institute for Plant and Food Research Ltd.	21
7	Driscoll Strawberry Associates. Inc.	20
8	Prunus Persica Pty Ltd.	18
9	Berry Blue. LLC	15
10	Next Progeny Pty. Ltd	14
11	Research Institute for Fruit Growing. Pitești-Mărăcineni	9

Brevis (2019)

Table 6. Blueberry cultivars registered in the last decade (2009-2019)

No.	Continent/Country	No. of cultivars
1	Europe	154
2	USA	131
3	Australia	97
4	Chile	87
5	New Zealand	80
6	Mexico	77
7	South Africa	75
8	Peru	62
9	Canada	40
10	Japan	37
11	Turkey	29
12	Ukraine	21
13	Argentina	20
14	Colombia	19
15	Brazil	18
16	Morocco	18
17	Serbia	18
18	Georgia	15
19	Ecuador	10
20	Israel	9
21	Russia	7
22	Uruguay	7
23	Switzerland	6
24	Kenya	5
25	China	4
26	Estonia	4
27	Sweden	3
28	Latvia	2
29	Costa Rica	1
30	Finland	1
31	Poland	1

Brevis (2019)

In late 2019, this company launched The Fall Creek Collection, its new blueberry genetics assuring blueberry varieties for all chill levels.

Mountain Blue Orchards Pty Ltd is a centre in Australia dedicated to blueberry culture with 26 years of experience. It produces 250,000 plants annually of warm climate southern highbush and rabbiteye blueberry varieties for Australia and various export destinations. The latest varieties from Florida, Georgia and Mississippi are cultivated.

Planasa - Innovation in Plant Varieties, is another main centre with uses major part of its resources to develop new cultivars using selection breeding.

The centre began its activity in France, in 1887. Planasa has four major centres all around the world, and also smaller ones in different climatic areas to test new cultivars. It has more than 1,500 hectares in Spain, Poland, Morocco, California in the United States, Mexico and Peru (https://planasa.com/en/nursery/.

The New Zealand Institute for Plant and Food Research Ltd. - In New Zealand, the blueberry was introduced in the 1950s from North America. The blueberry breeding centres are located in North and South Island, New Zealand and a smaller programme at Dierking's Nursery in Germany. The breeding objectives of Plant & Food Research Ltd. are improving the quality parameters of the fruits (fruit size, firmness, taste, color), ripening season and disease resistance.

The Institute of Pomology and Floriculture (now the Institute of Horticulture) in Skierniewice, Poland, began the breeding programme of *Vaccinium corymbosum* L. in 2008 in the Plant Breeding Department using the first crossings of parental forms.

A few years later the first seedlings were planted in the selection plot in the Experimental Orchard in Dąbrowice. The targets of the blueberry breeding are high productivity of the shrubs, good quality of the berries, both internal and external, good firmness and shelf life. Poland is the first European producer and exporter of blueberries.

Over the years, due to the temperate climate of Romania favourable to the growth and development of fruit species, many fruit growers have selected particularly high quality local varieties enjoying appreciation both in the country and abroad (Cociu, 1977). The activity of breeding the assortment of highbush blueberry, carried out at the **Research Institute for Fruit Growing, Pitești-Mărăcineni** began in 1982 (Mladin P. et al., 2012) still has the objectives: increased adaptability on low acid soils (with pH up to 6), extending the harvest season, and improving the quality parameters of the fruit (weight, firmness, high sugar content, thick pruin layer). As a research methodology, the selection of germplasm genitors is used. The directed hybridization was mainly used, base on the rich genofond collected in Pitești and containing of varieties, species and native wild forms or introduced from abroad (Mladin P. et al., 2007).

The wide genetic diversity and the large volume of work made it possible after 1990, for a number of 9 cultivars ('Simultan', 'Pastel', 'Lax', 'Delicia', 'Prod', 'Azur', 'Augusta', 'Vital' and 'Safir') to be registered and introduced in the Official Catalogue of Cultivated Plants in Romania.

CONCLUSIONS

Blueberry is one of the most popular berries in North America, rich in many valuable compounds.

By breeding the existing blueberry assortment in Romania, the aim is to obtain new cultivars with special qualities of fruits, with high production capacity, with resistance to diseases and pests, as well as with the ability to adapt to less acid soils.

The breeding programme will continue in close relative with current market requirements (big fruit, extension of the ripening season). All in the field of hybrids and in comparative crops and microculture, contain a rich and diverse genetic material, in different stages of evaluation of the breeding process, as a new source for the continuation of this process.

Worldwide blueberry production shows an upward trend. If in 2009 a production of 314,895 tons was registered, in 2018 the production doubled reaching up to 682,790 tons, and the area harvested registered in 2008 was 74,912 ha and in 2018 the surface registered was 109,270 ha.

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