



Genotype and Year Effects on Some Production Characteristics in Three Blueberry Cultivars (*Vaccinium corymbosum* L.)

Sina Cosmulescu¹ · Maria Marina Merca Laies² · Veronica Sărățeanu³

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Abstract

The current trend of expanding blueberry plantations requires studies on the production capacity of blueberry cultivars in different cultivation areas. The paper's aim was to follow the effect of genotype and environment on some production characteristics of three blueberry cultivars ('Duke', 'Hannah's Choice' and 'Elliott') grown in the Banat region of Romania. The average fruit weight, production per bush and production per hectare were calculated. The analysis of obtained data highlighted a variability from one cultivar to another, and within the cultivar from one year to another. The simulated models have highlighted the highly significant influence of considered factors combined (cultivar*year) on production features. 'Duke' and 'Elliott' cultivars have the best results in the study area, that is, 'Duke' cultivar can provide blueberries for market early (from June) and 'Elliott' cultivar provides blueberries during the summer–autumn time interval. The outputs are very useful, bearing in mind the low amount of available information from the literature.

Keywords Agronomic performance · Adaptability · Yield · Genotype-environment interaction · Blueberry

Introduction

Blueberry (*Vaccinium corymbosum* L.) production is a topic of global interest due to an improved understanding of the important role of dietary fruits in the maintenance of the human health (Sumedrea et al. 2016; Tundis et al. 2021). Blueberries play a crucial role both nutritionally and commercially. Their health benefits are supported by their content rich in antioxidants, vitamins, and fibers (Nour et al. 2015; Tundis et al. 2021), while their commercial impact

is evident through the increase in global demand. The increased demand of blueberry fruit is limited by the consequent cultivation areas determined by the reduced adaptability of cultivars to different soils and climates. To overcome these limitations, further research and development of new varieties that are more resistant and adaptable to various environmental conditions would be necessary. Assortment and technology of cultivation have great importance for economic efficiency (Esau et al. 2019). There is a different range of cultivars that capitalize differently the area of cultivation. However, breeding research is still done through inter- and intra-specific hybridization on plants from the *V. corymbosum* (Hera et al. 2021). Overall, the industry responses signalled that the most important trait cluster was the fruit quality including the firmness, flavour, and shelf life (Gallardo et al. 2018). Fruits have distinctive features depending on cultivar, soil conditions, climate and growing techniques (Sava and Caterenciu 2021). In addition, variability in geographic and climatic growing conditions between environments or within the same environment across different years may be further affecting fruit and plant phenotypic expression (Merca and Cosmulescu 2020; Cosmulescu et al. 2022). Taking into account the issue of global warming, blueberry growers must pay particular attention to assortment selection. The results of some studies suggest that there is a strong interaction between the

✉ Sina Cosmulescu
sina.cosmulescu@edu.ucv.ro

✉ Veronica Sărățeanu
veronica.sarateanu@gmail.com

¹ Department of Horticulture and Food Science, Faculty of Horticulture, University of Craiova, A.I. Cuza Street, no.13, 200585 Craiova, Romania

² Doctoral School of Plant and Animal Resources Engineering, Faculty of Horticulture, University of Craiova, A.I. Cuza Street, no. 13, 200585 Craiova, Romania

³ Department of Agricultural Technologies, Faculty of Agriculture, University of Life Sciences "King Michael I of Romania" Timișoara, Calea Aradului Street, no. 119, 300645 Timișoara, Romania

cultivation environment and the genotype, associated with their tolerance to cold, or with the presence of significant interactions between genotypes, years, environments and harvests for fruit quality parameters (Sater et al. 2021). In Romania, the first blueberry plantation was established in 1968, and now there is a trend of rapid growth of blueberry planted areas, motivated by the growing market demand for fresh fruit consumption and the profit incentive compared to other fruits. The assortment is different from one area to another, and the behaviour of the cultivars in plantation is necessary to be checked to create competitive plantations (Asănică, 2018; Moldovan et al. 2017; Mladin et al. 2013). The paper's aim was to analyze the effects of genotype and year on some production characteristics of three cultivars of blueberry cultivated in specific conditions of Banat region, Romania, to recommend a specific assortment. The relevance of study on blueberry culture is evident from its significant commercial impact and favourable market trends. This culture not only responds to a growing global demand for healthy food, but it also contributes to economic development and sustaining of local economies.

Materials and Methods

Experimental Site and Plant Material

The experiment was performed in Gherteniş town (4525'48" N 2134'55" E), Caraş-Severin County, Romania. Caraş-Severin area has a moderate temperate-continental climate, with sub-Mediterranean nuances. During the research period, in the experimental plantation, the average annual temperature was 12.3 °C, while the average temperature in July was 22.5 °C, then in January the temperature was 0.9 °C; the sum of average annual rainfall was 828 mm. The soil has a medium clay-clay texture, with a clay content between 35–45% and a humus content between 2.3–2.7%. The cultivation system is super-intensive, the plantation was established in 2015 at a density of 4700 bushes per hectare. The planting was carried out on bins covered with black agrotexile-type foil. The study was carried out during the years 2020–2022. Biological material used was represented by three highbush blueberry cultivars, namely 'Duke', 'Hanna's Choice' and 'Elliott'.

Methods

For the experiment, observations were made every year on 30 bushes that were marked, in three replicates for each cultivar. The fruits were hand-harvested by staggering at the fruit colour phase (blue fruit in clusters); the yield from each plant was harvested separately. Fruits from each harvest were weighed to determine the production per plant (kg

per plant), which was then expressed per unit area (t/ha). After harvesting, the samples were placed in a cooler and then quickly carried to the lab for the evaluation of fruit weight using a technical balance (Kern, Germany). The mean of berry weight was determined taking randomly 20-fruit sample per plant at each harvest date.

Statistical Analysis

Analysis of variance (ANOVA) was used to analyze within-group and between-group variance and the grand mean (overall mean). For statistical analysis, the software JASP 0.17.10 (University of Amsterdam, Netherlands) and Excel 2019 were used. Descriptive analyses of data and ANOVA were performed with JASP 0.15.3 software, and the significance of obtained results was determined by post-hoc Tukey analysis and bootstrapping of marginal means. Marginal means were based on 500 replicates of sampling data. Marginal means were compared with 0 by applying Bonferroni adjustment of confidence interval. This method has capacity to provide the increase of accuracy of interpretation of statistical analysis.

Results and Discussions

Characterization of the Average Weight of a Blueberry Berry, Compared by Cultivar and Experimental Year

Average weight of a berry in blueberry is an important production feature that can influence production. Figure 1 shows the descriptive statistics regarding the average weight of a berry depending on cultivar and the experimental year. Strik et al. (2003) found that pruning severity affects yield, berry weight, and hand-harvesting efficiency of highbush blueberry. Larger fruits increase the efficiency of manual harvesting and are also better priced. In the present study, the average fruit weight was below 1.56 g. Fruit weight decreased with each subsequent harvest, the largest fruits were obtained at the first harvest: 1.6 g/fruit in 'Hanna's Choice',

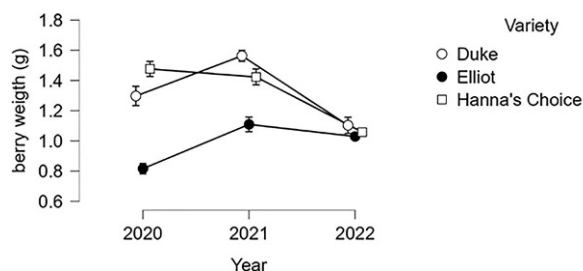


Fig. 1 The average weight of a blueberry berry (g) compared by cultivar and experimental year (standard error displayed)

while in ‘Duke’ and ‘Elliott’ cultivars the average weight of a fruit was 1.5 g/fruit at the first harvest. During the 3 years of the experiment, ‘Elliott’ cultivar had the smallest fruits. Low grain weight during successive harvests may be associated with high temperatures and increased solar radiation at the end of the harvest season, impacting plant water status and reducing photosynthesis, an aspect also observed by Zorenc et al. (2016) under similar climate conditions, in Slovenia. Milivojević et al. (2016) have also reported that

the fruits of two commercial cultivars, ‘Duke’ and ‘Bluecrop’, tend to be small, with fruit weight less than 1.5 g per berry, especially towards to the end of the harvesting season, due to the environmental conditions of the respective time interval. However, the average weight of the fruit, from one harvest to another, in the present study showed a low and medium variability, the coefficient of variation was below 15.65%, indicating stable fruit quality.

Table 1 Analysis of variance on average berry weight in blueberry under the combined influence of cultivar and year, Tukey’s test

Post hoc comparisons—cultivar*year		95% CI for mean difference					
		Mean difference	Lower	Upper	SE	t	P_{Tukey}
‘Duke’ 2020	‘Elliott’ 2020	0.481	0.278	0.684	0.064	7.555	<0.001***
	‘Hanna’s Choice’ 2020	−0.179	−0.382	0.024	0.064	−2.812	0.128
	‘Duke’ 2021	−0.266	−0.469	−0.063	0.064	−4.178	0.002**
	‘Elliott’ 2021	0.188	−0.015	0.391	0.064	2.953	0.091
	‘Hanna’s Choice’ 2021	−0.126	−0.329	0.077	0.064	−1.979	0.562
	‘Duke’ 2022	0.194	−0.009	0.397	0.064	3.047	0.072
	‘Elliott’ 2022	0.268	0.065	0.471	0.064	4.209	0.002**
	‘Hanna’s Choice’ 2022	0.239	0.036	0.442	0.064	3.754	0.009**
‘Elliott’ 2020	‘Hanna’s Choice’ 2020	−0.660	−0.863	−0.457	0.064	−10.366	<0.001***
	‘Duke’ 2021	−0.747	−0.950	−0.544	0.064	−11.733	<0.001***
	‘Elliott’ 2021	−0.293	−0.496	−0.090	0.064	−4.602	<0.001***
	‘Hanna’s Choice’ 2021	−0.607	−0.810	−0.404	0.064	−9.534	<0.001***
	‘Duke’ 2022	−0.287	−0.490	−0.084	0.064	−4.508	<0.001***
	‘Elliott’ 2022	−0.213	−0.416	−0.010	0.064	−3.346	0.032*
‘Hanna’s Choice’ 2020	‘Hanna’s Choice’ 2022	−0.242	−0.445	−0.039	0.064	−3.801	0.008**
	‘Duke’ 2021	−0.087	−0.290	0.116	0.064	−1.366	0.907
	‘Elliott’ 2021	0.367	0.164	0.570	0.064	5.764	<0.001***
	‘Hanna’s Choice’ 2021	0.053	−0.150	0.256	0.064	0.832	0.996
	‘Duke’ 2022	0.373	0.170	0.576	0.064	5.859	<0.001***
	‘Elliott’ 2022	0.447	0.244	0.650	0.064	7.021	<0.001***
‘Duke’ 2021	‘Hanna’s Choice’ 2022	0.418	0.215	0.621	0.064	6.565	<0.001***
	‘Elliott’ 2021	0.454	0.251	0.657	0.064	7.131	<0.001***
	‘Hanna’s Choice’ 2021	0.140	−0.063	0.343	0.064	2.199	0.416
	‘Duke’ 2022	0.460	0.257	0.663	0.064	7.225	<0.001***
	‘Elliott’ 2022	0.534	0.331	0.737	0.064	8.387	<0.001***
‘Elliott’ 2021	‘Hanna’s Choice’ 2022	0.505	0.302	0.708	0.064	7.932	<0.001***
	‘Hanna’s Choice’ 2021	−0.314	−0.517	−0.111	0.064	−4.932	<0.001***
	‘Duke’ 2022	0.006	−0.197	0.209	0.064	0.094	1.000
	‘Elliott’ 2022	0.080	−0.123	0.283	0.064	1.257	0.941
	‘Hanna’s Choice’ 2022	0.051	−0.152	0.254	0.064	0.801	0.997
‘Hanna’s Choice’ 2021	‘Duke’ 2022	0.320	0.117	0.523	0.064	5.026	<0.001***
	‘Elliott’ 2022	0.394	0.191	0.597	0.064	6.188	<0.001***
	‘Hanna’s Choice’ 2022	0.365	0.162	0.568	0.064	5.733	<0.001***
‘Duke’ 2022	‘Elliott’ 2022	0.074	−0.129	0.277	0.064	1.162	0.962
	‘Hanna’s Choice’ 2022	0.045	−0.158	0.248	0.064	0.707	0.999
‘Elliott’ 2022	‘Hanna’s Choice’ 2022	−0.029	−0.232	0.174	0.064	−0.455	1.000

P -value and confidence intervals adjusted for comparing a family of nine estimates (confidence intervals corrected using the Tukey method)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2 Analysis of variance on average berry weight in blueberry under the combined influence of cultivar and year, bootstrapped marginal means (Bonferroni adjustment of the confidence interval)

Bootstrapped marginal means—Cultivar*year									
Cultivar	Year	Marginal mean	Bias	95% bca ¹ CI		SE	t	Df	p
				Lower	Upper				
'Duke'	2020	1.300	-5.681×10^{-4}	1.125	1.396	0.063	28.810	81	<0.001
'Elliot'		0.819	0.001	0.731	0.871	0.035	18.126	81	<0.001
'Hanna's Choice'		1.478	0.002	1.372	1.575	0.049	32.786	81	<0.001
'Duke'	2021	1.562	-1.806×10^{-4}	1.500	1.644	0.037	34.718	81	<0.001
'Elliot'		1.105	1.423×10^{-4}	1.027	1.221	0.050	24.634	81	<0.001
'Hanna's Choice'		1.426	0.002	1.311	1.519	0.054	31.609	81	<0.001
'Duke'	2022	1.103	-0.001	1.005	1.216	0.055	24.501	81	<0.001
'Elliot'		1.031	1.636×10^{-4}	0.970	1.065	0.023	22.857	81	<0.001
'Hanna's Choice'		1.059	-6.958×10^{-4}	1.003	1.097	0.024	23.501	81	<0.001

Bonferroni CI adjustment; Bootstrapping based on 500 replicates; Marginal Means estimate is based on the median of the bootstrap distribution

¹Bias corrected accelerated

With regard to the fruit weight, Masłowska and Liberacki (2018) found an average fruit weight of 0.8 kg per plant in 'Duke' cultivar under the specific cultivation conditions of the western part of Poland. Genetic differences mean a phenotypic variability that was observed among blueberry accessions, a fact also noted by Redpath et al. (2021).

The very large variation between the number of fruits harvested at different stages is due to the different vigour of the plant. Blueberry plants are pruned to maintain consistent productivity and to increase berry weight (Gough 1994), and removal of some flower buds during pruning can increase fruit set on the remaining buds and concentrate the ripening (Strik et al. 2003). A factorial analysis of variance between the three cultivars and over the 3 consecutive years, that were different in terms of climatic characteristics, showed very significant differences in terms of average fruit weight between years and cultivars, as well as significant interactions of cultivar with the year. Table 1 analyses the combined influence of the cultivar factor with the year factor on the average weight of a blueberry berry. Thus, it was found that most of the year × cultivar combinations significantly influenced the average weight of a blueberry berry ($p < 0.05^*$, $p < 0.01^{**}$, $p < 0.001^{***}$). A total of 23 combinations of cultivar × year from all 36 were statistically significant, showing their simultaneous influence on the average weight of a blueberry berry.

The simulated model of the cultivar × year influence on the average berry weight in blueberry (Table 2) has highlighted the existence of a very strong significance for all the combinations between the cultivar and year. The presence of significant interactions among genotypes, years, environments, and harvests for all measured fruit quality parameters was also supported by Redpath et al. (2021). Ehlenfeldt and Martin (2010) reported significant interactions between harvest year and cultivar, thereby confirming the dependence of fruit firmness on the environmental conditions.

Characterization of Blueberry Production per Plant (kg) Compared by Cultivar and Experimental Year

Fruit production per plant is an important indicator of blueberry plantation productivity that directly influences the berry production per hectare. In the present study, the lowest average production per bush was determined in 2020 in 'Elliot' cultivar (0.965 kg), while the highest was recorded in 2020 in 'Duke' cultivar, namely, 3.04 kg. The average production/bush varied from one cultivar to another, and within the cultivar with the year, the values of variation coefficient were medium, high and very high (CV% 15.26 and 39.69). Figure 2 shows the descriptive diagram for average blueberry production per plant by cultivar over the analyzed experimental years, which supports the above conclusion regarding the variability within the cultivar and between the cultivars.

As was noticed in the case of blueberry weight, ANOVA analysis show the same significance trend from the point of view of their combined cultivar × year effect on the average production of blueberry per plant.

The difference between cultivars can be due to the structural features such as height, diameter of the bush and the number of leaves that can lead to more flowers, and finally

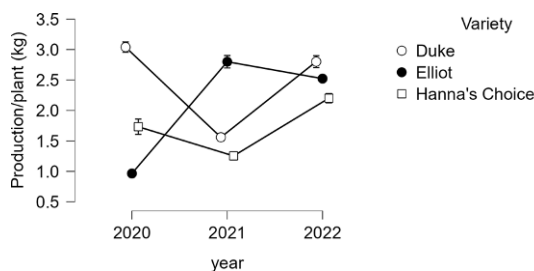


Fig. 2 Average blueberry production per plant (kg) compared by cultivar and experimental year (standard error displayed)

Table 3 Analysis of variance on mean average blueberry production per plant (kg) under the combined influence of cultivar and year, Tukey's test
Post hoc comparisons—cultivar*year
95% CI for mean difference

		Mean difference	Lower	Upper	SE	t	P_{Tukey}
'Duke' 2020	'Elliott' 2020	2.075	1.703	2.446	0.119	17.475	<0.001***
	'Hanna's Choice' 2020	1.307	0.936	1.678	0.119	11.009	<0.001***
	'Duke' 2021	1.480	1.109	1.851	0.119	12.466	<0.001***
	'Elliott' 2021	0.240	-0.131	0.611	0.119	2.021	0.530
	'Hanna's Choice' 2021	1.786	1.414	2.157	0.119	15.041	<0.001***
	'Duke' 2022	0.238	-0.133	0.609	0.119	2.005	0.542
	'Elliott' 2022	0.517	0.146	0.888	0.119	4.355	<0.001***
	'Hanna's Choice' 2022	0.839	0.467	1.210	0.119	7.064	<0.001***
'Elliott' 2020	'Hanna's Choice' 2020	-0.768	-1.139	-0.396	0.119	-6.466	<0.001***
	'Duke' 2021	-0.595	-0.966	-0.223	0.119	-5.009	<0.001***
	'Elliott' 2021	-1.835	-2.206	-1.463	0.119	-15.453	<0.001***
	'Hanna's Choice' 2021	-0.289	-0.660	0.082	0.119	-2.434	0.270
	'Duke' 2022	-1.837	-2.208	-1.465	0.119	-15.470	<0.001***
	'Elliott' 2022	-1.558	-1.929	-1.186	0.119	-13.120	<0.001***
	'Hanna's Choice' 2022	-1.236	-1.607	-0.865	0.119	-10.411	<0.001***
'Hanna's Choice' 2020	'Duke' 2021	0.173	-0.198	0.544	0.119	1.457	0.874
	'Elliott' 2021	-1.067	-1.438	-0.696	0.119	-8.987	<0.001***
	'Hanna's Choice' 2021	0.479	0.107	0.850	0.119	4.032	0.002**
	'Duke' 2022	-1.069	-1.440	-0.698	0.119	-9.004	<0.001***
	'Elliott' 2022	-0.790	-1.161	-0.419	0.119	-6.654	<0.001***
	'Hanna's Choice' 2022	-0.468	-0.840	-0.097	0.119	-3.945	0.003**
'Duke' 2021	'Elliott' 2021	-1.240	-1.611	-0.869	0.119	-10.444	<0.001***
	'Hanna's Choice' 2021	0.306	-0.066	0.677	0.119	2.575	0.203
	'Duke' 2022	-1.242	-1.613	-0.871	0.119	-10.461	<0.001***
	'Elliott' 2022	-0.963	-1.334	-0.592	0.119	-8.111	<0.001***
	'Hanna's Choice' 2022	-0.641	-1.013	-0.270	0.119	-5.402	<0.001***
'Elliott' 2021	'Hanna's Choice' 2021	1.546	1.174	1.917	0.119	13.019	<0.001***
	'Duke' 2022	-0.002	-0.373	0.369	0.119	-0.017	1.000
	'Elliott' 2022	0.277	-0.094	0.648	0.119	2.333	0.326
	'Hanna's Choice' 2022	0.599	0.227	0.970	0.119	5.043	<0.001***
'Hanna's Choice' 2021	'Duke' 2022	-1.548	-1.919	-1.176	0.119	-13.036	<0.001***
	'Elliott' 2022	-1.269	-1.640	-0.897	0.119	-10.686	<0.001***
	'Hanna's Choice' 2022	-0.947	-1.318	-0.576	0.119	-7.976	<0.001***
'Duke' 2022	'Elliott' 2022	0.279	-0.092	0.650	0.119	2.350	0.316
	'Hanna's Choice' 2022	0.601	0.229	0.972	0.119	5.059	<0.001***
'Elliott' 2022	'Hanna's Choice' 2022	0.322	-0.050	0.693	0.119	2.709	0.150***

K-value and confidence intervals adjusted for comparing a family of nine estimates (confidence intervals corrected using the Tukey method)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

to a larger amount of fruits. Plant stem height and diameter are known to be closely related to biomass production and are important morphological traits that are affecting the yield (Yan et al. 2021). Bush dimensions have also influence on the hydraulic conductance (Sperry et al. 2006); a higher hydraulic conductance facilitates a higher stomatal conductance, leading to a higher photosynthetic carbon gain (Santiago et al. 2004). Therefore, it is necessary to create an optimal architecture of the plants in order to obtain

a high yield (Xue et al. 2008), and for this it is necessary to know the characteristics of the cultivar and to apply the maintenance works correctly. The combined effect of the year and cultivar on the average blueberry production per plant (kg) (Table 3) expressed with Tukey's post-hoc test highlights the fact that most of the combinations have a highly significant influence on blueberry production per plant from statistical point of view. Thus, the results obtained were highly significant in 27 combinations from all

Table 4 Analysis of variance on mean average blueberry production per plant (kg) under the combined influence of cultivar and year, bootstrapped marginal means (Bonferroni adjustment of the confidence interval)

Bootstrapped marginal means—cultivar*year				95% bca ¹ CI		SE	t	Df	p
Cultivar	Year	Marginal mean	Bias	Lower	Upper				
'Duke'	2020	3.042	−0.002	2.849	3.194	0.083	36.208	261	<0.001
'Elliott'		0.969	0.004	0.850	1.076	0.058	11.495	261	<0.001
'Hanna's Choice'		1.733	3.427×10^{-4}	1.478	1.974	0.128	20.639	261	<0.001
'Duke'	2021	1.563	9.976×10^{-4}	1.427	1.668	0.060	18.578	261	<0.001
'Elliott'		2.794	-1.955×10^{-4}	2.612	3.038	0.106	33.349	261	<0.001
'Hanna's Choice'		1.252	−0.002	1.125	1.389	0.064	14.937	261	<0.001
'Duke'	2022	2.801	9.650×10^{-4}	2.602	3.023	0.101	33.373	261	<0.001
'Elliott'		2.524	-4.086×10^{-4}	2.399	2.623	0.057	30.049	261	<0.001
'Hanna's Choice'		2.194	−0.002	2.080	2.416	0.078	26.218	261	<0.001

Bonferroni CI adjustment; Bootstrapping based on 500 replicates; marginal means estimate is based on the median of the bootstrap distribution

¹Bias corrected accelerated

36 analyzed here, demonstrating that the considered factors (cultivar*year) concomitantly influence the production of berries per plant.

The productivity of a plant is also different from one year to another (Table 4). Differences in productivity among the years can also be explained by different annual climatic characteristics. One of the determining factors for productivity is the temperature of the environment. The temperature of the environment influences the temperature of the plant and this is related to the stomatal duct and the water stress, a fact also demonstrated by Silva-Pérez et al. (2020). Temperature is the factor that also influences the photosynthetic capacity of the leaves, and this is positively correlated with the yield (Ghimire et al. 2015). In turn, photosynthetic capacity is influenced by leaf chlorophyll concentration and it depends on the nitrogen and moisture availability in the soil (Percival and Sanderson 2004). Thus, understanding the relationships between genotype and the environmental factors that are essential in the stability of a cultivar specific to each crop area, in terms of productivity, such a research is necessary.

Table 4 presents the analysis based on the bootstrapped marginal means of blueberry production per plant in relationship with the combined influence of the cultivar and

year. The results obtained are confirming the strong significance among all the considered combinations cultivar*year.

The results obtained with regard to the productivity of blueberry cultivars analyzed, confirm that this is a complex trait affected by the interactions between horticultural management, genotype and environment.

Characterization of Blueberry Production per Hectare (t) Compared by Cultivar and Experimental Year

The average blueberry production per hectare is important to analyze because the results obtained can bring new information for this crop in the study area. Figure 3 shows the descriptive statistics regarding the average of the blueberry production per hectare depending on cultivar and the experimental year. The lowest blueberry production per hectare was determined in 2020 in 'Elliott' cultivar (4.60 t/ha). The highest average production per hectare was determined in 2020 in 'Duke' cultivar, that is, 14.49 t/ha. And in this case too, the cultivar and the year influenced the production per hectare. A variability was found from one cultivar to another, and in the case of cultivar, the differences are influenced by the year of cultivation.

The combined influence of cultivar factor with the year factor on the average of the blueberry production per hectare was analyzed in Table 5. Thus, it was found that most of the year*cultivar combinations have a statistically significant influence on blueberry production per hectare ($p < 0.001^{***}$), according to the results obtained. Thus, significance was statistically provided for 27 cultivar*year combinations from the 36 analyzed. This fact proves that the two considered factors (cultivar*year) simultaneously influence the average of the blueberry production per hectare.

In the experiments carried out by Ciucu Paraschiv and Hoza (2022), the most productive cultivar was 'Elliott', fol-

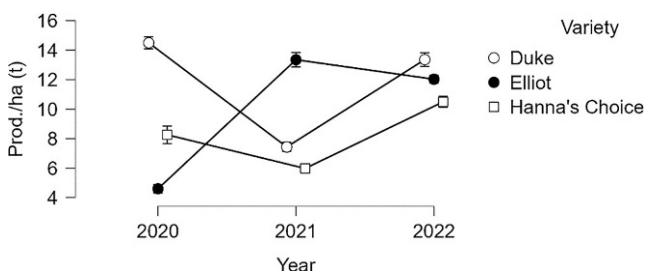


Fig. 3 Average blueberry production per hectare (t/ha) compared by cultivar and experimental year (standard error displayed)

Table 5 Analysis of variance on blueberry production (t/ha) under the combined influence of cultivar and year, Tukey's test

Post hoc comparisons—cultivar*year

95% CI for mean difference

		Mean differ- ence	Lower	Upper	SE	t	P_{Tukey}
'Duke' 2020	'Elliott' 2020	9.892	8.121	11.663	0.566	17.475	<0.001***
	'Hanna's Choice' 2020	6.232	4.461	8.002	0.566	11.009	<0.001***
	'Duke' 2021	7.057	5.287	8.828	0.566	12.467	<0.001***
	'Elliott' 2021	1.145	-0.626	2.916	0.566	2.023	0.529
	'Hanna's Choice' 2021	8.514	6.743	10.285	0.566	15.041	<0.001***
	'Duke' 2022	1.135	-0.635	2.906	0.566	2.006	0.541
	'Elliott' 2022	2.465	0.695	4.236	0.566	4.355	<0.001***
'Elliott' 2020	'Hanna's Choice' 2022	3.999	2.229	5.770	0.566	7.065	<0.001***
	'Hanna's Choice' 2020	-3.660	-5.431	-1.890	0.566	-6.466	<0.001***
	'Duke' 2021	-2.835	-4.605	-1.064	0.566	-5.008	<0.001***
	'Elliott' 2021	-8.747	-10.518	-6.976	0.566	-15.452	<0.001***
	'Hanna's Choice' 2021	-1.378	-3.149	0.393	0.566	-2.434	0.270
	'Duke' 2022	-8.757	-10.527	-6.986	0.566	-15.469	<0.001***
	'Elliott' 2022	-7.427	-9.197	-5.656	0.566	-13.120	<0.001***
'Hanna's Choice' 2020	'Hanna's Choice' 2022	-5.893	-7.663	-4.122	0.566	-10.410	<0.001***
	'Duke' 2021	0.826	-0.945	2.596	0.566	1.459	0.873
	'Elliott' 2021	-5.087	-6.857	-3.316	0.566	-8.986	<0.001***
	'Hanna's Choice' 2021	2.282	0.512	4.053	0.566	4.032	0.002**
	'Duke' 2022	-5.096	-6.867	-3.326	0.566	-9.003	<0.001***
	'Elliott' 2022	-3.766	-5.537	-1.996	0.566	-6.653	<0.001***
	'Hanna's Choice' 2022	-2.232	-4.003	-0.462	0.566	-3.944	0.003**
'Duke' 2021	'Elliott' 2021	-5.912	-7.683	-4.142	0.566	-10.445	<0.001***
	'Hanna's Choice' 2021	1.457	-0.314	3.227	0.566	2.573	0.203
	'Duke' 2022	-5.922	-7.693	-4.151	0.566	-10.462	<0.001***
	'Elliott' 2022	-4.592	-6.363	-2.821	0.566	-8.112	<0.001***
	'Hanna's Choice' 2022	-3.058	-4.829	-1.287	0.566	-5.402	<0.001***
'Elliott' 2021	'Hanna's Choice' 2021	7.369	5.598	9.140	0.566	13.018	<0.001***
	'Duke' 2022	-0.010	-1.780	1.761	0.566	-0.017	1.000
	'Elliott' 2022	1.320	-0.450	3.091	0.566	2.332	0.327
	'Hanna's Choice' 2022	2.854	1.084	4.625	0.566	5.042	<0.001***
'Hanna's Choice' 2021	'Duke' 2022	-7.379	-9.149	-5.608	0.566	-13.035	<0.001***
	'Elliott' 2022	-6.049	-7.819	-4.278	0.566	-10.685	<0.001***
	'Hanna's Choice' 2022	-4.515	-6.285	-2.744	0.566	-7.975	<0.001***
'Duke' 2022	'Elliott' 2022	1.330	-0.441	3.101	0.566	2.350	0.317
	'Hanna's Choice' 2022	2.864	1.093	4.635	0.566	5.059	<0.001***
'Elliott' 2022	'Hanna's Choice' 2022	1.534	-0.237	3.305	0.566	2.710	0.149

 P -value and confidence intervals adjusted for comparing a family of nine estimates (confidence intervals corrected using the Tukey method)* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

lowed by 'Duke', while the cultivar with the lowest production per plant was 'Hanna's Choice'. In the following section, the average blueberry production (t/ha) was characterized using ANOVA according to the combined effect of cultivar*year. According to the preliminary obtained results, the influence of factors taken into account (cultivar*year) was established, all having a statistically significant influence ($p < 0.001$) on blueberry production per hectare (Table 6). Thus, in the study carried out by

Strik et al. (2017), the cultivar significantly affected the yield in each year of study. As in case of production per plant, the importance of choosing an appropriate assortment is evident, considering that, depending on morphological characteristics and the requirements for environmental factors, each variety responds differently in terms of productivity. The yield differs among years for several reasons. For example, Nemeth et al. (2017) reported an increased plant growth (biomass) and yield from the year 9 to 10

Table 6 Analysis of variance on blueberry production (t/ha) under the combined influence of cultivar and year, bootstrapped marginal means (Bonferroni adjustment of the confidence interval)

Bootstrapped marginal means—cultivar*year				95% bca ¹ CI					
Cultivar	Year	Marginal mean	Bias	Lower	Upper	SE	t	Df	p
'Duke'	2020	14.518	−0.006	13.388	15.217	0.433	36.210	261	<0.001
'Elliott'		4.578	−0.010	4.127	5.226	0.266	11.496	261	<0.001
'Hanna's Choice'		8.297	0.045	6.899	9.298	0.582	20.641	261	<0.001
'Duke'	2021	7.430	−0.013	6.802	7.993	0.303	18.578	261	<0.001
'Elliott'		13.368	−9.541 × 10 ^{−5}	12.411	14.202	0.483	33.349	261	<0.001
'Hanna's Choice'		5.983	0.005	5.396	6.601	0.315	14.939	261	<0.001
'Duke'	2022	13.327	−0.026	12.519	14.446	0.473	33.373	261	<0.001
'Elliott'		12.030	0.002	11.493	12.537	0.253	30.050	261	<0.001
'Hanna's Choice'		10.491	0.002	9.879	11.214	0.348	26.218	261	<0.001

Bonferroni CI adjustment; bootstrapping based on 500 replicates; marginal means estimate is based on the median of the bootstrap distribution¹Bias corrected accelerated

in 'Elliott' cultivar. The results of this study indicated that the two considered factors (cultivar*year) act simultaneously on production characteristics. Genotype is a significant source of variation for the production per hectare as well as for the other analyzed production characteristics, a fact demonstrated by other studies (Redpath et al. 2021). As the genotype response was influenced by environmental factors, the climatic year also had a significant influence on productivity. Air and soil temperature, and rainfall amount varied among years, and suggested an influence on the yield features (Ehlenfeldt and Martin 2010; Strik et al. 2017). Overall, the obtained results provide a valuable basis for growing blueberries in different locations and enables the understanding of climatic effects on productive characteristics.

Following the obtained results, it was found that the commercial value of fruits and the production was influenced by the genetics of cultivars and by agroclimatic conditions specific to the area and the year of cultivation. The main criterion for evaluating the success of a cultivar introduction in a certain region is to analyze the correspondence of seasonal development rhythms related with climatic conditions of that region. From this point of view, the conditions in the agroclimatic region that are specific to the low hills of Banat region (Romania), ensure the completion of the entire seasonal development cycle of blueberry cultivars. Considering the analyses and observations made in the present study, the first cultivar recommended for the studied area is 'Duke', because it is a very productive variety, resilient to atmospheric drought, with large fruits and an early ripening period, which allows superior exploitation of the fruits. For the other cultivars from the study, a more in-depth analysis is recommended, since 'Hanna's Choice' cultivar shows early flowering, from this reason being affected by late frosts, with repercussions on production, and 'Elliott' cultivar shows some negative effects on produc-

tion during the periods of hot summer (the fruits lose their turgidity and raisin). In terms of market demand covering, the selection and cultivation of 'Duke' and 'Elliott' cultivars proved to be effective, because 'Duke' cultivar covers the early demand for berries, starting in June, and 'Elliott' cultivar covers the summer–autumn period (the month of September).

Conclusions

It was found that in terms of production characteristics of blueberry cultivars studied in the Banat region, the average weight of fruit, production per plant and average production per hectare have varied from one cultivar to another, and within the cultivar with the year of cultivation. The simulated models have highlighted the highly significant influence of considered factors combined (cultivar*year) on production features studied in this paper. Such data are important for the proper choice of biological material for planting and zoning of cultivars. The outputs in this field are very useful, bearing in mind the low amount of available information from the literature.

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Conflict of interest S. Cosmulescu, M.M. Merca Laies and V. Sărățeanu declare that they have no competing interests.

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