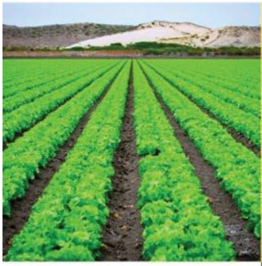

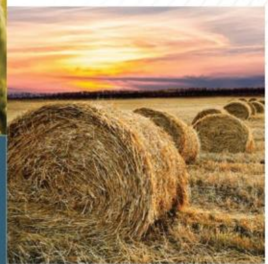


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TUBER YIELD AND STARCH CONTENT IN POTATO OF A DIFFERENT RIPENING IN AGRO-ECOLOGICAL CONDITIONS OF NORTHERN MONTENEGRO

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Abstract

The results of multi-year research on tuber yield and starch content of several potato varieties in the agro-ecological conditions of northern Montenegro are presented. The investigated varieties were of different ripening times, from early varieties (Riviera), medium early (Almera, Aladin and Bounty) to medium late (Agria, Margarita, Kennebec and Desiree). Research was conducted in 2015., 2016. and 2017, on acidic, brown soil. The experiments were placed at three different altitudes and therefore at three different climatic locations: Nedakusi (556 m), Sutivan (680 m) and Orahovica (900 m). Trials were set up in three replicas, using standard methodology in a random block design. Analysis of variance showed that the yield of tubers for sale and the total yield of tubers varied significantly depending on the genotype, year and altitude, that is, the location of the experiment, as well as their interactions.

Key words: Potato, variety, yield, tuber, starch

Introduction

Potato (Solanum tuberosum L.) holds an important place in the world food system as the fourth most important crop and is one of the leading agricultural and vegetable crops in Europe and the Balkans (Camire et al., 2009, Bishvong and Svarnima, 2016). Cultivated species originate from wild species that occur in spontaneous flora in a broad region of South America. Tubers have been used as food for more than 12,000 years. The Spanish brought the potato to Europe in 1536, but it was grown as a decorative plant in botanical gardens of Europe for almost two centuries (Đurić et al. 2015). It is used for human consumption and has a huge roal in the industry and as fodder (Donnelly and Kubov, 2011). Potatoes were brought to Montenegro later, in the 18th century, when St. Petar of Cetinje gave some cachets to be planted in the courtyard of the Monastery in Cetinje, from where it spread to other regions.

Potatoes first arrived in Montenegro by sea, and it was believed that they came from Russia. Russian early potato varieties were brought to Montenegro in 1786 (Ražnjatović, 1962). In the structure of arable land in Montenegro, potatoes occupy more than 23% (http://www.monstat.org). Areas under potatoes and yields in the world, Europe and Montenegro for the 2010-2019 period are presented in Table 1 (FAO, 2019).

Table 1. Areas under potatoes and yields in the world, Europe and Montenegro for the period 2010-2019

Year	**World**		**Europe**		**Montenegro**	
	Area (ha)	**Yield (t ha^{-1})**	**Area (ha)**	**Yield (t ha^{-1})**	**Area (ha)**	**Yield (t ha^{-1})**
2010	18,173,634	18. 08	6,013,351	17.85	1,214	14.60
2011	18,699,577	19. 68	6,146,793	21.24	1,286	16.50
2012	18,698,323	19. 31	5,962,821	19.56	1,327	11.80
2013	18,507,308	19. 73	5,725,810	20.15	1,345	14.90
2014	18,052,066	20. 50	5,619,154	22.17	1,645	14.78
2015	18,068,799	20. 26	5,540,376	21.04	1,616	16.83
2016	17,409,789	20. 34	4,883,324	22.35	1,613	18.55
2017	17,443,203	21. 22	4,832,677	23.81	1,616	17.02
2018	17,164,096	21. 28	4,733,273	22.14	1,619	16.12
2019	17,340,986	21. 36	4,696,336	22.84	1,620	16.40

Source: FAOSTAT-http://www.fao.org/faostat/en/#data/QC (retrieved on 1 April 2021).

Determining the optimal areas for growing potatoes is directly related to climatic conditions. Production of early potatoes is mainly located in the Zeta-Bjelopoljska plain and the littoral, with a share in the total production of 16.8%. Production of potatoes intended for storage is the dominant type of production (83.2%) and refers to the central-mountainous region (Jovović et al., 2012). Potato yield depends on the variety, genetic potential, agro-ecological conditions, level of applied agrotechnical measures and tuber viability, seed tuber size, number of stems per plant and number of tubers per plant (Bus and Wustman, 2007; Poštić et al. 2012; Poštić et al. 2013; Momirović et al. 2016; Arslanović Lukač et al., 2021). As a result of global warming in the next 30 years, for the region of Southeast Europe, including Montenegro, a decrease in potato yields of 10-26% is predicted, which could be reduced to 5-11% by using tolerant varieties and applying good agricultural practices (Hijmans, 2003). The quality of potato tubers and their chemical composition is influenced by genetics, factors, soil fertility, weather conditions and chemical treatments applied (Ritell et al., 2013). Quality of potato tubers is determined by many features, the most important of which are dry matter content, type and amount of starch and protein (Van Eck, 2007). Hoffler and Ochieng, (2008) point out that the high energy content of the potato and the simplicity of its production have made it a suitable component of urban agriculture, which globally ensures food security for at least 800 million people. Thus, potatoes are a crop vith high potential for solving the possible needs of low-income households, both in urban and in rural areas (FAO, 2008). Also, it has significant untapped potential to further increase yields and productivity, especially in some marginal farming societies, where other crops have extremely low yield potential (FAO, 2008). Potato yields in Montenegro are very unstable and very susceptible to the influence of meteorological conditions (Jovović et al., 2012; Arslanović Lukač et al., 2021).

With a correct selection of varieties, it is possible to overcome the negative impact of agro-ecological factors, especially the water and air regime of the soil and high temperatures during the growing season in the area of northern Montenegro. Therefore, the goal of this research was to examine the tuber yield and starch content in the tubers of different genotypes under the agro-ecological conditions of northern Montenegro and to find genotypes that will give satisfactory and stable yields.

Materials and methods

Experiments were done in 2015, 2016 and 2017 at three locations in the north of Montenegro. Subjects of the research were: early (Riviera), medium early (Almera, Aladin and Bounty) and medium late potato (Agria, Margarita, Kennebec and Desiree) varieties. Experiments were done under different agro-ecological conditions and on the same types of acid brown soil in: Nedakusi (556 m), Sutivan (680 m) and Orahovica (900 m). Experiments were laid out in a randomized block design with three replications. The size of a plot was 16 m^2. Potatoes were planted by hand with a distance of 70 cm between rows and 40 cm within the row, creating a density of 35,714 plants per hectare. Planting material belonged to the category of original (certified) seed, the fraction of 35-55mm. Sowing in all locations was done at the end of April. Cultivation was under dry farming conditions, usual for potato production. Appropriate plant protection products were used to control diseases and pests. After harvesting, the market yield of tubers and the total yield were precisely established. Data was converted into tons per hectare.

The soil on which experiments were conducted, like most soils in the western region of Montenegro, is characterized by favorable water and air properties and a high humus content. On the other hand, these soils have a high acidic pH, are poor in phosphorus and calcium and have a low (Nedakusi) to high potassium content (Sutivan and Orahovica), Table 2.

Table 2. Chemical characteristics of soil

Depth (cm)	Location	pH		$CaCO_3$ %	Humus %	mg 100 g^{-1} content	
		H_2O	n KCl			P_2O_5	K_2O
30	Nedakusi	5.00	4.41	2.57	2.77	5.27	8.33
	Sutivan	5.17	4.57	2.60	5.04	3.53	25.13
	Orahovica	4.63	4.03	2.47	3.62	3.17	24.60

Data in Tables 3 and 4 shows that that meteorological data differed significantly in different locations and between years. Average air temperatures decreased with higher altitude, while precipitation during the potato vegetation period was unevenly distributed, with a deficit during the period of intensive growth and tuber filling. This deficit was most pronounced in 2015, leading to a significant decrease in yield in that year under review.

Table 3. Average monthly air temperatures (°C) at all locations during the 2015, 2016 and 2017 trials

Year	Location	Month						
		April	May	June	July	August	Sept.	Average
2015	Nedakusi	9.7	16.9	18.9	23.4	22.6	18.7	18.37
	Sutivan	9.0	16.4	18.3	22.9	21.8	18.2	17.77
	Orahovica	8.4	15.8	17.9	22.5	21.2	18.0	17.3
2016	Nedakusi	13.6	13.9	20.5	21.5	19.8	16.6	17.65
	Sutivan	12.9	13.4	19.9	21.0	19.1	16.0	17.05
	Orahovica	12.3	12.9	19.5	20.4	18.4	15.7	16.53
2017	Nedakusi	10.3	15.3	20.0	21.3	21.9	16.7	17.58
	Sutivan	9.7	14.7	19.4	20.8	21.0	16.2	16.97
	Orahovica	9.2	14.1	18.8	20.3	21.5	15.8	16.62

Table 4. Amount and distribution of precipitation (mm) at all locations during the experiment in 2015, 2016 and 2017

Year	Location	Month						
		April	May	June	July	August	Sept.	Total
2015	Nedakusi	53.5	35.5	90.4	15.5	30.7	59.0	284.6
	Sutivan	56.1	38.4	34.0	8.2	22.3	63.8	222.8
	Orahovica	61.4	42.5	47.1	20.3	16.7	48.6	236.6
2016	Nedakusi	48.2	120.0	86.0	76.0	85.3	74.6	490.1
	Sutivan	50.6	126.1	90.3	79.8	88.1	78.2	513.1
	Orahovica	53.0	132.8	95.1	89.2	97.3	82.5	549.9
2017	Nedakusi	49.0	78.9	75.4	102.4	44.8	19.4	369.9
	Sutivan	51.4	83.0	79.8	106.7	47.5	22.4	390.8
	Orahovica	60.5	89.6	87.2	117.3	53.0	25.8	433.4

Obtained results were analyzed by analysis of variance (ANOVA, F-test; $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$) and the effect of factors (year, genotype, location and their interaction). Data was processed using the STATISTICA program, version 8 (StatCoftInc, Tulsa, OK, USA).

Results and discussion

Analysis of market yield (Table 5) showed very significant statistical differences under the influence of year (Factor A), location (Factor B) and variety (Factor

C). A very high significance of the mutual effect of examined factors in terms of the trend for market yield was obtained for all mutual interactions of the examined factors A x B, A x C, B x C and A x B x C.

On the average the highest market yield of tubers (25,46 t ha^{-1}) was established in 2016, followed by 2017 (21,21 t ha^{-1}), while the lowest market yield (18,19 t ha^{-1}) was established in in 2015. Observing the effect of the year on average (Table 5), a very significantly higher yield of marketable tubers was recorded in 2016, compared to market yields established in 2015 and 2017. A very significantly higher market yield was established in 2017, compared to the market yield established in 2015.

Observed by locations, the highest market yield of tubers (29.20 t ha^{-1}) was established at the Nedakusi location, followed by the Sutivan location (19.90 t ha^{-1}), while the lowest market yield (15.80 t ha^{-1}) was realized at the Orahovica location. Statistical analysis of the yield of marketable tubers revealed a very significantly lower market yield of tubers at the Sutivan and Orahovica locations, compared to the recorded yield of marketable tubers at the Nedakusi location. A significantly higher market yield of tubers was established at the Sutivan location, compared to the market yield achieved at the Orahovica location.

Table 5. Effect of year, location and variety on the yield of marketable tubers (t ha^{-1})

Variety (C)	Year (A)											
	2015				2016				2017			
	Location (B)											
	Ne	Su	Or	X(A)	Ne	Su	Or	X(A)	Ne	Su	Or	X(A)
Riviera	36.19	19.69	7.75	21.21	19.37	19.69	14.73	17.93	15.73	16.18	12.50	14.8
Almera	40.68	9.87	10.59	20.38	21.59	27.25	22.00	23.61	17.11	22.12	17.28	18.84
Aladin	38.96	9.16	12.06	20.06	37.35	36.46	24.37	32.73	31.79	33.04	20.38	28.4
Bounty	33.83	2.17	8.33	14.78	25.56	28.01	17.81	23.79	20.26	23.30	15.13	19.56
Agria	32.08	7.20	10.78	16.69	35.99	29.28	24.82	30.03	30.98	25.73	20.00	25.57
Margarita	43.13	5.61	12.43	20.39	26.89	29.48	21.56	25.98	21.92	25.24	18.29	21.82
Kennebec	32.29	5.22	8.03	15.18	25.71	23.05	15.95	21.57	18.11	19.06	13.58	16.92
Desiree	33.71	7.05	9.70	16.82	33.14	28.49	22.57	28.07	28.90	23.93	18.36	23.73
X(C)	36.36	8.25	9.96	18.19	28.20	27.71	20.48	25.46	23.1	23.58	16.94	21.21

	A	B	C	AB	AC	BC	ABC
F	65.52**	242.7**	18.34**	111.6**	6.11**	1.55**	2.18**
$LSD_{0.05}$	1.26	1.25	2.05	2.18	3.56	3.55	6.16
$LSD_{0.01}$	2.15	2.15	3.51	3.73	6.08	6.09	10.54

The yield of marketable tubers (> 70 g) depends on the genetic potential of the variety, agro-ecological conditions, applied technology (fertilization, irrigation, protection, cultivation system) and the length of the vegetation period, which means that under conditions of longer tuber filling, larger tubers are formed and the total yield is higher (Knowles et al., 2003; Khan et al., 2004; Doring et al., 2005; Kar and Kumar, 2007; Singh and Ahmet, 2008; Momirović et al., 2010; Poštić et al., 2012; Poštić 2013; Gvozden, 2014; Poštić et al., 2015; Momirović et al., 2016; Gvozden, 2016; Oljača, 2016). However, this does not always have to be confirmed in practice, because early and mid-early varieties, characterized by early tuberization and rapid filling of tubers in dry summer conditions usually give higher yields than native mid-late and late varieties. The yield of commercial tubers in 2016 (Table 5) was on average significantly higher compared to 2015 and 2017, as a result of more favorable weather conditions in 2016 (Table 3 and Table 4). Such results are in agreement with the research of numerous authors (Momirović et al., 2010; Jovović et al. 2011; Poštić et al. 2012; Poštić, 2013; Gvozden, 2016; Momirović et al., 2016; Oljača, 2016), who state that production conditions significantly affect the yield of mercantile or marketable tubers.

Analysis of total yield (Table 6) showed statistically very significant differences under the influence of year (Factor A), location (Factor B) and variety (Factor C). Very significant interactions of the examined factors in terms of total yield were seen with the mutual effect of factors A x B, A x C and B x C, while there was no effect of the interaction A x B x C.

On average, the highest total yield (26.73 t ha^{-1}) was established in 2016, followed by 2017 (23.92 t ha^{-1}), while the lowest total tuber yield (19.47 t ha^{-1}), was recorded in 2015. When observing the average effect of the year (Table 6), a significantly higher total yield of tubers was recorded in 2016, compared to the total yields recorded in 2015 and 2017. A very significantly lower total yield was established in 2015, compared to the total yield established in 2017.

Observed by locations, the highest total yield of tubers (31.40 t ha^{-1}) was established at the Nedakusi location, followed by the Sutivan location (21.40 t ha^{-1}), while the lowest total yield (17.40 t ha^{-1}) was recorded at the Orahovica location. Statistical analysis of the yield of marketable tubers revealed a very significantly lower total yield of tubers at the Sutivan and Orahovica locations, compared to the recorded total yield of tubers at the Nedakusi location. A significantly higher total tuber yield was recorded at the Sutivan location, compared to the total yield recorded at the Orahovica location.

Table 6. Effect of year, location and variety on total tuber yield (t ha^{-1})

Variety (C)	Year (A)											
	2015				2016				2017			
	Location (B)											
	Ne	Su	Or	X(A)	Ne	Su	Or	X(A)	Ne	Su	Or	X(A)
Riviera	38.10	15.93	8.67	20.9	20.58	21.19	15.81	19.19	18.56	19.18	14.79	17.51
Almera	41.73	11.29	11.98	21.67	23.06	28.75	23.05	24.95	19.48	25.45	20.09	21.67
Aladin	40.48	10.24	13.04	21.25	38.76	38.27	25.35	34.13	35.36	34.95	23.02	31.11
Bounty	34.96	3.73	9.33	16.01	26.11	29.15	18.63	24.63	23.09	26.13	17.28	22.17
Agria	34.02	8.18	11.83	18.01	37.22	30.55	26.09	31.29	33.60	27.23	23.11	27.98
Margarita	45.32	6.63	13.48	21.81	28.16	30.77	22.64	27.19	24.95	27.64	20.86	24.48
Kennebec	34.04	6.19	9.24	16.49	27.28	24.59	17.00	22.96	23.67	21.28	15.66	20.2
Desiree	39.43	8.78	10.68	19.63	34.5	30.26	23.75	29.5	31.29	26.14	21.30	26.24
X(C)	38.51	8.878	11.03	19.47	29.46	29.19	21.54	26.73	26.25	26.00	19.51	23.92

	A	B	C	AB	AC	BC	ABC
F	64.20**	250.8**	19.43**	120.3**	4.72**	1.61**	1.49ns
$LSD_{0.05}$	1.28	1.28	2.09	2.21	3.62	3.63	
$LSD_{0.01}$	2.19	2.19	3.58	3.79	6.19	6.20	

When choosing an assortment, fertility is one of the most important qualitative characteristics. In the last few years, in the production of all agricultural plant species, the aim is to precisely recommend the assortment for a certain region (Arslanović-Lukač et al. 2012; Poštić, 2013; Oljača, 2016; Gvozden, 2016). Such a strong influence of location on total tuber yield agrees with the results of other authors (Hassanpanah, 2010; Jovović et al., 2012; Poštić et al., 2012; Momirović et al., 2016; Oljača, 2016; Gvozden, 2016). Owing to their ability to grow quickly, good coverage and earlier formation of tubers (Desiree), some varieties go through critical stages of development more easily (tolerant varieties) reducing the negative impact of environmental factors (Rukaaczevska, 2015; Momirović et al., 2016).

Analysis of starch content in the tuber (Table 7) showed statistically very significant differences under the influence of year (Factor A), location (Factor B) and variety (Factor C). A very high significance of the mutual influence of the examined factors in terms of starch content was seen for all mutual interactions of the examined factors A x B, A x C, B x C and A x B x C.

On average, the highest starch content (18.41%) in the tuber was established in 2015, followed by 2017 (18.22%), while the lowest starch content in the tuber (17.33%) was recorded in 2016. Observing the influence of the year on average (Table 7), a significantly higher starch content in the tuber was recorded in 2015, compared to the starch content established in 2016 and 2017. A significantly higher starch content in the tuber was found in 2017, compared to the starch content in 2016.

Observed by locations, the highest starch content in the tuber (18.9%) was found at the Sutivan location, followed by the Orahovica location (18.4%), while the lowest starch content in the tuber (16.7%) was achieved at the Nedakusi location. Statistical analysis of the starch content in tubers revealed a significantly lower starch content at Nedakusi and Orahovica locations, compared to the recorded starch content in tubers at the Sutivan location. A significantly higher starch content in tubers was found at the Orahovica location, compared to the starch content in tubers at the Nedakusi location.

Table 7. Effect of year, location and variety on starch content in tubers (%)

Variety (C)	Year (A)											
	2015				2016				2017			
	Location (B)											
	Ne	Su	Or	X(A)	Ne	Su	Or	X(A)	Ne	Su	Or	X(A)
Riviera	15.12	15.34	16.43	15.63	13.29	20.31	13.87	15.82	16.24	16.43	15.65	16.11
Almera	15.46	15.21	18.75	16.47	12.11	15.17	12.59	13.29	15.02	16.89	17.24	16.38
Aladin	17.19	18.75	19.22	18.39	16.89	20.12	14.82	17.28	17.42	19.31	20.08	18.94
Bounty	19.27	19.74	22.42	20.48	19.36	24.05	16.34	19.92	18.05	18.84	19.21	18.70
Agria	17.67	14.99	22.52	18.39	14.55	21.56	17.99	18.03	18.32	19.73	20.42	19.49
Margarita	16.83	16.16	20.74	17.91	15.99	19.68	13.53	16.40	17.24	18.52	18.17	17.98
Kennebec	19.97	19.81	20.14	19.97	15.70	20.40	19.14	18.41	17.69	19.63	19.56	18.96
Desiree	19.17	20.25	20.65	20.02	14.78	21.99	21.66	19.48	18.04	19.71	19.85	19.20
X(C)	17.59	17.53	20.11	18.41	15.33	20.41	16.24	17.33	17.25	18.63	18.77	18.22

	A	B	C	AB	AC	BC	ABC
F	2870**	10829**	8714**	9287**	676.1**	589.9**	740.1**
$LSD_{0.05}$	0.03	0.03	0.05	0.05	0.09	0.09	0.15
$LSD_{0.01}$	0.05	0.05	0.08	0.09	0.15	0.15	0.25

Measurement results presented in the table show that the highest starch content in the tubers was recorded in the variety Bounty (19.70%), followed by the varieties Desiree (19.57%), Kennebec (19.11%), Agria (18.64 %) and Aladin (18, 20%), while the lowest starch content in the tuber (15.38%) was recorded in the variety Almera. On average, the highest starch content (18.41%) in the tuber was recorded in 2015, followed by 2017 (18.22%), while the lowest starch content in the tuber (17.33%) was achieved in 2016. Starch content of in our research decreases with the increase in precipitation, which is not in agreement with the research of Rudack et al., (2014) and Gvozden (2016), who state that the deficit of precipitation and drought stress reduce the starch content in tubers.

The nutritional value of potato tubers is determined by the content of chemical components (starch, proteins, vitamins, total sugars, reducing sugars and minerals) that play a very important role in human nutrition, as well as by the concentration of toxic compounds (glycoalkaloids, nitrates, heavy metals, pesticides), Lisinska, (2006); Love and Pavek, (2008). Eilers and Hanf, (1999) believe that for industrial processing, the optimum starch content in tubers is around 15%. Singh et al., (2008) state that the starch content in tubers is an indicator of quality, i.e., its purpose, whether it is for cooking or processing. Starch content in the total chemical composition of tubers is 8.0-29.4% (on average 14.1%). The quality of puree, the flouriness and the texture of the boiled potato are determined by the starch content in the tuber (Van Eck, 2007).

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Conclusion

Based on three-year research on tuber yield and starch content of potato varieties with different ripening times in different agro-ecological conditions of northern Montenegro, the following can be concluded:

Different locations and years individually and via their interactions significantly influenced the production properties of studied varieties (genotypes).

It can be concluded that under agro-ecological conditions of northern Montenegro at locations of Nedakusi, Sutivan and Orahovica, the highest total yield within the three-year average was recorded for the medium-early variety Aladin, which had the highest market yield. The Aladin variety was followed by mid-late varieties Agria and Desiree that also had a high and stable total yield at the experiment locations.

For the three-year average, the lowest total tuber yield at experiment locations was established with the early variety Riviera.

Contrary to the assumption and results of other authors, the highest starch content in tubers by year, was recorded in 2015 (when the amount of precipitation was the lowest and the average air temperature the highest), followed by 2017, while the lowest starch content was recorded in 2016.

To achieve high yields with a high share of marketable tubers, the varieties Aladin, Agria and Desiree should be grown, due to their high tolerance to drought, good resistance to potato pathogens and high yield potential.

For production of potatoes for industrial processing, where a high proportion of large A-class tubers is required, as well as a high starch content, we recommend varieties Agria, Kennebec and Desiree.

The region of northern Montenegro is a favorable location for the production of high-quality and health-safe potatoes.

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