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Heritability of Yield and Yield Components of Autochthonous Populations of Jerusalem Artichoke (*Helianthus tuberosus* L.)

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Abstract

Examination of heritability of yield and yield components of autochthonous populations of Jerusalem artichoke was conducted in the experimental field of the Agricultural Institute in Banja Luka during 2015 and 2016. The trials were set up in four replications with ten populations of Jerusalem artichoke in the late October 2014. During the study, the following parameters were observed: plant height, number of stems per plant/clone, stem thickness and dry matter yield per plant/clone. Population Razboj had the highest yield of dry matter per plant/clone. In the first year, the population of Irić bašta had the largest number of stems per plant/clone. Broad sense heritability for plant height and number of stems per plant/clone indicates intermediate hereditary traits. A significant positive genetic correlation between yield of dry matter and plant height was determined.

Key words: Jerusalem artichoke, yield, heritability, plant height, stem thickness

Introduction

Jerusalem artichoke originates from America, from where it was brought to Europe in the beginning of the seventeenth century. It belongs to the *Asteraceae* family.

Botanically speaking, it is an annual plant, but is considered as a perennial species due to the tubers retained in the soil with the ability to provide new plants (Erić et al., 2004). Jerusalem artichoke has a high yield potential and a wide possibility of applications. It could be used as a forage species in a form of green mass or silage. Tubers can be used for human consumption. There is an increasing interest in processing by chemical and pharmaceutical industries. Jerusalem artichoke is one of the most important crops for the industrial production of inulin (Kays & Nottingham, 2008). Herbal etheric oils and its extracts are used in medicine, for food conservation and natural therapies. Helmi et al. (2014) conducted a study in Ukraine, which for the first time evaluated the content of etheric oils in the leaves and tubers. According to Yuan et al. (2012), the leaves of the Jerusalem artichokes can be a significant source of natural antioxidants. The Jerusalem artichoke is an interesting culture that has a potential as a Bioenergy crop for bioethanol production because it is fast growing and has a high biomass production (Long et al. 2016). Above-ground parts fresh or fermented, may also be used for biogas production and dry matter for direct burning or for the production of briquettes and pellets (Majtkowski, 2003; Stolarski, 2004).

The Jerusalem artichoke is a particularly interesting plant species for cultivation in hilly mountain areas for the production of green forage or silage, as well as for tubers, that can be used as a winter fodder. Although it has a great adaptability to various growing conditions, the Jerusalem artichoke are grown sporadically, mainly as an ornamental plant, and more recently for the production of animal feed. In Bosnia and Herzegovina, it occurs in arable land as weed and causes a serious problem being considered an invasive plant species. In nature, it can often be found along rivers and stream banks, roads, forest edges, embankments and in deserted areas.

The aim of this study was to evaluate the production potential for the autochthonous populations of Jerusalem artichoke collected in the Republic of Srpska.

Material and Methods

The study of autochthonous populations of Jerusalem artichoke was carried out at the experimental field of the Agricultural Institute of the Republic of Srpska in Banja Luka during 2015 and 2016.

The vegetative material was collected in the wider area of the Republic of Srpska and identified as populations Razboj, Dolina, Kneževo, Delića njiva, Trn, Jakeš, Irić bašta, Nasip, Ciglana and Župa. Tubers were planted in rows at a distance of 70 cm, with a distance of 50 cm between rows.

The planting depth was 10 cm. The experiment was designed in four replications in a randomized block design. Weight of tubers planted ranged from 25 to 82 grams.

The planting was done in the late October of 2014. NPK (300 kg ha^{-1} in the 15:15:15 form) was used to prepare the experimental field. In both years plants were fertilized with 100 kg ha^{-1} KAN (27% N) at the plant height of 35 - 40 cm. During these studies several parameters were analyzed: plant height (cm), a number of stems per clone (plant), stem thickness (cm) and dry matter yield per clone (kg). Obtained results were evaluated using analysis of variance (ANOVA), and for each property the sum of squares, mean squares and error was determined.

Heritability coefficients were determined for relevant properties based on the relation of genotypic and phenotypic trait variances. The model was applied to desegregate the entire variance in components, where values of *MS* (medium square) were taken as *MS* over two years of testing, i.e. as values of repetition in time. Measured phenotypic values are not inherited entirely. A part of the phenotypic variability generated under the influence of external factors, pertains solely to the generation analyzed. Only generic variability of property analyzed is transferred to the next generation. If the genetic variability of a property is high, there is a greater possibility that these properties would be transferred to the next generation. The relation between genotype and total phenotypic variances represents heritability in a wider sense.

Tab. 1. The model of desegregation of phenotypic variation in single-factorial experiments (Eberhart & Russell, 1966)
Модел растављања фенотипског варирања у једнофакторијалним огледима

Source of variation *Извор варијације*	*Df*	MS_{izr}	$MS_{oč}$
Repetition (R) *Понављање*	R - 1	MS_R	$\sigma_E^2 + G \cdot \sigma_R^2$
Genotype (G) *Генотип*	G - 1	MS_G	$\sigma_E^2 + R \cdot \sigma_G^2$
Error (E) *Грешка*	(R - 1) · (G - 1)	MS_E	σ_E^2

According to this model, the following variances are separated:

$$\sigma_E^2 = MS_E \ ; \ \sigma_R^2 = (MS_R - MS_E)/G \ ; \ \sigma_G^2 = (MS_G - MS_E)/R .$$

Total phenotypic variance is: $\sigma_F^2 = \sigma_G^2 + \sigma_E^2 / R$. Heritability in a wider sense (Borojević, 1986): $h^2 = (\sigma_G^2 / \sigma_F^2) \cdot 100$ (%).

Based on the obtained coefficient values, it is possible to calculate the potential genetic gain from the selection of each analyzed parameter.

$G = k \times S_F \times H$, where:

- k is a value which includes a selection differential containing a medium genotypic value of q selected strains and an initial strain of populations, phenotypic standard deviation and selection intensity, i.e. the percentage of plants selected for conceiving the next generation (q/n). Since "k" is expressed in standard deviation values, it is slightly changed and mainly depends on the selection intensity. At the selection intensity of 10%, value "k" is 1.76.

- S_F is the phenotypic standard deviation from medium values of the property to which a selection is conducted of an initial strain.

- H is a coefficient of heritability obtained from the relation between genetic variance and total phenotypic variance.

To determine dependencies on the examined properties, the Pearson's coefficient of correlation was carried out between yield components and dry matter yield of the Jerusalem artichoke populations studied.

The experimental fields at the Agricultural Institute of the Republic of Srpska, where the experiment was conducted lay on a valley-brown soil, being alluvial substrate of Vrbas river belonging to the clay-loam group. The results of the chemical analysis of the experimental field's arable layer are shown in Table 2.

Tab. 2. Results of chemical analysis of the soil

Резултати хемијске анализе ораничног слоја земљишта

Depth *Дубина* (cm)	Humus *Хумус* %	pH in H_2O *pH у H_2O*	pH in KCl *pH у KCl*	P_2O_5 mg/100g of soil *mg/100g земљишта*	K_2O mg/100g of soil *mg/100g земљишта*
0 - 30	1.9	7.9	6.9	20.3	16.1

Regarding pH, the soil is alkaline with low humus content. The provision of the exchangeable phosphorus is good, while the presence of potassium in the soil is moderate. Based on the results of the soil chemical analysis, it can be concluded that the experimental field is suitable for the cultivation of Jerusalem artichokes.

For the analysis of weather conditions, meteorological data from meteorological stations of Banja Luka were used (Table 3). The average value of temperature for the period from 1961 to 2013 was 17.6 ^{0}C.

The total amount of precipitation in the vegetation period (IV-IX) for the same period was 566.7 mm.

Tab. 3. Average temperatures (°C) and precipitation (mm) in Banja Luka for 2015 and 2016
Просјечне температуре (°C) и падавине (mm) за Бања Луку у 2015. и 2016. години

Month / *Mjesec*	IV	V	VI	VII	VIII	IX	X*/Σ**
Temperature °C (2015) *Температура °C (2015)*	12.1	17.8	20.8	24.6	23.7	17.9	19.5*
Temperature °C (2016) *Температура °C (2016)*	13.5	16.2	21.5	23.3	20.5	17.8	18.8*
Temperature °C (1961-2013) *Температура °C (1961-2013)*	11.2	16.1	19.7	21.3	20.8	16.3	17.6*
Precipitation mm (2015) *Падавине mm (2015)*	13.0	113.0	17.0	26.0	106.0	41.0	316.0**
Precipitation mm (2016) *Падавине mm (2016)*	70.5	100.6	117.8	125.9	100.2	63.2	578.2**
Precipitation mm (1961-2013) *Падавине mm (1961-2013)*	89.4	93.6	112.0	92.5	85.9	93.3	566.7**

**X -average. **Σ-sum.*

Average temperatures for both examined years during the growing season were higher, compared to the many-year average. During the first year of the experiment, the precipitation was lower by 250.7 mm compared to the many-year average and in 2016 higher than the many-year average.

Results and Discussion

For successful breeding of any plant species, it is necessary to know their genetic potential, the structure of the genetic and phenotypic variance, heritability and interdependence of functionally related traits. The variability and heritability of several quantitative traits of Jerusalem artichoke were analyzed in this study (Table 4). Statistically significant differences in all parameters measured during the study were confirmed. Statistically significant difference among populations was found for the plant height while the other characteristics did not show this trend.

Among the factors observed during this study, the interaction effect has not been determined. For this reason, the conclusions were obtained using basic parameters.

Tab. 4. Analysis of variance for the observed traits
Анализа варијансе праћених особина

Source of variation / *Извори варијације*	df	Traits / *Особине*			
		Dry matter yield/plant *Принос суве материје/ биљци*	Stem number/plant *Број стабљика/ биљци*	Stem thickness *Дебљина стабљике*	Plant height *Висина биљке*
Treatment / *Третман*	19	**	**	**	**
Year / *Година*	1	**	**	**	**
Populations /*Популације*	9	ns	ns	ns	**
Populations x Year *Популације х Година*	9	ns	ns	ns	ns
Error / *Грешка*	60	$1.49x10^{-6}$	$5.27x10^{-4}$	1.96	$2.32*10^{-4}$
Total / *Укупно*	80	$1.12x10^{-7}$	$3.47*10^{-5}$	78.6	$2.56*10^{-6}$

*ns ($P > 0.05$), ** ($P \leq 0.01$)*

The significance of differences among the populations of Jerusalem artichoke was analyzed by Duncan's post-hoc test (Table 5).

The difference in plant height among genotypes was only found in 2015. The Župa population had statistically significant difference in plant height during the first year compared to Dolina, Trn, Jakeš and Ciglana populations. Plant height varied from 168.5 cm (Dolina) to 217.5 cm (Ciglana) in the 2015 growing season. In 2016, plant height was slightly lower, ranging from 141.8 cm (Jakeš) to 184.3 cm (Razboj). Ragab et al. (2003) obtained similar results. They found that plant height of Jerusalem artichokes ranged from 1.20 to 2.30 cm. Liu et al. (2012) concluded that the Jerusalem artichokes plant height varied from 227 cm and 343 cm in the province of Gansu, China. Puttha et al. (2013) concluded that plant height of Thailand varies from 41.1 cm to 112.7 cm (average 70.1 cm).

The thickness of the stems in this study ranged from 0.80 cm in 2016 (Trn, Župa) to 1.18 cm (Kneževo) in 2015. According to Puttham et al. (2013) measured values of the thickness of the stems were lower than in this study and ranged between 0.41 cm and 1.11 cm. (average thickness was 0.66 cm).

Tab. 5. Average values for observed traits of Jerusalem artichoke populations in 2015 and 2016

Просјечне вриједности испитиваних особина популација чичоке у 2015. и 2016. години

Population *Популација*	Dry matter yield per plant *Принос суве материје по биљци* (g)		Stem number per plant / *Број стабљика по биљци*		Stem thickness / *Дебљина стабљике* (cm)		Plant height / *Висина биљке* (cm)	
	2015	2016	2015	2016	2015	2016	2015	2016
Razboj	232.5^{B}	643.3^{A}	3.0^{B}	95.8^{A}	0.97^{A}	0.94^{B}	204.3^{AB}	184.3^{B}
Dolina	150.0^{B}	424.8^{A}	4.3^{B}	83.0^{A}	1.02^{A}	0.95^{B}	168.5^{C}	159.5^{B}
Kneževo	167.5^{B}	436.0^{A}	2.8^{B}	91.3^{A}	1.18^{A}	0.85^{B}	198.3^{ABC}	148.5^{B}
Delića njiva	153.8^{B}	425.3^{A}	3.0^{B}	89.5^{A}	1.05^{A}	0.95^{B}	189.8^{ABC}	147.5^{B}
Trn	145.0^{B}	397.5^{A}	2.8^{B}	76.5^{A}	1.06^{A}	0.80^{B}	184.3^{BC}	166.5^{B}
Jakeš	172.5^{B}	432.3^{A}	3.8^{B}	90.3^{A}	1.00^{A}	0.89^{B}	173.3^{BC}	141.8^{B}
Irića bašta	181.3^{B}	445.3^{A}	4.8^{B}	79.8^{A}	1.00^{A}	0.86^{B}	189.3^{ABC}	171.5^{B}
Nasip	172.5^{B}	445.5^{A}	3.0^{B}	69.8^{A}	1.07^{A}	1.03^{B}	191.8^{ABC}	170.0^{B}
Ciglana	143.8^{B}	444.0^{A}	3.3^{B}	90.0^{A}	0.95^{A}	1.02^{B}	170.3^{C}	149.0^{B}
Župa	185.0^{B}	485.0^{A}	3.0^{B}	89.0^{A}	1.09^{A}	0.80^{B}	217.5^{A}	181.8^{B}
Average *Просјек*	170.4^{B}	457.9^{A}	3.4^{B}	85.5^{A}	1.04^{A}	0.91^{B}	188.7^{A}	162.0^{B}

$^{A,B,C....}$ *Values denoted by the same letter are not significantly different at the p=0. 01 level of probability (Duncan's Multiple Range Test).*

According to our results, the average number of stems per plant/clone was 3.4 in 2015. Le Cochec (1990) reported on average 2.9 stems per plant in the first year. These values are much lower compared to the results in this study. There was no significant difference in the yield of dry mass per plant among examined populations of Jerusalem artichokes. There was no significant difference in the dry mass per plant yield among populations of Jerusalem artichoke in our study.

Significant variations in the tuber characteristics and yield between varieties and hybrids of Jerusalem artichokes were reported by Kiru & Nasenko, 2010.

Heritability is an important parameter for breeding of Jerusalem artichokes. It is easier to select traits with higher heritability. The results show that the highest heritability coefficient was obtained for plant height (43%), while dry matter yield expressed low heritability coefficient (8%), (Table 6).

Tab. 6. Components of phenotypic variability and coefficients of heritability for tested parameters

Компоненте фенотипске варијабилности и коефицијент херитабилност испитиваних параметара у огледу популацијских линија

Heritability components / *Компоненте херитабилности*	Dry matter yield/plant *Принос суве материје/ биљци*	Stem number/plant *Број стабљика/ биљци*	Stem thickness *Дебљина стабљике*	Plant height *Висина биљке*
MS_R	1653125.0	134890.3	0.331	14231.1
MS_G	17456.3	125.9	0.013	1552.1
$MS_E = V_E$	24765.3	877.8	0.033	386.9
$V_R = (MS_R-MS_E) /G$	162836.0	13401.3	0.030	1384.4
$V_G = (MS_G-MS_E) / R$	1827.2	188.0	0.005	291.3
$V_F = V_G + V_E$	22938.0	689.8	0.028	678.2
$h^2 = (V_G / V_F) \times 100$	8.0	27.3	17.9	43.6

*G = 10, R = 4, MS_R – medium square repetition, MS_E – medium square errors, MS_G- medium square genotype, V_G- genotype variance, V_F- phenotypic variance, V_E- environmental variance, h^2- heritability

Broad-sense heritability for plant height (43.66%) and number of stems per plant/clone (27.3%) indicate that these properties are intermediately inherited. The results of this study show a moderate heritability for the height of plants and the number of stems per plant. Le Cochec (1990) reported a broad-sense heritability ranging between 19.5% and 98.1%. He pointed out that the number of stems per plant/clone determined the broad - sense heritability of 25.0%.

The relative genetic gain from selection represents the relationship between the obtained values of genetic gain and the mean value of a specific property expressed in percentage (Table 7). Applied statistical methods made it possible to analyze the variability of quantitative traits, to estimate the heritability and to estimate the genetic gain by selection.

It is necessary to know the correlation between the most important properties of the material selected due to the compensatory change of other properties. Correlation analysis determines the degree of concordance between the properties regardless of the dependent and independent variable (Hallauer end Miranda. 1988).

Tab. 7. Potential selection gain from autochthonous populations
Потенцијална селекциона добит од аутохтоних популација

Traits / *Особине*	Average population value *Просјечна вриједност популације*	K	Phenotype variance *Фенотипска варијација*	Phenotype standard deviation *Фенотипска стандардна девијација*	h^2	Genetic gain (G) *Генетска добит*	Relative genetic gain (%) *Релативна генетска добит*
Dry matter yield/plant (*g*) *Принос суве материје/ биљци*	314.1	1.76	22938	205.4	0.08	28.9	0.09
Stem number/plant *Број стабљика/ биљци*	44.4	1.76	689.8	49.0	0.27	23.3	0.52
Stem thickness (*mm*) *Дебљина стабљике*	1.000	1.76	0.028	0.000	0.18	0.0	0.00
Plant height (*cm*) *Висина биљке*	175.4	1.76	678.2	26.2	0.43	19.8	0.11

Table 8 shows the Pearson-correlation coefficients for the analyzed properties of the tested populations. In the case of correlation relationships between the yield components and yield of dry matter, a significant positive genetic correlation was observed between dry matter yield and plant height (r = 0.655*). These values indicate the possibility of improving yields by using individual components as well as the selection criteria during the breeding process.

Tab. 8. Simple correlation coefficients between characteristics for 10 evaluated populations

Прости коефицијенти корелације између 10 испитиваних популација

Traits / *Osobine*	Dry matter yield/plant *Принос суве материје/ биљци*	Stem number/ plant *Број стабљика/ биљци*	Stem thickness *Дебљина стабљике*	Plant height *Висина биљке*
Dry matter yield / plant *Принос суве материје / биљци*	-	0.461	-0.102	0.655*
Stem number / plant *Број стабљика / биљци*	0.180	-	-0.252	-0.023
Stem thickness *Дебљина стабљике*	0.779	-0.252	-	-0.092
Plant height *Висина биљке*	0.040	-0.023	-0.092	-

**significant at P > 0.05*

Genetic and phenotypic correlations between the traits evaluated among the populations of Jerusalem artichoke indicate the complexity of the yield inheritance and its components. There is a great environmental impact on factors and interactions (population x year). Diederichsen (2010) found positive correlation (0.29) between plant height and tuber yield among 161 genotypes studied.

Conclusion

During these studies, the impact of the year on the yield and yield components to examined population of Jerusalem artichoke was highly significant.

Dancan's test indicates three intervals of significance for the plant height.

Population Župa had the highest average plant height during the two-year study. The largest number of stems per plant/clone during the second year was found in the Razboj population (95.8).

During both years, Razboj population had the highest dry matter yield per plant/clone. Established broad-sense heritability for plant height (43.66%) and number of stems per plant/clone (27.3%) indicate that these properties are intermediately inherited.

A significant positive genetic correlation was found between dry matter yield and plant height (r = 0.655*).

On the bases of the results of this study, the populations Razboj and Irić bašta are selected as a valuable genetic material for further breeding programs.

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Херитабилност приноса и компоненти приноса аутохтоних популација чичоке (*Helianthus tuberosus* L.)

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Сажетак

Испитивање херитабилности приноса и компоненти приноса аутохтоних популација чичоке обављено је на огледном пољу Пољопривредног института Републике Српске у Бањалуци током 2015. И 2016. године. За ова испитивања коришћено је 10 аутохтоних популација чичоке. Популације чичоке су вегетативно умножене. Оглед је постављен у четири понављања. Садња је обављена крајем октобра 2014. године. Током ових истраживања праћени су сљедећи параметри: висина биљака, број стабљика по биљци/клону, дебљина стабљике и принос суве материје по клону. Популације Разбој имала је током испитивања највећи принос суве материје по биљци/клону. Највећи број стабљика по биљци/клону у првој години имала је популација Ирић башта, а у другој популација Разбој. Утврђена херитабилност у ширем смислу за висину биљке и број стабљика по биљци/клону указује да су ова својства средње насљедна. Значајна позитивна генетичка корелација констатована је између приноса суве материје и висине биљака.

Кључне ријечи: чичока, принос, херитабилност, дебљина стабљике, висина биљке

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