www.nsseme.com/journal.html

Genetics and Breeding / Genetika i oplemenjivanje

Ratar. Povrt. / Field Veg. Crop Res. 48 (2011) 333-340
original research article / originalni naučni rad

Correlations of Root Traits in Monogerm Sugar Beet from Open Pollination and Their Variability

Dario Danojević • Živko Ćurčić • Nevena Nagl • Lazar Kovačev

received / primljeno: 11.04.2011. revised / prerađeno: 30.05.2011. accepted / prihvaćeno: 07.06.2011.

Summary: The aim of this study was to analyze six open-pollinated monogerm sugar beet genotypes for the important root traits, to examine their hybrids with one (CMS) tester and to estimate the correlation between the traits. Root weight, dry matter content, dry matter yield per root, circumference of root and height of the root head were analyzed. All of the tested hybrids showed better results for root weight and dry matter yield per root than their parents. It was not possible to predict superior hybrid combination based solely on the characteristics of parents. Parents with the lowest root weight *per se* produced the test hybrid with the highest root weight. Parents showed a positive correlation between root weight and dry matter content and this could help sugar beet breeders to choose the most suitable selection criteria.
Key words: breeding, correlations, open pollination, sugar beet, testcrosses

Introduction

Great progress in increasing sugar content in sugar beet began when Vilmorin introduced a new method of selection (progeny test) in France in the 1850s. The method included the polarimeter analysis of the sugar content in individual roots as a means to check the progeny of next generation, which was a way to create varieties with sugar content ranging from 13% to 17% that served as the initial material for all the subsequently created varieties. Therefore, the genetic base of sugar beet is considered to be narrower than in the majority of open-pollinated crops (Bosemark 1989). Sugar beet breeding is time consuming and rather complex due to biennial life cycle of the crop, presence of both, cytoplasmic and nuclear male sterility, and use of maintainers of cytoplasmic male sterility (Hjerdin-Panagopoulos 2003). In sugar beet production F_1 hybrid is used, so it is important to know the combining abilities. Sugar beet is a wind pollinated, strongly outcrossing crop (Frese et al. 2001). The invention of the dominant gene for self-fertility achieves 90-95% homozygosity of offspring plants in open pollination, which in a way facilitates the creation of inbred lines.

D. Danojević (✉) • Ž. Ćurčić • N. Nagl • L. Kovačev
Institute of Field and Vegetable Crops, Maksima Gorkog 30, 21000 Novi Sad, Serbia
e-mail: dario.danojevic@ifvcns.ns.ac.rs

Sugar content and root weight are the most important features for sugar beet producers. Breeding for these two traits is exceptionally difficult due to their negative correlation. Root weight is a quantitative trait highly influenced by environment and highly variable (Khan at al. 2005). Water comprises 73-77% of the total root weight, while dry matter comprises 16-22% (80% of it is sucrose) (Bichel 1988, Bohn et al. 1998). Sugar content and dry matter in sugar beet root are highly positively correlated, which is understandable since they are inherited in a very similar way. Root circumference is positively correlated with root yield and can be used as a selection criterion for high yield (Campbell & Cole 1986). Beet root with a smaller head proportion is desirable in the sugar industry. Head of the root has lower sugar content than the tap root and the concentration of impurities in the root head is about 70% higher than in roots. The proportion of the root head cannot be determined directly without damaging the root, thus the height of the root head is usually measured for this purpose.

For further progress and efficiency of sugar beet breeding, it is essential that breeding program has the initial material with wide genetic variability (Kovačev 1985). Improvement of the existing resources and the introduction of new genetic variability, knowledge of the genetic basis and mode of inheritance of certain traits and combining ability is the way to further increase the productivity of sugar beet (Stojaković 1986). Many

authors believe that one tester only is insufficient for reliable determination of the combining ability. Examining the general combining ability (GCA), Dolotij et al. (1984) found that negative selection on the GCA can be performed with one tester only. Klotzowski (1967) considered that one tester can be sufficient if the investigated cultivar is heterozygous, while Fan et al. (2010) confirmed that one inbred line tester in maize had the same efficiency as two or more inbred line testers in selecting top best lines.

The aim of this study was to analyze six open-pollinated monogerm sugar beet genotypes for the important root traits, to examine their hybrids with one (CMS) tester and to estimate the correlation between traits.

Materials and Methods

Outcrosses roots were picked from several monogerm inbreed lines in 2007. After analysis the six outcrosses roots (A-111, A-114, A-178, A-252, A-289 and A-769) with a desirable root form, small furrows and high dry matter content were chosen (Tab. 1).

Roots were transplanted in March 2008 using hemp as an isolation crop. All bigerm plants (two connected flowers) were rejected during flowering, as well as those with fasciated terminal branch. The selected plants were selfed. Seedlings were grown from the obtained seed and transplanted in March 2009, on individual plots, to be crossed with cms tester, in isolation of hemp. Cytoplasmic sterile line CMS-138 with good general combining ability was used as a tester. Hybrids (F_1 A-111, F_1 A-114, F_1 A-178, F_1 A-252, F_1 A-289 and F_1 A-769) and their parents were sown in March 2010 at the experimental field of Institute of Field and Vegetable Crops, Rimski Šančevi, Serbia (45° 20' N, 19° 51' E, 84 m elevation), in a randomized block design with three replications. The basic plot size was 8 m x 1 m, with two rows of plants. Hybrid variety Lara was used as a standard. Spacing between plants after hand thinning was 50 cm x 20 cm. Common sugar beet cultural practices were applied during growing season. Ten plants per replication were taken for root analysis.

Root weight, dry matter content, circumference and height of root head were measured in the Laboratory for sugar beet root quality testing of the Institute of Field and Vegetable Crops, Novi Sad, Serbia. Dry matter content was determined using a digital universal refractometer (DUR-W, SCHMIDT + HAENSCH GmbH & Co.). The yield of dry matter per root was obtained from the root weight and dry matter content. The root circumference was measured at the widest part of the root head, and height of root head was measured from the lowest leaf buds to the top of the root head. Data were processed in the statistical software Statistica 9 (StatSoft Inc. Corporation, Tulsa, USA). Means were compared using Least Significant Differences (LSD) tests at the probability levels 0.05 and 0.01. Pearson's correlation analysis was used to obtain correlation coefficients and tested at the probability levels 0.05 and 0.01.

Table 1. Average values of root weight and dry matter content for parents and their roots from open pollination in 2007.
Tabela 1. Prosečne vrednosti mase korena i sadržaja suve materije roditelja i njihovih korenova iz slobodne oplodnje u 2007.

Genotype Genotip	Self-pollinated/samooplodnja		Open pollinated/slobodna oplodnja	
	Root weight Masa korena	Dry matter content Sadržaj suve materije	Root weight Masa korena	Dry matter content Sadržaj suve materije
	(g)	(%)	(g)	(%)
A-111	814	17.84	2350	19.66
A-114	1490	17.55	3687	19.01
A-178	775	17.10	1534	18.95
A-252	898	19.59	1953	19.86
A-289	783	16.98	1510	17.44
A-769	1185	20.33	2869	20.38
Mean/Prosek	991	18.20	2317	19.21

Results and Discussion

Root Weight

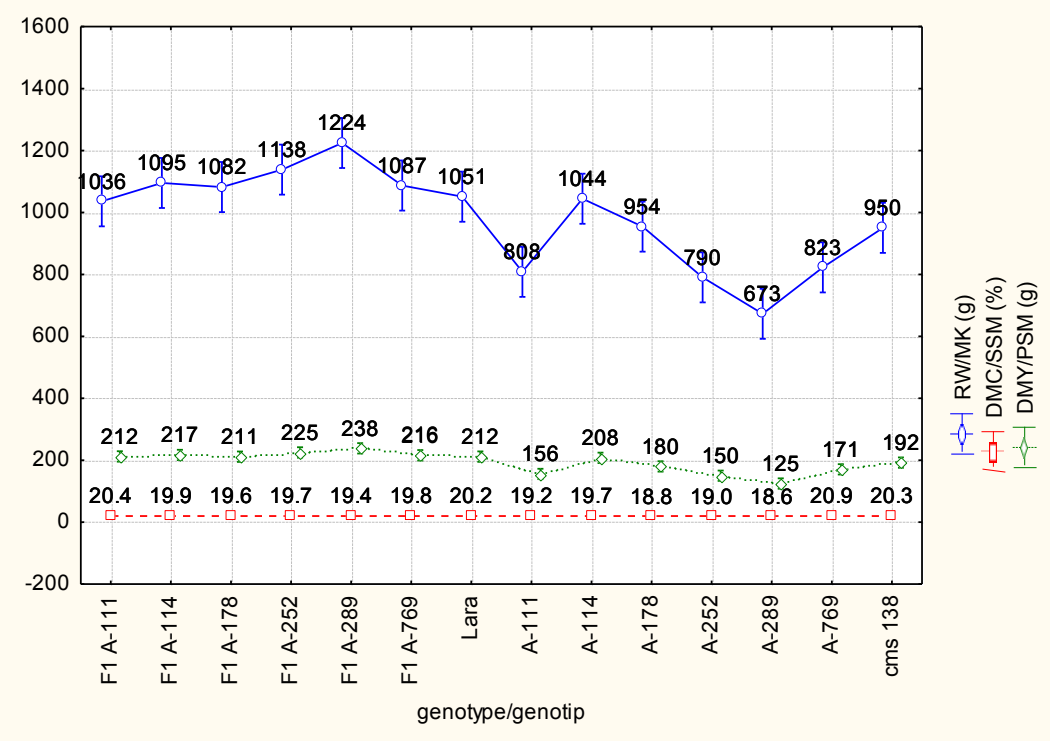
The average root weight of parents was 863 g ranging from 673 g (parent A-289) to 1044 g (parent A-114). Parents A-178 and CMS 138 had a lower root weight than parent A-114 but this difference was insignificant (Fig. 1).

Hybrids had an average root weight of 1102 g ranging from 1036 g (F_1 A-111) up to 1224 g (F_1-A 289). Hybrids F_1 A-111, Lara, F_1 A-769 and F_1 A-178 had a lower root weight ($p < 0.05$) compared to the top-ranking hybrid F_1 A-289. Parent A-114 had the highest root weight of 1044 g, and gave a hybrid with a root weight of only 1095 g. Contrary to this, parent A-289 which had the lowest root weight of 673 g, in crosses with CMS-138 gave a hybrid with the greatest root weight of 1224 g.

Dry Matter Content

The average dry matter content of the parents was 19.5% ranging from 18.6% (parent A-289) to 20.9% (parent A-769). Genotype A-769 had the highest dry matter content, but between this and the second ranged line CMS 138 there was no difference (Fig. 1). These values of dry matter content are similar to the results obtained by other authors (Ćurčić 2007, Danojević 2010).

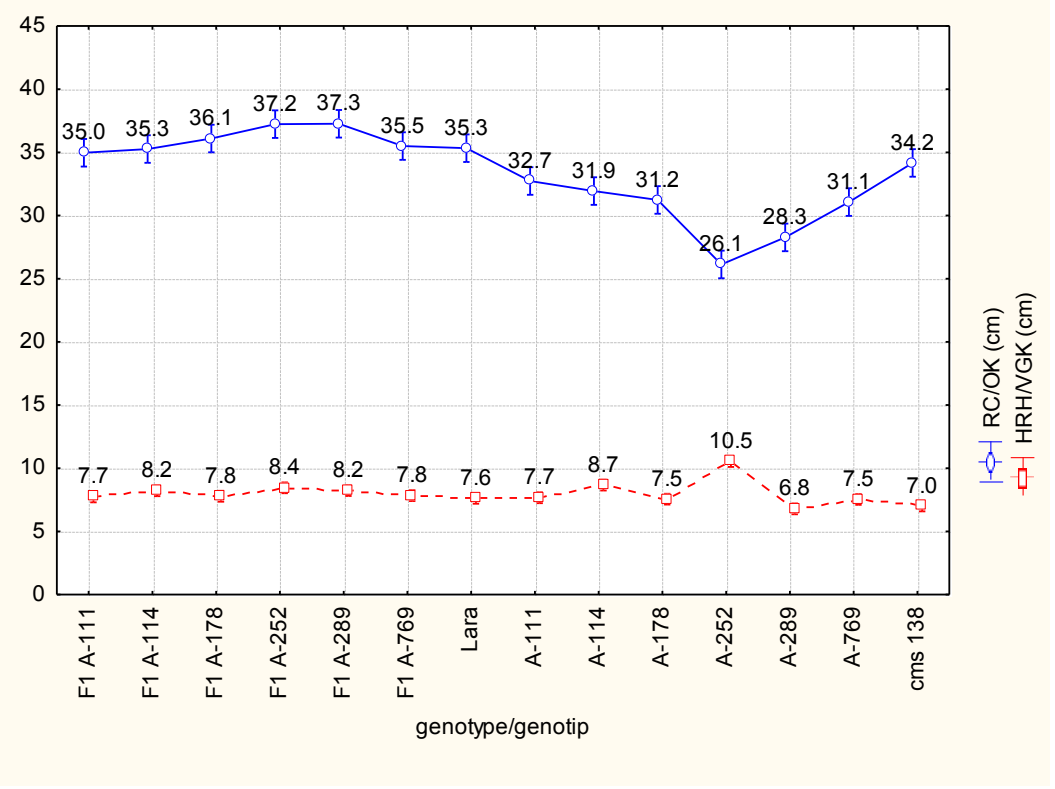
Test hybrids F_1 A-178, F_1 A-252 and F_1 A-289 had lower dry matter content compared to the first ranked F_1 hybrid A-111. Out of all parents, A-289 had the lowest dry matter content, and the hybrid F_1 A-289 had the lowest dry matter content of 19.4% (Fig. 1).



		Hybrids/Hibridi			Parents/Roditelji		
		RW/MK	DMC/SSM	DMY/PSM	RW/MK	DMC/SSM	DMY/PSM
LSD/ NZR	0.05	130.0	0.49	26.65	99.0	0.76	21.24
	0.01	171.5	0.65	35.16	130.6	1.01	28.03

Graph 1. Average root weight (RW), dry matter content (DMC), dry matter yield per root (DMY) and their LSD values for examined sugar beet genotypes

Grafikon 1. Prosečne vrednosti mase korena (MK), sadržaja suve materije (SSM), prinosa suve materije po korenu (PSM) i njihove vrednosti NZR za ispitivane genotipove šećerne repe



		Hybrids/Hibridi		Parents/Roditelji	
		RC/OK	HRH/VGK	RC/OK	HRH/VGK
LSD/ NZR	0.05	1.48	0.68	1.67	0.53
	0.01	1.95	0.9	2.21	0.71

Graph 2. Average root circumference (RC), height of root head (HRH) and their LSD values for examined sugar beet genotypes
Grafikon 2. Prosečne vrednosti obima korena (OK), visine glave korena (VGK) i njihove vrednosti NZR za ispitivane genotipove šećerne repe

Dry Matter Yield Per Root

The average yield of dry matter per root in parents was 169 g ranging from 125 g (parent A-289) to 208 g (parent A-114). Third ranged parent A-178 had a lower dry matter yield per root ($p < 0.05$) compared to the top-ranking parent A-114 (Fig. 1).

Hybrids had an average yield of dry matter per root of 219 g ranging from 211 g (in F_1 A-178) to 238 g (in F_1-A 289). There were no differences among hybrids in dry matter yield, except between F_1 hybrids A-178 and A-289 ($p < 0.05$). The reason for small differences in dry matter yield among the tested hybrids could probably be associated with good general combining ability by CMS-138 tester (Fig. 1).

The Circumference of Root

Circumference of roots in the parents ranged from 26.1 cm in A-252 to 34.2 cm in CMS-138. The average root circumference for all parents was 30.8 cm. CMS-138 had a greater root circumference ($p < 0.05$) than other parents, except A-111 (Fig. 2).

The average root circumference for all hybrids was 36.0 cm and ranged from 35.0 cm in F_1 A-111 to 37.3 cm in F_1 A-289. Between the F_1 A-178, F_1 A-252 and F_1 A-289 there was no significant difference in the circumference

root. Parents A-252 and A-289 which have the lowest circumference of roots gave the hybrids with the most extensive root circumference (Fig. 2).

Height of the Root Head

Height of the root head in parents ranged from 6.8 cm in A-289 to 10.5 cm in A-252. Lara had the lowest height of the root head, but between test hybrids F_1 A-111, F_1 A-178, F_1 A-769 and Lara variety there were no significant differences. Line A-252, which had the largest root head height, also gave a hybrid with a maximum root head height (Fig. 2). Mesken & Dielman (1988) reported that it is possible to reduce height of the root head for 18% per one cycle of selection. This information is very useful for sugar beet breeders, especially if a parent with good GCA has a large root head height.

Correlation

Correlation coefficient between the test hybrids and fertile parents were all negative except for the height of the head (Tab. 2). Significant correlations were obtained for root weight and circumference of root. Parents A-252 and A-289 had the most influence on the negative correlation, with the lowest root weight and circumference, while their test hybrids showed the highest values (Fig. 1 and 2).

Relating the test hybrids with cms 138 showed positive and significant correlations for root weight, dry matter yield and circumference of root (Tab. 2). These positive correlations indicate good combining ability of this CMS tester. Previous studies found negative correlation between root yield and sugar content (Đorđević 1972, McGrath 2005), as well as between root weight and dry matter content (Danojević 2010). Low positive

Table 2. Correlation coefficients between test hybrids and their parents for the investigated traits
Tabela 2. Koeficijenti korelacija između test hibrida i njihovih roditelja za ispitivana svojstva

Trait Svojstvo	Test hybrids/fertile parents Test hibridi/fertilni roditelji	Test hybrids/cms-38 Test hibridi/cms-138
Root weight/masa korena	-0.15*	0.16*
Dry matter content/sadržaj suve materije	-0.04	0.02
Dry matter yield per root/prinos suve materije po korenu	-0.14	0.17*
Circumference of root /obim korena	-0.24**	0.16*
Height of root head/visina glave korena	0.12	0.02

* and ** significant at 0.05 and 0.01 probability level, respectively
* i ** značajni na nivou od 0,05 odnosno 0,01

Table 3. Correlation coefficients between investigated traits for parents
Tabela 3. Koeficijenti korelacija ispitivanih svojstava za roditelje

Trait Svojstvo	Dry matter content Sadržaj suve materije	Circumference of root Obim korena	Height of root head Visina glave korena
Root weight/masa korena	0.14*	0.72**	0.29**
Dry matter content/sadržaj suve materije		0.13	-0.09
Circumference of root /obim korena			-0.14*

* and ** significant at 0.05 and 0.01 probability level, respectively
* i ** značajni na nivou od 0,05 odnosno 0,01

correlation of 0.14 was found in this study in parents between root weight and dry matter content (Tab. 3).

In addition to numerous results where a negative correlation between root yield and sugar content was found, McLachlan (1972) analyzed families of sugar beet and detected a positive correlation between these two traits, but in the whole population this link had a negative correlation. It was concluded that the wide genetic variability of the tested populations was the main reason for a negative correlation between root yield and sugar content. Positive low correlation between the root weight and dry matter content was found in a small number of six selected parents in our study. This is very important information for further breeding efforts, because it means that in some genotypes the roots with a high content of dry matter and large root weight can be selected. A positive correlation between root weight and circumference of root was also found in parents and test hybrids, which is in accordance to Campbell & Cole (1986). Correlation was positive between root weight and height of the root head. Sklenar et al. (1997) also found positive correlation between root weight and height of the root head in certain monogerm populations. Relationship between circumference of root and height of the root head for parents was negative, but it was positive for their test hybrids (Tab. 4 and 5).

In their research on maize, Lonnquist & Lindsay (1964) found that the correlation coefficients between the characteristics of lines and test crosses do not permit the use of mean values for lines *per se* as a reliable criterion for estimating their combining abilities. Our results are similar to previous authors' because parents with the lowest root weight *per se* produce the test hybrid with the greatest root weight. Further breeding of the most interesting parents A-252 and A-289 should increase dry matter content and enable developing hybrids with high yield of dry matter per root, and thus higher sugar yield per unit.

Table 4. Correlation coefficients between investigated traits for test hybrids
Tabela 4. Koeficijenti korelacija ispitivanih svojstava za test hibride

Trait Svojstvo	Dry matter content Sadržaj suve materije	Circumference of root Obim korena	Height of root head Visina glave korena
Root weight/masa korena	0.00	0.86**	0.68**
Dry matter content/sadržaj suve materije		-0.05	0.09
Circumference of root / obim korena			0.59**

** significant at 0.01 probability level
** značajni na nivou od 0,01

Table 5. Correlation coefficients between investigated traits for all genotypes
Tabela 5. Koeficijenti korelacija ispitivanih svojstava za sve genotipove

Trait Svojstvo	Dry matter content Sadržaj suve materije	Circumference of root Obim korena	Height of root head Visina glave korena
Root weight/masa korena	0.13*	0.83**	0.38**
Dry matter content/sadržaj suve materije		0.13*	-0.05
Circumference of root /obim korena			0.09

* and ** significant at 0.05 and 0.01 probability level, respectively
* i ** značajni na nivou od 0,05 odnosno 0,01

Conclusions

All the tested hybrids showed higher values for root weight and dry matter yield per root than parents.

Based on the knowledge of the parental phenotype it was not possible to predict the superior hybrid combination for the most important traits (root weight and dry matter content).

The parents with the lowest root weight *per se* produced the test hybrid with the greatest root weight and root circumference. Information on correlations among different traits in sugar beet could help breeders to choose the most suitable selection criteria. These results show that roots from open pollinations are an interesting source for new variability in sugar beet.

References

Bichel SE (1988): An overview of the U.S. beet sugar industry. In: M.A. Clarke and M.A. Godshall (eds.), Chemistry and Processing of Sugar Beet and Sugar Cane. Elsevier Sci. Publ., Amsterdam, 1-8

Bohn K, Clark MA, Buchholc K, Bliesiner KM, Buczys R, Thielicki R (1998): Composition of sugar beet and sugarcane and chemical behavior of constituent in processing. In: PW Van der Poel, H Schiweck, T Schwartz (eds.), Sugar Technology, Beet and Cane Manufacture. Verlag Dr. Albert Bartens, Berlin, 115-208

Bosemark NO (1989): Prospects for beet breeding and use of genetic resources, Report of an International Workshop on Beta Genetic Resources, International Crop Network Series 3, International Board for Plant Genetic Resources, Rome, Italy

Campbell LG, Cole DF (1986): Relationships between taproot and crown characteristics and yield and quality traits in sugar beets. Agron. J. 78: 971-973

Ćurčić Ž (2007): Uticaj izvora otpornosti prema rizomaniji na kombinacione sposobnosti i kvantitativna svojstva šećerne repe. Magistarska teza, Poljoprivredni fakultet, Novi Sad

Danojević D (2010): Karakteristike monogermnih i multigermnih genotipova šećerne repe. Magistarska teza, Poljoprivredni fakultet, Novi Sad

Dolotij LA, Ševcov IA, Parij FN (1984): Primenenie različnih testerov dlja ocenki obšei kombinacionnoi sposobnosti inbrednih linii saharnoj svekli. Citologija i genetika 18: 97-101

Đorđević R (1972): Korelacija između nekih svojstava šećerne repe. Zbornik radova Instituta za poljoprivredna istraživanja, Novi Sad 8: 57-61

Fan XM, Zhang YD, Liu L, Chen HM, Yao WH, Kang M, Yang JY (2010): Screening tropical germplasm by temperate inbred testers. Maydica 55: 55-63

Frese L, Desprez B, Ziegler D (2001): Potential of Genetic Resources and Breeding for Base broadening in Beta in Brodening the Genetic Base of Crop Production In: HD Cooper, C Spillane, T Hodgkin (eds), Broadening the genetic base of crop production. FAO, IBPRGI jointly with CABI Publishing, Rome, Italy, 295-309

Hjerdin-Panagopoulos A (2003): Application of molecular markers in sugar beet breeding. Dissertation, Lund University, Sweden

Khan MF, Nelson R, Campbell L (2005): Comparing yield and quality of sugarbeet planted in 22 and 11 inch rows. Sugarbeet Res. Ext. Rep. 35: 121-124

Klotzowski Z (1967): Badania nad metodami usyskana heterozyi w hodowli sloneznika oleistego. Cz. I. Hodowla Rosl. Aklimat. Nasien. 2: 11-22

Kovačev L (1985): Ispitivanje kombinacionih sposobnosti roditeljskih komponenata i osobine F1 generacije monogermnih triploidnih hibrida šećerne repe. Doktorska disertacija, Poljoprivredni fakultet, Univerzitet u Novom Sadu.

Lonnquist JH, Lindsay MF (1964): Top cross versus S1 line performance in corn (Zea mays L.). Crop Sci. 4: 580-584

McGrath M (2005): Sugar Content, Root Weight and Sugar Yield. In: E Biancardi et al. (eds), Genetics and Breeding of Sugar Beet. Science Publishers Inc, Enfield, NH, USA, 119-122

McLaughlan JB (1972): Estimation of genetic parameters in a population of monogerm sugar beet (Beta vulgaris L.). Sib analysis of motherline progenies. Ir. J. Agric. Res. 11: 237-246

Mesken M, Dielman J (1988): Breeding sugar beets with globe-shaped roots: selection and agronomical performance. Euphytica Suppl.: 37-44

Sklenar P, Kovačev L, Čačić N (1997): Karakteristike korena S3 populacija monogermnih održivača citoplazmatsko-nuklearne muške sterilnosti kod šećerne repe. Sel. Semen. 1-2: 119-126

Stojaković M (1986): Nasleđivanje nekih kvantitativnih svojstava kod šećerne repe. Savrem. Polj. 34: 239-246

Korelacije korenskih svojstava monogermnih genotipova šećerne repe iz slobodne oplodnje i njihova varijabilnost

Dario Danojević • Živko Ćurčić • Nevena Nagl • Lazar Kovačev

Institut za ratarstvo i povrtarstvo, Maksima Gorkog 30, 21000 Novi Sad, Srbija

Izvod: Cilj ovog rada je bilo ispitivanje šest novih jednokličnih genotipova šećerne repe poreklom iz slobodne oplodnje, kao i njihovi hibridi za najvažnija korenska svojstva. Određeni su koeficijenti korelacije između svojstava. Nakon završene vegetacije analizirani su: masa korena, sadržaj suve materije, prinos suve materije po korenu, obim korena i visina glave korena. Utvrđeno je povećanje mase korena i prinosa suve materije po korenu kod svih test hibrida u poređenju sa roditeljima. Za razliku od hibrida, kod roditelja je ustanovljena pozitivna korelacija između mase korena i sadržaja suve materije. Na osnovu karakteristika roditelja *per se* nije moguće predvideti superiorno hibridno potomstvo, jer su roditelji sa najmanjom masom korena dali hibride sa najvećom masom korena.
Ključne reči: korelacije, oplemenjivanje, stranooplodnja, šećerna repa, test ukrštanje