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SEED PLANT CHARACTERISTICS OF MONOGERM AND MULTIGERM RED BEET

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Summary

The objective of this research was to study the seed stalk morphology, cluster yield and quality of 20 mono – and multigerm breeding lines as well as cultivars of red beet. The seed plants derived from the roots of the two sizes, during 2012 and 2013 in field conditions, were evaluated. Large stecklings formed plants with a higher number of shoots and lower percentage of the single seed stalks, and produced higher yields, and thousand-cluster weight compared to small stecklings. The monogerm genotypes developed higher plants with higher number of shoots and a lower number of a single seed stalks than the multigerm ones. The open-pollination and hybrid cultivars, as well as the cytoplasmic male sterile (CMS) and their maintainer fertile lines, mostly presented comparable values of the studied traits. The cultivars yielded better and formed higher plants, and produced seeds with better quality than the CMS lines, which in turn formed more shoots and a higher number of bushes with the main stem plants compared to the cultivars. The characteristics of the generative plant development stage of different genotypes of red beet will be useful in breeding programs designed to create new, especially, monogerm hybrid cultivars.

Key words: *Beta vulgaris* L., breeding line, germination, hybrid, seed production

INTRODUCTION

Red beet (*Beta vulgaris* L.) is a biennial vegetable of the *Chenopodiaceae* family, derived from sea beet (*B. vulgaris* ssp. *maritima* L.) (George 2009). The red beet, cultivated for its roots as well as leaves, is widely consumed particularly in traditional Western cooking. The popularity of this vegetable is mainly associated with its renewable and cheap source of nutrients (Goldman and Navazio 2008). Poland, with a production of about 345,000 tons a year, is one of the leading European countries in terms of acreage, production and consumption of red beet (CSO 2013).

Nowadays, sugar beet cultivars are monogerms, but in the case of red beet, multigerm cultivars that produce several seedlings still dominate. Actually, red beet monogermity is one of the most common breeding target that is needed in order to be able to perform precision seed sowing. Moreover, in the present breeding program, the open-pollinated cultivars of red beet have been replaced by hybrids that are based on cytoplasmic male sterile (CMS) lines. Although, modern agriculture requires seeds of the highest quality, still little research is based on the generative growth period and concerns the evaluation of the factors determining the yield and quality of red beet sowing material (Goldman and Navazio 2008).

The effect of genotype and the environmental conditions have a considerable impact on beet seed stalk growth as well as cluster yield and quality. Michalik (1993), Michalik and Kozak (1993), Apostolides and Goulas (1998) and Jagosz (2013) reported differences in the structure and yielding seed plants of red and sugar beet cultivars and lines. Wawrzyniak (1991a, 1991b) mentioned the huge impact of Polish weather conditions, in particular the distribution of temperature and precipitation, on the red beet cluster yields.

Researchers have found an increase in the number and the height of sugar beet seed stalk branches and yield of clusters observed with the rise in the size of planted stecklings (Saini *et al*. 1977, Balan *et al*. 1978, Balan and Zagorodnii 1986, Podlaski *et al*. 1987b, Hemayati *et al*. 2008). Podlaski *et al*. (1987a) reported an improvement in the germination percentage and rate of sugar beet seeds together with increasing steckling weight. Hemayati *et al*. (2008) noted that the steckling size did not exhibit an effect on the percentage and the rate or the uniformity of germination, but they suggested higher thousand-germ weight when larger roots were grown. Saini *et al*. (1977) reported, that cluster maturity as well as germination rate and thousand-cluster weight were not dependent on the root size .

The objective of the research, conducted in 2012 and 2013, was to evaluate the effects of genotype and steckling size on morphological structure of red beet seed stalk and cluster characteristics. The purpose of the research was to analyse the generative growth period of different red beet genotypes. In this study, the seed stalk height and construction, the cluster yield and quality of 20 mono – and multigerm breeding lines and cultivars were evaluated. The results of the experiment will be useful in breeding programs aimed at creating new, hybrid red beet cultivars that are beneficial in terms of seed production, especially with the trait of cluster monogermity.

MATERIAL AND METHODS

The study was performed in the years 2012 and 2013 under open field conditions at the Experimental Field of the Unit of Genetics, Plant Breeding and Seed Science at Prusy near Krakow, in southern Poland. The plant material consisted of 20 genotypes of red beet (*Beta vulgaris* L.). The stecklings of six mono – and multigerm cytoplasmic male sterile (CMS) breeding lines (A) and their respective maintainer fertile lines (B), five mono – and three multigerm cultivars (Table 1) were planted at the beginning of April. The experiment was conducted as a randomised complete block with three replications. Two sizes of the stecklings were used: small with a diameter of 4-6 cm and large with a diameter of 8-10 cm. Eight small and 8 large roots of each genotype were planted in each replication. The space between rows was 50 cm and between plants 25 cm. The seed production was managed according to standard crop management practices as recommended for red beet under Polish conditions. The harvesting of ripened seed stalks was conducted in August and September. The collection began when the clusters at the base of each branch were brown. The cut stems were dried for a week. The clusters were hand-threshed and air-dried for a month at room temperature.

The collected data includes seed plant structure, yield and qualitative traits of clusters. At the time of plants collection, the height (cm) of the highest stem of each plant was measured. The seed stalk type was determined according to Janas and Grzesik (2007) plants were assigned to one of three types and the percentage of 'single', 'bush', or 'bush with main stem' plants was calculated. In the case of bush and bush with main stem types, the number of shoots was counted. After threshing and drying, the clusters were evaluated in terms of yield (g). The measurements of thousand-cluster weight (g) and germination capacity (%) were performed according to ISTA recommendations (Don 2009, ISTA 2012). The mean germination time (MGT) was calculated according to the following formula: $MGT = \Sigma(T \times G)/F$, where T denotes the day of germination, G – number of germinated clusters on the counting day and F – final number germinated clusters. Germination capacity as well as MGT were assessed on the germination test established in four replications, each consisting of 100 clusters taken at random. Statistical analysis was conducted using the software STATISTICA (ver. 9). The data from the experiment were subjected to a general analysis of variance (ANOVA). The comparison of means for the plant height, cluster yield, number of shoots, thousand-cluster weight, MGT and germination capacity were calculated using the Duncan least significant difference test at $P = 0.05$.

Table 1. Plant material tested in the years 2012-2013

Genotype designation	Breeding status	Germity
218 A	CMS line	multigerm
218 B	fertile line	multigerm
279 mono A	CMS line	monogerm
279 mono B	fertile line	monogerm
357 A	CMS line	multigerm
357 B	fertile line	multigerm
391 A	CMS line	multigerm
391 B	fertile line	multigerm
AR79 A	CMS line	monogerm
AR79 B	fertile line	monogerm
Astar F_1	hybrid cultivar	multigerm
Modana	open-pollination cultivar	monogerm
Moneta	open-pollination cultivar	monogerm
Monika	open-pollination cultivar	monogerm
Monorubra	open-pollination cultivar	monogerm
Okragły C.	open-pollination cultivar	multigerm
Patryk	open-pollination cultivar	monogerm
Polglob F_1	hybrid cultivar	multigerm
W411 A	CMS line	monogerm
W411 B	fertile line	monogerm

RESULTS AND DISCUSSION

The seed stalk height of the CMS lines tested in this study was lower than in the cultivars, but mostly at a similar level as in the corresponding fertile lines (Table 2). Currently, as in the studies reported by Jagosz (2013), differences in red beet seed plant growth between open-pollination than hybrid cultivars were not visible. However, Michalik and Kozak (1993) and Jagosz (2013) testing red beet seed plants noted higher stalks in open-pollination than hybrid cultivars. The monogerm plants, tested now as well examined by Michalik and Kozak (1993) and Jagosz (2013), were one of the highest. In the present research the seed stalks tested in the year 2012, were clearly shorter when in 2013. The height of the shoots was not dependent on the stecklings size. However, Saini *et al*. (1977), Balan *et al*. (1978), Balan and Zagorodnii (1986), Podlaski *et al*. (1987b) and Jagosz (2013) reported that the large beet roots generally formed higher plants compared to the small ones.

Table 2. The seed stalk morphological structure

Treatment	Seed stalk height (cm)	Seed stalk type					
		single		bush		bush with main stem	
		no. of shoots	% of plants	no. of shoots	% of plants	no. of shoots	% of plants
Genotype (G)							
218 A	98.7^{efg}	1.0	13.75	9.5^{ab}	53.00	$7.7^{a–d}$	33.25
218 B	91.1^{gh}	1.0	10.50	8.6^{bc}	68.00	5.8^{cd}	21.50
279 mono A	101.3^{ef}	1.0	11.00	8.5^{bc}	11.75	8.3^{abc}	77.25
279 mono B	99.8^{ef}	1.0	18.25	7.1^{bcd}	33.00	6.3^{bcd}	48.75
357 A	94.4^{fgh}	1.0	46.25	7.4^{bcd}	30.50	5.8^{cd}	23.25
357 B	101.1^{ef}	1.0	55.50	6.6^{bcd}	37.00	9.3^{a}	7.50
391 A	90.1^{h}	1.0	22.50	11.9^{a}	48.25	9.1^{ab}	29.25
391 B	90.0^{h}	1.0	30.00	8.3^{bc}	34.50	6.0^{cd}	35.50
AR79 A	138.5^{a}	0.0	0.00	7.0^{bcd}	87.50	5.7^{cd}	12.50
AR79 B	118.2^{bc}	0.0	0.00	9.0^{bc}	41.75	$6.5^{a–d}$	58.25
Astar F_1	115.2^{cd}	1.0	29.75	7.9^{bc}	36.25	$6.4^{a–d}$	34.00
Modana	114.2^{cd}	1.0	14.25	8.3^{bc}	56.00	6.0^{cd}	29.75
Moneta	117.6^{bc}	1.0	54.00	4.8^{d}	16.75	5.5^{cd}	29.25
Monika	111.0^{cd}	1.0	21.00	8.0^{bc}	32.00	$7.1^{a–d}$	47.00
Monorubra	124.0^{b}	1.0	12.75	6.8^{bcd}	50.00	4.9^{d}	37.25
Okragły C.	133.0^{a}	1.0	34.25	8.3^{bc}	19.50	5.6^{cd}	46.25
Patryk	107.1^{de}	1.0	23.50	6.1^{cd}	37.50	$7.1^{a–d}$	39.00
Polglob F_1	115.8^{bc}	1.0	31.25	7.8^{bc}	38.00	$6.5^{a–d}$	30.75
W411 A	95.9^{fgh}	0.0	0.00	5.0^{d}	20.75	$7.7^{a–d}$	79.25
W411 B	87.7^{h}	1.0	14.50	6.5^{cd}	25.75	6.1^{bcd}	59.75
Year (Y)							
2012	103.8^{b}	1.0	34.33	8.0_{NS}	23.50	6.6_{NS}	42.17
2013	114.1^{a}	1.0	9.98	8.0_{NS}	54.28	6.9_{NS}	35.74
Steckling size (S)							
Small	106.3_{NS}	1.0	31.00	6.3^{b}	32.00	5.7^{b}	37.00
Large	108.4_{NS}	1.0	13.30	9.1^{a}	45.78	7.3^{a}	40.92

Treatment	Seed stalk height (cm)	Seed stalk type					
		single		bush		bush with main stem	
		no. of shoots	% of plants	no. of shoots	% of plants	no. of shoots	% of plants
LSD$_{0.05}$ for:							
G × Y	13.9			2.2		NS	
G × S	13.9			2.2		NS	
G × Y × S	19.6			NS		NS	

Means in columns followed by the same letter are not significantly different at $P < 0.05$
NS – not significant at $P < 0.05$

A bush with a main stem seed stalk, considered the best for beet seed production, occurred in about 40% of the plants (Table 2). The same percentage of plants developed the bush stalks. 20% of the plants produced a single seed stalk, which is the least favourable in terms of seed production. Michalik and Kozak (1993) noted about 43% and Jagosz (2013) almost 60% of plants developed bushes with main stems, but they found much lower percentage of single seed stalks. Presently tested CMS lines produced fewer single and more bushes with main stems but the same percentage of bush plants than the cultivars. The differences in stalk structure between hybrids and open-pollination cultivars were small. Michalik and Kozak (1993) also found a larger tendency to form the bush stalks in CMS lines then in the cultivars, but hybrids were bushier, than open-pollination cultivars. Jagosz (2013) reported comparable plant construction within CMS lines and cultivars, as well as within open-pollination and hybrid cultivars. Both in the present experiment, as well as in the study by Jagosz (2013) CMS lines showed a lower tendency to form single seed stalks than fertile lines, but the number of plants of two other types was comparable. Contrary, Michalik and Kozak (1993) reported a large variation between the CMS and fertile lines in respect to the percentage of bush plants. Presently, as well as in the test conducted by Jagosz (2013), monogerm genotypes produced almost twice less of single stalks, than the multigerm ones. The large stecklings tested currently forming only 13% of the single seed stalks showed a higher trend in generating bushy plants than the small ones that produced about one third of the single stalks. As has already published by Michalik and Kozak (1993), the structure of seed plants was dependent on the year of the study. The results obtained in 2012 revealed until 34% of single stalks, while less than a quarter of plants were bushy. By contrast, only 10% of the plants were single and up to 54% were bushy in 2013.

The bush and bush with main stem seed stalks were composed of 7.7 and 6.7 shoots per plant, respectively (Table 2). Both, presently, as well as in the study by Jagosz (2013) CMS lines produced the same number of shoots as the fertile lines, and generated one more shoot than the cultivars. Currently tested hybrids were bushier than open-pollination cultivars, but Jagosz (2013) did not observe differences between the two kinds of cultivars. In the present study the monogerm plants were bushier than the multigerm ones, as noted also by Jagosz (2013). The year of the current study had no effect on the number of shoots. However, the plants grown from large roots developed more shoots than smaller ones. Balan and Zagorodnii (1986), Podlaski *et al*. (1987b) and Hemayati *et al*. (2008) also noted a rise in the number of shoots in sugar beet seed stalks when large stecklings were planted.

The cluster yield of the CMS lines was about 25% lower than in the cultivars, but the CMS and fertile lines produced a similar yield (Table 3). Michalik and Kozak (1993) and Jagosz (2013) noted related observations. The mono – and multigerm genotypes currently evaluated yielded at the same level. However, the monogerm plants tested by Michalik and Kozak (1993) formed lower yield than the multigerm ones, but Jagosz (2013) found higher yielding of mono – than multigerm plants. Both hybrids and open-pollination cultivars observed presently as well tested by Michalik and Kozak (1993) yielded at the same level. The recent study has shown that in 2013 the yield was about 25% higher when compared to 2012. The plants derived from large stecklings formed a higher yield by 20% than roots with a small diameter. Saini *et al*. (1977), Balan *et al*. (1978), Balan and Zagorodnii (1986), Podlaski *et al*. (1987a, 1987b), Hemayati *et al*. (2008) and Jagosz (2013) also noted an increase in yield when beet roots weight increased.

Table 3. The yields and qualitative traits of clusters

Treatment	Cluster yield (g per plant)	Thousand-cluster weight (g)	MGT (day)	Germination capacity %
Genotype (G)				
218 A	22.37^{de}	23.40^{a}	3.16^{a}	90.4^{abc}
218 B	18.09^{e}	22.83^{ab}	3.24^{abc}	90.4^{abc}
279 mono A	31.17^{cd}	12.84^{gh}	$3.38^{b–e}$	86.0^{abc}
279 mono B	27.32^{de}	15.38^{def}	3.43^{def}	71.0^{d}
357 A	30.69^{cd}	17.16^{d}	3.67^{g}	67.8^{d}
357 B	33.57^{bcd}	14.95^{efg}	3.43^{def}	86.5^{abc}
391 A	31.74^{bcd}	17.35^{d}	$3.27^{a–d}$	91.6^{ab}
391 B	24.88^{de}	13.65^{fgh}	3.19^{a}	94.9^{a}
AR79 A	27.03^{de}	12.80^{gh}	3.39^{cde}	73.5^{d}

Treatment	Cluster yield (g per plant)	Thousand-cluster weight (g)	MGT (day)	Germination capacity %
		Genotype (G)		
AR79 B	24.85[de]	12.33[h]	3.21[ab]	82.8[bc]
Astar F_1	43.67[bcd]	19.49[c]	3.17[a]	89.0[abc]
Modana	34.96[bcd]	16.43[de]	3.54[efg]	85.0[bc]
Moneta	42.40[bcd]	16.32[de]	3.65[fg]	94.8[a]
Monika	30.78[cd]	10.16[i]	3.50[ef]	82.0[c]
Monorubra	31.88[bcd]	13.77[fgh]	3.18[a]	83.8[bc]
Okragły C.	56.82[a]	21.54[b]	3.51[efg]	90.9[abc]
Patryk	33.37[bcd]	14.62[efg]	3.24[abc]	84.5[bc]
Polglob F_1	34.37[bcd]	24.13[a]	3.19[a]	90.3[abc]
W411 A	41.15[bcd]	14.14[fgh]	3.45[ef]	68.1[d]
W411 B	35.00[bcd]	14.43[fgh]	3.53[efg]	66.1[d]
		Year (Y)		
2012	29.61[b]	15.94[b]	3.44[b]	83.8_{NS}
2013	39.25[a]	16.83[a]	3.28[a]	83.1_{NS}
		Steckling size (S)		
Small	29.39[b]	15.91[b]	3.33_{NS}	82.9_{NS}
Large	36.31[a]	16.86[a]	3.39_{NS}	84.0_{NS}
		$LSD_{0.05}$ for:		
G × Y	18.98	2.87	0.16	5.5
G × S	18.98	2.87	NS	5.5
G × Y × S	NS	3.70	NS	7.7

Means in columns followed by the same letter are not significantly different at $P < 0.05$
NS – not significant at $P < 0.05$

The thousand-germ weight of red beet is associated with the type of clusters. The value of this feature in the tested mono – and multigerm genotypes was 12.30 and 19.56 g, respectively (Table 3). The thousand-cluster weight of multigerm cultivars was higher compared to the multigerm CMS lines, while in the case of both monogerm cultivars and CMS lines, and between most of the CMS and fertile lines, was comparable. Jagosz (2013) also reported a similar level of the thousand-cluster weight within the CMS and fertile lines as well as within CMS lines and cultivars in both types of clusters. In the study reported by Michalik (1993), red beet CMS lines produced a thousand-cluster weight lower than the cultivars, but in the corresponding lines the value of this trait was comparable. In the present study the thousand-cluster weight was lower in the year 2012 than in 2013. Moreover, plants derived from large roots produced bigger clusters than plants developed from small roots. Hemayati *et al*. (2008) also reported higher value of this trait when larger sugar beet roots were grown, but Saini *et al*. (1977) found no such relationship.

The beet seeds have strong dormancy mechanisms, therefore their germination is slow and asynchronous (Taylor *et al*. 2003). Moreover, Michalik (1993) reported the strong relationship between genotype and seed germination. Today, very high seed quality requirements, in terms of the above information, are difficult to achieve in the case of red beet seed material. The germination parameters evaluated in the present study showed a good level of the seed vigour of the tested genotypes. The MGT was low, with no indication of a clear differentiation between mono – and multigem clusters (Table 3). The MGT of CMS lines, among which one third were slower than the fertile lines, were at the same level as the cultivars. The monogerm clusters tested by Jagosz (2013) germinated quicker than the multigerm ones, similarly as cultivars that germinated quicker than CMS lines, which were slower than the fertile lines. The germination capacity observed currently, amounted 83%, was lower in the CMS lines than in the cultivars, what was also recorded by Michalik (1993) and Jagosz (2013). Large differences in germination capacity, contrary to Michalik (1993) and Jagosz (2013), were found in 50% of the corresponding lines. Presently, as well in the experiments published by Michalik (1993) and Jagosz (2013), the cluster germination capacity was higher for multi – than monogerm genotypes. Currently, the size of the planted stecklings did not affect the parameters of germination. The results published by Saini *et al*. (1977) and Hemayati *et al*. (2008) also did not detect an effect of sugar beet root size on the germination. However, Podlaski *et al*. (1987a) reported an enhanced rate and percentage of sugar beet cluster germination together with an increase in steckling weight. The effect of the year of study was observed only for the MGT, the clusters collected in 2013 germinated quicker compared to 2012.

In conclusion, the data reported in this paper is one of the first that describes generative growth period in so many monogerm red beet genotypes grown in Poland. The presented fetures described the seed plants of different mono – and multigerm breeding lines and cultivars. It was found that both the influence of the genotype as well as the steckling size are of great importance in the evolution of most of the studied traits. The monogerm genotypes developed higher seed plants with higher numbers of shoots and a lower number of a single seed stalks than the multigerm ones. The plants produced by stecklings with a larger diameter yielded better and resulted in higher thousand-cluster weights as well as higher number of shoots, and thus lower percentage of single seed stalks, than the roots with a smaller diameter. The results of the study will be useful in breeding programs designed to aid in the selection of breeding lines for creating new red beet cultivars, especially monogerm hybrids performance producing good yields of highly valuable clusters.

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