

**THE EFFECT OF DIFFERENT GENOTYPES ON THE SEED STALK CONSTRUCTION,
YIELD AND QUALITY OF TABLE BEET (*BETA VULGARIS* L.) CLUSTERS**

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Abstract

*The present experiment evaluated the seed stalk morphology, cluster yield and seed quality of 12 genotypes of mono- and multigerm seed lines and cultivars of table beet (*Beta vulgaris* L.). This particular study included a new monogerm seed line – AR79. The experiment was conducted over two years (2011-2012) in field conditions. Two sizes of red beet stecklings were planted; small with a diameter between 4-6 cm and large with a diameter over 8 cm. Standard crop management practices, as recommended for table beet production under Polish conditions, were followed.*

The seed stalk architecture of new monogerm seed line AR79 was typical for the species, but it showed a tendency to form bush type seed stalks with greater numbers of late-maturing shoots, as compared to the other genotypes. The mean cluster weight per plant for AR79 was almost two times lower than the other lines and cultivars. The germination capacity of AR79 seeds was slightly lower than in the other genotypes, but the germination rate was very high. The steckling size did have an effect on the seed stalk height and cluster yield. The seed stalks of larger stecklings were higher and better yielded than the smaller ones. This study has expanded the knowledge about the generative growth period of table beet. The obtained results will facilitate Polish breeding programs aimed at the selection of new monogerm seed red beet lines.

Key words: germination, monogerm seed, multigerm seed, red beet, stecklings

1. INTRODUCTION

Red beet (*Beta vulgaris* L.), a member of Chenopodiaceae, is one of the major Polish root vegetable crops in terms of acreage, production and consumption (Nowak and Syta, 2007). Table beet is a component of many traditional dishes, especially in Central and Eastern Europe. Its popularity also stems from the possibility of long-term storage of its roots and its very high nutritional properties beneficial for human health (Goldman and Navazio, 2008). Beetroot is rich in several microelements, vitamins, mainly A, B, C, as well as antioxidants, among which the most important are betalain pigments, which are used as a natural dye for many food products (Nowak and Syta, 2007).

Today, all cultivated varieties fall into the subspecies *Beta vulgaris* subsp. *vulgaris*, while *Beta vulgaris* subsp. *maritima* can be found throughout the Mediterranean, the Atlantic coast of Europe, the Near East, and India. Red beet is a biennial vegetable that produces green tops and a swollen root during the first growing season, which requires a cool vernalisation period in order to bolt, flower and produce seeds in the second growing season (Black et al., 2006, Goldman and Navazio, 2008, Ijorah et al., 2008). The vegetative growth of beetroot has low requirements. However, the reproductive seed crops in Poland are associated with a high risk. On the one hand, the seed yield depends on the genotype, and on the other hand, the environmental conditions (Michalik, 2000).

The literature reveals that little research applies to studying the generative growth period in vegetable crop species. The knowledge about the factors affecting the yield and quality of clusters in European red beet cultivars is still incomplete. In Polish climatic conditions, temperature and rainfall in particular have a decisive influence on the yield of table beet seed plants (Wawrzyniak, 1991a, 1991b). Mikita and Gutmański (2002a, 2002b) observed correlations between yield as well as quality of sugar beet seeds and soil as well as climatic conditions. The seed plants growth also depends largely on the genotype. The research conducted by Michalik and Kozak (1993) revealed lower yielding, as well as shorter seed stalks of red beet breeding lines when compared to the hybrids. Michalik (1993) also reported a higher seed quality of red beet cultivars than breeding lines. Additionally, these researchers note the dependence of field emergence on germination capacity of the clusters. Apostolides and Goulas (1998) proved that differences among cultivars in seed size were observed throughout the year, but these differences were not associated with germination and/or field emergence. Several studies reveal that the size of the stock seed roots affect the number of shoots or the morphological structure of the seed stalks. Hemayati et al. (2008), Podlaski et al. (1987b) and Balan and Zagorodnii (1986) found a significant effect of increased steckling size on the increase of stem number and cluster yield of sugar beet seed stalks. Moreover, they obtained a rise in seed yield with greater plant density. Studies conducted by Saini et al. (1977), Balan et al. (1978), Nicolau (1978) and Podlaski et al. (1987b) also suggest that larger sugar beet stecklings produce a higher cluster yield than smaller ones. According to Saini et al. (1977), Balan et al. (1978), Nicolau (1978), Balan and Zagorodnii (1986) and Podlaski et al. (1987b) likewise the seed stalk growth increases as the steckling weight increases. Whereas Balan and Zagorodnii (1986) noted positive effects on the number of seed stalk branches as well as yield and seed qualitative characteristics, then small stecklings were compensated by the greater density of plants while growing. The studies carried out by Podlaski et al. (1987a) show that an increase in steckling weight led to an increased germination percentage and germination rate. On the other hand, Hemayati et al. (2008) did not find a significant effect of sugar beet root size on the percentage, rate or uniformity of cluster germination. The research presented by Saini et al. (1977) suggested no effect of steckling size on seed maturity and germination rate as well as thousand-seed weight of sugar beet. On the other hand, Hemayati et al. (2008) obtained significantly higher thousand-germ weight and monogermity percentage using larger stecklings.

Currently, open-pollinated cultivars have been replaced by hybrids in red beet breeding programs, whose production is based on cytoplasmic male sterile and maintainer lines. Contemporary table beet breeding aims must take into account both the characteristics associated with yield, root morphology and their nutritive quality and disease resistance, as well as its features, including the seed stalk construction, yield and seed quality. In recent years, one of the most common breeding purposes is also the creation of monogerm clusters, which enable precision cluster sowing that is more difficult in the case of multigerm seeds (Michalik, 2000, Goldman and Navazio, 2008). The beet seed ball is botanically a fructification consisting of 1-5 achenes. In the case of multigerm seed cultivars, each cluster has the potential to germinate, resulting in up to five closely intertwined plants that are difficult to thin (Desai et al., 1997, McDonald and Copeland, 1997). The monogerm seed trait was identified as a wild-growing mutant for the first time in the year 1937. Today, the monogerm characteristic is found in most or even all sugar beet cultivars, but still only in a few table beet cultivars (Jassem et al., 1988, Goldman and Navazio, 2008)

The objectives of this study were to evaluate the height and morphological structure of seed stalks, as well as the seeds yield and quality of 12 genotypes of mono- and multigerm seed lines and cultivars of table beet. The study examined whether the effects of genotype as well as the size of the stecklings affected the seed plant characteristics. The research investigated if the generative growth period of monogerm seed red beet lines could be useful for a breeding program in hybrid performance.

2. MATERIAL AND METHODS

2.1. Plant material

The plant material used in the study consisted of 12 genotypes of table beet (*Beta vulgaris* L.). This included the seed stalks of two monogerm seed cytoplasmic male sterile (CMS) breeding lines, AR79 A and W411 A, and their respective maintainer fertile inbred lines, AR79 B and W411 B, as well as two multigerm seed CMS lines, 218 A and B and 391 A and B, furthermore, four cultivars; three multigerm seed, 'Astar' F₁, 'Okragly Ciemnoczerwony' and 'Polglob' F₁, and the only Polish cultivar – 'Patryk' – with a high percentage of monogerm clusters, were tested in the experiment.

The red beetroots for seed production were grown in 2010 and 2011 according to standard crop management practices as recommended for this species under Polish conditions. During the winter, the stecklings were stored in boxes filled with moist peat placed in an air-conditioned chamber with a temperature of about 2°C and relative humidity of about 95%.

2.2. Field experiment

The study was performed during two years, 2011-2012, under open field condition in the Experimental Field of the Department of Genetics, Plant Breeding and Seed Science at Prusy near Krakow, in southern Poland (50°06'N, 19°96'W). The trial field was managed following standard agricultural practices for red beet seed production under Polish conditions. The experimental design was a randomised complete block with three replications. Two sizes of stecklings were planted: "small" with a diameter between 4-6 cm, and "large" with a diameter equal to or greater than 8 cm. In the case of all of the genotypes in every replication, 10 stockseed roots of each of the two sizes were planted.

The red beet stecklings of the lines and cultivars were planted at the beginning of April in rows spaced 50 cm each year. The space between plants was about 25 cm. The ripened seed stalks were hand-collected from the middle of August to the end of September. After harvest, which was initiated when the clusters at the base of each branch were mature and brown, the seed stalks were dried in plastic tunnels for a few days, and later the seed balls were threshed, and again air-dried for four weeks at room temperature.

2.3. Plant measurements

During harvesting the evaluation of the red beet seed stalk morphological structure was conducted. At first the height (cm) of the highest stem of each plant was measured, then the percentage of the type of seed stalk, among which three kinds were distinguished: single, bush, and bush with main stem was observed (Janas and Grzesik, 2007). Additionally, the number of shoots was counted for bush type and bush type with main stem seed stalks. Next, after drying, the cluster yield (g) per plant was estimated. The plant height and cluster yield were measured separately for plants produced by small and large stecklings. Qualitative traits, such as the thousand-germ weight (g), number of clusters in 1 g samples, as well as germination energy (first count – percentage of normal seedlings after four days of seed germination) and germination capacity (final count – percentage of normal seedlings after 14 days of seed germination) according to ISTA rules (Don, 2003, ISTA, 2012), were observed. The mean germination time (MGT) in four replications, each consisting of 100 clusters taken at random, was calculated using the equation: $MGT = \sum (G \times T) / F$, where T – day of germination, G – number of clusters germinated on the counting day and F – the final number germinated clusters. In the case of the monogerm seed genotypes, the percentage of monogermity was evaluated as the percentage of all germinated clusters.

The data based on two years of the experiment were subjected to a general analysis of variance (ANOVA). The variation in characteristics such as the height of the seed stalks, the yield of the clusters,

the thousand-germ weight, the MGT and the germination energy and capacity of the seeds were determined using the Duncan least significant difference test (LSD) at $p = 0.05$.

3. RESULTS AND DISCUSSION

The research revealed that the height of the tested red beet seed stalks ranged from 84 to 134 cm, and the yield from 12.5 to 83.3 g per plant (Table 1). Similarly, the height of table beet seed plants studied by Michalik and Kozak (1993) ranged between 58-119 cm, and the cluster yield amount from 8 to 93 g per plant. Generally, the monogerm seed stalks tested in the experiment were about 12 cm higher, and yielded about 4.4 g per plant more, in comparison to multigerm seed genotypes. The mean height of the breeding lines was 10 cm lower, and the mean weight of clusters per plant was more than 6 g lower in comparison to the cultivars. The results presented by Michalik and Kozak (1993) also reported that table beet lines were shorter and less fertile than the cultivars. However, the seed stalks of new monogerm seed breeding lines AR79, tested in the present study, were relatively high (mean 130 cm), but low-yielding (mean 23 g of clusters per plant). Similarly, the monogerm seed lines examined by Michalik and Kozak (1993) were one of the highest (about 116 cm), but they produced a very low yield of clusters (about 24 g per plant).

Table 1. The seed stalk morphological structure and yield of table beet clusters.

Lines and cultivars	Steckling size	Seed stalk height (cm)	Cluster yield (g per plant)	Seed stalk type					
				single		bush		bush with main stem	
				no. of shoots	% of plants	no. of shoots	% of plants	no. of shoots	% of plants
Monogerm seed genotypes									
AR79 A	small	129 ab ¹	22.6 f-h	1.0	2	11.2	45	9.2	53
	large	130 ab	30.2 d-h						
AR79 B	small	134 a	12.5 h	1.0	0	8.2	27	9.3	73
	large	126 ab	27.6 e-h						
W411 A	small	132 a	55.6 bc	1.0	3	7.4	23	8.2	74
	large	118 a-c	83.3 a						
W411 B	small	93 e-g	45.3 b-e	1.0	14	7.2	24	8.3	62
	large	111 a-f	62.3 b						
Patryk	small	110 a-f	33.5 d-g	1.0	25	5.9	27	8.2	48
	large	122 a-c	42.0 b-f						
Multigerm seed genotypes									
218 A	small	90 fg	20.8 gh	1.0	14	8.5	29	6.1	57
	large	95 d-g	25.4 e-h						
218 B	small	89 fg	17.9 gh	1.0	14	8.6	20	7.8	66
	large	84 g	22.1 f-h						

391 A	small	107 b-f	36.0 c-g	1.0	16	9.0	33	9.0	51
	large	114 a-e	51.5 b-d						
391 B	small	101 c-g	30.6 d-h	1.0	18	8.6	24	7.6	58
	large	107 b-f	45.9 b-e						
Astar F ₁	small	119 a-c	32.9 d-h	1.0	24	8.2	18	7.7	58
	large	115 a-d	45.5 b-e						
Okrągły Ciemnoczerwony	small	119 a-c	50.6 b-d	1.0	25	7.5	15	7.4	60
	large	134 a	59.3 b						
Polglob F ₁	small	120 a-c	35.4 c-g	1.0	25	6.3	21	6.8	54
	large	123 a-c	45.9 b-e						

¹Values marked with the same letters do not differ significantly at $p = 0.05$.

The red beet seed stalks formed by the large stecklings, with a diameter equal to or greater than 8 cm, yielded significantly better than the seed stalks of the small beetroots, with a diameter between 4 and 6 cm (Table 1). The large stecklings produced over 45 g of clusters per plant, while the small ones had only about 33 g per plant. The large roots also formed visibly higher seed stalks than the small ones. Some authors also present a strong influence of steckling size on the seed plant architecture, where planting bigger roots resulted in an increase in seed stalk growth (Saini et al., 1977, Balan et al., 1978, Nicolau, 1978, Balan and Zagorodnii, 1986, Podlaski et al., 1987b). A significant increase in cluster yield with increased steckling weight was also reported for sugar beet by Saini et al. (1977), Nicolau (1978), Balan et al. (1978), Balan and Zagorodnii (1986), Podlaski et al. (1987a, 1987 b) and Hemayati et al. (2008).

The bush type of seed stalk with a main stem was typical for 62% of monogerm seed and 58% of multigerm seed plants, while the bush type was specific for 29 and 30% of plants, respectively (Table 1). Those two kinds of seed stalks on average were composed of 8.1 shoots per plant. The single seed stalk construction was found only in the case of 14% of the plants. Michalik and Kozak (1993) identified as many as 57% of bush type seed plants of red beet and the rest of the tested seed stalks presented a bush type with main stem. AR79 lines generated 37% of bush type and 63% of bush type with main stem seed stalks, which were composed of 9.5 shoots per plant. Several studies reveal a significant rise in the stem number of sugar beet seed stalks when large roots were planted (Hemayati et al., 2008, Podlaski et al., 1987b, Balan and Zagorodnii, 1986). Additionally, it was noted in the present experiment that the stems of AR79 plants showed a strong tendency towards late maturing, as compared to the other genotypes, which probably largely affected the low yield of the clusters. In the case of the monogerm seed breeding lines, a clear distortion of the flower stalks was noted, which was based on a flattened flower stem, called fasciation. Goldman (1998), describing these traits that arose spontaneously in the W411 breeding line, believed that they would be useful to seed production by increasing the cluster yield, while the present study did not confirmed that supposition.

In most cases vegetable seeds are relatively free of dormancy mechanisms, however beet are among the families with erratic germination due to seed dormancy, thus according to Lee et al. (2003) table beet has slow and asynchronous germination, which is caused by the mucilaginous layer that surrounds the seed ball, the ovary cap tenacity of the seed ball, and the phenolic germination inhibitors (Taylor et al., 2003). In consideration of the above information, the germination parameters obtained in the present

study were very satisfactory. The germination capacity ranged from 79 to 96% (Table 2). Multigerm seed genotypes germinated 5% better than monogerm ones. It was also observed that the number of normal seedlings in breeding lines was 3% lower than in the case of cultivars. This was confirmed by research conducted by Michalik (1993), which showed a dependence of the effect of genotype on seed quality; therefore, the results presented a lower sowing value of inbred lines than cultivars, and significantly lowered the germination capacity of monogerm seed genotypes compared to multigerm. The germination rate, revealed in the study, was relatively high. The germination energy accounted after four days of germination amounted to over 71%, which was only 13% lower than the germination capacity evaluated after 14 days of germination. Michalik (1993) reported only about 7% of the difference between those two germination parameters, with a germination energy of just less than 63%. The mean germination time ranged from 2.98 to 4.20 days, with a mean for monogerm seed lines and cultivars of 3.37 days and multigerm seed genotypes of 3.62 days. Lines AR79 produced quite a high amount of normal seedlings (over 81%), and they presented a very high germination rate, with a germination energy of 77% and with an MGT of 2.99 days. The thousand-germ weight of all of the tested monogerm seed genotypes was similar and averaged over 16 g. In the case of multigerm seed lines and cultivars the value of this feature was more varied, ranging from 16.5 to 26.6 g, with a mean of almost 23 g. Both the thousand-germ weight and the number of clusters in one-gram samples indicate seed quality and shape (Janas and Grzesik, 2007). In the case of beet the thousand-germ weight depends on the type of clusters; therefore, for monogerm it was about 11 g and for multigerm it was 20 g (Michalik, 2000). Due to these factors, the AR79 A clusters with a thousand-germ weight of 15.8 g and number of clusters in one-gram sample of 64 were well-formed but still typical for monogerm seed genotypes. All of the tested monogerm seed genotypes presented high monogermity, ranging between 86 and 99%. For the AR79 line, 98% of cluster monogerm characteristics were calculated.

This study has expanded our knowledge about the generative growth period of table beet. The research has shown that the problem, which was the low cluster yield of the AR79 monogerm seed line, was probably the result of a very late ripening of seed stalks, which showed a tendency to form seed stalks with many more stalks as compared to other plants. The obtained results will facilitate Polish breeding programs aimed at the selection of new monogerm seed red beet lines for hybrid performance. However, it still demonstrated the necessity of improving the new monogerm seed inbred lines in order to enhance seed production.

Table 2. The qualitative characteristics of red beet clusters.

Lines and cultivars	Thousand-germ weight (g)	No. of clusters in 1 g samples	Mean germination time (days)	Germination energy (% of germination after 4 days)	Germination capacity (%)	% of monogerm seeds
Monogerm seed genotypes						
AR79 A	17.5 de ¹	57	3.00 a	75 a-c	81 b	99
AR79 B	14.0 e	71	2.98 a	79 ab	82 b	97
W411 A	18.5 c-e	54	3.83 cd	66 b-d	80 b	96
W411 B	16.6 de	60	3.98 be	66 b-d	79 b	95
Patryk	15.3 e	65	3.05 a	85 a	90 ab	86

Multigerm seed genotypes						
218 A	26.6 a	38	3.68 bc	62 cd	96 a	-
218 B	24.7 ab	40	3.73 b-d	51 d	95 a	-
391 A	20.5 b-c	49	4.20 e	64 b-d	79 b	-
391 B	16.5 de	61	3.80 cd	79 ab	81 b	-
Astar F ₁	22.5 a-c	44	3.00 a	84 a	87 ab	-
Okragly Ciemnoczerwony	24.6 ab	41	3.48 b	74 a-c	90 ab	-
Polglob F ₁	24.2 ab	41	3.45 b	71 a-c	81 b	-

¹Explanations: see Table 1.

4. CONCLUSIONS

1. The seed stalk height and the structure of new monogerm seed breeding line AR79 was typical for the species, but it showed a tendency to form greater numbers of late-maturing shoots, as compared to other lines and cultivars.
2. The mean cluster weight per plant for the AR79 line was as many as two times lower than the other genotypes.
3. The seed stalks produced by stecklings with a diameter equal to or greater than 8 cm were higher and better yielded than the small ones, with a diameter between 4 and 6 cm.
4. The quality of AR79 clusters was satisfactory, especially the mean germination time, which was better than in other genotypes. The AR79 clusters presented high monogermity, and a thousand-germ weight typical for monogram genotypes.

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