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ORIGINAL PAPER

RESEARCH ON THE NUTRITIVE VALUE OF SELECTED MONO- AND MULTIGERM BREEDING LINES AND CULTIVARS OF RED BEET ROOTS*

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Abstract

The aim of the study was to evaluate the nutritive quality of 21 red beet genotypes, including mono- and multigerm breeding lines and cultivars. The content of dry matter, total sugar, nitrates, betanin and vulgaxanthin in the roots was tested in beets harvested in 2011-2012. Special attention was given to new monogerm breeding lines AR79 A and AR79 B. The field experiment conducted in a randomized complete block design with three replications was carried out according to standard crop management practices recommended for red beet cultivation under Polish conditions. After 4 months of storage, representative samples of 10 roots from each of 3 replications were crushed and used to determine the chemical composition of the lines and cultivars studied. Analysis of variance showed a significant influence of both the year and genotype on the nutritive value of red beet roots. In 2011, the content of dry matter, nitrates and vulgaxanthin was visibly higher than in 2012, while the levels of total sugar, betanin and the ratio of betanin to vulgaxanthin were lower in 2011. The lines and cultivars varied in the levels of all the measured chemical components. Comparing to the other genotypes, lines AR79 A and AR79 B produced moderate but satisfactory amounts of dry matter, total sugar and vulgaxanthin, while having a high level of betanin and a good betanin to vulgaxanthin ratio. Statistical differences between lines AR79 A and AR79 B in the level of betanin and the betanin to vulgaxanthin ratio were observed only in 2011. Summarizing, the new breeding lines denoted as AR79 A and AR79 B present a desirable content of the tested nutrients, and can therefore be useful in red beet breeding programs.

Keywords: *Beta vulgaris* L., dry matter, betanin, nitrates, sugar, vulgaxanthin.

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INTRODUCTION

In Poland, red beet (*Beta vulgaris* L.) is a traditional vegetable, widely popular in the Polish kitchen. Red beet plants are easy to grow; they can be cultivated on soil poor in organic matter as well as under drought and light stress conditions (Stagnari et al. 2014). In Poland, red beet crops cover 6.2% of the total cultivated area of vegetable fields. In 2015, 297,000 tonnes of red beet roots were harvested in Poland (CSO 2016). Red beet contains many healthful nutrients, beneficial for human health, including minerals, antioxidants, sugars, dietary fibre, vitamins, fatty acids and betalains, which remain in red beet roots even after many months of storage (Ninfali, Angelino 2013). Unfortunately, red beet roots can also accumulate high amounts of harmful compounds like nitrates (Wruss et al. 2015).

Betalains, which produce desirable biological effects by acting as antioxidant, anti-inflammatory, hepatoprotective and anticancer agents, are among the most valuable ingredients of red beet roots in human diet (Wruss et al. 2015). Ravichandran et al. (2013) and Sawicki et al. (2016) have found that red beet's antioxidant capacity was positively correlated with the level of betalains. Nowadays, betalains, consisting of the water soluble nitrogenous red-violet pigments called betacyanins (mainly betanin) and yellow-orange pigments known as betaxanthins (mainly vulgaxanthin), are approved by the food industry as natural colorants labelled E-162 (Ravichandran et al. 2013). The strong influence of a genotype on the content of total betalains in red beet was observed by Lee et al. (2014) and Wruss et al. (2015). In contrast, the growing conditions of red beet also greatly modify the level of betalains, hence the amount of betalains in the research of Stagnari et al. (2014) increased demonstrably under drought stress, while organic cultivation, according to Szopińska, Gawęda (2013), reduced the content of these nutrients. Finally, Michalik et al. (1995*b*), Michalik, Grzebelus (1995) and Nizioł-Łukaszewska, Gawęda (2014) pointed to the influence of both a cultivar and the duration of its cultivation period on the level of betanin in red beet. Michalik et al. (1995*a*) and Michalik, Grzebelus (1995) demonstrated an impact of both genotypes and nitrogen fertilization doses on the amount of red pigments in beetroot.

Dry matter and sugar are the nutrients that decide about the use of red beet roots, such as consumption of fresh beetroots, different processing methods or storage. The sugars of red beet have a profile preferable in human nutrition, i.e. low in fructose and high in sucrose, which largely determines the taste of beetroots (Wruss et al. 2015). According to Michalik et al. (1995*a*,*b*), Michalik, Grzebelus (1995) and Nizioł-Łukaszewska, Gawęda (2014), the levels of sugars and dry matter in beetroots are affected mostly by a genotype, but also by the length of the plant growing period. In contrast, Wruss et al. (2015) observed a similar content of total sugar in all the tested red beet cultivars. Stagnari et al. (2014) reported a strong influence of water stress on the reduction of sugars and dry matter content in red beet roots, while Szopińska, Gawęda (2013) demonstrated that crop cultivation methods, such as conventional, integrated or organic approaches, did not cause changes in the levels of these nutrients. Finally, Salo et al. (1992) noted that high nitrogen fertiliser doses decreased the dry matter content in red beet, but Michalik, Grzebelus (1995) and Ugrinović et al. (2012) did not observe such a relationship.

Red beet is prone to accumulating much nitrates, which are considered a highly undesirable compound of the human diet and depressing the nutritive value of this vegetable. Excessive consumption of nitrites can cause anaemia -like disorders and even neoplasms, which explains why the content of nitrates in red beet roots should be as low as possible (Wruss et al. 2015). According to Salo et al. (1992), Ugrinović et al. (2012) and Szopińska, Gawęda (2013), the amount of nitrates in red beet roots is strongly dependent on the method and doses of nitrogen fertilisation. In contrast, Grzebelus, Barański (2001) and Wruss et al. (2015) found large differences in the levels of nitrates among different red beet genotypes. Finally, Michalik et al. (1995*a*), Michalik, Grzebelus (1995) and Feller, Fink (2004) observed a significant influence both the nitrogen supply and cultivar on the content of nitrates in red beet roots.

Today, the Polish red beet breeding programme strives to achieve monogermity and to produce commercial hybrids (Jagosz 2015). The Polish National List of Vegetable Plant Varieties (PNLVPV) contains 27 red beet cultivars, but hardly any is a monogerm with an open-pollinated character (RCCT 2016). Only five cultivars on the PNLVPV are hybrids, but all have multigerm clusters. In order to produce monogerm hybrid cultivars of red beet, breeders have to create inbreed lines that must be valuable, both in terms of the yield and the quality of roots as well as seeds (Jagosz 2015).

The purpose of this study has been to assess the nutritive quality of 21 red beet genotypes, including 12 mono- and multigerm breeding lines, and 9 cultivars. For two years, the content of dry matter, total sugar, nitrates, betanin, vulgaxanthin and the ratio of betanin to vulgaxanthin in the roots was evaluated. Particular attention was paid to the comparison of the level of chemical compounds in the roots of new monogerm breeding lines AR79 A and AR79 B with respect to the other tested genotypes.

MATERIAL AND METHODS

The plant material used in the study consisted of 21 red beet (*Beta vulgaris* L.) genotypes, including 6 pairs of cytoplasmatic male sterile lines (218 A, 279 mono A, 357 A, 391 A, AR79 A and W411 A) and their respective maintainer fertile lines (218 B, 297 mono B, 357 B, 391 B, AR79 B and W411 B), as well as 9 commercial cultivars, including 2 hybrids (Astar F_1 and Polglob F_1) and 7 open-pollinated cultivars (Czerwona Kula, Modana, Moneta, Monika, Monorubra, Okrągły Ciemnoczerwony and Patryk). Among the tested genotypes, 3 pairs of breeding lines (279 mono A and 297 mono B, AR79 A and AR79 B, and W411 A and W411 B) and 5 cultivars (Modana, Moneta, Monika, Monorubra and Patryk) produced monogerm clusters; the other genotypes were multigerm. Lines AR79 A and AR79 B are new monogerm breeding lines selected in the Institute of Plant Biology and Biotechnology (IPBB) at the University of Agriculture in Krakow.

The field experiment was performed in 2011-2012, at the Experimental Field of the IPBB in Prusy near Krakow, southern Poland. The plants were grown on black degraded soil of pH 6.1 and the nutrient content analysed before cultivation was as follows: 65 mg N-NO_3 dm^{-3}, 96 mg P dm^{-3}, 125 mg K dm^{-3}, 1200 mg Ca dm^{-3} and 80 mg Mg dm^{-3} in 2011, at pH 6.0, and 70 mg N-NO_3 dm^{-3}, 130 mg P dm^{-3}, 140 mg K dm^{-3}, 1200 mg Ca dm^{-3} and 80 mg Mg dm^{-3} in 2012. During the experiment, the air temperature and the precipitations were recorded (Table 1). Standard crop management practices, as recommended for red beet production under Polish conditions, were applied. The experimental design was a randomized complete block with three replications. Each replication consisted of six, 2-metre-long rows spaced 35 cm apart. In both years, at the end of May, 70 or 140 clusters of multigerm and monogerm genotypes, respectively, were sown on each plot. The roots were manually harvested in the middle of September, i.e. 15 weeks after sowing. Marketable roots, with a diameter of 4-12 cm, were mixed with peat and placed in openwork plastic boxes, then stored in a cooling chamber at temp. 2-3°C and 90% RH.

Table 1

Air temperature and rainfall during plant growing seasons in 2011 and 2012

Months	Temperature (C°)			Rainfall (mm)		
	year 2011	year 2012	mean for 2003-2012	year 2011	year 2012	mean for 2003-2012
May	13.3	14.8	13.3	52.8	34.0	79.9
June	18.0	17.6	17.0	35.6	145.0	82.9
July	17.4	20.1	18.3	191.8	41.6	110.9
August	18.9	18.7	18.4	56.6	53.6	67.0
September	15.2	14.3	13.4	9.2	89.8	44.9
Mean temperature and sum of rainfall for growth period	16.6	17.1	16.1	346.0	364.0	385.6

After storage, in the middle of January, representative samples of 10 roots from each of the three replications (totaling 30 for each genotype) were used to assess the quality indicators, such as dry matter, total sugar, betanin, vulgaxanthin and nitrates content. The chemical analyses were based on mixed tissue of all crushed roots from each genotype. For dry matter (% f.w.) determination, two 10 g root samples of each replication were dried at temp. 65°C for 16 h, then at 95°C for one hour. Total sugar (% f.w.) was measured using the colorimetric technique according to the methodology described in PN 90/A-75101.07:1990. Betanin and vulgaxanthin (g 100 g^{-1} of sap) were determined by the NILLSON'S spectrophotometric method (1970) in the sap of beet roots. The procedure with an ionoselective electrode as recommended in PN 92/A-75112:1992 was applied for determination of nitrates (mg KNO_3 kg^{-1} f.w.).

The results were statistically analysed using the package Statistica (ver. 12). Data were analysed according to general analysis of variance (ANOVA, $p < 0.01$). The study was carried out as a two-factorial experiment. The first factor comprised the two years of cultivation and the second factor consisted of 21 red beet genotypes. To estimate significant differences between the means for the content of dry matter, total sugar, nitrates, betanin, vulgaxanthin and the betanin to vulgaxanthin ratio, the Duncan's test at $p = 0.05$ was applied.

RESULTS AND DISCUSSION

The mean temperature recorded over the growth period (from May to September) in 2012 was by 0.5°C higher than in 2011 (Table 1). The average temperature in the period of 2003-2012 was by 0.5 and 1.0°C lower than in the years 2011 and 2012, respectively. Comparing to the year 2011, the average monthly temperatures in May and July in 2012 were higher by 1.5 and 2.7°C, respectively. In July 2011 and in June and September 2012, the monthly rainfalls were almost double the average rainfall in 2003-2012. In June 2011, the sum of precipitation was four-fold lower, while in July it was fourfold higher than in the same months in 2012. In September 2011, the rainfall was tenfold lower than in 2012.

The analysis of variance showed a significant influence of the year on the chemical composition of red beet roots (Table 2). Previously, differences

Table 2

Influence of the year on the nutritive quality of red beet roots

Chemical compounds	Years		Mean
	2011	2012	
Dry matter (% f.w.)	14.10*a*[*]	13.49*b*	13.80
Total sugar (% f.w.)	7.66*b*	8.48*a*	8.07
Nitrates (mg KNO_3 kg^{-1} f.w.)	3666*b*	2078*a*	2872
Betanin (g 100 g^{-1} of sap)	0.104*b*	0.114*a*	0.109
Vulgaxanthin (g 100 g^{-1} of sap)	0.065*a*	0.050*b*	0.058
Ratio betanin to vulgaxanthin	1.644*b*	2.488*a*	2.066

* Means in the rows followed by the same letter are not significantly different at $\alpha = 0.05$.

in the nutritive value of red beet roots depending on the year of cultivation had been observed by Grzebelus, Barański (2001), Feller, Fink (2004), Ugrinović et al. (2012), Szopińska, Gawęda (2013) and Nizioł-Łukaszewska, Gawęda (2014). In 2012, the levels of dry matter, nitrates and vulgaxanthin were notably lower than in 2011, which was probably due to the higher rainfall sum in 2012 than in 2011. Additionally, high precipitation in September 2012 could have effected the reduction in the dry matter and vulgaxanthin content, as well as the decreased accumulation of nitrates. In contrast, the levels of total sugar and betanin were lower in 2011 than 2012, which may have been an effect of the higher rainfall and lower temperature in July 2011 compared to 2012. In 2011, the betanin to vulgaxanthin ratio was also significantly lower than in 2012, which was the result of a higher level of betanin and lower content of vulgaxanthin in 2012 than in 2011.

In the present study, a significant effect of a genotype on the level of quality compounds in red beet roots was also observed (Tables 3 and 4). The lines and cultivars were distinctly varied in terms of the content of all the measured chemical components. The amount of dry matter in the tested lines and cultivars ranged from 12.35 to 16.37% f.w. in 2011 and from 11.68 to 18.51% f.w. in 2012 (Table 3). The differences between the cultivars in the level of dry matter were also noted by Nizioł-Łukaszewska, Gawęda (2014), where the range was between 12.36 and 15.90% f.w. Furthermore, Michalik et al. (1995*a*,*b*) and Michalik, Grzebelus (1995) observed some diversity among the tested red beet cultivars in the content of dry matter. In the present study, the levels of dry matter in monogerm cultivars, such as Monorubra, Monika, Modana and Moneta, rose by 5.09, 2.22, 2.83 and 2.59 per cent points, respectively, between 2011 and 2012. The monogerm lines AR79 A and AR79 B presented similar dry matter levels, which on average reached 13.42 and 13.07% f.w. in 2011, and 13.71 and 12.88% f.w. in 2012, respectively. Two other pairs of monogerm lines, that is 279 mono A and 279 mono B, and W411 A and W411 B, also contained comparable levels of dry matter in both years of the study, but their amounts, on average for two years, were much higher in lines 279 A and 279 B (14.84 and 15.13% f.w., respectively) than in lines W411 A and W411 B (12.16 and 12.86% f.w., respectively).

The content of total sugar in the roots of the genotypes ranged from 5.71 to 8.98% f.w. and from 5.89 to 14.46% f.w. in 2011 and 2012, respectively (Table 3). The level of soluble sugars measured in four red beet cultivars by Nizioł-Łukaszewska, Gawęda (2014) varied between 6.44 and 10.15% f.w. Also Michalik et al. (1995*a*,*b*) and Michalik, Grzebelus (1995) noted significant diversity among the cultivars they studied in the sugar content. Wruss et al. (2015), who tested roots of seven red beet cultivars, found no significant differences in the total sugar level, which ranged from 6.2 to 9.2% f.w. In 2012, some monogerm genotypes, including Moneta, Modana, Monika, 279 mono A and Monorubra, had a high total sugar content, which varied between 9.12 and 14.46% f.w., but in 2011, the same genotypes produced only from 6.95 to 8.15% f.w. of this nutrient. Medium but comparable total

Table 3

Content of dry matter, total sugar and nitrates in the roots of red beet genotypes

Genotypes	Dry matter (% f.w.)			Total sugar (% f.w.)			Nitrates (mg KNO_3 kg^{-1} f.w.)		
	2011	2012	mean	2011	2012	mean	2011	2012	mean
218 A	13.45 *c-g*[*]	11.84 *fg*	12.64 *h-j*	7.27 *a-c*	5.89 *h*	6.58 *f-g*	2877 *ab*	2101 *b-d*	2489 *a-e*
218 B	14.08 *b-g*	12.11 *e-g*	13.10 *g-j*	7.65 *a-c*	6.45 *gh*	7.05 *e-h*	2136 *a*	1601 *a-d*	1868 *ab*
279 mono A	15.05 *a-d*	15.20 *bc*	15.13 *ab*	7.40 *a-c*	11.71 *b*	9.55 *bc*	3844 *a-c*	754 *a*	2299 *a-d*
279 mono B	15.43 *ab*	14.25 *cd*	14.84 *a-d*	7.95 *a-c*	7.63 *d-h*	7.79 *c-h*	2484 *a*	1207 *a-c*	1845 *a*
357 A	15.79 *ab*	13.53 *d-f*	14.66 *b-f*	8.97 *a*	10.57 *bc*	9.77 *ab*	2642 *ab*	1742 *a-d*	2192 *a-d*
357 B	14.42 *b-f*	12.00 *fg*	13.21 *g-j*	7.86 *a-c*	8.56 *c-g*	8.21 *b-f*	3846 *a-c*	2734 *d-f*	3290 *b-f*
391 A	14.41 *b-f*	13.08 *d-g*	13.74 *d-h*	8.37 *ab*	7.83 *d-h*	8.10 *b-f*	3476 *a-c*	2170 *b-d*	2823 *a-e*
391 B	14.88 *a-e*	12.66 *d-g*	13.77 *d-h*	7.73 *a-c*	8.47 *c-h*	8.10 *b-f*	2829 *ab*	1919 *b-d*	2374 *a-d*
AR79 A	13.42 *c-g*	13.71 *c-e*	13.57 *e-h*	7.41 *a-c*	7.62 *d-h*	7.52 *d-h*	4494 *a-c*	2242 *cd*	3368 *c-f*
AR79 B	13.07 *e-g*	12.88 *d-g*	12.98 *g-j*	6.75 *a-c*	7.22 *f-h*	6.98 *e-h*	3382 *a-c*	2092 *b-d*	2737 *a-e*
W411 A	12.55 *g*	11.77 *g*	12.16 *j*	5.71 *c*	6.25 *gh*	5.98 *h*	5211 *bc*	3666 *fg*	4439 *f*
W411 B	13.13 *e-g*	12.59 *d-g*	12.86 *g-j*	5.96 *bc*	6.33 *gh*	6.15 *gh*	4429 *a-c*	3308 *e-g*	3868 *ef*
Astar F_1	14.58 *b-f*	12.40 *e-g*	13.49 *f-i*	8.63 *a*	8.84 *c-g*	8.73 *b-e*	3750 *a-c*	1671 *a-d*	2711 *a-e*
Czerwona Kula	15.19 *a-c*	12.65 *d-g*	13.92 *c-g*	8.69 *a*	7.28 *f-h*	7.98 *b-g*	2202 *a*	2072 *b-d*	2137 *a-d*
Modana	13.32 *d-g*	15.91 *b*	14.62 *b-f*	6.95 *a-c*	9.88 *b-e*	8.42 *b-f*	4068 *a-c*	1620 *a-d*	2844 *a-e*
Moneta	12.35 *g*	15.18 *bc*	13.76 *d-h*	7.84 *a-c*	9.12 *c-f*	8.48 *b-f*	4420 *a-c*	2021 *b-d*	3220 *a-f*
Monika	13.97 *b-g*	16.19 *b*	15.08 *a-c*	7.76 *a-c*	10.02 *b-d*	8.89 *b-e*	3011 *ab*	1074 *ab*	2042 *a-c*
Monorubra	13.42 *c-g*	18.51 *a*	15.96 *a*	8.15 *a-c*	14.46 *a*	11.31 *a*	5987 *c*	1012 *ab*	3500 *d-f*
Okrągły Ciemnoczerwony	16.37 *a*	13.14 *d-g*	14.76 *b-e*	8.98 *a*	9.17 *c-f*	9.07 *b-d*	2594 *ab*	2102 *b-d*	2348 *a-d*
Patryk	14.15 *b-g*	12.04 *e-g*	13.09 *g-j*	7.33 *a-c*	7.49 *d-h*	7.41 *d-h*	4679 *a-c*	4058 *g*	4369 *f*
Polglob F_1	13.00 *fg*	11.68 *g*	12.34 *ij*	7.47 *a-c*	7.36 *e-h*	7.41 *d-h*	4631 *a-c*	2474 *de*	3553 *d-f*

* Key under Table 2

Table 4

Content of betanin and vulgaxanthin, and the ratio of betanin to vulgaxanthin in the roots of red beet genotypes

Genotypes	Betanin (g 100 g^{-1} of sap)			Vulgaxanthin (g 100 g^{-1} of sap)			Ratio betanin to vulgaxanthin		
	2011	2012	mean	2011	2012	mean	2011	2012	mean
218 A	0.077 *g**	0.077 *f*	0.077 *f*	0.046 *gh*	0.034 *d*	0.040 *j*	1.700 *b-e*	2.590 *bc*	2.145 *b-d*
218 B	0.091 *d-g*	0.087 *ef*	0.089 *ef*	0.056 *e-h*	0.039 *d*	0.048 *g-j*	1.658 *c-e*	2.290 *bc*	1.974 *b-d*
279 mono A	0.128 *a-c*	0.168 *a*	0.148 *a*	0.077 *a-d*	0.071 *ab*	0.074 *a-c*	1.660 *c-e*	2.517 *bc*	2.088 *b-d*
279 mono B	0.116 *a-f*	0.131 *bc*	0.124 *a-d*	0.077 *a-d*	0.062 *a-c*	0.069 *b-d*	1.517 *c-f*	2.160 *bc*	1.838 *cd*
357 A	0.118 *a-f*	0.090 *d-f*	0.104 *c-f*	0.093 *a*	0.062 *a-c*	0.078 *ab*	1.255 *ef*	1.457 *c*	1.356 *d*
357 B	0.090 *d-g*	0.128 *b-d*	0.109 *c-e*	0.061 *c-g*	0.048 *cd*	0.055 *e-j*	1.458 *c-f*	2.720 *bc*	2.089 *b-d*
391 A	0.089 *d-g*	0.109 *b-f*	0.099 *d-f*	0.066 *c-g*	0.046 *cd*	0.056 *d-i*	1.355 *d-f*	2.410 *bc*	1.883 *b-d*
391 B	0.135 *ab*	0.109 *b-f*	0.122 *a-d*	0.078 *a-d*	0.045 *cd*	0.062 *c-g*	1.737 *b-d*	2.640 *bc*	2.188 *b-d*
AR79 A	0.094 *c-g*	0.171 *a*	0.132 *a-c*	0.054 *e-h*	0.060 *a-c*	0.057 *d-i*	1.753 *b-d*	3.015 *b*	2.384 *b-d*
AR79 B	0.141 *a*	0.137 *a-c*	0.139 *ab*	0.053 *f-h*	0.046 *cd*	0.049 *f-j*	2.725 *a*	3.092 *b*	2.909 *ab*
W411 A	0.082 *fg*	0.116 *b-f*	0.099 *d-f*	0.055 *e-h*	0.051 *b-d*	0.053 *e-j*	1.514 *c-f*	2.313 *bc*	1.914 *b-d*
W411 B	0.091 *d-g*	0.100 *c-f*	0.096 *d-f*	0.089 *a-c*	0.047 *cd*	0.063 *c-f*	1.150 *f*	2.123 *bc*	1.637 *cd*
Astar F$_1$	0.103 *b-g*	0.103 *b-f*	0.103 *d-f*	0.068 *c-f*	0.035 *d*	0.052 *e-j*	1.543 *c-f*	3.123 *b*	2.333 *b-d*
Czerwona Kula	0.088 *e-g*	0.112 *b-f*	0.100 *d-f*	0.065 *c-g*	0.037 *d*	0.051 *e-j*	1.358 *d-f*	3.067 *b*	2.213 *b-d*
Modana	0.096 *c-g*	0.102 *b-f*	0.099 *d-f*	0.059 *d-g*	0.069 *ab*	0.064 *b-e*	1.615 *c-e*	1.477 *c*	1.546 *cd*
Moneta	0.119 *a-e*	0.106 *b-f*	0.113 *b-e*	0.070 *b-f*	0.068 *ab*	0.069 *b-d*	1.725 *b-d*	1.550 *c*	1.638 *cd*
Monika	0.121 *a-e*	0.123 *b-e*	0.122 *a-d*	0.089 *ab*	0.078 *a*	0.083 *a*	1.372 *d-f*	1.570 *c*	1.471 *cd*
Monorubra	0.074 *g*	0.078 *f*	0.076 *f*	0.039 *h*	0.048 *cd*	0.043 *ij*	1.915 *bc*	1.623 *c*	1.769 *cd*
Okrągły Ciemnoczerwony	0.125 *a-d*	0.141 *ab*	0.133 *a-c*	0.074 *a-e*	0.043 *cd*	0.058 *d-h*	1.703 *b-e*	3.313 *b*	2.508 *a-c*
Patryk	0.117 *a-f*	0.131 *bc*	0.124 *a-d*	0.054 *e-h*	0.031 *d*	0.043 *ij*	2.142 *b*	4.533 *a*	3.338 *a*
Polglob F$_1$	0.089 *d-g*	0.080 f	0.085 *ef*	0.056 *e-h*	0.032 *d*	0.044 *h-j*	1.665 *c-e*	2.657 *bc*	2.161 *b-d*

* Key under Table 2

sugar levels, which amounted to 7.41 and 6.75% f.w. in 2011, and 7.62 and 7.22% f.w. in 2012, were determined in monogerm lines AR79 A and AR79 B, respectively.

In general, the nutrients found in the red beet roots have a beneficial influence on the human health. However, red beet can also accumulate notable amounts of harmful nitrates. In the present study, strong diversity among the genotypes in the level of nitrates was observed (Table 3). Previously, large differences in nitrate accumulation between red beet cultivars had been found by MICHALIK et al. (1995*a*), MICHALIK, GRZEBELUS (1995), GRZEBELUS, BARAŃSKI (2001), FELLER, FINK (2004) and WRUSS et al. (2015). In the current research, the content of nitrates ranged from 2136 to 5987 mg KNO_3 kg^{-1} f.w. in 2011 and from 754 to 4058 mg KNO_3 kg^{-1} f.w. in 2012. Most of the tested genotypes, in both years of the study, showed a similar trend in the nitrate accumulation that indicated a strong genetic effect on this chemical compound. In both years, the genotypes, such as Patryk, W 411 A, W 411 B, AR79 A, AR79 B, Moneta, Polglob F_1, 357 B and 391 A, contained high levels of nitrates, between 2021 and 4679 mg KNO_3 kg^{-1} f.w. In contrast, a tendency towards low nitrate accumulation, under 2000 mg KNO_3 kg^{-1} f.w. on average for two years, was noted in the lines 279 mono B and 218 B. In 2012, the cultivars such as Modana and Astar F_1 contained more than 2-fold and Monorubra almost 6-fold less nitrates than in 2011.

The content of betanin varied between 0.074 and 0.141 in 2011, and from 0.077 to 0.171 g 100 g^{-1} of sap in 2012 (Table 4). The genotypes such as 279 mono A, 279 mono B, 391 B, Monika, Moneta, Okrągły Ciemnoczerwony and Patryk produced high levels of betanin, at least 0.110 g 100 g^{-1} of sap on average for the two years. Also, lines AR79 A and AR79 B were among the genotypes with a high content of betanine, which in 2011 was much lower in AR79 A than AR79 B, while in 2012 both lines produced statistically similar amounts of this nutrient. The genotypes with a low content of betanin, in both years of the study, were Monorubra, Polglob F_1, 218 A and 218 B. Over 66% of the tested lines and cultivars contained comparable amounts of betanin in both years of the study (with differences of less than 0.02 g 100 g^{-1} of sap), thus indicating a genotype as the factor playing the major role in the betanin accumulation. Previously, strong gene control over the betanin content in red beet had been observed by MICHALIK et al. (1995*a*,*b*), MICHALIK, GRZEBELUS (1995), LEE et al. (2014), NIZIOŁ-ŁUKASZEWSKA, GAWĘDA (2014) and WRUSS et al. (2015).

The level of vulgaxanthin in the roots of the tested genotypes varied between 0.039 and 0.093 in 2011 and between 0.031 and 0.078 g 100 g^{-1} of sap in 2012 (Table 4). High level of vulgaxanthin of over 0.060 g 100 g^{-1} of sap in both years of the present research was noted in the genotypes Monika, Moneta, 279 mono A, 279 mono B and 357 A. In contrast, the genotypes with a low content of vulgaxanthin, on average for two years, included the cultivars Patryk, Monorubra, Polglob F_1 and the lines 218 A, and 218 B. In the roots of AR79 A and AR79 B lines, the levels of vulgaxanthin were comparable and amounted to 0.054 and 0.053 g 100 g^{-1} of sap, respectively, in 2011 and 0.060, and 0.046 g 100 g^{-1} of sap, respectively, in 2012. High variation among the red beet genotypes with respect to their content of vulgaxanthin was also observed by MICHALIK et al. (1995*b*), NIZIOŁ-ŁUKASZEWSKA, GAWĘDA (2014), LEE et al. (2014) and WRUSS et al. (2015).

According to MICHALIK et al. (1995b), the ratio of betanin to vulgaxanthin of less than 2.0 may negatively influence the final colour and hence the marketable value of red beet roots. In 2011, the ratio of betanin to vulgaxanthin found in the current study ranged from 1.150 to 2.725, and it was higher than 2.0 only for Patryk and AR79 B (Table 4). In 2012, the lowest value of the ratio was 1.457 and the highest one was 4.533, while being less than 2.0 in only five genotypes (357 A, Modana, Moneta, Monika and Monorubra). In the study reported by NIZIOŁ-ŁUKASZEWSKA, GAWĘDA (2014), the ratio of betanin to vulgaxanthin was between 2.46 and 3.25, while in the research presented by WRUSS et at. (2015) it was much lower and varied from 1.00 to 1.75. The ratio of betanin to vulgaxanthin calculated for lines AR79 A and AR79 B was 2.384 and 2.909, respectively, as an average for two years. However, the ratio for AR79 B was much higher than for AR79 B in 2011, while being similar in both lines in 2012.

CONCLUSIONS

The results of the present experiment showed significant influences of both a year and a genotype on the nutritive value of red beet roots. The new monogerm breeding lines AR79 A and AR79 B, compared to the other genotypes, produced moderate amounts of dry matter, total sugar and vulgaxanthin, but contained high levels of betanin and a satisfactory ratio of betanin to vulgaxanthin. Statistical differences between lines AR79 A and AR79 B were observed only in 2011 and appeared in the betanin content and in the betanin to vulgaxanthin ratio. In conclusion, lines AR79 A and AR79 B had a satisfactory content of the nutrients and can be used in breeding programmes aimed at creating new monogerm cultivars of red beet.

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