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Combining ability of morphological traits and biochemical parameters in carrot (*Daucus sativus* Röhl.) CMS lines

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In 2003–2004, at the Lithuanian Institute of Horticulture, the heritability of root morphological traits and biochemical composition in carrot (*Daucus sativus* Röhl.) lines with cytoplasmic male sterility was investigated in a topcross system.

In the carrot CMS lines, genes with additive effects were gound to be more significant for the inheritance of root diameter, and non-additive genes for root length inheritance in the progeny.

It was shown that both carrot genotype and environmental conditions are significant for the inheritance of the content of total sugar, soluble solids, carotene and nitrates. Estimation of GCA effects of total sugar revealed the CMS line NS 744 to be the most valuable transmitter of this trait while NS 557 was best for carotene content. A comparison of GCA and SCA of carotene in CMS lines and testers has shown that its content to a higher degree is controlled by genes with additive effects. Both genes with additive effects and non-additive genes genetically control total sugar, soluble solids and nitrates to the same degree.

Key words: carrots, general combining ability (GCA), specific combining ability (SCA), cytoplasmic male sterility lines (CMS)

INTRODUCTION

Lately, first generation heterotic carrot hybrids have widely spread. Under more favorable conditions they exceed varieties in productivity and root quality [1–3]. Only some intercrossed lines exert a high heterotic effect. Therefore, in carrot breeding, while developing heterotic hybrids it is important to select properly parental pairs with corresponding morphological traits and biological parameters related to valuable traits of carrots [4, 5]. It is not always possible to measure trait inheritance by the phenotype of parental forms. Phenotypically similar parents can transmit their traits to the progeny very differently. The value of parental forms is best outlined by the combining ability, which is established by trait inheritance in hybrids [6]. Knowledge of trait inheritance allows an effective selection of plant genotypes and crossing components for crossing programs, prognosis of new hybrids' parameters and accelerating the breeding process [7].

The aim of the work was to determine the combining ability of sterile carrot analogues developed from Lithuanian varieties.

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MATERIALS AND METHODS

The investigation was carried out at the Lithuanian Institute of Horticulture in 2003–2004. Carrot hybrids were obtained according to a topcross scheme. For this purpose, we applied two testers (male components), No. 2010 and No. 1898, and three carrot lines with cytoplasmic male sterility (female components): ŠS 494 (of 'Šatrija' parentage), NS 557 (of 'Vytënø nanto' parentage), and NS 744 (of 'Vytënø nanto' parentage). Six crossing combinations were performed.

In 2003–2004, at the beginning of plant vegetation the meteorological conditions were unfavorable for carrot growth. In May, particularly in 2003, the temperature was higher than the multiannual value and the precipitation was low. In 2004, the cool and rainy weather was recorded over the whole June. The ample precipitation in August influenced the maturation of carrot roots. The summer of 2003 was more favorable for carrot growth.

Hybrid trials were established in three replications. The length, diameter and biochemical composition of carrot roots were recorded by assessing 10 roots from each replication. Soluble solids (%) were determined with a refractometer, carotene (mg %) was measured

Table 1. **Disperse analysis of general (GCA) and specific (SCA) combining ability of morphological traits in carrot CMS lines and testers**
Babtai, 2003–2004

Morphological traits	Mean square		SCA	GCA/SCA ratio	
	GCA				
	CMS lines	testers		CMS lines	testers
Root length, cm	11.89**	8.46*	47.52**	0.25	0.18
Root diameter, cm	41.73**	0.31	1.94	21.51	0.16

Significant at ** P < 0.01; * P < 0.05.

Table 2. **GCA effects and GCA and SCA variances of morphological traits in carrot CMS lines and testers**
Babtai, 2003–2004

Parental forms	Traits					
	Root length			Root diameter		
	gi	δ^2gi	δ^2si	gi	δ^2gi	δ^2si
CMS lines						
ŠS 494	0.83	0.65	0.53	–0.13	0.02	0.01
NS 557	–0.73	0.51	3.12	–0.25	0.06	0.01
NS 744	–0.09	–0.03	6.24	0.38	0.14	0.01
LSD_{05}	0.42			0.09		
Testers						
Nr. 2010	–0.38	0.13	2.42	–0.02	0	0.01
Nr. 1898	0.38	0.13	2.42	0.02	0	001
LSD_{05}	0.29			0.07		

Table 3. **Disperse analysis of general (GCA) and specific (SCA) combining ability of biochemical parameters in carrot CMS lines and testers**
Babtai, 2003–2004

Parameters	Mean square		SCA	GCA/SCA ratio	
	GCA				
	CMS lines	testers		CMS lines	testers
Total sugar, %	1.16	5.97*	7.93**	015	0.75
Soluble solids, %	19.05**	99.74**	24.94**	0.77	4.00
Carotene, mg%	69.27**	171.64**	14.55**	1.12	11.80
Nitrates, mg kg^{-1}	5.56*	3.45	15.69**	0.35	0.22

Significant at ** P < 0.01; * P < 0.05.

by J. K. Murri's method, total sugar (%) by the Bertran method, and nitrate content (mg/kg^{-1}) was established potentiometrically with an ion selective electrode [8].

Experimental data on hybrids F_1 were processed by the disperse analysis method. General and specific combining ability was established in the CMS lines and testers, employing a computer programme worked out at the Lithuanian Institute of Agriculture [9].

RESULTS

Disperse analysis of the combining ability of carrot morphological traits showed reliable differences of specific combining ability (SCA) and general combining ability (GCA) of carrot length (Table 1). In the study years, reliable differences of GCA were established by assessing root diameter in CMS lines. A reliable relationship of the GCA and SCA of CMS lines (21, 51) shows that in the study group of carrot CMS lines, genes with additive effects were more significant for root diameter inheritance.

Differences between the crossed CMS lines and the testers determining root length and diameter of F_1 generation were assessed by comparing the values of GCA effects (gi) (Table 2). The longest roots were in the progeny of CMS line ŠS 494. The highest positive (0.83) GCA effect was obtained in this line.

Table 4. **GCA effects and GCA and SCA variances of biochemical composition in carrot CMS lines and testers** Babtai, 2003–2004

Parental forms	Parameters											
	Total sugar			Soluble solids			Carotene			Nitrates		
	gi	δ^2gi	δ^2si	gi	δ^2gi	δ^2si	gi	δ^2gi	δ^2si	gi	δ^2gi	δ^2si
CMS lines												
ŠS 494	–0.07	0	0.17	–0.26	0.06	0.21	–1.60	2.56	0.17	0.94	–341.18	9232.90
NS 557	–0.04	0	0.04	0.57	0.32	0.21	0.59	0.33	0.17	–53.89	2561.94	2281.88
NS 744	0.11	0.01	0.05	–0.31	0.09	0.86	1.01	1.00	0.40	52.94	2461.04	20694.82
LSD_{05}	017			0.21			0.31			41.21		
Testers												
Nr. 2010	0.13	0.01	0.06	–0.66	0.43	0.31	–1.28	1.62	0.38	24.28	418.37	7539.29
Nr. 1898	–0.13	0.01	0.06	0.66	0.43	0.31	1.28	1.62	0.38	–24.28	418.37	7539.29
LSD_{05}	0.12			0.15			0.22			29.14		

The progeny of line NS 744 was distinguished for the largest diameter. Shorter and smaller roots were obtained in hybrids from crosses with CMS line NS 557. In the study years, SCA variances were higher than GCA variances nearly in all the CMS lines and testers, implying that in the combinations studied non-additive genes are more important for root length inheritance. The genetic control of root diameter in paternal forms (testers) was determined by genes with both additive effects and non-additive genes.

Disperse analysis of the combining ability of biochemical composition revealed reliable differences in the specific combining ability of all the parameters studied. Reliable differences of general combining ability were obtained for the contents of soluble solids and carotene (Table 3). At reliable differences of GCA mean squares of carotene content the ratio of GCA and SCA was computed, which demonstrated a higher importance of genes with additive effects for the inheritance of this trait.

On assessing the GCA effects of total sugar, the CMS line NS 744 was characterized as having the highest combining ability of this trait. Line NS 557 was distinguished by the highest combining ability of carotene content (Table 4). Comparison of GCA and SCA variances according to carotene content in CMS lines and testers demonstrated a higher carotene control by genes with additive effects, but non-additive genes were important as well. In the group of the lines studied, the content of total sugar, soluble solids and nitrates equally depended on genes with both additive effects and non-additive genes. The inheritance of biochemical components parameter is influenced not only by carrot genotype but also by environmental conditions.

DISCUSSION

Data of our investigation showed that carotene content inheritance is controlled by genes with additive effects. It means that selection of parental lines according to the phenotype expression permits a fast breeding progress as regards carotene content. It was corroborated also by data of other researchers [10, 11]. To obtain heterotic hybrids with a desirable root diameter, it is necessary to select CMS lines with the optimal expression of this trait. This is secured by genetic control of this trait predetermined by genes with additive effects.

When seeking progress regarding other traits in crosses, parental forms with the highest GCA values should be employed. In interbreeding, heterotic hybrids should be sought. Differently from Þidkova [12], in our trials total sugar content inheritance in carrots was determined rather by non-additive genes. The research material of different genetic origin and unequal breeding practice can be the reason for this observation.

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MORKØ (*DAUCUS SATIVUS* RÖHL.) CVS LINIJØ MORFOLOGINIØ POÞYMIØ IR BIOCHEMINËS SUDËTIES KOMBINACINË GALIA

Santrauka

Lietuvos sodininkystës ir darþininkystës institute 2003–2004 m. tirtas topkroso kryþminimo sistemoje valgomøjø morkø (*Daucus sativus* Röhl.) linijø su vyriðkuoju citoplazminiu sterilumu (CVS) ðakniavaisiø morfologiniø poþymiø ir biocheminës sudëties paveldëjimas. Nustatyta, kad tirtoje morkø CVS linijø grupëje paveldëti palikuoniø ðakniavaisio skersmená labiau linkæ genai su adityviniais efektais, o ilgá – neadityviniai genai. Bendrojo cukraus, tirpiø sausøjø medþiagø, karotino ir nitratø kiekio paveldëjimui turi reikðmës ne tik morkø genotipas, bet ir aplinkos sàlygos. Ávertinus bendrojo cukraus BKG efektà nustatyta, kad perduodant ðá poþymá vertingiausia yra NS 744 CVS linija, o karotino kieká geriausiai perduoda NS 557. Morkø karotino BKG ir SKG variantø palyginimas CVS linijose ir testeriuose rodo, kad jo kieká daþniausiai kontroliuoja genai su adityviniais efektais. Bendrojo cukraus, tirpiø sausøjø medþiagø, nitratø genetinæ kontrolæ vienodai lemia tiek genai su adityviniais efektais, tiek neadityviniai genai.