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THE USE OF TOP CROSS MATING SYSTEM IN THE STUDY OF GENERAL COMBINING ABILITY AND HERITABILITY IN STRAWBERRY (*FRAGARIA* × *ANANASSA* DUCH.)

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ABSTRACT

A top cross scheme was used to assess the effects of general combining ability and narrow-sense heritability coefficients in four strawberry cultivars. Maternal parent plants of four cultivars: 'Elkat', 'Filon', 'Heros' and 'Seal' were crossed with two paternal cultivars: 'Pastel' and 'Jota'. The hybrids derived in this way were assessed for number of inflorescences, fruit yield, average fruit mass, and leaf mass in 2010–2012. Estimated heritability coefficients were 0.63–0.64 for number of inflorescences, 0.32–0.45 for fruit yield, 0.29–0.40 for average fruit mass and 0.31–0.38 for leaf mass. The high estimated heritability for number of inflorescences indicates that selection may help to effectively increase the value of the trait in the offspring. The effects of general combining ability in the investigated cultivars varied. 'Elkat' presented high values regarding fruit yield and number of inflorescences for both paternal forms used as testers. The 'Filon' cultivar responded similarly to applied paternal forms with regard to individual fruit weight. The effects of combining ability of leaf mass trait were dependent upon the paternal form used in the crossing scheme.

Key words: general combining ability, heritability coefficient, quantitative traits.

INTRODUCTION

In 2013, Poland's production of strawberry fruit reached about 162 000 tons. This fact places strawberry at the leading position among other berry crops produced in this country. The most desired cultivar in the processing industry is still 'Senga Sengana', since other cultivars have less desirable processing characteristics [1–3]. In the case of dessert cultivars of strawberries, growers can choose cultivars of domestic or foreign breeding, since the register made up by the Research Centre for Cultivar Testing lists as many as 44 genotypes [4]. Many of these cultivars are used in breeding programmes whose objective is to obtain new, valuable genotypes. Crosses between these cultivars, carried out in different designs, such as diallelic, [6, 10, 14, 15], hierarchic, [7], and factorial design [29], allow researchers to assess a cultivar's usefulness for breeding by identifying its effects of general combining ability.

In this study, the effects of general combining ability (GCA) for the investigated set of genotypes were estimated on the basis of a top-cross scheme. Also, the application of this crossing scheme enabled the estimation of the narrow-sense heritability coefficient for several quantitative traits using parent-offspring regression.

MATERIALS AND METHODS

Four strawberry cultivars: 'Elkat', 'Filon', 'Heros' and 'Seal', bred in the Research Institute of Pomology and Floriculture (recently Research Institute of Horticulture) in Skierniewice, Poland were chosen for the experiment. These genotypes were used as maternal parents in crosses with two testers, the 'Jota' and 'Pastel' cultivars, bred at the University of Life Sciences in Lublin. The description of morphological and practical characteristics of investigated cultivars can be found in numerous studies [19, 30–32]. The crosses were performed in an open field in the spring of 2008. Hybrid seedlings derived from these crosses, together with the parental cultivars, were represented by 3 replicates of 20 plants each, planted in August 2009 at a spacing of

0.35 × 1.0 m and evaluated during three subsequent vegetative seasons in 2010–2012. During the experiment typical agronomic procedures recommended in commercial plantations were applied. In periods of water shortage the fields were irrigated. The following characteristics were assessed: number of inflorescences, fruit yield per plant, individual fruit mass, and leaf mass. The number of inflorescences was determined after the flowering period by counting all inflorescences produced by each plant. The fruit yield was assessed by weighing the fruit crops successively as they were ripening. Mean weight of individual fruits was estimated by dividing the total fruit mass by the number of fruits. After harvest was completed in each year, the leaves of each plant were cut off at about 5 cm above the ground and weighed to determine their total mass. The data obtained in this way were evaluated using the analysis of variance method and significant differences were verified in Tukey's test at the level of $\alpha = 0{,}05$. The effects of general combining ability were estimated according to the top cross scheme and the value of heritability coefficient was estimated by linear regression of offspring compared to the average of both parental forms, based on the models proposed by Ubysz-Borucka et al. [24].

RESULTS AND DISCUSSION

In the crossing scheme applied in this study the highest effects of general combining ability regarding fruit yield have been recorded for maternal cultivar 'Elkat' when crossed with paternal form 'Pastel' (Tab. 1). The obtained values were more than twice as high compared to the crosses of the same maternal form with 'Jota' cultivar (Tab. 2). The effects of 'Heros' and 'Seal' varieties were varied and depended upon the paternal form that was used. The lowest effects for this trait, regardless of applied paternal form, were recorded for 'Filon' cultivar. Although studies by Masny et al. [14] have reported that GCA effects of 'Filon' cultivar were higher than those of 'Elkat', these results may be due to the different choice of genotypes, which were mid- and late-season bearing cultivars, whereas the present study concerned mostly early or mid-early ones. The research carried out by Masny et al. [18] on the combining ability in 10 strawberry varieties showed positive effects with regard to fruit yield for 'Granda' and 'Vikat' cultivars, although the results were varied in different years. Negative effects were recorded for 'Rosie' cultivar throughout the whole observation period. Variable estimates of GCA effects for this trait over the years of study were also observed by Masny and Żurawicz [17].

Table 1. General combining ability effects for the studied properties in crosses with 'Pastel' cultivar

The combination of crossing	GCA effects			
	Fruit yield per plant	Mean weight of single fruit	Number of inflorescences per plant	Leaf weight from plant
Elkat × Pastel	124.72 a*	0.07 b	1.00 a	26.28 a
Seal × Pastel	6.07 b	-2.26 c	-1.60 b	-14.58 b
Filon × Pastel	-100.64 c	2.45 a	0.70 a	-11.40 b
Heros × Pastel	-30.14 bc	-0.24 b	0.10 a	-0.28 b
* Means in the columns marked with the same letter do not differ significantly at $\alpha = 0.05$				

Table 2. General combining ability effects for the studied properties in crosses with 'Jota' cultivar

The combination of crossing	GCA effects			
	Fruit yield	Mean weight of single fruit	Number of inflorescences	Leaf weight from plant
Elkat × Jota	55.80 a*	0.09 ab	1.30 a	-8.48 bc
Seal × Jota	-58.19 c	-1.19 b	-2.60 b	10.06 ab
Filon × Jota	-21.50 bc	1.40 a	1.20 a	19.46 a
Heros × Jota	23.91 ab	-0.30 b	0.10 a	-21.03 c
* Means in the columns marked with the same letter do not differ significantly at $\alpha = 0.05$				

The best-yielding maternal cultivar was 'Elkat' (Tab. 3). Its yield was slightly higher than that reported by Małodobry et al. [11]. In addition, COBORU research [3] showed that this cultivar yielded better than 'Jota' and 'Pastel' in the first year of full fruiting. In the second year 'Pastel' gave slightly higher general yield in one of the two research farms. Good general yield potential and high disease resistance make 'Elkat' a desirable cultivar recommended for organic farming [20].

Table 3. Fruit yield per plant in maternal cultivars and hybrids, and narrow-sense heritability coefficients of this trait

Maternal form	Trait value for maternal forms [g]	Trait value for hybrids with paternal form [g]		Heritability coefficient	
		Jota	Pastel	Jota	Pastel
Elkat	457.81 a*	512.62 a	631.68 a	0.45	0.32
Filon	391.03 b	435.32 ab	406.22 c		
Heros	312.60 d	480.73 ab	476.72 bc		
Seal	349.24 c	398.63 b	512.93 b		
*Means in the columns marked with the same letter do not differ significantly at $\alpha = 0.05$					

Mean individual fruit mass was the highest for hybrid families of 'Filon' × 'Pastel' as well as 'Filon' × 'Jota' (Tab. 4), therefore the GCA effects of this maternal form were also high (Tab. 1, 2). By contrast, maternal form 'Seal' presented negative values of

GCA regarding this trait in the case of both tested paternal forms. Similar response, though at a slightly lower level, was observed in 'Heros' cultivar. High GCA effects for individual fruit weight were found in 'Granda', 'Darselect' [18] and 'Selva' [13] cultivars. 'Darselect', characterized by high GCA effects, was included in the crossing schemes. Selection in the progeny permitted for the derivation of two new cultivars 'Tianxiang" and 'Yanxiang" with higher fruit mass than in the initial cultivar [28]. In the present research, the maternal cultivar 'Elkat' was found to produce fruits of higher individual mass than other cultivars (Tab. 4). In other experiments individual fruit mass was similar (12.1 g) or slightly lower (10.8 g) [3, 5, 12]. For the maternal cultivar 'Heros' the observed individual fruit mass was in the range established for this variety by Gwozdecki [9] (from 8.3 g to 11.8 g). In the case of 'Filon' this author obtained fruits of slightly higher mass (10.0–14.5 g) compared to the present study. Bieniasz et al. [2] also have reported high fruit weight for this cultivar. Considering the fruit size of the maternal cultivars in this study, 'Filon' cultivar, characterized by large fruit size, passes this trait to the progeny more effectively than other cultivars, as indicated by the value of this trait in the hybrids as well as by its GCA effects.

Table 4. Mean weight of single fruit in maternal cultivars and hybrids, and narrow-sense heritability coefficient of this trait

Maternal form	Trait value for maternal forms [g]	Trait value for hybrids with paternal form [g]		Heritability coefficient	
		Jota	Pastel	Jota	Pastel
Elkat	12.91 a*	10.50 ab	11.10 b	0.29	0.40
Filon	10.14 b	11.81 a	13.48 a		
Heros	9.33 b	10.10 ab	10.79 b		
Seal	9.52 b	9.22 b	8.77 c		
* Means in the columns marked with the same letter do not differ significantly at $\alpha = 0.05$					

Crosses of 'Seal' with 'Jota' and 'Pastel' resulted in lower number of inflorescences per plant in the offspring (Tab. 5). Hence, 'Seal' was the only tested cultivar with negative GCA effects (Tab. 1, 2). The remaining cultivars presented positive values of GCA with regard to this trait, the highest being that of 'Elkat' cultivar. Whitehouse et al. [27] assumed that the fruit yield is mainly dependent on the number of inflorescences and distinguished 3 out of 51 genotypes that are significantly more effective in passing this trait to the offspring. In addition, these authors indicate that this trait has a high correlation with fruit yield ($r = 0.757$). Other authors also reported high correlation of these traits [6, 7, 22]. Therefore, using 'Elkat' in crossing programs should facilitate obtaining higher number of inflorescences in the offspring, especially as compared to 'Seal'. Also, 'Elkat' may indirectly contribute to increasing yield potential.

Table 5. Number of inflorescences per plant in maternal cultivars and hybrids, and narrow-sense heritability coefficient of this trait

Maternal form	Trait value for maternal forms [pc]	Trait value for hybrids with paternal form [pc]		Heritability coefficient	
		Jota	Pastel	Jota	Pastel
Elkat	11.34 a*	12.00 a	11.12 a	0.64	0.63
Filon	9.22 b	11.93 a	10.84 a		
Heros	8.82 b	10.81 a	10.03 ab		
Seal	9.81 b	8.14 b	8.51 b		
* Means in the columns marked with the same letter do not differ significantly at $\alpha=0.05$					

The plant vigour of individual plants expressed in the leaf mass was varied (Tab. 6) and ranged from 104.63 g for 'Heros' × 'Jota' combination to 145.78 g for 'Elkat' × 'Pastel' combination. 'Elkat' crossed with 'Pastel' was also remarkable in the assessment of GCA effects of this trait, whereas the effects of other maternal forms combined with this father were negative (Tab. 1). 'Jota' exhibited low GCA effects for crosses with 'Heros' and 'Elkat'. In the case of the remaining two maternal cultivars GCA effects were positive but statistically non-significant. (Tab. 2) Selection of cultivars with higher leaf mass (vigour) is important, since it has significant positive correlation with the fruit yield. [25]

Table 6. Leaf weight from plant in maternal cultivars and hybrids, and narrow-sense heritability coefficient of this trait

Maternal form	Trait value for maternal forms [g]	Trait value for hybrids with paternal form [g]		Heritability coefficient	
		Jota	Pastel	Jota	Pastel
Elkat	118.33 b*	117.18 ab	145.78 a	0.38	0.31
Filon	135.14 a	145.12 a	108.12 b		
Heros	116.21 b	104.63 b	119.22 ab		
Seal	94.82 c	135.72 a	104.92 b		
* Means in the columns marked with the same letter do not differ significantly at $\alpha = 0.05$					

The estimated heritability coefficients varied and depended on the evaluated trait as well as on the population in which the estimates were performed (Tab. 3–6). The highest degree of heritability was obtained for number of inflorescences per plant in the cases where 'Pastel' and 'Jota' were tested as parental cultivars. Varied values of heritability of this trait may have resulted

from the chosen model of breeding the hybrid progeny. In previous studies, heritability of this trait was estimated as 0.38 in hierarchic crossing design and 0.21 in a diallelic crossing design [6, 7]. The value of heritability coefficient for fruit yield per plant was at moderate level, though slightly higher in the population where the paternal form 'Jota' was applied. Similar effects of this cultivar were observed for leaf mass. A high estimate of broad-sense heritability coefficient for fruit yield was obtained based on cultivars and breeding clones, which amounted to 0.64 [25]. However, the level of narrow-sense heritability of this trait can be much lower, as was observed in the research on ever-bearing strawberry hybrids, where it ranged from 0.01 to 0.07 [16]. Heritability of individual fruit mass was higher in the population derived from 'Pastel' cultivar. Higher levels of heritability have been reported in the studies by Whitaker et al. [26] and Masny et al. [16], whereas Shaw [21] obtained a lower level of heritability. The obtained values of heritability coefficient for fruit yield, fruit mass and leaf mass indicate the predominance of non-additive genetic or environmental effects in the control of these traits. The influence of this type of genes on analyzed properties was indicated by Whitaker et al. [26] as well as by Gawroński and Hortyński [7], whereas the influence of additive genes was reported by Kaczmarska [10].

CONCLUSION

1. Maternal cultivars and their progenies varied for the traits examined in this study.
2. Based on the estimated GCA effects, the 'Elkat' cultivar seems to be the most useful parent for gains in the yield, whereas 'Filon' shows high probability of gains in fruit mass.
3. Estimated values of heritability coefficient were at a moderate level which promises slow progress towards the improvement of investigated traits except for the number of inflorescences, where more rapid progress may be possible.

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