COMBINING ABILITY FOR IMPORTANT HORTICULTURAL TRAITS IN MEDIUM- AND LATE-MATURING STRAWBERRY CULTIVARS

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A B S T R A C T

The study concerned the progeny of ten medium- and late-maturing strawberry cultivars (‘Pandora’, ‘Vicoda’, ‘Vikat’, ‘Pegasus’, ‘Elkat’, ‘Marmolada’, ‘Filon’, ‘Segal’, ‘Sophie’ and ‘Camarosa’), which were crossed in 1999 in a complete diallel design in accordance with Griffing’s fourth method. In 2001-2002, 2700 plants of the diallel progeny were individually assessed in terms of the following traits: plant growth habit, growth vigour, fruit ripening time, marketable yield, fruit weight and fruit susceptibility to grey mould, as well as plant susceptibility to white leaf spot, leaf scorch and powdery mildew. The obtained results were evaluated statistically by means of an analysis of variance in accordance with the Griffing’s fixed-effect model and Bonferroni’s t-test.

It was found that the general and specific combining ability effects (GCA and SCA) differed significantly for most of the traits, which means that the both types of effects are very important in the genetic determination of those traits in progeny. On the basis of the estimates of the GCA effects it was found that among the parental cultivars under assessment the highest usefulness for breeding late cultivars was shown by ‘Pandora’, ‘Vicoda’, ‘Vikat’ and ‘Sophie’. However, ‘Pandora’ and ‘Vikat’ can also contribute to a reduction in fruit size in progeny. ‘Pandora’ passed on to its progeny low susceptibility of fruit to grey mould, but also high susceptibility to the two leaf diseases, i.e. white leaf spot and leaf scorch. The cultivars ‘Segal’ and ‘Camarosa’ show high usefulness for breeding large-fruited cultivars of relatively early maturity. Moreover, the cultivar ‘Segal’ is a donor of low susceptibility to powdery mildew.

Significantly positive SCA effects for marketable fruit yield were found in two families (‘Pandora’ x ‘Filon’ and ‘Vikat’ x ‘Marmolada’), for fruit size in eight families (‘Pandora’ x ‘Vikat’, ‘Pandora’ x ‘Elkat’, ‘Pandora’ x ‘Marmolada’, ‘Vicoda’ x ‘Segal’, ‘Vicoda’ x ‘Camarosa’, ‘Marmolada’ x ‘Camarosa’, ‘Segal’ x ‘Camarosa’ and ‘Sophie’ x ‘Camarosa’), and for late fruit ripening also in eight families (‘Pandora’ x ‘Filon’, ‘Pandora’ x ‘Sophie’, ‘Vicoda’ x ‘Pegasus’, ‘Vicoda’ x ‘Marmolada’, ‘Vicoda’ x ‘Sophie’, ‘Vikat’ x ‘Elkat’, ‘Marmolada’ x ‘Segal’ and ‘Filon’ x ‘Camarosa’).

Key words: strawberry, general combining ability (GCA), specific combining ability (SCA), parental form

INTRODUCTION

The main aim of the breeding programme in strawberry carried out at the Research Institute of Pomology and Floriculture in Skierniewice is to obtain new cultivars of high fruit quality (large, shapely, firm and tasty fruits, with bright-red skin and high gloss) and varied fruit ripening time, that is, cultivars that in field conditions of moderate climate would ripen from May to September. In order to obtain desired cultivars quickly, it is necessary to carry out cross-fertilization programmes based on a thorough knowledge of the breeding value of the parental genotypes. Breeding value of a parental genotype (parental form) is usually described by means of the general and specific combining abilities (GCA and SCA) of the parental forms for the important horticultural traits.

The general combining ability of a given parental form in respect of the quantitative trait under consideration is the average level of that trait in the progeny (in half-siblings) of the parental form being considered. It is a measure of the additive action of genes on the trait in question (Griffing, 1956ab). It describes the general usefulness of the parental form in terms of that trait for creating new cultivars. The most valuable hybrid progeny in terms of a trait of interest is obtained as a result of crossing those parental forms that are marked by favourable values of the general combining ability effects for that trait.

The specific combining ability for a trait under consideration pertains to a pair of parental forms and represents the interaction (joint action) of both parents that manifests itself in the preservation of that trait in their progeny. SCA is a result of the non-additive action of genes (domination and epistasis). A considerable variability in the effects of the specific combining ability for a trait within the studied cross design is a proof of the great importance of the joint action of the genes of the pairs of parental forms in determining that trait in the hybrid progeny (Baker 1978). SCA usually emerges in some cross combinations only and may increase or decrease the biological and horticultural values of the hybrid progeny. In general, the occurrence of a considerable variability in SCA effects for a given trait in the starting material for breeding is unfavourable because it increases the probability of obtaining hybrid progenies with an average value of that trait, which is less desirable than it would appear from the sum of the GCA effects of both parents. SCA can also make the mean values of a trait in some hybrids less desirable in relation to the sum of the GCA effects of both parents.

In order to determine which genetic effects (additive or non-additive) have the predominant importance in the inheritance of a given quantitative trait by the progeny under study, the mean square ratio for GCA and SCA (s^2_{GCA} / s^2_{SCA}) is usually used in the analysis of variance according to the fixed model for data in a diallel or factorial cross design (Hortyński, 1987; Żurawicz et al., 1995; Cho and Scott, 2000; López-Sese and Staub, 2002; Mwanga et al., 2002; Lagunes-Espinoza et al., 2003). A high value of the ratio s^2_{GCA} / s^2_{SCA} indicates that additive genetic effects have an advantage over non-additive effects in determining that particular quantitative trait in the progeny under consideration. In such a case there is a relatively high probability of achieving progress in breeding for that trait in cross-breeding within the gene pool represented by the parental forms studied. In the studies by Żurawicz et al. (1995), the estimates of a low value of the ratio s^2_{GCA} / s^2_{SCA} for susceptibility to grey mould and of a high value for fruit size indicate low effectiveness in breeding strawberry cultivars that would be low-susceptible to grey mould and a much higher probability of producing strawberry cultivars with large fruits. The studies by Simpson and Sharp (1988), carried out on the progeny of strawberry genotypes of short-day and ever-bearing types, indicate that GCA effects are of relatively high significance for blooming and yield-related traits, whereas SCA effects are relatively important for the ability to form runners. In the inheritance of resistance to powdery mildew, both the general and specific combining abilities are important (MacLachlan, 1978; McNicol and Gooding, 1979).

The most useful mating design for assessing GCA and SCA effects of parental forms is the diallel cross design. This design is most often used in quantitative genetics and in breeding agricultural and horticultural plants, both annual and perennial (Hortyński, 1987; Żurawicz, 1990; Żurawicz et al., 1995, Dias and Kageyama 1997, Zhang and Kang, 1997; Cilas et al., 1998; Cho and Scott, 2000, Bourion et al., 2002; López-Sese and Staub, 2002; Mwanga et al., 2002; Boros, 2003; Lagunes-Espinoza et al., 2003; Ray et al., 2003; Anido et al., 2004; León et al., 2004).

The aim of this study was to assess the general and specific combining abilities of ten medium- and late-maturing strawberry cultivars for nine useful traits on the basis of data obtained in field experiments with hybrid progeny plants produced in a complete diallel cross design.

MATERIAL AND METHODS

The experiment was carried out at the Research Institute of Pomology and Floriculture in Skierniewice in the years 2001-2002. The experimental material consisted of seedlings of F_1 progeny belonging to 45 hybrid families obtained as a result of crossing 10 medium- and late-maturing strawberry cultivars (‘Pandora’, ‘Vicoda’, ‘Vikat’, ‘Pegasus’, ‘Elkat’, ‘Marmolada’, ‘Filon’, ‘Segal’, ‘Sophie’ and ‘Camarosa’) in a complete diallel cross design according to Griffing’s fourth method (1956b; Dobek et al., 1977; Garretsen and Keuls, 1978; Mądry and Ubysz-Borucka, 1982), which takes into account only direct crosses (Tab. 1). A detailed description of most of the cultivars studied is available in the paper by Żurawicz (2005). Crossing of the cultivars was carried out in 1999. For the purpose of the experiment, plants were used which had been selected randomly from a larger population of seedlings obtained from the seeds from each of the cross combinations. The field experiment with the plants of the hybrid families were set up in the spring of 2000 in a randomized complete block design with 4 replicates of 15 plants each. The plants were planted in a podsolic, Grade 4 soil, at a spacing of 0.4 x 1.1 m. In total, 2700 seedlings were planted in the experiment.

All maintenance and plant protection treatments were carried out in accordance with recommendations for commercial plantations (except leaf diseases – plants were not protected against these diseases). During periods without rain, the plants were irrigated at least once a week by means of a self-propelled sprinkling machine Polymat 130.

In 2001-2002, individual assessment of all the seedlings was carried out. The following traits were assessed: plant growth habit (1-3 rating scale, where 1 – upright, 2 – intermediate, 3 – spreading); growth vigour (1-5 rating scale, where 1 – very poor, 5 very strong); fruit ripening time (number of days from 1st January to the first fruit harvest); marketable fruit yield (g/plant); fruit weight (g); fruit susceptibility to grey mould (% of affected fruits in the total number of fruits collected); as well as plant susceptibility to leaf diseases, i.e. white leaf spot (*Mycosphaerella fragariae*), leaf scorch (*Diplocarpon earliana*) and powdery mildew (*Sphaerotheca macularis*) (0-5 rating scale, where 0 – no disease symptoms, 5 – plants withering away as a result of infection).

Statistical analysis. Using data from the observations of each trait in individual plants, means were determined for each plot. The mean values were used in a preliminary statistical analysis using one-factor analysis of variance based on the randomized complete block model in which hybrid families where the factor.

Table 1. Layout of the diallel cross design based on the Griffing's fourth method for ten strawberry cultivars bearing fruit at different times

Maternal parent ♀	Paternal parent ♂								
	Vicoda	Vikat	Pegasus	Elkat	Onebor-Marmolada	Filon	Segal	Sophie	Camarosa
Pandora	x	x	x	x	x	x	x	x	x
Vicoda		x	x	x	x	x	x	x	x
Vikat			x	x	x	x	x	x	x
Pegasus				x	x	x	x	x	x
Elkat					x	x	x	x	x
Onebor-Marmolada						x	x	x	x
Filon							x	x	x
Segal								x	x
Sophie									x

The hypotheses that the hybrid families did not differ in respect of the mean values for the individual traits were then verified. Because the mean traits were found to differ significantly among the studied hybrids, they were subsequently subjected to the analysis of variance for a complete diallel cross design based on the fixed model (Griffing, 1956b) for Griffing's fourth method using the algorithm developed by Garretsen and Keuls (1978), and Mądry and Ubysz-Borucka (1982).

The fixed model of variance analysis for the data from the diallel cross design has the following form (Griffing 1956b, Mądry and Ubysz-Borucka 1982):

$$\bar{y}_{ij} = m + g_i + g_j + s_{ij} + \bar{e}_{ij}$$

(*i,j = 1, 2..., p; p* denotes the number of parents included in the cross design)

where:

$\bar{y}_{ij}$ is the mean of *n* plots of a trait for the hybrid progeny of the *i*-th maternal parent (♀) and the *j*-th paternal parent (♂),

m is the general mean,

g_i (g_j) is the GCA effect of the *i*-th (*j*-th) parent,

s_{ij} is the SCA effect of the (*i,j)*-th pair of parents,

$\bar{e}_{ij}$ is the random error of the mean $\bar{y}_{ij}$.

The analysis of data according to the fixed model of variance analysis for the data from the diallel cross design consists of estimating the GCA and SCA effects for the traits under consideration, testing the hypothesis that these effects do not vary and examining the significance of their values for each parental form and the significance of the differentces among the GCA effects. Detailed analyses of the significance of the GCA and SCA effects were carried out using the procedure of multiple comparisons based on Bonferroni's inequality (Garretsen and Keuls, 1978). This procedure was also used in multiple comparisons of the GCA effects for each pair of the parents.

All calculations concerning the estimation of GCA and SCA effects in the above model, and those concerning the variance analysis and detailed multiple comparisons were carried out using the DIALLEL computer program, written in Basic (Mądry and Ubysz-Borucka, 1982; Górczyński and Mądry, 1983).

RESULTS AND DISCUSSION

The variance analysis of the data for the progeny in the studied diallel cross design based on Griffing's model revealed that in both years of the experiment the GCA values as well as the SCA values varied significantly for most of the traits (Tab. 2 and 3). This means that most of the traits under assessment were determined by both additive and non-additive genetic effects. The values of the GCA effects showed no significant variability only for plant susceptibility to powdery mildew and only in the first year of the experiment, whereas the values of the SCA effects showed no significant variability for plant growth vigour and plant susceptibility to white leaf spot and leaf scorch, and to powdery mildew (also only in one year of the experiment).

The highest values of the mean square ratios for the GCA and SCA effects, ranging from 14.34 to 17.63, were obtained for fruit ripening time. This means that in the genetic determination of this trait the additive effects predominate, with the trait being highly inheritable in a narrow sense. The lowest values of the mean square ratios were found for plant growth vigour, marketable fruit yield, and plant susceptibility to powdery mildew. This is an indication of a great advantage of non-additive (interactive) effects over additive effects in the process of the inheritance of those traits. Hsu et al. (1969) had developed a hypothesis for the inheritance by strawberry plants of the susceptibility to powdery mildew based on a quantitative analysis of data. The hypothesis emphasizes that in the inheritance of that trait the non-additive variance is more important than the additive variance, and indicates particular significance of epistatic components. The studies by Daubeny (1961) had indicated that several genes took part in the inheritance of susceptibility to powdery mildew, but also emphasized the high importance of non-additive components. In practice, the significant share of non-additive effects in the genetic determination of plant resistance/susceptibility to powdery mildew in strawberry means that it is very difficult to quickly breed cultivars that are resistant or low-susceptible to that disease.

For the remaining traits, the values of the mean square ratios for the GCA and SCA effects ranged from 2.78 to 8.24, which means that in the genetic determination of those traits both additive parental effects and interactive effects are important. According to Sherman et al. (1967), improvement in the values of many traits in strawberry progeny (e.g. yield, fruit weight, fruit firmness) can be significantly affected by both

T a b l e 2. Analysis of variance of a diallel cross design of ten strawberry cultivars with different fruit ripening times for vegetative traits and plant susceptibility to leaf diseases

Source of varia-bility	Degrees of freedom	Mean squares of deviations														
		Plant growth habit			Average growth vigour			Susceptibility to								
								White leaf spot			Leaf scorch			Powdery mildew of strawberry		
		2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean
GCA	9	4.95**	0.0529**	0.0315**	2.21*	0.0918**	0.0565**	14.13**	0.1987**	0.1832**	4.21**	0.6111**	0.2627**	1.28 ns	0.2458**	0.0930**
SCA	35	1.66*	0.0156**	0.0084*	1.48ns	0.0349**	0.0298*	2.82**	0.0241ns	0.0256**	1.36ns	0.1063**	0.0555**	1.29 ns	0.0671**	0.0335**
Random error	132	0.0071	0.0087	0.0056	0.0254	0.0189	0.0175	0.0155	0.0168	0.0094	0.0261	0.0362	0.0177	0.0196	0.0255	0.0137
S^2_{GCA}/S^2_{SCA} [a]		2.9819	3.39	3.75	1.4932	2.63	1.90	5.0106	8.24	7.16	3.0956	5.75	4.73	0.9922	3.66	2.78

Explanations: ** – significant differences in effects at p = 0.01
* – significant differences in effects at p = 0.05
ns – differences in effects not significant at p = 0.05
/a – ratio of mean squares for GCA and SCA

T a b l e 3. Analysis of variance of a diallel cross design of ten strawberry cultivars with different fruit ripening times for yield-related traits

Source of varia-bility	Degrees of freedom	Mean squares of deviations											
		Fruit ripening time			Marketable yield			Fruit weight			Fruit susceptibility to grey mould		
		2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean
GCA	9	80.90 **	89.3564**	82.0003**	17788.35**	13690.50**	4572.40**	15.94 **	4.6024**	3.2082**	4.80 **	122.7452**	37.0884**
SCA	35	4.59 **	6.2325**	4.8421**	10278.60**	4018.62**	5171.06**	5.74 **	0.9063**	0.8765**	1.09 ns	18.7961**	5.8413**
Random error	132	0.9368	0.7064	0.5891	3822.50	1725.85	1601.20	0.1985	0.1872	0.1333	1.2738	7.2906	2.3959
S^2_{GCA}/S^2_{SCA} [a]		17.6252	14.34	16.93	1.7234	3.24	0.87	2.7770	5.08	3.66	4.4036	6.53	6.35

Explanations: ** – significant differences in effects at p = 0.01
* – significant differences in effects at p = 0.05
ns – differences in effects not significant at p = 0.05
/a – ratio of mean squares for GCA and SCA

additive and non-additive effects, but their share in determining those traits varies depending on the parental forms involved.

The estimates of the GCA effects of the parental forms of strawberry in respect of the studied traits are presented in Tables 4 and 5. These effects describe the breeding value of those cultivars. As can be seen, the cultivars ‘Pandora’ and ‘Vikat’ had the highest, significantly positive values of the GCA effects for plant growth habit; therefore, plants with a spreading habit will predominate in their progeny. By contrast, the progeny of the cultivar ‘Elkat’ will be characterized by an upright habit, because the GCA effect for this trait was significantly negative.

The significantly positive value of the additive effects for plant growth vigour in the cultivar ‘Sophie’ indicates a relative ease of obtaining progeny of this cultivar that will be characterized by strong growth. However, the large share of epistatic effects in the inheritance of that trait, arising from the low value of the mean square ratio of the GCA and SCA effects, is an indication that breeding vigorously growing cultivars, even with the use of that cultivar as one of the parents, may be relatively difficult.

The cultivars ‘Pegasus’, ‘Elkat’ and ‘Filon’, with significantly negative values of the GCA effects for the susceptibility of leaves to white leaf spot (in this case they indicate low susceptibility to that disease, and are thus favourable from the breeding point of view) may be a good source of resistance/low susceptibility to that disease. Significantly negative (favourable) values of GCA effects were also obtained for the cultivars ‘Vicoda’ and ‘Vikat’ for leaf scorch, and for the cultivars ‘Elkat’ and ‘Segal’ for powdery mildew.

Fruit ripening time (Tab. 4) was one of the traits for which all the GCA effects were significantly different from zero (with both positive and negative values). The highest, statistically significant values of the GCA effects, signifying a late ripening time, were obtained for the cultivars ‘Vikat’ and ‘Pandora’, and slightly lower but also statistically significant values for the cultivars ‘Vicoda’ and ‘Sophie’. The four cultivars are thus especially valuable in breeding strawberry with the aim of obtaining late cultivars. The very high ratio of the mean squares of deviations for the GCA and SCA effects for that trait is an additional indication of the ease of obtaining late-ripening cultivars by including the above cultivars in breeding programmes. The cultivars for which the calculated GCA effects took statistically significant, negative values (denoting a relatively early fruit ripening time) included: ‘Pegasus’, ‘Elkat’, ‘Marmolada’, ‘Filon’, ‘Segal’ and ‘Camarosa’. These genotypes can therefore be used in breeding programmes as parents for obtaining earlier-ripening cultivars.

GCA effects significantly different from zero for marketable fruit yield were obtained only for four out of the ten parental genotypes studied and only in one year of the experiment.

T a b l e 4. Estimates of GCA effects of strawberry parental forms with different fruit ripening times for vegetative traits and plant susceptibility to leaf diseases

Cultivar	Growth habit[1]			Growth vigour[2]			Susceptibility to								
							White leaf spot[3]			Leaf scorch[3]			Powdery mildew of strawberry[3]		
	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean
Pandora	0.09*	-0.03	0.03	0.03	0.19*	0.11	0.31*	0.28*	0.29*	0.27*	0.35*	0.31*	0.02	0.12	0.07
Vicoda	0.00	0.06	0.03	-0.02	-0.07	-0.04	0.07	0.16*	0.12*	-0.03	-0.21*	-0.12*	-0.05	0.01	-0.02
Vikat	0.04	0.18*	0.11*	0.01	-0.13	-0.06	-0.18*	0.05	-0.07	-0.11	-0.57*	-0.34*	0.02	0.18*	0.10
Pegasus	-0.03	-0.01	-0.02	-0.09	0.02	-0.03	-0.08	-0.17*	-0.12*	-0.02	0.01	-0.00	0.06	0.20*	0.13*
Elkat	-0.13*	-0.07	-0.10*	0.06	0.06	0.06	-0.25*	-0.24*	-0.24*	-0.01	-0.16	-0.09	-0.06	-0.20*	-0.13*
Marmolada	0.02	0.01	0.02	-0.10	-0.05	-0.08	0.11	-0.08	0.01	0.11	0.25*	0.18*	0.09	0.16*	0.13*
Filon	-0.02	-0.04	-0.03	0.02	0.01	0.01	-0.13*	-0.13*	-0.13*	-0.14	-0.09	-0.11	-0.03	0.01	-0.01
Segal	-0.02	-0.03	-0.03	0.04	-0.07	-0.02	0.09	0.05	0.07	-0.08	0.26*	0.09	-0.09	-0.27*	-0.18*
Sophie	0.08	0.05	0.07	0.16*	0.15*	0.15*	-0.03	0.02	-0.00	0.01	0.00	0.00	0.04	-0.22*	-0.09
Camarosa	-0.04	-0.11*	-0.07	-0.11	-0.11	-0.11	0.09	0.05	0.07	-0.01	0.16	0.08	0.00	0.01	0.00
Total mean	2.42	2.47	2.44	3.06	3.60	3.33	1.85	0.89	1.37	1.09	1.73	1.41	1.81	1.91	1.86
$SE(g_i) \times 2.85$	0.0855	0.09	0.09	0.1425	0.14	0.11	0.1140	0.11	0.09	0.1425	0.17	0.11	0.1425	0.14	0.11
$SE(g_i - g_j) \times 3.33$	0.1332	0.17	0.13	0.2664	0.23	0.23	0.1998	0.20	0.17	0.2664	0.33	0.23	0.2331	0.27	0.20

Explanations: [1] – rating scale, where 1 – upright, 2 – intermediate, 3 – spreading habit
[2] – rating scale 1-5, where 1 – very weak, 5 – very strong growth
[3] – rating scale 0-5, where 0 – no symptoms, 5 – pathogen-affected plants withering away
* – GCA effects significantly different from zero (positive or negative) according to Bonferroni's t-test at p = 0.05

Table 5. Estimates of GCA effects of strawberry parental forms with different fruit ripening times for yield-related traits

Cultivar	Fruit ripening time			Marketable yield [g]			Fruit weight [g]			Fruit susceptibility to grey mould [%]		
	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean
Pandora	3.54*	4.62*	4.09*	-43.32	51.72*	4.20	-0.68*	-1.17*	-0.92*	-0.75	-9.25*	-5.00*
Vicoda	2.66*	2.76*	2.71*	50.85	-13.88	18.48	0.62*	-0.04	0.29	0.58	-2.05	-0.73
Vikat	5.74*	5.74*	5.74 *	57.14	-78.53*	-10.69	-0.79*	-1.46*	-1.12*	1.60*	1.54	1.57*
Pegasus	-2.35*	-2.25*	-2.30*	-49.36	9.13	-20.11	0.22	0.44*	0.33	-0.56	-1.61	-1.09
Elkat	-3.35*	-3.53*	-3.44*	7.92	38.37	23.62	-0.94*	0.15	-0.40*	-0.30	3.24*	1.47
Marmolada	-2.27*	-1.73*	-2.01*	-55.55	6.31	-24.61	0.70*	0.40	0.55*	-0.73	-2.04	-1.39
Filon	-1.33*	-2.26*	-1.79*	30.56	52.34*	41.45*	-0.18	0.13	-0.03	-0.15	1.54	0.69
Segal	-2.24*	-2.41*	-2.33*	-18.54	-5.42	-11.99	0.67*	0.44*	0.55*	-0.42	3.61*	1.59*
Sophie	1.21*	1.35*	1.28*	61.22*	-36.11	12.56	-0.04	0.08	0.02	1.37*	3.14*	2.25*
Camarosa	-1.61*	-2.29*	-1.95*	-40.91	-24.93	-32.90	0.42	1.04*	0.73*	-0.63	1.88	0.62
Total mean	171.99	156.98	164.48	680.00	477.75	578.87	11.16	8.35	9.75	4.79	20.57	12.69
SE (g_i) x 2.85	0.9120	0.80	0.74	59.109	39.70	38.25	0.4275	0.43	0.34	1.0830	2.59	1.48
SE (g_i - g_j) x 3.33	1.5984	1.4	1.27	104.8284	69.13	67.77	0.7326	0.73	0.60	1.8648	4.50	2.56

Explanations: % – percentage share of rotten fruits in the total number of fruits collected
* – GCA effects significantly different from zero (positive or negative) according to Bonferroni's t-test at p = 0.05
SE (.) – standard error of the estimates of GCA effects or their differences

Significantly positive GCA effects for that trait were found in 2001 for the cultivar 'Sophie', and in 2002 for the cultivars 'Pandora' and 'Filon'. This means that the three cultivars may be useful for breeding highly productive progeny.

The GCA effects estimated for fruit size were statistically significant for most of the parental genotypes. Only the GCA effects for the cultivars 'Filon' and 'Sophie' took values close to zero. The highest, statistically proven values of the GCA effects were obtained for the cultivars 'Segal' and 'Camarosa' in both years of the experiment, and in one year for the cultivars 'Pegasus' and 'Marmolada'. This means that the four genotypes show high usefulness for breeding large-fruited cultivars. Quite useless for this purpose, however, are the cultivars 'Pandora', 'Vikat' and 'Elkat', for which the GCA effects for that trait were found to be significantly negative.

For five out of the ten genotypes studied, the GCA effects were found to be significantly different from zero for the trait of fruit susceptibility to grey mould, but only for one of the cultivars ('Sophie') the obtained effects were significant in both years of the experiment. The GCA effects with significantly negative values (favourable from the breeding point of view, as they denote low susceptibility of fruit to that disease) were estimated only for the cultivar 'Pandora', which means that that cultivar is a valuable donor of low fruit susceptibility to grey mould. The cultivars 'Sophie', 'Segal', 'Vikat' and 'Elkat', with significantly positive (unfavourable for breeding) GCA effects for fruit susceptibility to grey mould, are completely useless for breeding for resistance, as they would pass on to their progeny high susceptibility to that disease. The relatively high ratio of the mean squares of deviations of the GCA and SCA effects for fruit susceptibility to grey mould, calculated earlier (ranging from 4.40 to 6.53 – Table 3), indicates a significant share of both additive and non-additive effects in the expression of that trait in the progeny. Żurawicz (1990), in his experiment on ten other strawberry cultivars, also found a highly significant share of additive and non-additive variance in the genetic determination of that trait and pointed out a much greater difficulty in breeding cultivars that would bear fruit with low susceptibility to grey mould in comparison with breeding, for example, large-fruited cultivars, as a consequence of low inheritability of that trait.

Estimates of SCA effects for the traits under assessment are given in Tables 6 and 7. Significantly positive values of the SCA effects on plant growth habit were obtained only for the family 'Marmolada' x 'Camarosa' in 2001. It means that the progeny plants obtained as a result of crossing the two cultivars were characterized by a spreading growth habit.

For plant growth vigour, the significance of the SCA effects was statistically proven for two families: 'Vicoda' x 'Sophie' and 'Elkat' x 'Sophie, with the SCA effect taking

T a b l e 6. Estimates of SCA effects of cross combinations of strawberry parental forms with different fruit ripening times for vegetative traits and plant susceptibility to leaf diseases

Cross combinations of parents	Growth habit[1]			Growth vigour[2]			Susceptibility to White leaf spot[3]			Susceptibility to Leaf scorch[3]			Susceptibility to Powdery mildew of strawberry[3]		
	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean
Pandora x Vicoda	0.01	-0.00	0.01	0.15	0.23	0.19	-0.07	0.05	-0.01	-0.01	-0.00	-0.00	-0.13	-0.04	-0.09
Pandora x Vikat	0.10	0.02	0.02	0.05	0.15	0.10	0.19	-0.04	0.08	0.17	0.51	0.34	-0.03	-0.14	-0.09
Pandora x Pegasus	0.05	-0.02	0.02	-0.09	0.01	-0.04	0.21	-0.13	0.04	0.20	0.18	0.19	-0.10	0.06	-0.02
Pandora x Elkat	-0.02	-0.15	-0.08	0.09	0.02	0.06	0.07	-0.02	0.02	-0.10	-0.05	-0.08	-0.08	-0.23	-0.16
Pandora x Marmolada	-0.02	0.05	0.02	-0.10	0.03	-0.03	-0.13	-0.05	-0.09	-0.08	-0.03	-0.05	-0.04	0.16	0.06
Pandora x Filon	-0.08	-0.01	-0.04	0.37	0.07	0.22	-0.06	0.12	0.03	-0.05	-0.37	-0.21	0.07	0.14	0.10
Pandora x Segal	-0.03	0.01	-0.01	-0.16	-0.06	-0.11	-0.08	-0.13	-0.10	-0.03	-0.00	-0.02	-0.17	-0.08	-0.12
Pandora x Sophie	0.07	-0.03	0.02	-0.26	-0.10	-0.18	0.19	0.21	0.20	0.13	0.04	0.08	0.36	0.17	0.27
Pandora x Camarosa	-0.07	0.13	0.03	-0.04	-0.35	-0.20	-0.32	-0.01	-0.17	-0.25	-0.27	-0.26	0.12	-0.03	0.04
Vicoda x Vikat	-0.05	0.05	0.01	0.09	-0.11	-0.01	-0.22	-0.22	-0.22	0.08	0.12	0.10	-0.08	-0.28	-0.18
Vicoda x Pegasus	0.12	0.08	0.10	-0.15	-0.10	-0.13	0.21	0.18	0.19	-0.05	-0.02	-0.03	-0.14	-0.25	-0.20
Vicoda x Elkat	0.12	0.11	0.11	0.07	0.02	0.04	0.29	0.23	0.26	-0.20	-0.24	-0.22	-0.02	-0.26	-0.14
Vicoda x Marmolada	-0.11	0.05	-0.03	0.29	0.05	0.17	-0.39*	0.03	-0.18	-0.19	-0.38	-0.29	-0.04	-0.11	-0.08
Vicoda x Filon	-0.05	-0.06	-0.06	-0.33	-0.06	-0.20	0.26	0.04	0.15	0.12	0.61	0.36	-0.03	0.06	0.01
Vicoda x Segal	-0.02	-0.21	-0.12	0.08	0.26	0.17	0.09	-0.17	-0.04	0.22	0.15	0.18	0.28	0.45	0.37*
Vicoda x Sophie	0.07	0.11	0.09	-0.30	-0.41*	-0.36	-0.19	-0.09	-0.14	0.06	-0.19	-0.06	0.14	0.05	0.09
Vicoda x Camarosa	-0.08	-0.13	-0.11	0.12	0.13	0.12	0.02	-0.05	-0.02	-0.04	-0.04	-0.04	0.03	0.38	0.20
Vikat x Pegasus	-0.05	0.17	0.06	0.18	-0.12	0.03	-0.16	-0.02	-0.09	-0.30	-0.49	-0.39	-0.15	- 0.38	-0.26
Vikat x Elkat	0.07	0.06	0.07	-0.29	-0.21	-0.25	0.24	0.16	0.20	-0.07	0.11	0.02	0.07	0.08	0.08
Vikat x Marmolada	-0.08	-0.26	-0.17	0.13	0.20	0.16	0.30	0.36	0.33*	0.16	0.43	0.30	0.05	-0.20	-0.08
Vikat x Filon	0.13	0.01	0.07	-0.17	-0.12	-0.14	-0.03	-0.16	-0.09	-0.10	-0.21	-0.15	0.04	0.23	0.13
Vikat x Segal	-0.04	-0.03	-0.03	0.06	0.04	0.05	0.05	0.20	0.13	0.09	0.09	0.09	-0.01	0.28	0.14
Vikat x Sophie	-0.05	-0.03	-0.04	-0.01	0.01	0.00	-0.14	-0.14	-0.14	-0.01	-0.10	-0.05	0.15	0.28	0.21
Vikat x Camarosa	-0.03	0.02	-0.00	-0.04	0.15	0.06	-0.24	-0.16	-0.20	-0.03	-0.46	-0.24	-0.03	0.12	0.05

Pegasus x Elkat	0.07	-0.17	-0.05	0.16	0.13	0.15	0.12	-0.02	0.05	0.27	0.46	0.36	0.13	-0.04	0.04
Pegasus x Marmolada	-0.09	-0.19	-0.14	-0.02	0.07	0.03	-0.10	-0.14	-0.12	0.03	0.50	0.27	0.07	0.24	0.15
Pegasus x Filon	-0.11	-0.12	-0.12	0.04	0.11	0.08	-0.07	0.08	0.00	-0.11	-0.11	-0.11	0.12	0.00	0.06
Pegasus x Segal	0.07	0.15	0.11	-0.25	-0.08	-0.17	-0.17	-0.14	-0.15	0.00	-0.42	-0.21	0.26	0.53	0.39*
Pegasus x Sophie	-0.20	-0.10	-0.15	0.28	0.12	0.20	0.04	0.22	0.13	-0.37	-0.30	-0.33	-0.32	-0.02	-0.17
Pegasus x Camarosa	0.14	0.21	0.17	-0.14	-0.14	-0.14	-0.08	-0.03	-0.05	0.31	0.21	0.26	0.12	-0.14	-0.01
Elkat x Marmolada	-0.10	0.08	-0.01	-0.14	-0.10	-0.12	-0.06	-0.16	-0.11	0.03	0.04	0.03	0.08	-0.06	0.01
Elkat x Filon	0.03	0.14	0.08	-0.10	0.05	-0.03	-0.16	-0.14	-0.15	-0.15	-0.32	-0.23	0.00	0.32	0.16
Elkat x Segal	-0.08	0.09	0.00	-0.12	-0.20	-0.16	-0.28	-0.01	-0.14	-0.17	-0.21	-0.19	-0.06	0.16	0.05
Elkat x Sophie	-0.02	-0.17	-0.10	0.36	0.47*	0.42*	-0.24	-0.10	-0.17	0.23	-0.01	0.11	-0.07	0.04	-0.02
Elkat x Camarosa	-0.07	0.02	-0.03	-0.03	-0.19	-0.11	0.01	0.06	0.04	0.17	0.23	0.20	-0.04	-0.01	-0.03
Marmolada x Filon	-0.05	0.12	0.03	0.00	-0.15	-0.08	-0.10	-0.04	-0.07	0.00	-0.42	-0.21	0.03	0.09	0.06
Marmolada x Segal	0.14	-0.01	0.06	-0.03	-0.11	-0.07	0.17	0.18	0.18	0.19	-0.16	0.01	0.16	-0.14	0.01
Marmolada x Sophie	0.06	0.18	0.12	-0.18	-0.23	-0.21	0.27	-0.01	0.13	-0.09	0.07	-0.01	-0.23	0.02	-0.10
Marmolada x Camarosa	0.27*	-0.02	0.12	0.04	0.25	0.14	0.03	-0.20	-0.08	-0.06	-0.04	-0.05	-0.08	0.01	-0.04
Filon x Segal	-0.04	0.05	0.00	0.18	0.06	0.12	-0.12	0.03	-0.05	-0.19	0.11	-0.04	-0.28	-0.39	-0.33
Filon x Sophie	0.23	-0.01	0.11	-0.11	-0.06	-0.09	-0.12	-0.12	-0.12	0.14	0.11	0.13	-0.09	-0.39	-0.24
Filon x Camarosa	-0.06	-0.12	-0.09	0.14	0.11	0.12	0.39*	0.19	0.29	0.33	0.60*	0.47*	0.14	-0.05	0.04
Segal x Sophie	-0.03	0.05	0.01	0.26	0.13	0.19	0.16	-0.06	0.05	0.11	0.52	0.32	0.06	-0.34	-0.14
Segal x Camarosa	0.04	-0.10	-0.03	-0.01	-0.04	-0.02	0.16	0.11	0.13	-0.23	-0.07	-0.15	-0.25	-0.48*	-0.36*
Sophie x Camarosa	-0.13	-0.01	-0.07	-0.04	0.08	0.02	0.03	0.08	0.06	-0.21	-0.15	-0.18	-0.01	0.20	0.10
SE (s_{ij}) x 3.33	0.2331	0.27	0.23	0.4662	0.40	0.40	0.3663	0.37	0.30	0.4662	0.57	0.40	0.3996	0.47	0.33

Explanations: [1] – rating scale, where 1 – upright, 2 – intermediate, 3 – spreading habit
[2] – rating scale 1-5, where 1 – very weak, 5 – very strong growth
[3] – rating scale 0-5, where 0 – no symptoms, 5 – pathogen-affected plants withering away
* – SCA effects significantly different from zero (positive or negative) according to Bonferroni's t-test at p = 0.05
SE (s_{ij}) – standard error of the estimates of SCA effects

T a b l e 7. Estimates of SCA effects of cross combinations of strawberry parental forms with different fruit ripening times for yield-related traits

Cross combinations of parents	Fruit ripening time			Marketable yield [g]			Fruit weight [g]			Fruit susceptibility to grey mould [%]		
	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean	2001	2002	Mean
Pandora x Vicoda	-2.06	-2.70*	-2.38*	-16.15	-2.41	-6.90	-0.86	-0.43	-0.65	-1.07	2.48	0.70
Pandora x Vikat	-2.99*	-2.96*	-2.97*	-60.92	74.95	7.02	0.13	1.28*	0.70	0.04	-3.42	-1.69
Pandora x Pegasus	-0.50	0.35	-0.07	-21.04	-15.95	-18.51	-0.36	0.28	-0.04	0.28	1.55	0.92
Pandora x Elkat	-1.11	-1.87	-1.49	40.96	55.61	48.31	1.34*	0.13	0.73	-0.49	0.02	-0.24
Pandora x Marmolada	-0.44	-2.04	-1.23	-64.93	24.22	-20.38	1.81*	0.89	1.34*	0.49	4.31	2.40
Pandora x Filon	4.03*	4.50*	4.26*		37.24		-0.02	-0.56	-0.29	0.52	-3.25	-1.36
Pandora x Segal	1.74	0.16	0.96	-8.16	-32.95	-20.55	-0.07	0.12	0.02	0.57	0.12	0.34
Pandora x Sophie	1.86	4.22*	3.04*	-	-96.49	-	-0.81	-0.57	-0.66	0.37	-4.77	-2.20
Pandora x Camarosa	-0.55	0.34	-0.11	113.08	-49.04	32.01	-1.17	-1.14	-1.16*	-0.71	2.97	1.13
Vicoda x Vikat	-2.26	-2.69*	-2.48*	49.96	-1.82	24.07	-0.51	-0.08	-0.29	0.47	1.42	0.95
Vicoda x Pegasus	2.39	3.56*	2.98*	-52.67	-37.30	-44.99	-0.52	-0.24	-0.38	-0.27	-3.02	-1.65
Vicoda x Elkat	1.90	-0.27	0.81	149.73	24.99	87.40	0.58	1.01	0.80	0.56	8.02*	4.29
Vicoda x Marmolada	2.16	2.51*	2.34*	91.68	-25.08	33.29	-0.85	-1.03	-0.94	0.50	3.06	1.78
Vicoda x Filon	-1.35	-1.67	-1.51	-148.36	-9.63	-79.03	0.81	0.65	0.73	-2.06	-2.26	-2.16
Vicoda x Segal	-1.22	0.87	-0.17	57.67	70.83	64.29	1.79*	0.28	1.04	0.27	-2.05	-0.89
Vicoda x Sophie	3.20*	3.72*	3.46*	-155.59	-57.79	-106.71	-1.52*	-1.33*	-1.43*	1.17	-7.80	-3.32
Vicoda x Camarosa	-2.78	-3.33*	-3.06*	23.73	33.39	28.58	1.07	1.18	1.13*	0.43	0.15	0.29
Vikat x Pegasus	1.51	2.44	1.97	66.89	-112.50	-22.82	0.82	-0.83	-0.00	0.51	7.62	4.07
Vikat x Elkat	0.84	2.98*	1.91	-92.44	-68.82	-80.60	1.45*	0.25	0.85	0.02	-2.53	-1.26
Vikat x Marmolada	-0.64	-0.25	-0.44	114.18			-0.65	-0.36	-0.51	-1.96	-6.01	-3.99
Vikat x Filon	2.33	-1.67	0.33	-131.31	-99.01	-115.15	0.04	0.37	0.20	0.00	4.73	2.36
Vikat x Segal	1.30	1.61	1.46	4.20	5.43	4.81	-0.87	-0.48	-0.67	-1.35	-3.05	-2.20
Vikat x Sophie	0.18	0.35	0.26	75.61	39.21	57.41	-0.71	-0.37	-0.54	0.70	-3.02	-1.16

Vikat x Camarosa	-0.28	0.20	-0.04	-26.16	6.34	-9.93	0.30	0.23	0.27	1.58	4.27	2.92
Pegasus x Elkat	0.81	0.59	0.70	62.69	74.17	68.46	0.29	0.67	0.48	-1.29	-2.30	-1.79
Pegasus x Marmolada	-1.16	-1.96	-1.55	14.53	16.14	15.35	0.23	0.74	0.49	-0.12	-0.49	-0.30
Pegasus x Filon	-2.12	-2.62*	-2.37*	-25.13	31.05	2.94	0.24	0.23	0.24	2.07	-0.73	0.67
Pegasus x Segal	-1.05	-1.73	-1.38	-52.53	16.97	-17.75	-0.38	-0.23	-0.30	-1.54	-6.18	-3.86
Pegasus x Sophie	-1.67	-2.18	-1.93	93.69	66.50	80.08	0.69	0.43	0.55	-0.01	5.55	2.77
Pegasus x Camarosa	1.77	1.55	1.66	-86.43	-39.07	-62.76	-1.01	-1.05	-1.03	0.37	-2.01	-0.82
Elkat x Marmolada	-1.51	-0.58	-1.04	-79.39	-87.65	-83.50	-0.81	0.07	-0.37	-1.15	-3.17	-2.16
Elkat x Filon	-1.23	-0.35	-0.79	-90.11	-8.06	-49.07	0.09	0.24	0.16	1.93	3.49	2.71
Elkat x Segal	-0.37	-0.35	-0.36	-91.08	-54.30	-72.90	-2.89*	- 1.65*	-2.27*	1.61	1.13	1.37
Elkat x Sophie	0.75	0.17	0.46	103.14	84.64	93.92	0.86	0.21	0.53	0.24	-0.44	-0.10
Elkat x Camarosa	-0.09	-0.33	-0.21	-3.51	-20.59	-12.02	-0.90	-0.93	-0.92	-1.42	-4.21	-2.82
Marmolada x Filon	-3.12*	-2.31	-2.71*	11.44	-11.50	-0.01	-0.78	-0.13	-0.45	-0.88	0.53	-0.18
Marmolada x Segal	3.29*	3.98*	3.58*	-109.36	-11.23	-60.26	0.64	-0.34	0.15	0.95	-2.48	-0.77
Marmolada x Sophie	0.20	-0.71	-0.25	-2.67	-58.67	-30.69	-0.61	-0.95	-0.79	-0.40	1.94	0.77
Marmolada x	1.22	1.37	1.30	24.51	-2.45	11.02	1.04	1.12	1.08*	2.57	2.32	2.45
Filon x Segal	-0.81	0.40	-0.20	143.23	-32.59	55.35	-0.01	0.55	0.27	0.08	4.94	2.51
Filon x Sophie	-1.26	-0.52	-0.89	-8.41	-14.83	-11.63	0.66	1.03	0.84	-0.51	0.15	-0.18
Filon x Camarosa	3.54*	4.25*	3.89*	24.22	107.32	65.75	-1.02	-2.38*	-1.70*	-1.15	-7.60	-4.38
Segal x Sophie	-1.66	-2.97*	-2.31*	113.47	55.58	84.56	0.77	0.17	0.47	-0.24	5.93	2.85
Segal x Camarosa	-1.22	-1.98	-1.59	-57.45	-17.74	-37.55	1.02	1.58*	1.30*	-0.34	1.65	0.65
Sophie x Camarosa	-1.62	-2.07	-1.85	-11.98	-18.06	-15.10	0.68	1.38*	1.03	-1.33	2.47	0.57
SE (s_{ij}) x 3.33	2.8305	2.46	2.26	181.58	122.01	117.52	1.2987	1.27	1.07	3.3300	7.93	4.56

Explanations: % – percentage share of rotten fruits in the total number of fruits collected
* – SCA effects significantly different from zero (positive or negative) according to Bonferroni's t-test at p = 0.05
SE (s_{ij}) – standard error of the estimates of SCA effects

a negative value for the former, and a positive value for the latter family. It should thus be expected that the progeny of the family 'Vicoda' x 'Sophie' will always be characterized by weak growth, whereas the progeny of the family 'Elkat' x 'Sophie' will show a tendency towards vigorous growth.

Three SCA effects, with values significantly different from zero, were detected for plant susceptibility to white leaf spot. In the case of two hybrid families: 'Vikat' x 'Marmolada' and 'Filon' x 'Camarosa', the values of the SCA effects were significantly positive (unfavourable from the breeding point of view). The high susceptibility of their progeny to white leaf spot, especially in the case of 'Filon' x 'Camarosa' hybrids, is a result of the interactive effect of both parents revealed only in the F_1 progeny, since the cultivar 'Filon' normally passes on to its progeny low susceptibility to that disease (the GCA effects for that trait were found to be significantly negative (favourable) in both years of the experiments – Table 4).

The progeny of the family 'Filon' x 'Camarose' will also show high plant susceptibility to leaf scorch, as evidenced by the significantly positive (unfavourable) values of the SCA effects for that trait.

Two families: 'Vicoda' x 'Segal' and 'Pegasus' x 'Segal', were found to have significantly positive (unfavourable) values of the SCA effects for plant susceptibility to powdery mildew of strawberry, indicating susceptibility to that disease in the progeny of both families. Although the cultivar 'Segal' is known to have high breeding value for that trait (significantly negative, that is, favourable values of the GCA effects), when it is crossed with the cultivar 'Vicoda' or 'Pegasus', the interactive effect of the parents becomes apparent in the progeny, resulting in an increased susceptibility to that disease in comparison with either parent.

Many hybrid families had statistically significant values of the SCA effects for such traits as fruit ripening time, marketable yield and fruit size. Significantly positive values of the SCA effects for fruit ripening time were found for eight families: 'Pandora' x 'Filon', 'Pandora' x 'Sophie', 'Vicoda' x 'Pegasus', 'Vicoda' x 'Marmolada', 'Vicoda' x 'Sophie', 'Vikat' x 'Elkat', 'Marmolada' x 'Segal' and 'Filon' x 'Camarosa'. This means that the fruits of the hybrids belonging to these families ripen later than the fruits of the progenies of the other hybrid families. Also statistically significant, but carrying a negative sign, were the SCA effects for fruit ripening time obtained for seven families: 'Pandora' x 'Vicoda', 'Pandora' x 'Vikat', 'Vicoda' x 'Vikat', 'Vicoda' x 'Camarosa', 'Pegasus' x 'Filon', 'Marmolada' x 'Filon' and 'Segal' x 'Sophie'. For the progenies of these families, the earlier ripening time in comparison with the previously listed hybrid families is a consequence of the effect of interaction between the parents because four of the listed parental genotypes ('Pandora', 'Vicoda', 'Vikat' and 'Sophie') are known to be of a high breeding value for late fruit ripening time (Żurawicz et al., 2006).

Three values of the SCA effects, significantly different from zero, were obtained for marketable fruit yield. For two families ('Pandora' x 'Filon' and 'Vikat' x 'Marmolada') these effects were greater than zero; therefore one should expect the progenies of these families to yield more abundantly than those of the other families. Negative values for that trait were shown by the SCA effects for the family 'Pandora' x 'Sophie', which means that the hybrids belonging to that family will not be very productive.

Eight families showed significantly positive SCA effects for fruit size at least in one of the two years of the experiment. One should therefore expect that the progenies of those families will produce large fruits. The families were: 'Pandora' x 'Vikat', 'Pandora' x 'Elkat', 'Pandora' x 'Marmolada', 'Vicoda' x 'Segal', 'Vicoda' x 'Camarosa', 'Marmolada' x 'Camarosa', 'Segal' x 'Camarosa' and 'Sophie' x 'Camarosa'. On the other hand, numerous hybrids producing small fruits should be expected among the following families: 'Pandora' x 'Camarosa', 'Vicoda' x 'Sophie', 'Elkat' x 'Segal' and 'Filon' x 'Camarosa', for which the values of the SCA effects for fruit size were significantly negative.

Only for one hybrid family ('Vicoda' x 'Elkat'), and only in one year (2002), a statistically significant SCA effect with a positive value was obtained for fruit susceptibility to grey mould, which means that the fruits of that family's progeny will become more affected by grey mould in comparison with the other hybrid families.

CONCLUSIONS

1. In the inheritance by strawberry of such traits as: fruit ripening time, marketable fruit yield and its quality, and plant susceptibility to leaf diseases, both additive and non-additive genetic effects are important. The greatest contribution of additive effects to total genetic effects was found in the inheritance of fruit ripening time. In the genetic affecting of the other traits, significant role is played by both additive and non-additive effects.
2. In the environmental conditions of central Poland, the strawberry cultivars involved in the study were found to differ in terms of their usefulness for development of modern, desired cultivars.
3. Among the parental forms under assessment, the greatest usefulness for breeding late cultivars was shown by 'Pandora', 'Vicoda', 'Vikat' and 'Sophie'. However, 'Pandora' and 'Vikat' can also contribute to a reduction in fruit size in their progeny (signifycantly negative GCA effects). In addition, 'Pandora' passes on to its progeny low susceptibility of fruit to grey mould, but also sensitivity to such leaf diseases as white leaf spot and leaf scorch.
4. The cultivars 'Segal' and 'Camarosa' appear to be very useful for breeding large-fruited cultivars

with a relatively early fruit ripening time. Moreover, the cultivar ‘Segal’ is a donor of low susceptibility to powdery mildew.

REFERENCES

Anido F.L., Cravero Y., Asprelli P., Firpo T., García S.M., Cointry E. 2004. Heterotic patterns in hybrids involving cultivar-groups of summer squash, *Cucurbita pepo* L. EUPHYTICA 135: 355-360.

Baker R.J. 1978. Issues in diallel analysis. CROP SCIENCE 18: 533-536

Boros L. 2003. Ocena zdolności kombinacyjnej kilku cech użytkowych grochu siewnego (*Pisum sativum* L.). BIUL. INST. HOD. AKLIM. ROŚL. 226/227: 457-462.

Bourion V., Fouilloux G., Le Signor C. Lejeune-Hénaut I. 2002. Genetic studies of selection criteria for productive and stable peas. EUPHYTICA 127: 261-273.

Cho Y., Scott R.A. 2000. Combining ability of seed vigor and seed yield in soybean. EUPHYTICA 112: 145-150.

Cilas C., Bouharmont P., Boccara M., Eskes A.B., Baradat Ph. 1998. Prediction of genetic value for coffee production in *Coffea arabica* from a half-diallel with lines and hybrids. EUPHYTICA 104: 49-59.

Daubeny H.A. 1961. Powdery mildew resistance in strawberry progenies. CAN. J. PLANT SCI. 41: 239-243.

Dias L.A.S., Kageyama P.Y. 1997. Multivariate genetic divergence and hybrid performance of cacao (*Theobroma cacao* L.). BRAZ. J. GENET. 20: 63-70.

Dobek A., Kaczmarek Z., Kiełczewska A., Łuczkiewicz T. 1977. Podstawy i założenia analizy krzyżówek diallelicznych. Część I. Analiza wariancji. VII Coll. Agrobiometr., pp. 332-353.

Garretsen F., Keuls M. 1978. A general method for the analysis of genetic variation in complete and incomplete diallels and North Carolina II (NC II) designs.. Part II. Procedures and general formulas for the fixed model. EUPHYTICA 27: 49-68.

Górczyński J., Mądry W. 1983. Computer program DIALLEL. (unpublished).

Griffing B., 1956a. A generalised treatments of diallel crosses in quantitative inheritance. HEREDITY 10: 31-50.

Griffing B., 1956b. Concept of general and specific combining ability in relation to diallel crossing systems. AUSTR. J. BIOL. SCI. 9: 463-493.

Hortyński J.A., 1987. Dziedziczenie niektórych cech ilościowych truskawki (*Fragaria x ananassa* Duch.). Metody i problemy oszacowań. Praca hab. Wyd. AR Lublin, 98 p.

Hsu C.S., Watkins R., Bolton A.T., Spangelo L.P.S. 1969. Inheritance of resistance to powdery mildew in the cultivated strawberry. CAN. J. GEN. CYT. 11: 426-438.

Lagunes-Espinoza L.C., Huyghe C. Papineau J. 2003. Genetic inheritance of proportion of pod walls and other yield components in white lupin. EUPHYTICA 131: 305-311.

León L., Martín L.M., Rallo L. 2004. Phenotypic correlations among agronomic traits in olive progenies. J. AMER. SOC. HORT. SCI. 129: 271-276.

López-Sese A.L., Staub J. 2002. Combining ability analysis of yield components in cucumber. J. AMER. SOC. HORT. SCI. 127: 931-937.

MacLachlan J. B. 1978. Data on the inheritance of resistance to powdery mildew in the cultivated strawberry. SCI. HORT. 8: 43-49.

Mądry W., Ubysz-Borucka L. 1982. Biometryczna analiza zdolności kombinacyjnej w niekompletnym układzie diallel cross. Cz. I. Model stały dla cech ilościowych. ROCZ. NAUK ROLN. Ser. A, 105: 9-27.

McNicol R.J., Gooding H.J. 1979. Assessment of strawberry clones and seedlings for resistance to *Sphaerotheca macularis*. HORT. RES. 19: 35-41.

Mwanga R.O.M., Yencho G.C., Moyer J.W. 2002. Diallel analysis of sweet potatoes for resistance to sweet potato virus disease. EUPHYTICA 128: 237-248.

Ray I.M., Segovia-Lerma A., Murray L.W., Townsend M.S. 2003. Heterosis and AFLP marker diversity among nine alfalfa germplasms. GENOME 46: 51-58.

Sherman W.B., Janick J., Erickson H.T., 1967. Inheritance of fruit size in strawberry. PROC. AMER. SOC. HORT. SCI. 89: 309-317.

Simpson D.W., Sharp D.S., 1988. The inheritance of fruit yield and stolon production in everbearing strawberries. EUPHYTICA 38: 65-74.

Zhang Y., Kang M.S. 1997. DIALLEL-SAS: A SAS program for Griffing's diallel analyses. AGRON. J. 89: 176-182.

Żurawicz E. 1990. Odziedziczalność najważniejszych cech użytkowych truskawki (*Fragaria x ananassa* Duch.). Praca hab., ISK Skierniewice, 58 p.

Żurawicz E. 2005. Odmiany. In: Żurawicz E. (ed.), Truskawka i poziomka. PWRiL, Warszawa, pp. 34-66.

Żurawicz E., Masny A., Mądry W. 2006. Usefulness of selected strawberry (*Fragaria x ananassa*) genotypes for breeding late ripening cultivars. ACTA HORTIC. 708: 501-505.

Żurawicz E., Mądry W., Urlich M., 1995. Breeding value of several strawberry cultivars and clones. GARTENBAUWISSENSCHAFT 60: 115-118.

ZDOLNOŚĆ KOMBINACYJNA ŚREDNIO I PÓŹNO DOJRZEWAJĄCYCH ODMIAN TRUSKAWKI DLA NAJWAŻNIEJSZYCH CECH UŻYTKOWYCH

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STRESZCZENIE

Przedmiotem badań było potomstwo 10 odmian truskawki średnio i późno dojrzewających (‘Pandora’, ‘Vicoda’, ‘Vikat’, ‘Pegasus’, ‘Elkat’, ‘Marmolada’, ‘Filon’, ‘Segal’, ‘Sophie’ i ‘Camarosa’), skrzyżowanych w roku 1999 w układzie diallelicznym kompletnym według IV metody Griffinga. W latach 2001-2002 wykonano indywidualną ocenę 2700 roślin potomstwa diallelicznego pod względem takich cech, jak: pokrój roślin, siła wzrostu, termin dojrzewania owoców, plon handlowy owoców, masa owocu, podatność owoców na szarą pleśń, a także podatność roślin na białą i czerwoną plamistość liści oraz mączniaka prawdziwego truskawki. Uzyskane dane opracowano statystycznie z użyciem analizy wariancji według stałego modelu Griffinga oraz testu t-Bonferroniego.

Stwierdzono istotne zróżnicowanie efektów ogólnej (GCA) i specyficznej (SCA) zdolności kombinacyjnej dla większości cech, co wskazuje na duże znaczenie obu rodzajów efektów w genetycznym uwarunkowaniu tych cech u potomstwa. Na podstawie ocen efektów GCA stwierdzono, że spośród ocenianych odmian rodzicielskich, największą przydatność do hodowli odmian późnych wykazały ‘Pandora’, ‘Vicoda’, ‘Vikat’ i ‘Sophie’. Jednakże ‘Pandora’ i ‘Vikat’ mogą przyczyniać się jednocześnie do obniżenia wielkości owoców u potomstwa. ‘Pandora’ przekazywała potomstwu małą podatność na szarą pleśń owoców, ale też dużą podatność na dwie choroby liści, to jest białą i czerwoną plamistość. Odmiany ‘Segal’ i ‘Camarosa’ wykazują dużą przydatność do hodowli odmian wielkoowocowych o stosunkowo wczesnym terminie dojrzewania. Ponadto odmiana ‘Segal’ jest donorem małej podatności na mączniaka prawdziwego truskawki.

Stwierdzono istotnie pozytywne efekty SCA dla plonu handlowego owoców u dwóch rodzin (‘Pandora’ x ‘Filon’ oraz ‘Vikat’ x ‘Marmolada’) dla wielkości owoców u ośmiu rodzin (‘Pandora’ x ‘Vikat’, ‘Pandora’ x ‘Elkat’, ‘Pandora’ x ‘Marmolada’, ‘Vicoda’ x ‘Segal’, ‘Vicoda’ x ‘Camarosa’, ‘Marmolada’ x ‘Camarosa’, ‘Segal’ x ‘Camarosa’ oraz ‘Sophie’ x ‘Camarosa’), a także dla późnego terminu dojrzewania owoców u ośmiu rodzin (‘Pandora’ x ‘Filon’, ‘Pandora’ x ‘Sophie’, ‘Vicoda’ x ‘Pegasus’, ‘Vicoda’ x ‘Marmolada’, ‘Vicoda’ x ‘Sophie’, ‘Vikat’ x ‘Elkat’, ‘Marmolada’ x ‘Segal’ i ‘Filon’ x ‘Camarosa’).

Słowa kluczowe: truskawka, ogólna zdolność kombinacyjna, specyficzna zdolność kombinacyjna, forma rodzicielska