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COMBINING ABILITY ANALYSIS OF FRUIT YIELD AND FRUIT QUALITY IN EVER-BEARING STRAWBERRY CULTIVARS USING AN INCOMPLETE DIALLEL CROSS DESIGN

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A B S T R A C T

Eight strawberry genotypes (‘Selva’, ‘Capitola’, ‘Yolo’, ‘Calypso’, ‘Mara des Bois’, ‘Geneva’, ‘Ostara’ and ‘Redgauntlet’) capable of late-summer and autumn fruiting were crossed in an incomplete 8 x 8 half-diallel design to produce 32 F_1 full-sib families in accordance with Griffing’s second method. Several quantitative traits pertaining to vegetative growth, blooming, fruiting and leaf diseases were observed in 1999 and 2000. Data on five of these traits are presented in this paper: marketable yield, fruit weight, susceptibility to grey mould, fruit colour and fruit firmness. Variance analyses of mean values from two years of observations were carried out according to Griffing’s fixed model for the second method. The general and specific combining ability effects (GCA and SCA) differed significantly for most of the traits, indicating that both additive and non-additive genetic effects played a role in the heritability of these traits. The cultivars with the highest breeding value were ‘Selva’ and ‘Capitola’. ‘Selva’ would be useful for improving yield, fruit size, and fruit firmness, and for reducing susceptibility to grey mould. ‘Capitola’ would be useful for improving fruit size, fruit colour and fruit firmness, and for reducing susceptibility to grey mould. The cultivars with the lowest breeding value were ‘Ostara’ and ‘Geneva’, which had poor GCA’s for most of the traits studied.

Key words: strawberry, yield, fruit quality, combining ability, incomplete diallel cross design

INTRODUCTION

In Poland, interest in the production and sale of dessert strawberries increases not only during the traditional ripening period, but also in early spring, late summer and autumn, when both domestic and imported strawberries are on the market. Domestic strawberry production is based on both traditional and ever-bearing cultivars. Ever-bearing cultivars are becoming more and more popular because they produce high-quality fruit from July to September with relatively low financial outlays. Unfortunately, the ever-bearing and day-neutral cultivars currently available are not very frost resistant and often fail to perform well in Poland. Therefore, systematic breeding programs are needed to develop summer- and autumn-bearing strawberry cultivars adapted to growing conditions in Poland.

Thorough knowledge of the breeding value of the parental genotypes is essential for the success of cross-fertilization programs. Breeding value can be deduced from the general and specific combining abilities for key desirable traits, as well as from the phenotypic and genotypic value of the parental forms for highly inheritable traits.

The general combining ability (GCA) of a given parent for a particular trait is defined as the mean value of the trait in the half-sibling progeny of this parent. It is a measure of the additive effect of genes for this trait, and reflects the general usefulness of the parent for producing new cultivars (Griffing, 1956ab). The method most commonly used to ensure the presence of a valuable trait level in hybrid progenies is crossing parents with high GSA's for that trait.

The specific combining ability (SCA) reflects how a particular pair of parents contributes to the presence of a particular trait level in the hybrid progeny. SCA is defined as interaction between a pair of the parents for a progeny trait. It is a measure of the non-additive effect of genes for the trait, such as dominance and epistasis. SCA can vary widely among pairs in a crossing program (Baker, 1978). To much variability in the SCA for a particular trait in the breeding material is undesirable. High variability increases the risk of obtaining progeny of worse agronomic value than would be predicted on the basis of the GCA's of the parents, although progenies of better value in respect to GCA of parents are sometimes obtained.

In order to determine which additive and non-additive genetic effects contribute most in genetic affecting a particular trait, the mean square quotient of GCA and SCA (s^2_{GCA}/s^2_{SCA}) is used in an 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 quotient s^2_{GCA}/s^2_{SCA} indicates that additive effects are more important than non-additive effects in determining the trait in the progenies under consideration.

In the strawberry, particular parents most often have high positive SCA's for only one single trait, which severely complicates breeding programs directed at improving several traits at the same time (Spangelo et al., 1971; Żurawicz, 1990). In a breeding program of Żurawicz et al. (1995), a high quotient s^2_{GCA}/s^2_{SCA} for fruit size but a low quotient for susceptibility to grey mould meant that the program had a high chance of producing cultivars with large fruits, but a low chance of producing cultivars which were less susceptible to grey mould. In strawberries, the quotient s^2_{GCA}/s^2_{SCA} for calyx-fruit separation was twice as high than for fruit firmness, which meant that it would be much easier to obtain cultivars with better calyx-fruit separation than cultivars with firmer fruits (Hortyński, 1987).

Simpson and Sharp (1988) found short-day and ever-bearing strawberry genotypes, for which GCA effects were significant in determining blooming and yield-related traits, whereas SCA effects played an important role in determining traits having to do with runner formation. Both GCA and SCA played an important role in the inheritance of resistance to powdery mildew (MacLachlan, 1978; McNicol and Gooding, 1979). In a diallel cross design with ten strawberry cultivars, GCA played a major role and SCA a minor role in determining growth characteristics such as the weight of the root system in seedlings (Fort and Shaw, 2000).

The best method for assessing GCA and SCA effects of parents is the diallel cross design, which is the method most often used in quantitative genetics and plant breeding (Hortyński, 1987; Żurawicz, 1990; Burrow and Coors, 1994; Pluta, 1994; 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 evaluate GCA and SCA effects for yield and fruit quality traits in eight ever-bearing strawberry cultivars using an incomplete diallel cross design (Griffing, 1956b).

MATERIAL AND METHODS

Plant material, mating design and field experiment

The experiments were carried out for the F_1 progeny of thirty-two crosses of eight ever-bearing strawberry genotypes. The parents were crossed in a diallel cross design using Griffing's second method (1956b; Dobek et al., 1977; Garretsen and Keuls, 1978; Mądry and Ubysz Borucka, 1982). Twenty-six of the crosses were crosses between parents, and six were inbred crosses. The crossing scheme is presented in Table 1.

The parents evaluated were 'Ostara' from the Netherlands; 'Redgauntlet' and 'Calypso' from the United Kingdom; 'Mara des Bois' from France; and 'Selva', 'Capitola', 'Yolo' and 'Geneva' from the United States. All were capable of cropping twice during the summer-autumn bearing period. The cultivars varied widely in terms of their morphological and cultural characteristics, as well as in terms of their adaptation to growing conditions in Poland.

The parents were crossed in the field in the spring of 1997. Seedlings were raised in a greenhouse during the winter of 1997-98. For the main part of the experiment, seedlings were selected at random from among the hybrid progeny. In the spring of 1998, the field experiment was set up at the

T a b l e 1. Layout of the incomplete diallel cross design based on the Griffing's second method for eight ever-bearing strawberry cultivars

♂ ♀	Ostara	Selva	Geneva	Mara des Bois	Capitola	Yolo	Calypso	Redgauntlet
Ostara	-	x	x	x	x	x	x	X
Selva		x	x	-	x	x	x	X
Geneva			x	x	x	x	x	X
Mara des Bois				x	x	x	x	X
Capitola					x	-	x	X
Yolo						x	x	X
Calypso							x	X
Redgauntlet								-

+ (-) indicates that progeny was (was not) obtained in a given cross combination

Pomological Orchard of the Institute of Pomology and Floriculture in Skierniewice, central Poland. The strawberries were planted 0.4 × 1.0 m apart in a randomized block design with four replicates of fifteen plants each. The experimental area was surrounded on all sides by a protective strip consisting of extra seedlings not needed for the experiment.

All maintenance procedures during the vegetative period were carried out in accordance with recommendations for commercial plantations. Irrigation was carried out as needed. Plants were covered for the winter with agro-cloth, which was left in place until the second half of March. Flower heads were continuously removed until June 1, after which they were left in place to produce fruit in the summer and autumn. The first harvest was completed before the first frost, which occurred on October 6 in 1999, and on September 25 in 2000. Even though each plot contained the same number of plants, observations were carried out only on those plants which cropped a second time in a given year. That is why the number of plants observed varied from plot to plot, generally ranging from 10 to 15.

The main part of the experiment was carried out in 1999 and 2000. Various morphological and cultural traits were quantitatively evaluated in 1920 seedlings from the 32 hybrid families. The analysis presented in this paper was conducted for the five following traits:

1) marketable fruit yield per plant;
2) mean fruit weight;
3) susceptibility to grey mould (*Botrytis cinerea*);
4) fruit colour;
5) fruit firmness.

Further information on how and when these traits were evaluated is presented in Table 2.

Statistical analysis

Two-year means were calculated for each plant over the two year observation period. These means were more reliable than data from each year separately, and were therefore taken for statistical analysis.

Table 2. Assessment of traits in diallel hybrid progeny of ever-bearing strawberry

Traits under observation	Years of study (assessment period)	Trait definition	Scale
Marketable fruit yield per plant	1999-2000 (Jul-Oct)	weight of all healthy fruits	grams
Fruit mean weight	1999-2000 (Jul-Oct)	mean weight of a healthy fruit	grams
Susceptibility to grey mould	1999-2000 (Jul-Oct)	proportion of rotten fruit	percentage
Fruit colour	1999-2000 (Jul-Oct)	scale from 0 to 5	0 – very light 5 – very dark
Fruit firmness	1999-2000 (Jul-Oct)	scale from 0 to 5	0 – very soft 5 – very firm

The means for each trait and for each plot were subjected to preliminary analysis of variance in accordance with the model for hybrid families in the randomized block design. Because the means for individual traits differed significantly among hybrids, they were subjected to the analysis of variance for an incomplete diallel design using Griffing's fixed model in the second method. Statistical analysis was carried out using algorithms developed by Garretsen and Keuls (1978), and Mądry and Ubysz-Borucka (1982).

Griffing's fixed model for the second method is presented below (Griffing, 1956b; Mądry and Ubysz-Borucka, 1982):

$$\bar{y}_{ij} = m + g_i + g_j + s_{ij} + \bar{e}_{ij} \quad (1)$$

($i,j = 1, 2..., p; p$ 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 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 mean error of the (i,j)-th hybrid progeny.

For the parameters of the model 1 in the incomplete diallel cross design, the following assumptions were made (Garretsen and Keuls, 1978):

$$\sum_{i=1}^{p} N_i g_i = 0 \quad (N_i \text{ is the number of hybrids for the } i\text{-th parent})$$

$$\sum_{j=1}^{p} s_{ij} + s_{ii} = 0 \quad \text{for } i=1,...,p \qquad (2)$$

Summation of the SCA effects in the equation 2 pertains to those *j* indices of parents for which a cross combination with the *i*-th parent was obtained. This sum includes s_{ii} effects only for the inbred crosses obtained. Because of the incomplete diallel cross design, the SCA effects for the missing *i,j*-th cross combinations were assumed to be zero.

The GCA and SCA effects for each trait were estimated and analyses of their significance were made using the analysis of variance.

A detailed analysis of the significance of the GCA and SCA effects was carried out using a procedure 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 parents.

All calculations of the GCA and SCA effects estimating, 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, unpublished).

RESULTS AND DISCUSSION

The analyses of variance for the five traits studied are presented in Table 3.

GCA effects for all five traits varied significantly among the parents. For mean fruit weight, susceptibility to rotting, fruit colour and fruit firmness, GCA effects were significant at $\alpha<0.01$ level. For marketable fruit yield, GCA effects were significant at $\alpha<0.05$ level. GCA therefore plays an important role in determining these traits.

The SCA effects also played an important role in affecting most of these traits. For marketable fruit yield, mean fruit weight, susceptibility to rotting, and fruit firmness, SCA effects were significant at $\alpha<0.01$ level. For fruit colour, SCA effects were not significant.

The quotients of the mean squares of the GCA and SCA effects ranged from 0.84 to 15.01. This means that the relative contributions of additive and non-additive effects varied widely from trait to trait. The highest quotients were 15.01 for fruit firmness and 9.34 for fruit weight, which means that additive effects are predominant in genetic affecting these traits. Other researchers have reported that fruit size in strawberries is highly inheritable (Comstock et al., 1958; Watkins et al., 1970; Spangelo et al., 1971; and Hortyński, 1987). For susceptibility to grey mould, the quotient s^2_{GCA}/s^2_{SCA} was 5.83. For marketable

Table 3. Analyses of variance for five traits using model of Griffing's second method in an incomplete diallel cross design for eight ever-bearing strawberry cultivars

Source of variability	Degrees of freedom	Mean squares				
		marketable yield [g]	mean fruit weight [g]	susceptibility to grey mould [%]	fruit colour	fruit firmness
GCA	7	7090.96*	3.165 **	70.17 **	0.0461**	0.7173**
SCA	24	8546.18**	0.339 **	12.04 **	0.0129 [ni]	0.0478**
Random error	93	004.66	0.096	3.60	0.0105	0.0136
s^2_{GCA}/s^2_{SCA}		0.83	9.34	5.83	++	15.01

**significant differences in effects at α = 0.01
*significant differences in effects at α = 0.05
[ni] differences in effects not significant at α = 0.05

++the quotient s^2_{GCA}/s^2_{SCA} was not calculated because of not significant differences in the SCA effects

Table 4. Estimates of GCA effects of ever-bearing strawberry cultivars for yield and fruit quality traits

Cultivar	Marketable fruit yield [g]		Mean fruit weight [g]		Susceptibility to grey mould [%]		Fruit colour [rating scale]		Fruit firmness [rating scale]	
Ostara	4.91	ab	-1.24*	a	1.35	c	-0.19*	a	-0.65*	a
Selva	57.13*	b	0.79*	e	-2.16*	ab	0.05	b	0.17*	de
Geneva	-17.57	ab	0.11	c	4.63*	d	-0.01	b	-0.27*	b
Mara des Bois	13.92	ab	-0.28	bc	1.73*	cd	0.02	b	0.16*	de
Capitola	5.37	ab	0.64*	de	-4.15*	a	0.10*	b	0.27*	e
Yolo	-40.00	a	-0.42*	b	0.30	bc	0.03	b	0.04	cd
Calypso	-10.87	ab	0.08	bc	-1.77*	ab	-0.01	b	0.25*	e
Redgauntlet	-9.97	ab	0.18	cd	-0.13	bc	-0.01	b	-0.07	c
$SE(\hat{g}_i)$ x 2.80	45.33-58.49+		0.25-0.346		1.57-2.02		0.08-0.11		0.08-0.11	
$SE(\hat{g}_i - \hat{g}_j)$ x 2.80	68.63-88.62+		0.39-0.50		2.38-3.08		0.14-0.17		0.14-0.20	

$SE(\cdot)$ indicates standard error of the estimate of GCA effects or their difference
+because of the incomplete diallel design the range of different standard errors of GCA effects and their differences was given
*indicates the estimate of GCA effects significantly different from zero (positive and negative) based on the *t*-Bonferroni procedure at α = 0.05 ($t_{0.05/8\ Ve=93} = 2.80$)
The same letters at the estimates of GCA effects indicate not significant differences between them based on the *t*-Bonferroni procedure at α = 0.05 ($t_{0.05/8\ Ve=93} = 2.80$)

fruit yield, it was only 0.83, which means non-additive effects played a larger role than additive effects in the inheritance of yield. On the basis of the relative contributions of GCA and SCA effects for the traits examined in this experiment, it is far easier to breed for strawberries with large, firm, attractively coloured fruits than for cultivars with high yields or with reduced susceptibility to grey mould. This agrees with an earlier report that it is difficult to breed for reduced susceptibility to grey mould (Hondelmann, 1965).

If a particular cultivar has a high GCA effect for a trait with desirable high level, it means that the cultivar would be a valuable parental form in a breeding program designed to improve that trait. Conversely, if it has a low GCA effect for a trait with desirable low level, it would be also a good parental form in a breeding program designed to eradicate that trait. The estimates of the GCA effects for the parents and traits studied in this experiment are presented in Table 4.

For marketable yield, 'Selva' had the highest significantly positive GCA effect, which makes it a good parent to use when breeding for high yielding ever-bearing strawberry cultivars.

For mean fruit weight, the cultivars with the highest significantly positive GCA effects were 'Selva' and 'Capitola', which makes them highly useful parents for breeding cultivars which bear large fruit. On the other hand, 'Ostara' and 'Yolo' would be completely useless, because they have significantly negative GCA effects for fruit size.

For susceptibility to grey mould, the cultivars with the lowest GCA effects were 'Capitola', 'Calypso' and 'Selva'. These cultivars are useful for breeding. On the other hand, 'Geneva' and 'Mara des Bois' would be the least useful parents for transmitting low susceptibility to grey mould. It is extremely difficult to breed for resistance to grey mould because this trait is determined by many different genes. These genes affect various morphological, anatomical, physiological and chemical characteristics, which inhibit the development of the fungus (Hondelmann, 1965).

For fruit colour, the cultivar with the highest significantly positive GCA effect was 'Capitola', whereas the cultivar with the lowest significantly negative GCA effect was 'Ostara'. Of the cultivars studied, only 'Capitola' would be useful for breeding cultivars with dark red fruit.

For fruit firmness, the cultivars with the highest GCA effects were 'Capitola', 'Calypso', 'Selva' and 'Mara des Bois'. These cultivars would therefore be very useful for breeding cultivars with firm fruit, whereas 'Ostara' and 'Geneva' would be useless. Firmness is a desirable trait in strawberries, because it increases storability and reduces mechanical damage during harvest and transport. Firm strawberries also retain their texture during processing and freezing (Barritt, 1979).

Estimates of SCA effects for the parental pairs and traits studied in this experiment are listed in Table 5.

For marketable yield, three combinations had high positive SCA effects: 'Mara des Bois' x 'Calypso', T a b l e 5. Estimates of SCA effects of ever-bearing strawberry cultivars for yield and fruit quality traits

Cross combinations of parents	Marketable fruit yield [g]	Mean fruit weight [g]	Susceptibility to grey mould [%]	Fruit colour	Fruit firmness
Ostara x Selva	-97.54	-0.94*	-0.36	0.01	-0.61*
Ostara x Geneva	30.84	0.18	-4.59	-0.06	0.32
Ostara x Mara des Bois	49.79	0.27	-1.71	-0.01	0.05
Ostara x Capitola	85.13	0.07	2.51	-0.07	-0.01
Ostara x Yolo	-5.89	0.64	0.53	0.23	0.21
Ostara x Calypso	-6.48	0.27	2.10	-0.06	0.14
Ostara x Redgauntlet	-55.83	-0.50	1.52	-0.04	-0.11
Selva x self-pollination	35.34	-0.16	1.66	-0.04	0.05
Selva x Geneva	141.13*	0.65	-2.87	0.11	-0.02
Selva x Capitola	-18.01	0.39	-1.17	-0.03	0.14
Selva x Yolo	-107.75	-1.07*	6.94*	-0.04	0.10
Selva x Calypso	100.99	1.42*	-3.21	0.06	0.07
Selva x Redgauntlet	-89.50	-0.12	-2.64	-0.03	0.23
Geneva x self-pollination	-79.13	-0.15	-1.93	0.03	0.09
Geneva x Mara des Bois	-84.89	-0.39	-0.73	-0.12	0.05
Geneva x Capitola	147.47*	0.28	3.22	-0.01	-0.27
Geneva x Yolo	8.52	0.27	1.72	0.01	0.14
Geneva x Calypso	-64.67	-0.78	0.70	-0.03	-0.27
Geneva x Redgauntlet	-20.13	0.09	6.41*	0.04	-0.13
Mara des Bois x self-pollination	-96.81	-0.01	0.35	0.10	0.04
Mara des Bois x Capitola	19.38	-0.21	0.52	-0.02	-0.02
Mara des Bois x Yolo	-5.87	0.30	-1.19	0.16	0.22
Mara des Bois x Calypso	151.73*	0.11	6.28*	-0.26	-0.26
Mara des Bois x Redgauntlet	63.48	-0.06	-3.87	0.04	-0.11
Capitola x self-pollination	-52.96	-0.61	0.35	-0.04	-0.03
Capitola x Calypso	-54.54	0.13	-2.56	0.06	0.01
Capitola x Redgauntlet	-73.50	0.55	-3.23	0.15	0.21
Yolo x self-pollination	58.52	0.08	-1.12	-0.07	-0.28
Yolo x Calypso	-139.13*	0.03	-6.12	-0.10	0.09
Yolo x Redgauntlet	133.09	-0.33	0.34	-0.11	-0.19
Calypso x self-pollination	-15.14	-0.77	0.66	0.19	0.05
Calypso x Redgauntlet	42.39	0.36	1.48	-0.05	0.11
$SE(\hat{s}_{ij})$ x 3.25	135.7-61.4	0.78-0.91	4.71-5.59	0.26-0.29	0.29-0.36

*indicates SCA effects significantly different from zero (positive or negative) based on the *t*-Bonferroni procedure at $\alpha = 0.05$

($t_{0.05/32\ Ve=93} = 3.25$) $SE(\hat{s}_{ij})$ – standard error of the SCA effects estimates

'Geneva' x 'Capitola', and 'Selva' x 'Geneva'. One combination had a low negative SCA: 'Yolo' x 'Calypso'. The other combinations had SCA effects which did not significantly differ from zero.

For fruit weight, the only combination with a high positive SCA was 'Selva' x 'Calypso'. Two combinations had low negative SCA's: 'Ostara' x 'Selva' and 'Selva' x 'Yolo'.

For susceptibility to grey mould, three combinations had high positive SCA effects: 'Selva' x 'Yolo', 'Geneva' x 'Redgauntlet' and 'Mara des Bois' x 'Calypso'. A high positive SCA for this trait means that the parental forms are useless for breeding purposes.

For fruit firmness, one combination had a low negative SCA: 'Ostara' x 'Selva'.

For fruit colour, all combinations had SCA's which did not significantly differ from zero. Variance analysis had already shown that SCA effects for this trait did not significantly differ from each other (see Table 3).

CONCLUSIONS

The strawberry cultivars studied in this experiment differ in terms of their usefulness for breeding summer- and autumn-bearing strawberry cultivars adapted to growing conditions in central Poland. The investigated parents were all capable of cropping twice during the bearing period.

The cultivars with the highest breeding value were 'Selva' and 'Capitola'. 'Selva' would be useful for improving yield, fruit size, and fruit firmness, and for reducing susceptibility to grey mould. 'Capitola' would be useful for improving fruit size, fruit colour and fruit firmness, and for reducing susceptibility to grey mould.

The cultivars with the lowest breeding value were 'Ostara' and 'Geneva', which had poor GCA effects for most of the traits studied.

Two of the studied traits, fruit colour and fruit firmness were affected genetically mostly by additive effects but fruit yield was determined predominantly by non-additive genetic effects.

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.

Barritt B.H. 1979. Breeding strawberries for fruit firmness. J. AMER. SOC. HORT. SCI. 104: 663-665.

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.

Burrow M.D., Coors J.G. 1994. Diallel: A microcomputer program for the simulation and analysis of diallel crosses. AGRON. J. 86: 154-158.

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.

Comstock R.E., Kelleher T., Morrow E.B. 1958. Genetic variation in an asexual species of the garden strawberry. GENETICS 43: 634-646.

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. AGRO-BIOMETR: 332-353.

Fort S.B., Shaw D.V. 2000. Genetic analysis of strawberry root system traits in fumigated and non-fumigated soils. I. Inheritance patterns of strawberry root system characteristics. J. AMER. SOC. HORT. SCI. 125: 318-323.

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.

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.

Hondelmann W.H.J. 1965. Untersuchungen zur Ertragszuchtung bei der Gartenerdbeere (*Fragaria ananassa* Duch.). PFLANZENZUCHTUNG 54: 46-60.

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

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.

Pluta S. 1994. Analiza dialleliczna wybranych form rodzicielskich porzeczki czarnej (*Ribes nigrum* L.)

pod względem najważniejszych cech użytkowych. Ph.D. thesis, Inst. Sadow. Kwiac. Skierniewice, 63 p.

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.

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

Spangelo L.P.S., Watkins R., Hsu C.S., Fejer S.O. 1971. Combining ability analysis in the cultivated strawberry. CAN. J. PLANT SCI. 51: 377-383.

Ubysz-Borucka L., Mądry W., Muszyński S. 1985. Podstawy statystyczne genetyki cech ilościowych w hodowli roślin. In: H. Jakubczyk (ed.). Wyd. SGGW-AR, Warszawa.

Watkins R., Spangelo L.P.S., Bolton A.T. 1970. Genetic variance components in cultivated strawberry. CAN. J. GEN. CYT. 12: 52-59.

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.). Inst. Sadow. Kwiac. Skierniewice, 58 p.

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

ANALIZA ZDOLNOŚCI KOMBINACYJNEJ PLONU OWOCÓW I CECH JEGO JAKOŚCI DLA ODMIAN TRUSKAWKI POWTARZAJĄCEJ OWOCOWANIE NA PODSTAWIE NIEKOMPLETNEGO UKŁADU KRZYŻOWAŃ DIALLELICZNYCH

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S T R E S Z C Z E N I E

Przedmiotem badań było 8 genotypów truskawki zdolnych do powtórnego owocowania w okresie letnio-jesiennym (‘Selva’, ‘Capitola’, ‘Yolo’, ‘Calypso’, ‘Mara des Bois’, ‘Geneva’, ‘Ostara’ i ‘Redgauntlet’). Genotypy te skrzyżowano w niekompletnym układzie diallelicznym według II metody Griffinga, w wyniku którego otrzymano 32 rodziny mieszańców. W latach 1999-2000 prowadzono ocenę wielu cech ilościowych uwzględniających wzrost wegetatywny roślin, kwitnienie, owocowanie oraz porażenie przez choroby liści. W tej publikacji zamieszczono tylko pięć cech: plon handlowy, masę owoców, ich porażenie przez szarą pleśń, a także barwę i jędrność owoców. Analizę wariancji według II metody Griffinga w modelu stałym wykonano na podstawie średnich z dwóch lat obserwacji. Stwierdzono istotne zróżnicowanie efektów ogólnej (GCA) i specyficznej (SCA) zdolności kombinacyjnej dla większości cech, co wskazuje na duże znaczenie obu rodzajów efektów (addytywnych i nieaddytywnych) w warunkowaniu tych cech u potomstwa. ‘Selva’ i ‘Capitola’, odznaczające się pozytywnymi efektami GCA dla większości cech, wykazują największą przydatność jako formy rodzicielskie w hodowli ukierunkowanej na otrzymanie odmian truskawki „dwukrotnego owocowania”. Najmniej przydatne do hodowli są natomiast ‘Ostara’ i ‘Selva’.

Słowa kluczowe: truskawka, plonowanie, jakość owoców, zdolność kombinacyjna