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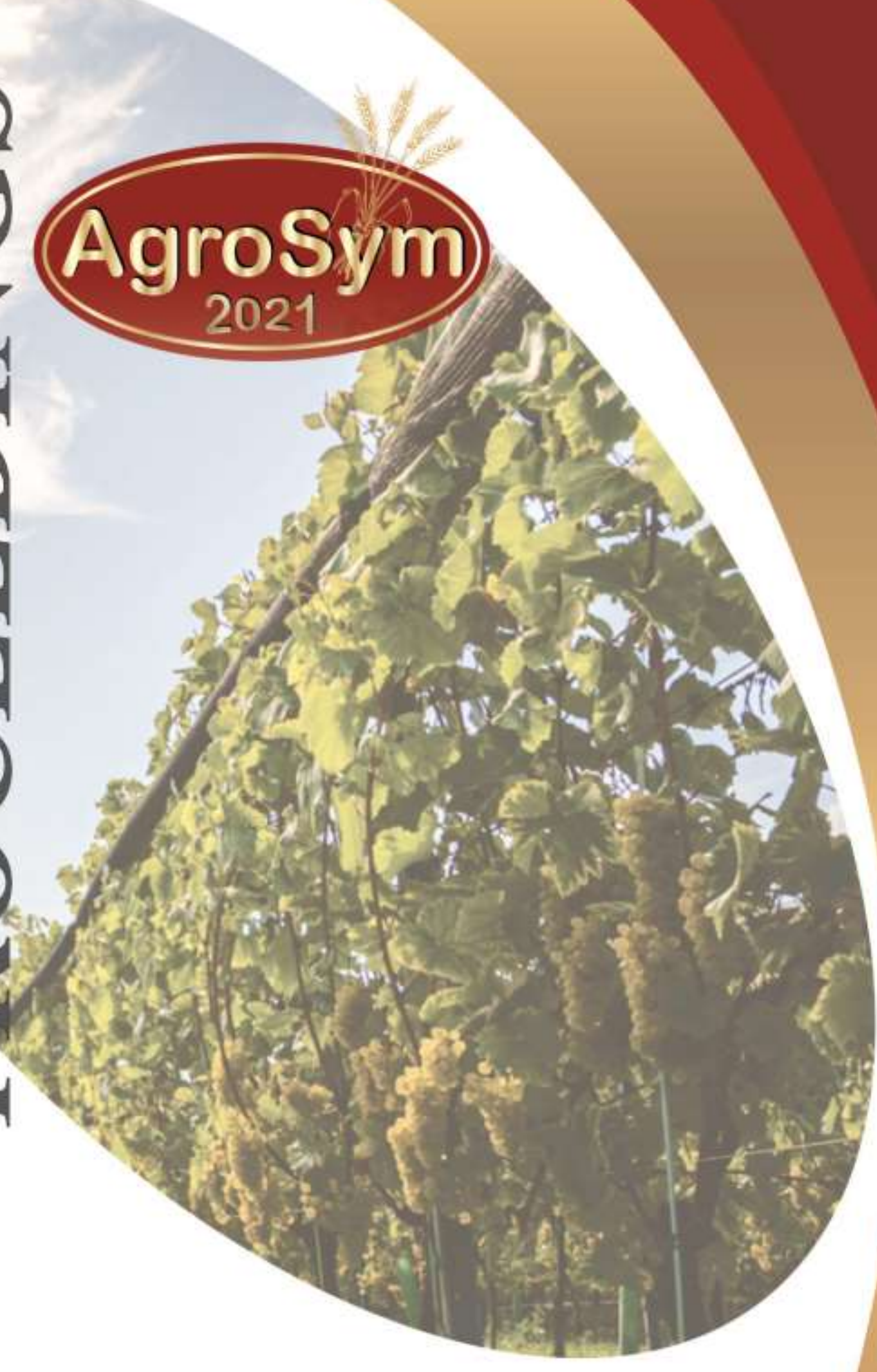

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GENERAL COMBINING ABILITY AND HETEROSIS OF SEX EXPRESSION TRAITS IN MELON

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Abstract

Melon is an annual, cross-pollinated species belonging to the family of *Cucurbitaceae*. Melon plants are usually monoecious: male and female flowers develop on one plant, but most commercial varieties and hybrids are andromonoecious, and on their plants develop male and hermaphrodite flowers. On melon plants, male flowers appear first, and then develop flowers with female reproductive organs. In this experiment, eight melon genotypes (parents), of which four were monoecious (Sesame, ED-3, ED-4, Pobeditel), and four andromonoecious (Chinese muskmelon, Anannas, Honey dew, A2-3lb), and their 20 hybrids (monoecious) were used. The experiment was conducted in Smederevska Palanka, during two vegetative seasons. Seven characteristics related to sex expression were observed. The aim was to determine the parents with the best general combining abilities (GCA) and to determine the heterosis in their hybrids for all seven observed traits. Negative heterosis for the trait period from sowing to the emergence of the first perfect/pistillate flower was recorded in 16 of 20 genotypes. A reduction of the period between the appearance of male (positive heterosis) and perfect/pistillate flowers on plants (negative heterosis) was found in 12 hybrid combinations. It was found that in as many as 17 hybrid combinations, the fruits ripen earlier than their parents. All eight observed parental genotypes showed significant GCA values for most of the observed traits. The results showed that the Sesame was the best general combiner, and represented a potential source of the desired alleles required for the melon breeding programs.

Keywords: *Cucumis melo L., monoecious, andromonoecious, hybrid, flowering.*

Introduction

Melon is an economically important, annual, cross-pollinated species belonging to the family of *Cucurbitaceae*. Melon (*Cucumis melo* L.) is the most diverse species of the genus *Cucumis*, and besides of a rich diversity of shapes and sizes of fruits, there is great variability in the morphology of the flower (Zhang et al., 2014).

Sexual reproduction is considered a turning point in the evolution of plant species (Rodriguez-Granados et al., 2016). Flower plays a major role in ensuring the continuation of the species in flowering plants. The flower, as a most important reproductive organ of the plant, is the least susceptible to changes under the influence of the external environment. The classification of flowering plants used today is, for this reason, based on parts of flowers or reproductive organs (Barret, 2010).

In order to increase the intensity of crossbreeding, plants have developed a number of different mechanisms to encourage sex determination, a process in which flowers become male or female.

In the majority of angiosperm species hermaphrodite flowers are formed on the plants, in which the male and female reproductive organs are formed within the same flower. Approximately 10% of angiosperm species develop unisexual flowers, flowers with only male or only female reproductive organs (Ming et al., 2011). Melon is especially interesting because of the biology of its flower. Three types of flowers can develop on melon plants: male - staminate, female - pistillate and hermaphrodite - perfect (Pitrat, 2008). Melon wild relatives are monoecious - male and female flowers are formed on the same plant, while about 70% of all commercial melon varieties and hybrids are andromonoecious - male and hermaphrodite flowers occurred on the same plant (Abdelmohsin and Pitrat, 2008). On melon plants, male flowers develop first, on the main stem, and on the first three nodes of side branches are formed flowers with female reproductive organs (Rodriguez-Granados et al., 2016).

Before choosing parental lines, it is very important to determine GCA and heterosis in the pre-breeding programs for all observed traits in all lines that are planned to be included in further hybridization (Olfati et al., 2012). General combining abilities for the observed characteristic are an important biometric parameter in determining the contribution of one parent to the positive or negative heterosis of his progeny (Fareghi et al., 2018). Heterosis is an agricultural phenomenon where, for some observed traits, hybrid genotypes demonstrated the phenotypic superiority compared to their parents (Yilmaz and Sari, 2012).

Many researches have studied and reported heterosis in melon for earliness (Abou Kamer et al., 2015; Choudhary et al., 2018), fruit yield (Abou Kamer et al., 2015; Selim, 2019), number of fruit per plant (Abou Kamer et al., 2015). Also, the combining ability for all this important traits in melon breeding programs was often determined by many researchers and breeders (Shashikumar et al., 2016). The aim of this study was to single out parental genotypes with the best general combining abilities, and to determine the heterosis of 20 hybrids for all seven observed traits.

Materials and methods

Four monoecious (Sesame, ED-3, ED-4, Pobeditel) and four andromonoecious (Chinese muskmelon, Anannas, Honey dew, A2-3lb) melon genotypes and their 20 hybrids were used as material in this study. Experiment was set up in Smederevska Palanka in Serbia (latitude 44°21'22.46"N, longitude 20°57'08.97"E, elevation 101 m), during two growing seasons (2011 and 2012). Melon plants were grown in clay pots (diameter 10 cm), and at the stage of 5-7 leaves they were transplanted to an open field. The trial was organized in three replications using complete randomized block design of 28 plots in one block (one plot for each genotype). Each plot consisted of 10 plants with a 150 cm distance between rows, and a 100 cm distance between plants. The soil type at this location is vertisol. Seven characteristics of sex expression in melon were monitored, measured and analyzed: total number of flowers per plant, number of pistillate/perfect flowers per plant, number of staminate flowers per plant, number of fruits per plant, period from sowing to the appearance of the first perfect/pistillate flower (in days), period from sowing to the appearance of the first staminate flower (in days), and period from sowing to full fruit ripening (in days). The aim of this study was to single out parental genotypes with the best general combining abilities, and to determine the heterosis of 20 hybrids for all seven observed traits.

Determination of general combination abilities was performed by the M x N hybridization method (Table 1).

Table 1. A method for determining the GCA by MxN hybridization

Genotype	5	6	7	8	T_N
1	F_{15}	F_{16}	F_{17}	F_{18}	Σ
2	F_{25}	F_{26}	F_{27}	F_{28}	Σ
3	F_{35}	F_{36}	F_{37}	F_{38}	Σ
4	F_{45}	F_{46}	F_{47}	F_{48}	Σ
T_M	Σ	Σ	Σ	Σ	Σ

General average: $G_M = \frac{\sum T_M}{NxM}$

For parents 1, 2, 3, 4: $GCA = \left(\frac{T_N}{M}\right) - G_M$

For parents 5, 6, 7, 8: $GCA = \left(\frac{T_M}{N}\right) - G_M$

To determinate heterosis in broader sense, the following formula was used:

$$H = F_1 - \left(\frac{(P_1 - P_2)}{2}\right)$$

where F_1 is a mean value of F_1 generation, and P_1 a mean value of first parent, and P_2 a mean value of second parent. All the obtained results were statistically analyzed, using the Fisher's Least Significant Difference (LSD) test (Fisher, 1935).

Results and discussion

Based on the results for all 7 observed traits variety Sesame was single out as the best general combiner (Table 2).

Table 2. General combining ability for seven sex expression traits in melon

Genotype	Parent	A	B	C	D	E	F	G
Sesame	Mother	8.64	0.67	-0.67	-5.52	-1.91	-5.24	0.43
ED-3	Mother	-8.85	-0.15	0.15	2.93	0.25	1.21	-0.29
ED-4	Mother	-6.61	-1.09	1.09	3.80	2.40	2.87	-0.20
Pobeditel	Mother	6.82	0.57	-0.57	-1.21	-0.74	1.16	0.06
Chinese muskmelon	Father	-3.60	-0.80	0.80	1.21	0.86	0.47	-0.08
Anannas	Father	-1.53	0.30	-0.30	-1.62	-0.28	-4.63	-0.05
Honey dew	Father	-3.08	-0.51	0.51	1.24	0.73	3.90	0.05
A2-3lb	Father	8.21	1.01	-1.01	-0.83	-1.31	0.26	0.08
$lsd_{0.05}$		0.46	0.10	0.10	0.55	0.54	3.06	0.15
$lsd_{0.01}$		0.62	0.14	0.14	0.74	0.73	4.11	0.21

A – Total number of flowers per plant, **B** - number of pistillate/perfect flowers per plant, **C** - number of staminate flowers per plant, **D** - period from sowing to the appearance of the first perfect/pistillate flower (in days), **E** - period from sowing to the appearance of the first staminate flower (in days), **F** - period from sowing to full fruit ripening (in days), **G** - number of fruits per plant

For five of seven traits genotype ED-4 was singled out as the worst combiner with all negative GCA values. Beside Sesame, A2-3lb was excellent general combiner for trait number of pistillate/perfect flowers per plant, with a high significant value of GCA. Earliness is one of the important traits in melon breeding programs (Glala et al., 2010). Melon growers prefer high-yielding hybrids that will be placed on the market at a time when supply of market is still low and price is high (Duradundi et al., 2018). In order to produce early melon hybrids, it is necessary that pistillate or perfect flowers on mother plants and male flowers on father plants occurred as early as possible. As the best general combinators for this trait were single out the monoecious genotype Sesame and the andromonoecious genotype Anannas, and it may be recommended to cross these varieties in order to produce an early-growing hybrid. It was concluded that the best general combiner for breeding late-maturing hybrids is the variety Honey dew. For the trait number of fruits per plant, based on the results of GCA, best general combiner was Sesame, while genotypes ED-3 and ED-4 were single out as bad general combiner for this trait (Table 2). The estimates and direction of GCA for earliness, number of flowers with female reproductive organs, number of fruits per plant are similar with those obtained by Duradundi et al. (2018), and Shajari et al. (2021).

Table 3. Heterosis for seven sex expression traits in melon

Genotype	**A**	**B**	**C**	**D**	**E**	**F**	**G**
1 x 2	26.28	1.80	-1.80	-9.22	-3.08	0.31	0.20
1 x 4	14.86	1.87	-1.87	-5.67	0.56	-3.78	0.20
1 x 5	-10.61	-2.50	2.50	-4.78	1.81	-2.47	-0.15
1 x 6	4.19	1.00	-1.00	-4.06	5.36	-4.64	0.50
1 x 7	17.56	1.49	-1.49	-5.00	-6.86	-17.39	0.80
1 x 8	-3.17	-1.14	1.14	-1.78	3.28	-1.94	-0.25
2 x 4	2.09	1.54	-1.54	-0.33	6.56	-4.97	1.15
2 x 5	-12.33	-1.15	1.15	-0.11	4.03	-1.56	-0.10
2 x 6	4.86	4.28	-4.28	-2.56	2.36	-7.39	0.40
2 x 7	1.56	3.79	-3.79	0.22	-5.31	-14.92	0.25
2 x 8	-23.16	-1.16	1.16	-1.33	3.11	-0.03	-0.95
3 x 4	6.58	1.00	-1.00	-0.28	8.33	-4.25	-0.05
3 x 5	-15.22	-2.81	2.81	1.94	5.19	-3.00	-0.40
3 x 6	-10.42	0.89	-0.89	0.94	8.25	-3.72	0.30
3 x 7	8.22	0.99	-0.99	-0.33	-2.36	-9.80	0.10
3 x 8	-11.83	1.99	-1.99	1.11	5.72	2.64	-1.05
4 x 5	-5.92	-0.02	0.02	-5.22	9.53	-1.42	-0.45
4 x 6	15.22	3.56	-3.56	-1.83	9.14	-3.97	0.20
4 x 7	11.53	3.39	-3.39	-2.94	-2.08	-14.94	0.45
4 x 8	5.53	1.80	-1.80	-8.33	3.67	-2.72	0.20
$lsd_{0.05}$	2.27	0.37	0.37	0.44	0.48	0.94	0.16
$lsd_{0.01}$	2.71	0.45	0.45	0.52	0.57	1.12	0.19

1 – Sesame, **2 –** ED-3, **3 –** ED-4, **4 –** Pobeditel, **5 –** Chinese muskmelon, **6 –** Anannas, **7 –** Honey dew, **8 –** A2-3lb
A – Total number of flowers per plant, **B** - number of pistillate/perfect flowers per plant, **C** - number of staminate flowers per plant, **D** - period from sowing to the appearance of the first perfect/pistillate flower (in days), **E** - period from sowing to the appearance of the first staminate flower (in days), **F** - period from sowing to full fruit ripening (in days), **G** - number of fruits per plant

On melon plants, male flowers are formed first, and then flowers with female reproductive organs. The more uniform time of their formation on the plant, the greater the possibility that fertilization and fruit formation will occur. Negative value of heterosis for the trait period from sowing to the appearance of the first perfect/pistillate flower represents decreasing of this period of F_1 generation compared to their parents, and was observed in 16 hybrids. Negative values of heterosis for the trait period from sowing to the appearance of the first perfect/pistillate flower and positive values of heterosis for the trait period from sowing to the appearance of the first staminate flower were recorded in 12 genotypes (Table 3). In these genotypes, an earlier appearance of flower with female reproductive organs and a later appearance of male flowers was occurred, compared to their parents, that is, a shortening of the period between the first male and the first pistillate/perfect flower on the plant. These results are similar with those obtained by (Yilmaz and Sari, 2012; Choudhary et al., 2018). Earliness is complex but important trait in melons. This trait is correlated with number of days to first female and first male flower, number of nodes to first female flower, days to first harvest, and negative values of heterosis for these traits are desirable (Duradundi et al., 2018). Seventeen of the twenty hybrids had a negative heterosis value for trait period from sowing to full fruit ripening (Table 3). The hybrid combinations Sesame x ED-3, ED-4 x Fiat, and ED-4 x A2-3lb were the only ones whose fruits matured later as compared to their parents. Regarding the trait number of pistillate/perfect flowers per plant, positive heterosis was recorded in 14 of 20 melon genotypes (Table 3). For this trait, the highest positive value of heterosis was observed in the combination ED-3 x Anannas, and the highest negative value of heterosis was observed in the ED-4 x Chinese muskmelon combination. On the plants of ED-4 x Chinese muskmelon were detected the largest decrease in the formation of flowers with female reproductive organs, and the highest increase in the formation of male flowers, compared to the parents.

Conclusion

Some of the primary objectives in melon breeding programs include earliness, high female reproductive organs flower to male flower ratio, high number of fruits per plant, high fruit yield per plant, etc. Hybrids often demonstrate superiority of some economically important traits compared to their parents (heterosis). All eight observed parental genotypes showed significant GCA values for most of the observed traits. From 8 studied genotypes monoecious variety Sesame, used in experiment as mother line, was single out with best combining abilities for all 7 observed traits. This genotype represented a potential source of the desired alleles required for the melon breeding programs. Combination of monoecious variety Sesame (mother) and andromonoecious variety Anannas (father) may be recommended for future production of an early-growing hybrid. A reduction of the period between the appearance of male (positive heterosis) and perfect/pistillate flowers on plants (negative heterosis) was found in 12 hybrid combinations. These results are of great importance for organization of further steps in melon breeding programs in our country.

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