The Asian and Australasian Journal of Plant Science and Biotechnology ©2012 Global Science Books

Heterosis in Fruit and Seed Characters of Muskmelon

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ABSTRACT

Two field experiments were conducted in the spring-summer seasons of 2008 and 2009 at the Newe Ya'ar Research Center (northern Israel), to examine heterosis in Galia-type muskmelon. The study includes three hybrid cultivars and their five parental cultivars/ accessions. The mean fruit yield and the mean seed yield per unit area of the hybrids were 57 and 35% higher than that of the maternal accessions and by 66 and 49% than that of the paternal accessions, respectively. Accordingly, heterosis values were highly significant (P = 0.01) for fruit yield and significant (P = 0.05) for seed yield. Superiority of the hybrids in fruit yield was mainly due to larger fruits rather than due to increased fruit number. Superiority of the hybrids in seed yield was about equally distributed between increased fruit number per unit area and by increased seed number per fruit. The hybrids showed significant advantages over their parental accessions in some fruit quality traits like uniform rind netting, fruit flesh width and small seed cavity. Germination percentage, germination speed and standard deviation of germination speed, in hybrids, were all close to paternal accessions values and significantly higher with respect to maternal accessions. The main conclusion of the present study is that heterosis is clearly evident in most characters of Galia-type muskmelon and there is a great advantage in growing these commercial muskmelon hybrids.

Keywords: *Cucumis melo*, Galia-type melon, heterozygosis, hybrid vigor

INTRODUCTION

The concept of heterosis or hybrid vigor is well known from early years of the last century (Schull 1908) in both the animal and plant kingdoms. Heterosis refers to the phenomenon by which a hybrid exhibits phenotypic characteristics superior to its parental lines/cultivars. This superiority is explained by three main hypotheses; dominance, overdominance and epistatic interactions. The genetic basis of heterosis may depend on the trait or cross, being one of the above hypotheses the major cause for a particular case. The dominance theory fits many cases and it is based mainly upon masking negative recessive genes existing in the parents, by the heterozygote status of the hybrid, and therefore is considered to be the contrasting phenomenon of inbreeding depression (Jones 1957; Xiao *et al*. 1995; Falconer and Mackay 1996). A series of review articles in the last decade demonstrates that the genetic basis of heterosis is still far from a definitive understanding (Birchler *et al*. 2003; Lippman and Zamir 2007; Springer and Stupar 2007). Heterosis can be quantified by measuring the superiority of the hybrid (F_1) over mid parents (H_1) or over the better parent (H_2) (Ghaderi and Lower 1978; Ghaderi and Lower 1979). In cucumber, heterosis has been documented from the early days of modern genetics nearly a century ago (Hayes and Jones 1916; Hutchins 1938). Hybrid cultivars of muskmelon have replaced in the last decades most of the open-pollinated cultivars in the "western-shipper" cantaloupe commercial group (Lippert and Hall 1972), as well as, in the honey dew group (Lester 1998). The reasons for this trend are: protection of proprietary lines, uniformity of fruit set and size, earliness of maturity, but primarily because of hybrid vigor and higher yield. Heterosis in melon was studied using exotic sources with a main emphasis on fruit and yield characteristics (Kitroongruang *et al*. 1992; Monforte *et al*. 2005; Eduardo *et al.* 2007; Luan *et al*. 2010). Study of heterosis in diverse genetic sources of melon using RAPD markers or agronomic traits may serve as an efficient tool in breeding programs (Garcia *et al*. 1998). However, in some cases like in Thai slicing melon (*Cucumis melo* L. var. conomon Makino), the performance of fruit characters of hybrids did not exceed those of the best parent values (Iathet and Piluek 2006).

The main purpose of the present study was to determine heterosis in Galia muskmelon, a relatively new commercial cultivar group. The research included fruit yield and fruit quality characters which were explored in earlier studies in other melon cultivar groups. However, the scope of the present study was expanded to include seed yield and seed quality traits which had not been previously studied.

MATERIALS AND METHODS

Two field experiments were conducted in the Newe ya'ar Research Center (northern Israel) in the spring-summer seasons of 2008 and 2009, in order to determine the existence of heterosis in fruit and seed characteristics of Galia-type muskmelons.

Genetic material

Three Galia-type hybrids and their five parental cultivars/lines were used in the present study. The parental genetic sources were as follows: a) 'Noy Yizre'el' (NY) – (P_1) an open-pollinated cultivar highly resistant to powdery mildew, derived by pedigree selection from the cross between the American old cantaloupe 'Seminol' and the 'Haogen' melon originating from Hungary (Karchi and Govers 1971); b) 'Krimka' (KR) – (P_2) a netted muskmelon cultivar originated from the Krym peninsula (Ukraine) in the Black Sea (Nunes-Palenius *et al*. 2006); c) Eshcolit (ES) – (P_3) a muskmelon line derived by selection for larger and sweeter fruit in the 'Krimka' cultivar; d) Freeman's Cucumber Noy Yizre'el (CNY) – (P_4) a muskmelon line derived from the cross between Freeman's cucumber melon having high field resistance to the viral disease CMV(Karchi *et al.* 1975) and Noy Yizre'el, using a backcross and pedigree selection program; e) Freeman's cucumber Krimka (CKR) – (P_5) a muskmelon line derived from the cross between Freeman's cucumber melon and Krimka using a backcross and pedigree selection breeding program. These five accessions were

Received: 23 February, 2012. Accepted: 5 November, 2012.

Original Research Paper

used as parents for the three hybrids (F_1) as follows: a) 'Galia' (GAL) – (P_1xP_2) a early yielding hybrid having a very sweet flesh (Karchi and Govers 1977); b) 'Arava' (ARA) – (P_1xP_3) a high yielding hybrid adapted to the southern semiarid area of Israel (Cohen *et al.* 2000); c) Gala (GLA) – (P_4xP_5) a high yielding hybrid with a small seed cavity and high field tolerance to CMV.

Experimental design and data collection

The five parental cultivars/lines and the three hybrids were directly seeded in the field on 10 April 2008 and on 12 April 2009. Each accession was grown on elevated beds in four replicates of 10 m^2 each, in a complete randomized block design. Two plants were grown per hill and the plant spacing was 50 cm between hills in the row and 2 m between bed centers (20 plants/10 m^2). Fruits were produced by controlled hand-pollination, using pistillate and staminate flowers from the same sub-plot. Fruits were harvested at full maturation (half-slip stage), and the fruit yield of each sub-plot was determined by counting and weighing all the mature fruits. Five representative fruits were selected from each sub plot in four harvests at 2-3 days intervals (20 fruits/sub-plot and 80 fruits/accession in total) for quality evaluation and for seed yield determination. Each of these fruits was weighed and evaluated for netting using a 0 -5 scale (0 = smooth fruit, 5 = Fully-netted fruit). The volume of these round fruits and the volume of the seed cavity were calculated by measuring the radius of each fruit and its seed cavity. The fruit flesh width was measured as well, and the total soluble solids (TSS) was determined in fruit juice using a digital refractometer. Seeds of each fruit were separately extracted. Dry seeds of each fruit were divided into two categories; fully developed and empty, counted and weighed. Seed yield index was calculated as seed yield per fruit (g)/fruit weight (kg). At this point, seeds of fruits from the same sub plots were pooled into a common seed lot and were stored at 10°C and 40-50% relative humidity. After 6 months of storage, four replicates of 50 seeds were taken from each seed lot for a standard germination test to determine germination percentage (after 7 days of incubation), germination rate (mean days to germination – MDG) and the standard deviation of MDG.

Statistical analysis

The data for the two years were very similar and therefore were pooled together for statistical analysis and their means are presented in the results and discussion section. All data were subjected to ANOVA and significant differences among accessions were determined by using the Duncan's multiple range test (P = 0.05). The two measurements of heterosis, i.e., superiority of F_1 over mid parents (H_1) and superiority of F_1 over the better parent (H_2), as well as the variances associated with the means of H_1 and H_2 were all calculated following formulas developed earlier for cucumbers (Ghaderi and Lower 1978).

RESULTS AND DISCUSSION

Fruit yield and yield components

The average fruit yield of the three Galia-type hybrids was 63% higher than the average fruit yield of their five parental accessions (**Table 1**). This increase in fruit yield was due to large difference in mean fruit weight (43%) and a smaller difference in fruit number per unit area (13%). The differences in fruit yield and fruit yield components among hybrids and their parental accessions is also well expressed by heterosis values of the mid-parents (H_1) or the best parent (H_2) (**Table 2**). Heretosis in fruit yield and fruit yield components was highest in GAL and lowest in ARA. A prerequisite for studying heterosis is to use parental accessions with a high degree of homozygosis. This goal was achieved in the present study by carrying out a series of controlled self-pollinations over several generations. All the five parental accessions used, were obtained after five or more generations of self-pollination, to meet this requirement for homozygosity. Under such circumstances the hybrids were heterozygous in almost all genes in which their parental accessions had different alleles. Theoretically, a character which is controlled by a single gene may not shows heterosis because the heterozygous hybrid has the phenotype of the dominant parental accession or a phenotype in-between the two parental accessions if there is partial or no dominance between the parental alleles. Thus, superiority of a hybrid over its parental lines, or heterosis, is relevant to quantitative, multiple-gene characters. Measurement of heterosis can be moderate by comparing hybrid and mid-parent values (H_1), or pedant, if superiority of the hybrid is measured in respect of the better parent value (H_2). Fruit yield and fruit yield components are quantitative characters, controlled by many genes, and are expected to show high degrees of heterosis. As expected, fruit yields of the three Galia-type hybrids were significantly higher than that of both their parents, based on higher mean fruit weight and to a lesser extent, on higher fruit numbers per unit area (**Tables 1, 2**). These data clearly demonstrate the advantage of using hybrid cultivars for melon fruit production, and confirm earlier findings in other melon groups (Foster 1967; Lippert and Hall 1972; Lester 1998; Luan *et al*. 2010).

Table 1 Fruit yield and yield components in five parental accessions and three hybrid cultivars of Galia-type muskmelons.

Accession/cultivar	Fruits/ 10 m^2	Mean fruit wt. (kg)	Fruit yield (kg/10 m^2)
Noy Yizre'el (NY) – P_1	33 c	1.22 c	40.3 d
Krimka (KR) – P_2	22 d	1.14 c	25.1 e
Galia (GAL) – P_1 x P_2	37 bc	1.79 a	66.2 ab
Eshcolit (ES) – P_3	44 a	1.25 c	55.0 c
Arava (ARA) – P_1 x P_3	38 b	1.57 b	59.7 b
C. Noy Yizre'el (CNY) – P_4	32 c	1.30 c	41.6 d
C. Krimka (CKR) – P_5	42 a	0.86 d	36.1 d
Gala (GLA) – P_4 x P_5	42 a	1.60 b	67.2 a

Statistics – ANOVA and Duncans' multiple range test (P = 0.05) for significant differences among accessions

Table 2 Heterosis (H) in three hybrid cultivars of Galia-type muskmelon.

Cultivar	Heterosis[z]	Fruits/ 10m^2	Mean fruit wt. (kg)	Fruit yield (kg/10 m^2)
Galia (GAL) – P_1 X P_2	H_1	34.5**	51.7**	102.4**
	H_2	12.1	46.7**	64.3**
Arava (ARA) – P_1 x P_3	H_1	0.0	27.1*	25.3*
	H_2	-13.6	25.6*	8.5
Gala (GLA) – P_4 x P_5	H_1	13.5	48.1**	73.0**
	H_2	0.0	23.1*	61.5**

[Z] $H_1 = 100 (F_1\text{-}M)/M$, $H_2 = 100 (F_1\text{-}P_1)/P_1$, where F_1 is the hybrid, M is the mean of both parents and P_1 is the value of the better parent
* Significant at (P = 0.05)
** Significant at (P = 0.01)

Table 3 Fruit quality characteristics in five parental accessions and three hybrid cultivars of Galia-type muskmelons.

Accession/cultivar	Rind netting (%)	Seed cavity volume/ fruit volume	Fruit flesh thickness (mm)	Total Soluble Solids (TSS)
Noy Yizre'el (NY) – P_1	16 c	0.142 bc	38 cd	12.5 a
Krimka (KR) – P_2	76 b	0.111 d	38 cd	9.5 b
Galia (GAL) – P_1 x P_2	92 a	0.112 d	45 a	11.6 a
Eshcolit (ES) – P_3	82 b	0.192 a	34 d	9.4 b
Arava (ARA) – P_1 x P_3	92 a	0.130 cd	40 bc	11.9 a
C. Noy Yizre'el (CNY) – P_4	24 c	0.149 b	39 b-d	12.5 a
C. Krimka (CKR) – P_5	96 a	0.113 d	35 d	9.4 b
Gala (GLA) – P_4 x P_5	98 a	0.116 d	43 ab	12.4 a

Statistics – ANOVA and Duncans' multiple range test (P = 0.05) for significant differences among accessions

Fruit quality characteristics

The three hybrid cultivars were superior to their parental accessions in some but not in all fruit quality traits (**Tables 3, 4**). The coverage of fruit rind by net was more complete and uniform in the hybrids, especially in GAL. The hybrid cultivars also have a thicker fruit flesh compared to the

Table 4 Heterosis (H) in three hybrid cultivars of Galia-type muskmelon.

Cultivar	Heterosis	Rind netting	Seed cavity volume/ fruit volume	Fruit flesh thickness (mm)	Total Soluble Solids (TSS)
Galia (GAL) – P_1 x P_2	H_1	100.0**	11.4*	18.4**	5.5
	H_2	21.1*	-0.9	18.4**	-7.2
Arava (ARA) – P_1 xP_3	H_1	87.8**	22.2**	11.1*	8.7
	H_2	12.2	8.4*	5.3	-4.8
Gala (GLA) – P_4 x P_5	H_1	63.3**	11.4*	16.2**	13.2*
	H_2	2.1	-2.7	10.3*	-0.8

[Z] $H_1 = 100 (F_1-M)/M$, $H_2 = 100 (F_1-P_1)/P_1$, where F_1 is the hybrid, M is the mean of both parents and P_1 is the value of the better parent
* Significant at (P = 0.05)
** Significant at (P = 0.01)

Table 5 Seed yield, seed yield components, seed yield index and empty seed percentage in five parental accessions and three hybrid cultivars of Galia-type muskmelon.

Accession/cultivar	Seed number/fruit	Mean seed wt. (mg)	Seed yield/fruit (g)	Seed yield/10 m^2 (g)	Seed yield index	Empty seeds (%)
Noy Yizre'el (NY) – P_1	425 d	38.7 a	16.4 b	541 b	13.4 a	8.2 c
Krimka (KR) – P_2	458 b-d	33.5 b	15.3 b	337 c	13.4 a	7.1 d
Galia (GAL) – P_1 x P_2	523 ab	36.7 ab	19.2 a	710 a	10.7 b	4.0 f
Eshcolit (ES) – P_3	464 b-d	34.8 ab	16.1 b	708 a	12.9 a	10.7 b
Arava (ARA) – P_1 x P_3	505 a-c	37.3 ab	18.8 a	714 a	12.0 ab	5.4 e
C. Noy yizre'el (CNY) – P_4	420 d	38.5 a	16.2 b	518 b	12.5 ab	9.2 c
C. Krimka (CKR) – P_5	447 cd	21.0 c	9.4 c	395 c	10.9 b	12.3 a
Gala (GLA) – P_4 x P_5	531 a	32.1 b	17.0 ab	714 a	10.6 b	4.0 f

Statistics – ANOVA and Duncans' multiple range test (P = 0.05) for significant differences among accessions

Table 6 Heterosis (H) in three hybrid cultivars of Galia-type muskmelon.

Cultivar	Heterosis	Seed number/fruit	Mean seed wt. (mg)	Seed yield/fruit (g)	Seed yield/10 m^2 (g)	Seed yield index	Empty seeds (%)
Galia (GAL) – P_1 X P_2	H_1	18.5*	1.7	21.1*	61.7**	-20.1	47.7**
	H_2	14.2	-5.2	17.1*	31.3**	-20.1	43.8**
Arava (ARA) – P_1 x P_3	H_1	13.6	1.5	15.7*	14.3*	-8.7	42.9**
	H_2	8.8	-3.6	14.6	0.8	-10.4	34.1**
Gala (GLA) – P_4 x P_5	H_1	22.5*	7.9	32.8**	56.4**	-9.4	62.8**
	H_2	18.8*	-16.6	4.9	37.8**	-15.2	56.5**

[Z] $H_1 = 100 (F_1-M)/M$, $H_2 = 100 (F_1-P_1)/P_1$, where F_1 is the hybrid, M is the mean of both parents and P_1 is the value of the better parent
* Significant at (P = 0.05)
** Significant at (P = 0.01)

parent accessions and a smaller seed cavity compared to their mid-parent values. Fruit sweetness (TSS) values in hybrid cultivars were a little bit higher than in their parents' means but never exceeded the values of the best parent (NY or CNY).

Seed yield and seed yield components

Seed yield per unit area and to a lesser extent seed yield per fruit were significantly higher in the hybrid cultivars as compared with their parental accessions (**Tables 5, 6**). The superiority of the hybrids was based mainly on increased seed number per fruit, but in GAL also on fruit number per unit area (**Table 1**) rather than on mean seed weight. Hybrid cultivars also had lower percentages of empty seeds than their parental accessions. Seed yield index (seed yield per fruit (g)/ fruit weight (kg)) of the three hybrid cultivars was generally lower than that of the parental accessions. This result suggests that the seed yield index is independent with respect to seed yield, but it is negatively correlated to fruit weight as was found earlier in melon and squash (Nerson *et al*. 2000; Nerson 2002). High heterosis values were calculated for seed yield per unit area and for low percentage of empty seeds, and medium values for seed number per fruit and seed yield per fruit.

Seed germination and seed germination rate

The maternal accessions NY and CNY have lower germination percentages, slower germination rates and larger germination rate standard deviations (SD) than the paternal accessions KR, CKR and ES and the hybrid cultivars GAL, GLA and ARA (**Table 7**). The values of these parameters in the hybrid cultivars were similar or at least closer to the values of the paternal accessions rather than to the values of the maternal accessions. The hybrid cultivars and their parental accessions did not differ in germination percentages, but GLA had a slower germination rate than CKR and GAL had a larger SD for the germination rate than KR. As long as heterosis was calculated as the difference of hybrids from mid-parents values, the germination parameters showed positive heterosis values (**Table 8**). The comparison in the present study is between the parental accessions seeds (P generation) and seeds produced by hybrid cultivars (F_2 generation). There is a lot of information in literature concerning germination of hybrid (F_1) seeds (Torres and Marcos-Filho 2005), but a lack of knowledge in germination of the next generation and especially in relation to their parental generation. High seed yield and high germination value in hybrids had no importance from an agricultural stand point, as seeds developed on hybrid plants are the F_2 segregating generation and have no commercial value.

Table 7 Germination percentage, germination rate (MDG) and standard deviation of germination rate in five parental accessions and three hybrid cultivars of Galia-type muskmelon.

Accession/cultivar	Germination (%)	Mean days to germination (MDG)	Standard deviation of MDG
Noy Yizre'el (NY) – P_1	76 b	4.2 a	1.67 a
Krimka (KR) – P_2	96 a	2.0 e	0.19 g
Galia (GAL) – P_1 x P_2	97 a	2.0 e	0.46 de
Eshcolit (ES) – P_3	95 a	2.3 de	0.33 f
Arava (ARA) – P_1 x P_3	98 a	2.5 d	0.36 ef
C. Noy yizre'el (CNY) – P_4	70 b	3.7 b	1.48 b
C. Krimka (CKR) – P_5	92 a	2.4 d	0.51 cd
Gala (GLA) – P_4 x P_5	96 a	2.9 c	0.58 c

Statistics – ANOVA and Duncans' multiple range test (P = 0.05) for significant differences among accessions

Table 8 Heterosis (H) in three hybrid cultivars of Galia-type muskmelon.

Cultivar	Heterosis	Germination (%)	Mean days to germination (MDG)	Standard deviation of MDG
Galia (GAL) –P_1 x P_2	H_1	12.8*	35.5**	50.5**
	H_2	1.0	0.0	-142.1
Arava (ARA) –P_1x P_3	H_1	14.6*	23.1**	64.0**
	H_2	3.2	-8.7	-9.1
Gala (GLA) – P_4 x P_5	H_1	18.5*	4.9	41.7**
	H_2	4.3	-20.8	-13.7

[Z] $H_1 = 100\ (F_1\text{-}M)/M$, $H_2 = 100\ (F_1\text{-}P_1)/P_1$, where F_1 is the hybrid, M is the mean of both parents and P_1 is the value of the better parent
* Significant at ($P = 0.05$)
** Significant at ($P = 0.01$)

However, this information is important in understanding evolutionary processes. The superiority of hybrids in seed (offspring) production provides them a survival advantage by increasing the proportion of new recombinants in the plant population.

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