Genotype and Plant Density Affect Watermelon Grown for Seed Consumption

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Abstract. The effects of plant spacing (5,000–40,000 plants per hectare) on watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] production for seed consumption were evaluated in two breeding lines, 203 and 239-4, and in the standard cultivar Malali in three field experiments in northern Israel. The two breeding lines produced more, but smaller fruits than did 'Malali', resulting in nearly double the seed yield per unit area. Seed size was not affected by fruit size, unless fruit size was <500 g. The total number of fruits per unit area was the most important component in determining seed yield. Increasing the plant population increased the seed yield in all three accessions. Breeding and agricultural practices that maximize fruit number per unit area are expected to be most beneficial in maximizing the yield of watermelon grown for seed consumption.

Seed consumption of watermelon is popular in several countries, such as China (Yang and Walters, 1992; Zhang, 1996), India (Singh and Naik, 1989) and those in the Mediterranean basin (Nerson et al., 1994). However, there are few reports on seed production, and seed yield was positively correlated with fruit number, which in turn was positively correlated with plant density of 3,000 to 12,000 plants/ha (Nerson et al., 1994). The desired seed size limit for commercial purposes in Israel is >120 mg/seed.

A literature review on the effects of plant spacing on fruit yield is presented due to the absence of seed yield data. The fruit yield of watermelon is a function of fruit number and fruit size: generally, high-density planting increases fruit number and decreases fruit size. There are many reports concerning the relationships among plant density, fruit yield and fruit yield components. In Georgia, marketable fruit yields increased by 29% to 34% as plant density increased from 3000 to 7410 plants/ha. In that study, plant density did not affect fruit size, but the number of fruits per unit area increased as plant density increased (NeSmith, 1993). In Oklahoma, total marketable yield increased linearly by 60% as the density increased from 1000 to 9000 plants/ha (Duthie et al., 1999). Similarly, the marketable watermelon fruit yield in Florida increased, while fruit weight decreased as plant density was increased from 916 to 11,000 plants/ha (Brinen et al., 1979). In Australia, increasing the plant density of mini-watermelons from 5,550 to 22,200 plants/ha also increased fruit yield and decreased fruit size (Barnes et al., 1994).

The primary objective of this study was to compare the seed-yielding potential of two

advanced breeding lines (203 and 239-4) selected from the variant 'Yellow Malali' (Nerson et al., 1994) with that of the Israeli standard 'Malali'. Our goal was to contribute to information on the effects of genotype and plant density on watermelon seed yield.

Materials and Methods

Three field experiments were conducted in northern Israel, two at the Newe Ya'ar Research Center in the spring–summer seasons of 1997 and 1998, and one near Daverat (25 km east of Newe Ya'ar) in the spring–summer season of 1998. On 1 Apr. of the first year experiment, two advanced breeding lines of watermelon designated 203 and 239-4, previously selected from 'Yellow Malali' for high seed yield (Nerson et al., 1994), were seeded on raised beds spaced 2 m from center to center. Each bed had one row with three within-row spacings: 0.25, 0.5, and 1 m. These provided plant population densities of 5,000, 10,000, and 20,000 plants/ha, respectively.

In the second year at Newe Ya'ar, the same two breeding lines were compared with the standard commercial 'Malali' (Hazera' Quality Seeds, Berurim, Israel). 'Malali', an old local cultivar used for fruit consumption, is now used primarily for seed consumption. Four population densities, 5,000, 10,000, 20,000, and 40,000 plants/ha were established in single rows on 2-m-wide raised beds.

The third experiment, conducted in a commercial seed production field near Daverat, the same two breeding lines were grown in 0.3-ha plots, within 40 ha of 'Malali'. The crop was grown without any irrigation (dryland farming) and the plant density was 5,000 plants/ha.

The Newe Ya'ar experiments were designed as randomized blocks with four replicates, and each subplot was 16 m². Standard cultural practices, including drip fertigation were employed (Nerson et al., 1994). In the autumn (6 months before transplanting) the field was supplied

with the following pre-planting fertilizers: nitrogen as ammonium sulfate at 100 kg·ha⁻¹ and phosphorus as superphosphate at 200 kg·ha⁻¹. The crop also received three side dressings: at sowing, at the four-leaf stage, and at male flowering, each included nitrogen (as ammonium sulfate) at 40 kg·ha⁻¹ and phosphorus (as phosphoric acid) at 40 kg·ha⁻¹, supplied through the irrigation system. Water was applied as required according to evapotranspiration data, with a total amount of ≈2000 m³·ha⁻¹ per season (20 cm). At Daverat, four replicates of 20 m² plots for each accession were randomly designated within the field during fruit development. Fruits were harvested when fully mature during July 1997 and July 1998. The total fruit number of each plot was recorded, and their seed yield was determined after drying. The seed yield index (Nerson et al., 1994) was calculated by dividing the fruit yield by the seed yield. At Newe Ya'ar 1998 experiment, the fruits of each subplot were sorted into five sizes: <500 g, 500–1000 g, 1000–1500 g, 1500–2000 g, and >2000 g. The seeds of each group were collected and weighed. Four samples of 100 seeds from each fruit size-group were used to determine the mean seed weights.

The data from all the experiments were subjected to SUPER ANOVA (analysis of variance) and in some cases to Duncan's multiple range tests to determine statistical differences between treatments. Regression was calculated using JMP software (Cary, N.C.).

Results and Discussion

Seed yield has three components: 1) fruit number per unit area; 2) number of seeds per fruit; and 3) mean seed weight. By multiplying the numerical values of these components one arrives at seed yield.

Number of fruits. The breeding lines 203 and 239-4 did not differ from each other in fruit number per unit area at both locations and years (Tables 1 and 2). Both lines produced significantly more fruits with less weight per fruit than the standard 'Malali' (Tables 2 and 3). Increasing plant density significantly increased the fruit number per unit area, but decreased the mean fruit weight (Tables 1 and 2). These findings are consistent with those reported in earlier studies (Brinen et al., 1979; Halsey, 1959). Although in the last decade there has been a strong tendency in many watermelon markets to shift from very large fruits toward mini or icebox fruits (Barnes et al., 1994), the two breeding lines used in the present study have little potential for fruit consumption, since 80% to 100% of their fruits were <1.5 kg.

Number of seeds per fruit. The breeding line 203 produced significantly fewer seeds per fruit than 239-4 or 'Malali' (Tables 1–3), whereas the breeding line 239-4 had about the same seed number per fruit as 'Malali' (Tables 2 and 3). In all three accessions increasing the plant density decreased the seed number per fruit, but to a lesser extent than the increase in fruit number.

Mean seed weight. The seeds produced by

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SEED TECHNOLOGY

Table 1. Effects of genotype and plant density on seed yield, seed yield components, and seed yield index (Newe Ya'ar, 1997).

Genotype	Density (plants/ha) ^z	Mean					
		Fruit no. (per 10 m ²)	Fruit wt (g)	Seed no. (per fruit)	Seed wt (mg)	Seed yield (g per 10 m ²)	Seed yield index
203	5000	40	1183	186	166	1218	24
	10000	57	1009	166	164	1543	23
	20000	83	767	129	164	1755	23
239-4	5000	48	1091	232	151	1670	19
	10000	57	963	199	155	1768	20
	20000	80	790	165	154	2023	20
LSD(<i>P</i> ≤ 0.05)	genotype	14.9	153.9	25.1	4.1	246	1.1
LSD(<i>P</i> ≤ 0.05)	density	7.1	10.6	25.4	8.1	292	2.7
Significance							
	G	NS	NS	***	***	**	***
	D lin	***	***	***	NS	**	NS
	D quad	NS	NS	NS	NS	NS	NS
	G × D lin	NS	NS	NS	NS	NS	NS
	G × D quad	NS	NS	NS	NS	NS	NS

^zG = genotype; D = density; lin = linear; quad = quadratic.NS, *, **, *** Nonsignificant or significant at *P* ≤ 0.05, 0.01 or 0.001, respectively.

Table 2. Effects of genotype and plant density on seed yield, seed yield components, and seed yield index (Newe Ya'ar, 1998).

Genotype	Density (plants/ha) ^z	Mean					
		Fruit no. (per 10 m ²)	Fruit wt (g)	Seed no. (per fruit)	Seed wt (mg)	Seed yield (g per 10 m ²)	Seed yield index
Malali	5000	19	2466	323	152	919	50
	10000	19	2527	361	150	1040	47
	20000	29	2139	315	152	1353	45
	40000	36	1492	213	165	1264	41
203	5000	30	1242	282	165	1412	27
	10000	43	1131	253	168	1798	26
	20000	54	979	234	169	2138	25
	40000	71	808	178	171	2163	27
239-4	5000	27	1575	388	145	1485	17
	10000	39	1007	308	156	1902	21
	20000	53	888	273	159	2314	21
	40000	59	752	289	161	2663	18
LSD(<i>P</i> ≤ 0.05)	genotype	12.5	290	46.0	5.5	330	2.8
LSD(<i>P</i> ≤ 0.05)	density	10.2	510	51.1	7.5	452	10.5
Significance							
	G	***	***	**	***	***	***
	D lin	***	***	***	NS	***	NS
	D quad	**	NS	NS	NS	NS	NS
	G × D lin	**	NS	NS	NS	NS	*
	G × D quad	NS	NS	*	NS	NS	NS

^zG = genotype ; D = density ; lin = linear ; quad = quadratic.NS, *, **, *** Nonsignificant or significant at *P* ≤ 0.05, 0.01 or 0.001, respectively.

Table 3. Effects of genotype and plant density on seed yield, seed yield components and seed yield index (Daverat, 1998).

Genotype	Mean					
	Fruit no. (per 10 m ²)	Fruit wt (g)	Seed no. (per fruit)	Seed wt (mg)	Seed yield (g per 10 m ²)	Seed yield index
Malali	7 b	2490 a	293 a	166 a	341 b	51 a
203	17 a	980 b	258 b	169 a	742 a	23 b
239-4	16 a	980 b	301 a	163 a	784 a	20 b

Means within columns in each experiment followed by different letters differ statistically at *P* = 0.05 (Duncan's multiple range test).

the breeding line 203 were heavier than those of 'Malali' (Table 2) and 239-4 (Tables 2 and 3) under irrigation, while dry-land conditions the mean seed weight (1000-weight) of all genotypes was similar (Table 3). Plant density did not affect the mean seed weight. By grouping the fruits according to their weight and harvesting their seeds separately, it was revealed that fruit size had no effect on seed size (Table 4). The mean seed weight did not change within any of the three accessions with fruit weight >500 g.

Seed yield. In the two experiments conducted in 1998, the seed yield of the two breed-

ing lines was about the same; both lines outyielded the standard cultivar Malali (Tables 2 and 3). Similar seed yield differences were obtained in a previous study (Nerson et al., 1994) in which the 'Yellow Malali' heterogeneous population (origin material for the breeding lines 203 and 239-4) was compared with 'Malali'. Increasing the plant density from 5,000 to 20,000 or 40,000 plants/ha increased the seed yield at Newe Ya'ar (Tables 1 and 2). However, the seed yield at the two highest densities in 1988 did not differ significantly from that at the intermediate density of 10,000 plants/ha (Table 2). Collectively, results of the

present study suggest that fruit number per unit area is the most important component in determining watermelon seed yield. Indeed, the two new breeding lines produced more fruits than 'Malali' and had double the seed yield.

Seed yield index. The seed yield index (fruit yield/seed yield), expressing the distribution of fresh matter between the whole fruit and the seeds, may serve as a reliable indicator of seed production efficiency. A low seed yield index means that the plant invests more resources in seed production than in developing the surrounding fruit tissues. In both experiments conducted in 1998, the two new breeding lines had

Table 4. Effects of genotype and mean fruit weight on seed mean weight (mg) (Newe Ya'ar, 1998).

Variety	Mean fruit wt (g)				
	<500	500–1000	1000–1500	1500–2000	>2000
Malali	136.6 b	140.8 ab	159.8 a	159.4 a	158.1 a
203	156.0 b	167.1 a	173.7 a	172.4 a	169.9 a
239-4	145.1 b	154.2 a	159.8 a	161.7 a	---

Means within rows followed by different letters differ statistically at $P = 0.05$ (Duncan's multiple range test).

significantly lower seed yield indexes than cultivar Malali (Tables 2 and 3). Line 239-4 had lower seed yield index than line 203 under a complete irrigation regime (Tables 1 and 2), but not under dry land farming (Daverat). Plant density had different effects on the seed yield

indexes of the three accessions (Fig. 1). Increasing plant density had only a slight and nonsignificant effect in 'Malali', a constant negative effect in line 239-4, and a significant negative effect over a density range of 5,000 to 10,000 plants/ha in line 203. Moreover, there was a

Fig 1. Effect of plant density on seed yield index in three watermelon accessions (Newe Ya'ar, 1998).

Fig 2. Effect of fruit weight on seed yield index in three watermelon accessions

clear difference between 'Malali' and the two breeding lines with respect to the effect of fruit weight on the seed yield index (Fig. 2). In 'Malali', the index tended to increase with increasing fruit weight, indicating that only very small fruits are efficient in seed production. Since 'Malali' rarely produces such small fruits the actual index for this cultivar was at least 40. In contrast, the seed yield indexes of the two breeding lines tended to decrease with increasing fruit weight. As almost all fruits of the breeding lines weighed between 500 and 2000 g, the actual seed yield indexes were 25 and 18 for lines 203 and 239-4, respectively.

Conclusions

The data of the present study showed that the three accessions differed mainly in fruit number per unit area and fruit size. The two new breeding lines, 203 and 239-4, produced substantially more but smaller fruits than did 'Malali'. Although the number of seeds per fruit was slightly lower in the two breeding lines as compared to 'Malali', and seed size was not affected by fruit size, the larger number of fruits in the two breeding lines resulted in doubling of seed yield as compared to 'Malali'. Thus, the total number of fruits per unit area was the most important factor in determining the seed yield. Seed yield per unit area of all of the accessions was increased by increasing plant density, as a result of a significant increase in fruit number and only a slight decrease in seed number per fruit. Finally, the seed yield index of the two breeding lines was significantly lower than that of 'Malali', indicating that these lines are more efficient in seed production than 'Malali'.

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