Spacing and Genotype Affect Fruit Sugar Concentration, Yield, and Fruit Size of Muskmelon

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Abstract. Muskmelon (*Cucumis melo* L.) genotypes, Birdsnest 1 ['Qalya' (BN1)], Birdsnest 2 (BN2), and 'Mission' (V) were used to determine the effects of differing plant architecture and spacing on fruit sugar concentration and yield. The BN1 and BN2 genotypes possessed a highly branched growth habit specific to birdsnest melon types, but not characteristic of standard indeterminate vining types (e.g., 'Mission'). Experiments were conducted at both the Hancock and Arlington Experimental Farms in Wisconsin, where plant response to two within-row spacings [35 cm (72,600 plants/ha) and 70 cm (36,300 plants/ha)] in rows on 210-cm centers was examined. Genotypes were grown in a randomized complete-block design with four replications at each location and evaluated for primary lateral branch number, fruit number per plant and per hectare, average fruit weight, yield per plant (g), yield per hectare (t), and fruit sugar concentration. Yield, fruit number, and sugar concentration were higher for all genotypes at Arlington than at Hancock. The main effect of genotype was significant for all traits examined. Genotypes BN1 and V had higher mean fruit weight, yield per plant and per hectare, and fruit quality (fruit sugar concentration) than did BN2. Spacing affected all traits, except primary branch number and fruit sugar concentration. Fruit number and yield per plant and average fruit weight were higher with wider spacing, but yield (t·ha⁻¹) and fruit number per hectare were lower.

Muskmelon is an important horticultural crop in the Cucurbitaceae family. Worldwide muskmelon production is ≈18 million t [Food and Agriculture Association (FAO) 1997], with China, Turkey, Iran, the United States, and Spain being the major producers. Arizona, California, and Texas are the primary muskmelon production areas in the United States [National Agricultural Statistics Service (NASS), 1995].

According to U.S. Dept. of Agriculture (USDA) standards, a high-quality muskmelon fruit has between 9% and 11% soluble solids (Pratt et al., 1977; Rubatzky and Yamaguchi, 1997). The soluble solids concentration varies with fruit maturity (Peirce, 1987); fruits have 8% to 12% soluble solids when harvested at

the hard-ripe or early-slip maturity stage, but fruits picked at full slip usually have closer to 15% soluble solids. The soluble solids concentration is an important quality determinant that has long been used as an indicator of muskmelon sweetness, flavor, maturity, and acceptability (Rosa, 1928). As the percentage of soluble solids increases, fruit quality also increases (Nonnecke, 1989). According to Bianco and Pratt (1977), soluble sugars account for >97% of the total soluble solids in maturing muskmelon fruits, with sucrose accounting for ≈50% of all sugars. Glucose and fructose account for >90% of the total soluble sugars during the first 24 d after antithesis (Lester et al., 1985; McCollum et al., 1988; Ofusu-Anim and Yamaki, 1994; Schafer et al., 1992). Thereafter, sucrose begins to accumulate and predominates in the ripe fruit. Fruits should be harvested when fully ripe to obtain the highest quality because sucrose accumulation takes place solely in fruit attached to the plant (Bianco et al., 1977; Schafer et al., 1992; Wang et al., 1996; Wyllie et al., 1995).

Muskmelon cultivars exhibit three major growth habits: vining, short internode, and birdsnest (multiple branching), but only prostrate vining melons are grown commercially in the United States. Vining types typically set fruit distal to the center of the plant. The fruits do not mature uniformly, and hence are harvested individually when mature. Since vines spread between rows, cultivation and weed management are difficult and require 30 to 60 cm within-row spacing on 200-cm centers (15,000 and 20,000 plants/ha) (Rubatzky and Yamaguchi, 1997).

Short internode (SI) muskmelons are indeterminate, but have fewer nodes, shorter internodes, and less leaf area per plant than the vining muskmelons (Knavel, 1991). They may have potential for culture at higher densities (Mohr and Knavel, 1966).

Birdsnest melons are unique because of their compact growth habit and ability to germinate rapidly at cool temperatures (Nelson et al., 1982, 1983; Paris et al., 1981, 1982). These melons possess a uniform, highly branched plant habit with shorter internodes than vining types (Paris et al., 1982), and have a relatively concentrated fruit setting period in comparison with short internode and vining types (Nelson et al., 1983). They also set fruit near the center of the plant, causing uniform fruit development and maturity (Paris et al., 1981). If high-yielding birdsnest type melons could produce early, uniformly mature, high-quality fruit, they might offer a financially viable alternative to muskmelon growers for once-over harvesting.

As within-row spacing increases, yield per plant, number of fruits per plant, weight per fruit, and percentage of soluble solids increase (Bhella, 1985; Davis and Meinert, 1965; Maynard and Scott, 1998; Mendlinger, 1994; Zahara, 1972). Although Bhella (1985) reported that plant density did not affect yield/ha of 'Classic' and 'Burpee hybrid' vining-type muskmelons, Knavel (1988) showed that as within-row spacing of short internode muskmelon decreased from 90 cm (8140 plants/ha) to 45 cm (16,268 plants/ha), fruit number and yield per plant decreased.

Fruit quality (sugar concentration of birdsnest melon types) as influenced by spacing and soil type has not been investigated. Thus, an experiment was designed to determine the effect of plant architecture on yield and fruit quality for several plant populations. Birdsnest melon types were compared with a vining type for their ability to produce early, uniform ripening, high-quality fruit for commerce.

Materials and Methods

Plant material. One vining (V) 'Mission' and two birdsnest muskmelon types were used. Birdsnest 1 (BN1) 'Qalya' was obtained from the Agricultural Research Organization, Newe Ya'ar Experiment Station, Hafia, Israel, and Birdsnest 2 (BN2) was an experimental line (F5) obtained from the USDA, Agricultural Research Service (ARS), Vegetable Crops Research Unit, Madison, Wis. This line originated from a cross between 'PMR 45' x Persia 201. The BN2 genotype was developed to obtain U.S. Western shipping market class melon genotypes with high, early yield for once-over harvest.

Experimental design. Experiments were conducted at the Hancock and Arlington Experimental Farms in Wisconsin utilizing a randomized complete-block design with four replications at each location. Replications consisted of 25 plants (i.e., five rows of five plants each) with the interior nine plants being sampled, and the remaining 16 plants being used as guards.

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Plant culture. In Hancock, which has Plainfield sandy soil (Typic updisamment, mixed mesic), 130 kg-ha⁻¹ 0N-0P-50K was applied preplant, while a total of 652 kg-ha⁻¹ of 20N-8.7P-16.6K was applied five times during the growing season to allow for nutrient leaching. On the plano silt loam (Typic argiudol; fine-silty, mixed mesic) soil at Arlington, 305 kg 34N-0P-0K, 55 kg 0N-20.1P-0K, and 305 kg 0N-0P-50K were preplant incorporated per hectare according to soil test recommendations (Binning et al., 1998).

Muskmelon seeds were sown into 48-cell packs (T.O. Plastic, Minneapolis) containing Faward Ag Mix No. 2 media (Faward, Agawam, Me.) on 15 and 23 May 1997 at Hancock and Arlington, respectively. Seedlings were watered daily and thinned to one seedling per cell pack at the two- to three-true-leaf stage. A total of 0.15 g N (0.025 g·L⁻¹ N in H₂O) was applied to plants three times while they were in the greenhouse to sustain normal growth. Seedlings were hardened-off for 2 d, then transplanted at Hancock and Arlington on 6 and 10 June 1997, respectively. A total of 81 kg-ha⁻¹ soluble plant starter fertilizer [10N-24P-8.3K (Peters, St. Louis)] (i.e., 160 mL of solution at 7.3 g·L⁻¹ to each transplant) was applied manually because of low soil temperatures during planting at both locations. The two within-row spacings used were 35 cm (72,600 plants/ha) and 70 cm (36,300 plants/ha) in rows on 210-cm centers. Seedlings were transplanted into 1 mm green thermal plastic mulch. Irrigation was provided by overhead sprinkler in Arlington and by traveling gun in Hancock to supplement rainfall as needed. Weeds were controlled manually by hand pulling.

Morphological measurement and sampling. Primary branches of each genotype were counted 30 d after planting at each location to evaluate the effects of genotype, spacing, and location. When fruit set started, the second fruit of each plant was tagged for future use in sugar analysis. Full-slip fruits were harvested, counted and weighed continuously to determine the fruit number per plant, yield per plant, and average fruit weight. The BN2 genotype was harvested first, followed by BN1, then V because of genotypic differences in maturity. There were seven harvests at each location, and one tagged fruit was harvested from each of the interior nine sample plants for sugar analysis. Fruits were washed, dried and weighed individually, and two samples of mesocarp tissue (≈50 g each) were taken from the center of the mesocarp on the exposed side of the fruit where sugar concentration was highest (Scott and Macgillivray, 1940). Each sample was placed into a tagged plastic bag and put into a cooler containing dry ice for transport to Madison. Samples were then kept at -80 °C until analyzed.

Sample preparation for sugar analysis. Total sugar contents were quantified by a colorimetric method described by Dubois et al. (1956). This method involves reaction of sugars with a phenol-sulfuric acid mixture that produces a stable orange-yellow color. Each tissue sample was blended with 200 mL of

95% ethyl alcohol for 1 min. Twenty µL of the homogenate was combined with 50 µL phenol, 5000 µL sulfuric acid, and 1980 µL of distilled water. Absorbance at 490 nm was recorded using a Beckman DU 50 spectrophotometer (Beckman Instruments, Fullerton, Calif.). Sugar concentration in the homogenate (x) was determined by reference to a linear standard curve [$y = m \cdot x + b$, where y = absorbency value and x = concentration of solution (µg·mL⁻¹)]. This method was used to calculate total mg sugar/g fruit tissue. The percentage of soluble solids in the juice of the fruit was determined using a hand refractometer (Currence and Larson, 1941).

Statistical analysis. Analyses of variance (ANOVA) were performed using SAS (SAS Institute, 1997) for each trait examined in order to evaluate treatment effects. Mean separations were performed using Fisher's LSD at the 5% level and Duncan's multiple range test at the 1% level (Snedecor and Cochran, 1980), while correlation (Pearson Product-Moment method) and regression analyses were performed among the variables examined using SAS (SAS Institute, 1997), and Minitab (Minitab, State College, Pa.), respectively.

Results and Discussion

There were few consistent interactions, except location × genotype for all variables examined (Table 1). Because of these significant interactions with location, the data were analyzed within locations (Table 2). The only other significant interactions involved yield/ha for all the two-way interactions. None of these data are shown, but can be explained by the small size of BN2 plants. The population densities used did not adversely affect fruit weight because, even at the narrowest spacing, the plants did not contact each other, much less compete for nutrients and water. Thus, all plants of these genotypes had ad-

equated room to produce the optimum numbers and weight of fruit at both spacings used.

Although genotypes differed in number of primary lateral branches, neither location nor spacing influenced this trait. Sugar concentration was higher at Arlington than at Hancock (Table 1), yet the ranking among genotypes remained the same at each location (Table 2). Although spacing was significant for average plant yield (g), it had surprisingly little effect on sugar concentration (Tables 1 and 2).

Fruit number. All genotypes set more fruit at Arlington than at Hancock. Although fruit number per plant was higher for BN2 than BN1 or V at Arlington, data for all genotypes were similar at Hancock ($P \leq 0.001$) (Tables 1 and 2). As within-row spacing increased from 35 to 70 cm, fruit number per plant increased at both locations (Table 1). Concomitantly, fruit number/ha decreased. This result supports the observations of Bhella (1985) and Maynard and Scott (1998) that plants produce more fruit at wider spacings. However, because of the increased plant populations at narrower spacings, fruit number/ha also increased.

Fruit weight. The average fruit weight of all genotypes was lower at Hancock than at Arlington (Table 1), and at each location, the average fruit weight was greatest in BN1 and least in BN2 ($P \leq 0.001$) (Table 2). Average weight of fruits was greatest at the wider spacing for BN1, followed by the vining type, and finally BN2 (Table 2). Again, both plants and fruits of BN2 were so small that spacing had little effect on fruit number or weight at either location.

Yield. At Hancock, yields per plant (g) of the BN1 and V genotypes were similar, but greater than that of BN2 (Table 2). However, at Arlington BN1 produced the highest yield per plant followed by V, then BN2. Yield differences associated with location ($P \leq 0.001$; Table 1) might be explained by differences in

Table 1. Main effects of genotype, plant spacing, and location on yield components and soluble solids of three melon genotypes.

Treatments	Branch no.	Fruit no.		Yield/ plant (g)	Avg fruit wt (g)	Total yield (t·ha ⁻¹)	Soluble solids	
		Per plant	Per ha				Sugar concn (mg·g ⁻¹ fruit)	% sugar in fruit juice
<i>Genotype (G)^c</i>								
BN1	3.4	2.7	35,304	3731	1382	49.8	64.9	11.5
BN2	4.5	3.7	46,848	1547	418	20.9	12.8	3.5
V	3.3	2.6	33,511	2998	1153	38.5	62.6	12.4
F value ^y	***	***	***	***	***	***	***	***
<i>Plant spacing (S)</i>								
S1 (70 cm)	3.8	3.4	30,559	3516	1034	29.7	47.0	9.2
S2 (35 cm)	3.7	2.6	46,549	2431	935	43.1	46.6	8.9
F value	NS	***	***	***	***	***	NS	NS
<i>Location (L)</i>								
Hancock	3.7	2.4	30,074	1932	805	23.4	42.6	8.3
Arlington	3.7	3.7	47,035	4303	1163	49.4	51.0	9.7
F value	NS	***	***	***	***	***	**	**
<i>Interactions</i>								
S × G	NS	NS	NS	NS	NS	*	NS	NS
L × S	NS	NS	NS	NS	NS	***	NS	NS
L × G	NS	***	***	**	***	***	NS	**
L × S × G	NS	NS	NS	NS	NS	NS	NS	NS

^aBN1 = Birdsnest 1 'Qalya', BN2 = birdsnest 2 Experimental F5 line, V = vining 'Mission'.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

Table 2. Main effects of genotype and plant spacing on yield, yield components, and soluble solids of three muskmelon genotypes within locations at Hancock and Arlington.^z

Variable	Fruit no.		Yield/plant (g)	Fruit wt (g)	Soluble solids	
	Per plant	Per ha			Sugar concn mg/g fruit	% sugar fruit juice
Hancock location						
Genotype ^y						
BN1	2.2 a	28,243 a	2460 a	1118 a	56.6 a	9.8 b
BN2	2.5 a	31,606 a	845 b	338 c	11.7 b	3.2 c
V	2.4 a	30,373 a	2302 a	959 b	59.5 a	12.4 a
Spacing ^x						
S1	2.7 a	23,984 b	2371 a	878 a	43.6 a	8.5 a
S2	2.0 b	36,163 a	1464 b	732 b	39.1 b	8.1 a
Arlington location						
Genotype						
BN1	3.2 b	42,365 b	5264 a	1645 a	73.3 a	13.1 a
BN2	4.9 a	62,090 a	2445 c	499 c	13.9 c	3.7 b
V	2.8 b	36,649 b	3772 b	1347 b	65.8 b	12.4 a
Spacing						
S1	4.1 a	37,135 b	4879 a	1190 a	50.4 a	9.9 a
S2	3.2 b	56,935 a	3638 b	1137 a	51.6 a	9.6 a

^zMeans of four replicate plots at each location; mean separation within columns, locations, and variables by Duncan's multiple range test, $P \leq 0.01$.

^yBN1 = 'Qalya', BN2 = birdsnest 2 Experimental F5 line, V = vining 'Mission'.

^xS1 70 cm, S2 35 cm within-row spacings.

Table 3. Correlation (r values) among observations on effects of genotype and spacing on melon size and yield.

Correlation	Genotype ^z	Spacing ^y	Hancock	Arlington
Branch number per plant vs. wt per fruit	BN1	1	-0.98*	0.14 ^{ns}
		2	-0.88*	0.11 ^{ns}
	BN2	1	0.29 ^{ns}	0.28 ^{ns}
		2	0.04 ^{ns}	-0.16 ^{ns}
	V	1	-0.39 ^{ns}	0.69 ^{ns}
		2	-0.44 ^{ns}	-0.02 ^{ns}
Fruits per plant vs. weight per plant	BN1	1	0.98*	0.95*
		2	0.90 ^{ns}	0.99*
	BN2	1	0.96*	0.95*
		2	0.86 ^{ns}	0.90 ^{ns}
	V	1	0.60 ^{ns}	0.49 ^{ns}
		2	0.76 ^{ns}	0.98*
Branch number per plant vs. weight per plant	BN1	1	-0.85 ^{ns}	0.07 ^{ns}
		2	-0.29 ^{ns}	0.26 ^{ns}
	BN2	1	0.64 ^{ns}	0.38 ^{ns}
		2	-0.11 ^{ns}	-0.55 ^{ns}
	V	1	0.12 ^{ns}	0.99*
		2	-0.51 ^{ns}	0.65 ^{ns}

^zBN1 = birdsnest 1 'Qalya', BN2 = birdsnest 2 experimental F5 line, V = vining 'Mission'.

^y1 = 70 cm, 2 = 35 cm within row spacing.

*Significant at $P \leq 0.05$, ns = nonsignificant.

plant growth. Arlington has mineral soil (3.1% O.M.) with higher nutrient content and water-holding capacity than the sandy Hancock soil (0.6% O.M.). Moreover, growth was better at Arlington than at Hancock. Perhaps vigorous growth increased the net photosynthetic capacity of plants, and thus plants produced more fruit per plant and per hectare at Arlington than at Hancock.

As within-row spacing increased, yield per plant increased, probably because wider spacing created less interplant competition. The greater yield/ha at the closer spacing was a result of more plants per unit area. Similar results were reported by Brinen et al. (1979), Knavel (1988), and Maynard and Scott (1998). In contrast with our study, Bhella (1985) reported that plant density had little effect on yield/ha. In his study, as within-row spacing was increased (from 25 to 100 cm), fruit number per plant increased dramatically, while

fruit weight increased only slightly. This was enough, however, to compensate for the reduced plant population in his experiment; hence total yield remained relatively constant.

The BN1 and V genotypes yielded more per hectare at the higher plant density, but yield of BN2 was similar at both densities because of compact growth habit (see explanation above).

Sugar concentration. Although both genotype ($P \leq 0.001$) and location ($P \leq 0.01$) affected fruit sugar concentration, spacing did not (Table 1). A location/genotype interaction was detected only for percentage of sugar (melon juice). Sugar percentages were similar for BN1 and V types at Arlington, but V type had higher levels than did BN1 at Hancock (Table 2). Based upon visual observations, total plant growth of both BN1 and the vining cultivar was less at Hancock than at Arlington.

Fruits grown at Arlington had higher sugar concentrations (Table 1), and plants had larger leaf canopies than did those grown at Hancock (visual observations). Since muskmelon fruit depends on photoassimilate from the leaf canopy for sugar accumulation during ripening (Hubbard and Pharr, 1990; Schafer et al., 1992), these larger canopies probably contributed to the higher fruit sugar levels. Although differences in sugar concentration and percentage of soluble solids were detected among genotypes, soluble solids levels (percentage of fruit juice sugars) for all genotypes except BN2 were commercially acceptable at both spacings and locations according to USDA standards (9% to 11%) (Tables 1 and 2).

The sugar concentrations of BN1 and V were higher ($P \leq 0.001$) than that of BN2 (Tables 1 and 2). Concentrations averaged over two locations were 65, 13, and 62 mg·g⁻¹ fruit for BN1, BN2, and V, respectively.

Spacing did not affect fruit sugar concentration or percentage of sugar in the juice of the fruits (Table 1). This result differs from that reported by Zahara (1972), who showed that as within-row spacing increased, soluble solid concentration also increased. This disparity might reflect the plant density differences between studies. Plant density in Zahara's study was 17,290 plants/ha, whereas in ours, it was 36,300 plants/ha.

Correlations and regression coefficients among observations. Given the importance of location-specific results (genotype $\times$ location being the only significant interactions except for total yield) of several examined variables in this study, Table 3 and Fig. 1 focus on areas of interest where significant differences could provide information that might increase melon earliness, yield, quality, and harvest-ripe uniformity.

The number of primary branches and average fruit weight of BN1 were negatively correlated ($r = -0.98$, $P \leq 0.05$) at the wider spacing at Hancock (Table 3) as well as displaying a negative coefficient of regression (Fig. 1A). An increase in the number of primary branches could lead to higher fruit-setting capacity.

Yield per plant was positively correlated with fruit number per plant at the wider spacing for BN1 ($r = 0.98$, $P \leq 0.05$) and BN2 ($r = 0.96$, $P \leq 0.05$) on the sands at Hancock (Table 3) while also demonstrating positive regression coefficients (Fig. 1B and C). The lower plant competition at the wider spacing increased yield per plant. At Arlington, a positive correlation was detected between fruit number and yield per plant at both spacings for BN1 [$r = 0.95$, $P \leq 0.05$ at lower plant density (LPD); $r = 0.99$, $P \leq 0.05$ at higher plant density (HPD)], at LPD for BN2 ($r = 0.95$, $P \leq 0.05$) and at HPD for V ($r = 0.98$, $P \leq 0.05$).

The negative coefficient of regression ($r^2 = 0.96$, $P \leq 0.05$) between fruit number per plant and average fruit weight for BN1 at Arlington for the higher plant density (Fig. 1D) is consistent with data from previous studies. (Richardson and MacAneney, 1990; Rowe and Johnson, 1992).

Fig. 1. Coefficients of regression demonstrating the relationships between muskmelon fruit number/plant vs. g/plant and g/fruit, and primary branch number vs. g/plant and g/fruit. (A) = BN1 at Hancock at the lower plant density (LPD), (B) = BN1 at Hancock at LPD, (C) = BN2 at Hancock at LPD, (D) = BN1 at Arlington at the higher plant density (HPD), and (E) = V at Arlington at LPD (* $P \leq 0.05$, ** $P \leq 0.01$). BN1 = Birdsnest 1 'Qalya', BN2 = birdsnest 2 experimental F5 line, V = vining 'Mission'.

Number of primary branches and yield per plant of the V genotype were positively correlated ($r = 0.99$, $P \leq 0.05$) at the wider spacing at Arlington (Table 3), and thus positively demonstrated the regression coefficient in Fig. 1E. An increase in the number of branches might increase fruit number per plant, which could increase sink demand (Marcelis, 1991). In turn, the increase in sink demand could improve net photosynthesis, resulting in a higher yield per plant.

When genotypes and locations were combined over spacings, a high correlation between sugar concentration and average fruit weight was detected ($r = 0.93$, $P \leq 0.001$ at LPD; $r = 0.84$, $P \leq 0.001$ at HPD). These results would indicate that soluble solids increased in proportion to fruit size (data

not shown). However, data from BN2 appeared to distort the data because of its poor growth and low soluble solids concentration. In actuality, fruit sugar concentrations seemed to remain fairly constant regardless of fruit size (personal observation) when fruit were harvested at full slip or complete ripeness.

Conclusions

Between- and within-row spacing can affect the productivity of melon genotypes (Bhella, 1985). Productivity under high plant density can differ depending upon plant architecture (Knave, 1988). Our results support these observations and indicate that both environment (location) and spacing can affect

the productivity of birdsnest-type melons (BN1 vs. BN2) (Tables 1 and 2).

Increased fruit weight at the lower plant density changed fruit sugar concentration and had no effect on percentage of soluble solids in the melon juice at Hancock, although no differences in soluble solids were observed at Arlington. Our results indicate that growers might obtain higher yield and greater fruit number per hectare, but smaller fruit at a narrower spacing. If a higher yield per plant is desirable, then wider spacing can be employed. Moreover, results suggest that birdsnest-type melon genotypes can be grown at relatively high plant populations without significant reductions in fruit quality.

Increasing yield potential of melon via breeding multiple lateral branching genotypes with small plant stature has been suggested as a means of improving fruit quality (Nelson et al., 1982; Paris et al., 1983). However, developing productive genotypes with high sugar content has been difficult. Nevertheless, differences among birdsnest breeding lines are often observed. For instance, although the BN2 type had some advantages over the vining type examined (a more compact growth habit, earlier fruit set and maturity, and the potential for once-over harvest), its sugar concentration was lower than those of the vining and the multiple branching type BN1. If plant improvement programs can increase the sugar concentration in BN2-like genotypes, then commercially acceptable derivatives of this muskmelon type might be developed for growers in once-over, early harvesting operations.

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