Influence of Plant Density and Cultivar on Mini Triploid Watermelon Yield and Fruit Quality

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SUMMARY. Mini triploid (seedless) watermelons (*Citrullus lanatus*) are a growing segment of the U.S. watermelon market due to their small, one-serving size. Although mini triploid watermelons were first released and commercially grown about 6 years ago, little information is available for optimum planting densities that are needed to achieve the greatest percentage of marketable fruit in the 3- to 8-lb range. In 2006 and 2007, the fruit grade distribution response to six plant densities (2489, 3111, 4149, 6223, 8297, and 12,446 plants/acre) of four mini watermelon cultivars (Betsy, Petite Treat, Valdoria, and Vanessa) was measured at the Southern Illinois University Horticulture Research Center in Carbondale. 'SP-1' was used as the in-row pollinizer at 25% of the total planting. Although all cultivars responded similarly to the plant densities evaluated, 'Vanessa' provided the greatest fruit number and weight per acre, and percentage of fruit in the mini grade, compared with the other cultivars. Marketable mini triploid watermelon yield dramatically increased with closer in-row spacings. At lower plant densities (wider in-row spacings), a greater proportion of icebox-sized fruit (>8 lb) was produced, and the amount of marketable, mini-sized fruit (3–8 lb) declined. The grade distribution of mini triploid watermelon numbers and weights were the greatest at the highest plant density evaluated [0.5 ft in-row spacing (12,446 plants/acre)], with about 80% of the total yield in the mini grade. The greatest net revenues were also obtained at this high density. This study indicated that it is critical for producers of mini triploid watermelons to recognize the dramatic impact that plant density has on marketable fruit yield (3–8 lb). Growers of mini triploid watermelons will see a drastic improvement in revenues with closer in-row spacings compared with the approximate 2 ft in-row spacings currently used (about 4000 plants/acre). The increased cost of higher plant densities are more than offset by the greater return on investment.

Although mini triploid watermelons are a relatively new specialty vegetable, they have captured a segment of the watermelon market due to their convenience (Maynard and Perkins-Veazie, 2004). These types of watermelons garner a premium retail price ranging from \$4 to \$5 for a marketable 3- to 8-lb fruit (Schultheis et al., 2007). Desirable traits for mini triploid watermelons include oval- or round-shaped fruit in

the 3- to 8-lb range, and an attractive solid or striped fruit rind that is also thin and tough. The flesh should be dark red, crisp, sweet, and seedless (Maynard and Perkins-Veazie, 2004).

Although extensive work has been done to identify high-yielding mini triploid watermelon cultivars (Maynard and Perkins-Veazie, 2004; Schultheis et al., 2007; Strang et al., 2004), little has been done to determine the optimum spacing for mini

triploid watermelon to obtain the highest percentages of marketable fruit (packout) in the 3- to 8-lb range. Increasing watermelon plant densities by using closer in-row plant spacings have generally resulted in reducing the fruit size of large and small seeded watermelon cultivars (Duthie et al., 1999b; NeSmith, 1993; Sanders et al., 1999). Preliminary reports suggest that the production of marketable mini triploid watermelons seems to increase with closer plant spacings (Thompson and Schultheis, 2008; Strang et al., 2005). Most commercial seed suppliers recommend using about half the standard in-row spacings (about 2 ft or ≈4000 plants/acre) that are used for large-sized watermelons to maximize mini triploid watermelon yields. Therefore, due to the limited information available from multiyear, replicated studies regarding mini triploid watermelon planting densities, a study was conducted to determine the plant densities needed to obtain the highest percentage of marketable (3–8 lb) mini triploid watermelon fruit.

Materials and methods

The experiment was conducted at the Southern Illinois University Horticulture Research Center in Carbondale during 2006 and 2007. The experiment was designed as a split-plot with three replications. The main plot treatments were six in-row plant spacings: 1) 0.5 ft (12,446 plants/acre), 2) 0.75 ft (8297 plants/acre), 3) 1 ft (6223 plants/acre), 4) 1.5 ft (4149 plants/acre), 5) 2 ft (3111 plants/acre), and 6) 2.5 ft (2489 plants/acre). Subplots consisted of four mini triploid watermelon cultivars: Betsy, Valdoria, and Vanessa from Nunhems USA (Parma, ID); and Petite Treat from Zeraim Gedera Seed (Palm Desert, CA). Plots were 10 ft in length. 'SP-1' pollinizer

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The use of trade names in this publication does not imply endorsement of the products named or criticism of similar ones not mentioned.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.1242	gal/100 ft	L·m ⁻¹	8.0520
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
0.0254	mil	mm	39.3701
2.3385	qt/acre	L·ha ⁻¹	0.4276
0.9072	ton(s)	Mg	1.1023

plants (Syngenta, Research Triangle Park, NC) were also planted every fourth plant in the row among the mini triploid watermelon plants. Although the number of pollenizer plants varied per 120-ft-long row from 12 to 60, a triploid to pollenizer ratio of 3:1 or 4:1 was always maintained in each plot, which should have provided sufficient amounts of pollen for triploid fruit set (Fiacchino and Walters, 2003).

Watermelon seeds were planted in early May into 72-cell plastic trays (TLC Polyform, Plymouth, MN) containing a soilless media consisting of peatmoss (Conrad Fafard, Agawam, MA), vermiculite (Sun Gro Horticulture, Pine Bluff, AR), and perlite (Lite Weight Products, KS City, KS) in a 2:1:1 ratio by volume. Seedlings remained in the greenhouse for 2 weeks after emergence until plants had reached the one- to two- true-leaf stage. Transplants were then hardened-off in coldframes for 1 week before transplanting. Watermelon plants were transplanted into 6-inch-high raised beds that were formed on 7-ft centers and covered with 6-ft-wide, 1.25-mil black plastic mulch. The field soil was a Hosmer silt loam (fine-silty, mixed, mesic Typic Fragiudalfs) (Herman, 1979). Before bed formation, 40 lb/acre nitrogen (N) from ammonium nitrate (NH_4NO_3), 52 lb/acre phosphorus pentoxide (P_2O_5), and 98 lb/acre potassium oxide (K_2O) from potassium chloride (KCl) were broadcast and incorporated. Beginning at the four- to five-true-leaf stage, 3 to 5 lb/acre N from calcium nitrate [$\text{Ca}(\text{NO}_3)_2$] was applied weekly through the drip fertigation system (0.22 gal/100 ft per minute) as recommended by Sanders et al. (1995). Diseases and insects were controlled with standard foliar sprays of esfenvalerate (Asana; E.I. du Pont de Nemours, Wilmington, DE) and chlorothanil (Bravo; Zeneca, Wilmington, DE) at 10-d intervals starting at the four- to five true-leaf stage (Egel et al., 2006). Applications of paraquat dichloride (Gramoxone Max; Syngenta Crop Protection, Greensboro, NC) at 1 qt/acre, as well as mechanical cultivation, were used to suppress weed growth between rows of plastic. When plants were in full flower, a honeybee colony (>25,000 bees) was placed within 50 m of the test site each year.

Mature watermelon fruit from each plot were harvested, weighed, and recorded twice during a 2-week period beginning in early August. Watermelons were harvested based on the presence of a desiccated tendril opposite the fruit pedicle and yellow coloration of the fruit belly (portion touching the ground). Four watermelons per plot were examined at the first harvest for hollow heart damage, soluble solids, rind thickness (in inches), and number of colored seed that were readily visible within the flesh on both halves of a longitudinally cut fruit. For hollow heart, the width of the gap in the flesh at its widest point was determined in inches. Soluble solids were also tested on the same watermelons using a hand-held refractometer (Fisher Scientific, Pittsburgh) measuring one sample from the central portion of the cut flesh at 0% to 18%. Fruit rind thickness was measured as the width of the white rind extending from the skin surface to the red flesh.

Watermelons were separated into three grade classifications before analysis: micro (<3 lb), mini (3–8 lb) and icebox (>8–13 lb). Analysis of variance procedures were performed using the general linear models procedure of SAS (version 8.2; SAS Institute, Cary, NC) to identify the seedless watermelon cultivars having the highest yields in the mini class, as well as superior horticultural quality characteristics. Regression analysis was also used to determine the relationship between plant density and yield for each grade (fruit numbers and weights per acre, as well as fruit numbers per plant). The impact of plant density on calculated gross and net revenues were also determined. Watermelon transplants are normally sold in bundles that contain 1000

mini triploid and 250 pollenizer plants for ≈\$415, which directly relates to a 4:1 seedless to pollenizer ratio (C. Mathis, personal communication); other fixed and variable costs (not including labor) are about \$4000 for watermelons produced on black plastic mulch and were based on watermelon production budgets from California (Meister, 2004) and Florida (Smith and Taylor, 2007). Although harvest costs will vary substantially depending on watermelon size, amount of resorting, container packed, transportation, and other miscellaneous fees, labor costs were estimated at \$0.0375/lb for the harvested fruit weight for a particular density. This estimate was based on paying laborers \$7.50/h, which related to about \$75/ton of harvested fruit based on the watermelon production budget for California (Meister, 2004). Locally grown mini seedless watermelon typically sell for about \$3.50 each in farm markets, while the grower that uses wholesale markets will garner about \$1.40 for each watermelon (J. Schultheis, personal communication). In many wholesale markets, the micro-sized fruit are considered culls and have no value. Partial budget analysis can be useful to determine if changes in watermelon management practices increase revenues and require three types of information including yield, market price, and production costs (Lu et al., 2003). Therefore, partial budget analysis was used to determine the effect of mini triploid watermelon plant density on revenues obtained in local and wholesale markets for mini-sized fruit.

Results

The analysis indicated no interactions ($P > 0.05$) between years and mini triploid watermelon cultivar or

Table 1. Mini triploid watermelon cultivar quality characteristics combined over the 2006 and 2007 growing seasons.

Cultivar	Hollow heart (inch) ^z	Colored seed (no.) ^y	Fruit rind thickness (inch) ^x	Soluble solids (%) ^w
Betsy	0.2 b ^v	1.4 ab	1.0 a	11.8 b
Petite Treat	4.1 a	0.7 b	0.5 a	12.6 a
Valdoria	0.3 b	2.4 a	0.5 a	11.8 b
Vanessa	0.7 b	0.6 b	0.8 a	11.6 b

^zHollow heart was measured as the width of the gap in the separated flesh at its widest point; 1 inch = 2.54 cm.

^yNumber of colored seed readily visible on or near the flesh surface of a longitudinally cut fruit.

^xFruit rind thickness was the width of the white rind extending from the red flesh to the skin surface.

^wSoluble solids were measured using a hand-held refractometer measuring from 0% to 18%.

^vMeans followed by the same letter within a column do not differ significantly according to Fisher's protected least significant difference at $P \leq 0.05$. Fruit harvested about 80 d after transplanting.

plant density for all dependent variables evaluated, therefore years were combined. Furthermore, no interactions ($P > 0.05$) were detected between cultivar and plant density for all variables evaluated, indicating that all cultivars responded similarly to the plant densities evaluated.

MINI TRIPLOID WATERMELON QUALITY CHARACTERISTICS. Watermelon fruit quality was not influenced by plant density (data not presented), but was frequently affected by cultivar (Table 1). 'Petite Treat' had low amounts of colored seed in the edible flesh and high soluble solids, but had the highest amounts of hollow heart compared with the other cultivars. 'Betsy', 'Valdoria', and 'Vanessa' had negligible hollow heart injury, with soluble solids not differing among these three cultivars. 'Vanessa' had low numbers of colored seed, similar to 'Petite Treat'. All four cultivars had similar fruit rind thickness, ranging from 0.8 to 1.0 inches.

MINI SEEDLESS WATERMELON CULTIVAR YIELDS. 'Vanessa' produced the greatest number (80% of total) and weight (81% of total) of fruit in the mini class (Table 2). 'Petite Treat' yielded the lowest total fruit number, weight per acre, and melon number per plant compared with the other cultivars. Furthermore, 'Petite Treat' and 'Valdoria' had the lowest percentages of mini-sized fruit numbers at 66% and 71%, respectively, as well as the lowest percentage of mini-sized fruit weights at 59% and 66%, respectively. 'Valdoria' produced large numbers of icebox-grade fruit that were greater than 'Betsy', 'Petite Treat', or 'Vanessa'.

SPACING EFFECTS ON MINI SEEDLESS WATERMELON YIELD. As in-row spacings were reduced from 2.5 to 0.5 ft, micro fruit number increased in a linear manner, and mini and total fruit number increased quadratically (Table 2); furthermore, icebox fruit number per acre decreased in a quadratic manner (from 2963 to 1245). The 0.5 ft in-row spacing provided the greatest micro, mini, and total fruit number per acre. Reducing the in-row spacing provided an increase in micro- and mini-grade fruit weight, as well as total fruit weight in the same trend response as fruit number had exhibited, while icebox fruit weight decreased.

The relationship of total fruit numbers produced per plant with

Table 2. Mini triploid watermelon yield characters as influenced by cultivar and density combined over the 2006 and 2007 growing seasons.

Cultivar/plant density		Watermelon yields ^z										
		Fruit (no./acre)			Fruit wt (lb/acre)			Fruit (no./plant)				
		Micro	Mini	Icebox	Total	Micro	Mini	Icebox	Total			
Cultivar												
Betsy		479 b ^y	7,396 b	1,632 b	9,507 bc	1,127 b	41,931 b	14,624 b	57,682 ab			2.5 a
Petite Treat		761 ab	5,946 c	1,673 b	8,380 c	1,639 b	32,484 c	15,051 b	49,174 b			2.0 b
Valdoria		765 ab	6,312 bc	2,518 a	9,595 bc	1,577 b	35,595 bc	22,737 a	59,909 a			2.5 a
Vanessa		1,186 a	9,665 a	1,270 b	12,121 a	2,678 a	51,529 a	9,782 b	63,989 a			2.7 a
Plant density	In-row											
	spacing (ft) ^x											
2,489	2.5	237	3,971	2,963	7,171	554	23,072	28,430	52,056			3.8
3,111	2.0	280	6,191	2,276	8,747	663	35,026	21,628	57,317			3.1
4,149	1.5	404	6,466	2,137	9,007	977	37,091	20,333	58,401			2.4
6,223	1.0	815	7,637	1,618	10,070	1,643	41,490	14,831	57,964			2.0
8,297	0.75	1,284	8,362	1,358	11,004	3,298	44,137	12,632	60,067			1.8
12,446	0.5	1,511	11,201	1,245	13,957	3,482	58,682	11,447	73,611			1.5
Significance												
Linear		*	**	*	**	*	**	*	*	*	*	*
Quadratic		NS	**	*	**	NS	**	*	*	*	*	*

^xWatermelons were separated into three grade classifications: micro (<3 lb), mini- (3–8 lb), and icebox size (>8–13 lb); 1 lb = 0.4536 kg, 1 fruit/acre = 2.4711/ha, 1 lb/acre = 1.1209 kg/ha⁻¹.

^yFor the four cultivars evaluated, means followed by the same letter within each column do not differ significantly according to Fisher's protected least significant difference at $P \leq 0.05$.

²Plant density included 20% to 25% 'SP-1' pollinizer plants in the plant total. Center to center row spacing was 7 ft; 1 plant/acre = 2.4711 plants/ha, 1 ft = 0.3048 m.

NS, *, **, Not significant or significant at $P \leq 0.05$ or $P \leq 0.01$, respectively.

Fig. 1. The effect of mini triploid watermelon plant density on the percentage of micro-, mini-, and icebox-sized watermelon fruit numbers produced. The grade distribution by fruit size class (%) was based on total fruit numbers produced per acre. Watermelons grade classes were: micro (<3 lb), mini (3–8 lb), and icebox (>8–13 lb) (1 lb = 0.4536 kg). Curves presented represent best-fit regressions with plant density. For percentage of micro and icebox fruit numbers produced per acre, quadratic models best explained the relationship with in-row plant density: y (% microsize fruit numbers) = $-3.964 + 0.003$ (plant density) $- 1.300 \times 10^{-7}$ (plant density)², $R^2 = 0.95$, $P = 0.0127$; y (% icebox-size fruit numbers) = $55.450 - 0.009$ (plant density) + 4.282×10^{-7} (plant density)², $R^2 = 0.90$, $P = 0.0328$. For mini fruit numbers produced per acre, a linear model best explained the relationship with in-row plant density: y (% mini-size fruit numbers) = $60.817 + 0.002$ (plant density), $R^2 = 0.60$, $P = 0.0725$. Plant density included 25% ‘SP-1’ pollinizer plants in the plant total; 1 plant/acre = 2.4711 plants/ha.

in-row spacings were best described by a quadratic model (Table 2). As in-row spacings increased from 0.5 to 2.5 ft, the number of fruits produced per plant also increased. Although only 1.5 fruit per plant were produced on average at the 0.5 ft spacing, a 5-fold increase in plant density almost doubled the total number of fruit from 7,171 to 13,957 per acre.

A quadratic relationship best described the slight increase of micro-sized fruit numbers produced per acre from 3.3% to 10.8% as plant density increased from 2,489 to 12,446 plants/acre (Fig. 1). The greatest percentage of mini-sized fruit numbers occurred at the closest in-row spacing, as about 80% were produced at the 12,446 plants/acre density. The percentage of icebox-size fruit decreased with density as

Table 3. The effect of mini triploid watermelon plant density on partial budget analysis using marketable yields combined over the 2006 and 2007 growing seasons.

Plant density (plants/acre) ^z	In-row spacing (ft) ^z	Costs (\$/acre) ^x			Gross revenues (\$/acre) ^y		Net revenues (\$/acre) ^u	
		Plant costs ^y	Labor ^x	Total ^w	Local	Wholesale	Local	Wholesale
2,489	2.5	826	1,952	6,778	13,899	5,559	7,121	-1,219
3,111	2.0	1,033	2,149	7,182	21,669	8,667	14,487	1,485
4,149	1.5	1,378	2,190	7,568	22,631	9,052	15,063	1,484
6,223	1.0	2,066	2,174	8,240	26,730	10,692	18,490	2,452
8,297	0.75	2,755	2,253	9,008	29,267	11,707	20,259	2,699
12,446	0.5	4,132	2,760	10,892	39,201	15,681	28,309	4,789
Significance								
Linear	—	—	*	*	**	**	**	**
Quadratic	—	—	**	**	**	**	*	NS

^z1 plant/acre = 2.4711 plants/ha, 1 ft = 0.3048 m, \$1/acre = \$2.4711/ha.

^yMini seedless watermelon plants for field planting costs figured at \$415 per 1250-plant bundles [1000 seedless and 250 pollinizer plants (4:1 seedless to pollinizer ratio) (C. Mathis, personal communication)].

^xLabor costs were also estimated at \$0.0375/lb (\$0.08267/kg) for all harvested fruit weight for a particular density. This estimate was based on paying laborers \$7.50/h, which related to about \$75/ton (\$82.67/Mg) of harvested fruit based on the watermelon production budget for California (Meister, 2004).

^wTotal costs were estimated from an approximate \$4000 fixed and variable costs (without labor) based on black plastic mulch watermelon production budgets in California (Meister, 2004) and Florida (Smith and Taylor, 2007) + plant costs + labor costs.

^yGross revenues were calculated from mini-sized triploid watermelon fruit number obtained per acre multiplied by \$3.50 and \$1.40 per piece for local and wholesale markets, respectively, for each plant density evaluated. Locally grown mini triploid watermelon typically sell for about \$3.50 each in farm markets, while the grower that uses wholesale markets will garner about \$1.40 for each watermelon (J. Schultheis, personal communication).

^uNet revenues were calculated based on: gross revenues – total costs.

NS, *, ** Not significant or significant at $P \leq 0.05$ or $P \leq 0.01$, respectively.

less than 10% were found in this grade at the highest plant density (12,446 plants/acre). Results for the percentages of micro-, mini-, and icebox-sized fruit weight per acre were similar to that obtained for fruit number (data not shown).

POTENTIAL REVENUE GENERATION BY PLANT DENSITY. Increased plant densities improved gross and net revenues from mini-sized triploid watermelon fruit. Although watermelon transplant and labor costs were the greatest at the 12,446 plants/acre density, the highest net revenues per acre occurred at this density with \$28,309 and \$4,789 for local and wholesale markets, respectively (Table 3). The net revenue generally dropped at each level of plant density as it declined from 8297 to 3111 plants/acre. At the 2489 plants/acre density, net revenues were \$7121 and -\$1219 for local and wholesale markets, respectively.

Discussion

It is critical that producers of mini triploid watermelons recognize the dramatic impact that plant density has on marketable fruit yields (3–8 lb). Our study indicated that the grade distribution of mini triploid

watermelon numbers and weights were the greatest at the highest plant density evaluated [0.5 ft in-row spacing (12,446 plants/acre)] with about 80% of the total yields in the mini-grade at this density. Using large triploid watermelon cultivars, Motsenbocker and Arancibia (2002) suggested that growers should be able to adjust in-row spacings to achieve a particular range in triploid watermelon fruit size; and, small-sized fruit (8–14 lb) provided the largest fruit category providing 54% of the total yield at the closest in-row spacing evaluated (2 ft). Furthermore, from a 1-year preliminary study, Strang et al. (2005) indicated that higher plant densities (7260 and 4840 plants/acre) provided the greatest marketable numbers of mini ‘Mohican’ triploid watermelons compared with lower densities (3630 and 2904 plants/acre), and similar to our results, wider in-row spacings (lower plant densities) resulted in high numbers of icebox-size (>8–13 lb) triploid watermelon fruit.

Several studies, including Duthie et al. (1999b), Motsenbocker and Arancibia (2002), and Sanders et al. (1999) indicated that closer in-row watermelon plant spacings result in lower fruit numbers per plant

compared with wider spacings, and this affect was also observed on the mini triploid watermelon cultivars evaluated (Table 2). Furthermore, Duthie et al. (1999a) indicated that watermelon yield per plant tends to decrease with higher plant densities because interplant competition intensifies and this directly suppresses plant growth, resulting in lower yields per plant.

Although Duthie et al. (1999a) states that the potential yield of watermelon genotypes varies with plant density (especially average fruit size at harvest), the four mini triploid watermelon cultivars evaluated herein responded similarly to plant density. However, 'Vanessa' clearly provided the greatest yields and a high percentage of mini-sized fruit compared with the other cultivars evaluated, which was similar to results from Maynard and Perkins-Veazie (2004) and Strang et al. (2005).

Although Strang et al. (2005) suggested that high plant populations (7260 and 4840 plants/acre) provided the greatest marketable numbers of mini 'Mohican' triploid watermelon, our results indicated that even higher plant densities (8,297 and 12,446 plants/acre) can be used to increase marketable triploid mini watermelon number and weight. However, growers should also consider the increase in seed or plant costs that are needed for these high plant populations. Seedless watermelon plant costs for field planting are five times greater when using 0.5 ft in-row spacing compared with 2.5 ft (Table 3). However, our study indicated that the greatest net revenues were obtained at the highest density evaluated (0.5 ft in-row spacing or 12,446 plants/acre). Growers should see a drastic improvement in revenues with closer in-row plant spacings (Table 3). Based on our results, growers can reduce their in-row spacing to 0.5 ft with a concomitant increase in net revenue. This would increase the mini triploid watermelon density by about 8000 plants/acre from the approximate

4000 plants/acre that most commercial growers currently use (J. Faison, personal communication). Lu et al. (2003) indicated that an increase in watermelon production management intensity (especially for triploid types) will often increase profitability as the higher net returns produced can compensate for the higher production costs. However, high plant densities may demand additional fertilizer applications, and extra pesticide applications may also be warranted due to possible increases in disease and insect incidence. Although the monetary inputs required to produce mini-triploid watermelons grown at high plant densities would be higher compared with lower plant densities, the slight risk incurred would more than compensate for the potential to improve marketable yields and provide greater percentages of fruit in the 3- to 8-lb class.

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