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Flowering Patterns of Pollenizer and Triploid Watermelon Cultivars

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***Abstract*. The past 10 years has seen a steep increase in production of seedless watermelon (*Citrullus lanatus*) in the United States. Seedless fruit is produced on triploid plants that require pollination from diploid pollenizers for fruit set. Synchronization of the staminate flowers on the pollenizers with the appearance of pistillate flowers on the triploids is a fundamental requirement for this production system. Previous research suggested that pistillate flowers reach peak production early in the season, but data are only available for a small number of triploid cultivars. We compared the flowering patterns of 29 triploid cultivars and 20 pollenizers, including 10 harvested pollenizers, during the first 6 weeks after transplanting over 2 years. The average number of days from transplanting (DAT) to the first staminate flower was between 5.3 days and 19.1 days in 2012 and 9.7 days and 24.4 days in 2013 for the pollenizers and between 18.7 days and 27.6 days and 22.1 days and 32.7 days for the pistillate triploid flowers in the 2 years, respectively. K-means clustering of the weekly percentage of plants with staminate and pistillate flowers for the different cultivars shows that different triploid and pollenizer cultivars have different flowering patterns and that some combinations have better synchronized flowering than others. Growers should take particular care when choosing pollenizers for early-flowering triploid cultivars. Harvested pollenizers are better suited to late-flowering triploids and growers should choose triploid and pollenizer cultivar combinations with flowering patterns that best satisfy their specific production goals.**

Watermelon (*Citrullus lanatus*) production acreage in the United States in 2010 was 132,600 acres with a value of ≈$500 million. The percentage of watermelon production devoted to seedless fruit has increased dramatically from 51% in 2003 to 85% in 2009 (U.S. Department of Agriculture, 2011). The seedless fruit is produced on triploid plants, but because pollination and fertilization are required for fruit set, and these plants produce negligible amounts of viable pollen, diploid pollen sources (pollenizers) are required (Boyhan et al., 2000; Maynard, 1992; Maynard and Elmstrom, 1992).

Growers interplant the triploid cultivars and diploid pollenizers in the production field and are then dependent on the pollenizers producing staminate flowers on the same days the triploids produce pistillate flowers. The system is complicated by the monoecious nature of watermelon with cultivars producing approximately one pistillate flower for every seven staminate flowers (Wehner, 2008). If a pistillate flower is not pollinated on the day it opens, it will abort and it may take days before the next pistillate flower opens, leading to delayed fruit set.

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Growers use either elite seeded cultivars as pollenizers (harvested pollenizers) or specialized non-harvested pollenizers developed specifically for this purpose. These specialized pollenizers are usually compact plants (so as not to compete with triploids), producing small inedible fruit with a rind pattern that can easily be distinguished from the triploid during harvesting. The choice of using edible or specialized pollenizers depends on whether the grower has a market for the seeded varieties. The choice of pollenizer affects yield (Dittmar et al., 2010; Fiacchino and Walters, 2002). There are several traits that are considered desirable for pollenizers such as compact growth habit (Freeman et al., 2007b) and flower attractiveness to pollinators (Freeman and Olson, 2007b). However, the most basic requirement is synchronized flowering patterns between the pollenizer cultivar and triploid cultivar (Dittmar et al., 2009, 2010). The goal is for the pollenizer to have plentiful staminate flowers at the time the triploid plant produces pistillate flowers, simulating the flowering pattern of a single plant on two different plants. The choice of pollenizer–triploid combination is critical for timely production (Dittmar et al., 2010; Freeman et al., 2007a; Maynard and Elmstrom, 1992).

Dittmar et al. (2009) compared flowering patterns of two triploids and 13 pollenizers by collecting data for the number of pistillate and staminate flowers from 4 to 9 weeks after transplanting and found that peak performance of pistillate flowers was often in Week 5 or 6, which was earlier than the peak production of staminate flowers for the pollenizers. In 2005 one of the triploid cultivars, Tri-X-313, already had a large number of pistillate flowers when the study started. If this is a common phenomenon, it could mean less than optimal amounts of pollen are available for early-flowering triploids.

The aim of the current study was to compare the flowering patterns of a large number of popular pollenizer and triploid cultivars early in the season to determine which triploid cultivars and pollenizers have complementary flowering patterns.

Materials and Methods

Plant material. In 2012, 17 pollenizers and 17 triploid cultivars were included and in 2013, 29 triploid and 20 pollenizer cultivars were included in this study (Table 1). In both years, 10 of the pollenizers were non-harvested pollenizers. Seeds were sown in seedling trays in the greenhouse on 23 Apr. 2012 and 29 Apr. 2013, and plants were hand-transplanted in the field at the Durham Horticulture Farm (Watkinsville, GA; sandy loam soil) on 21 May 2012 and 23 May 2013 after hardening off for 1 week. One plant per cultivar was planted per block in a completely randomized block design with 10 blocks. Plants were grown according to University of Georgia Cooperative Extension Service recommendations on plastic mulch with between-row spacing of 1.83 m and in-row spacing of 0.9 m. In both years, one-third of the total fertilizer for the 6-week study duration (100.8N–44P–83.7K $kg \cdot ha^{-1}$) was applied pre-plant and the rest using weekly fertigation. Drip tape was used for irrigation in both years. Four applications of chlorothalonil (1.9 $L \cdot ha^{-1}$ a.i.) were applied over the 6-week period, starting the second week after transplanting. Fields were scouted for insects and Asana XL (0.63 $L \cdot ha^{-1}$) or Brigade 2EC (0.45 $L \cdot ha^{-1}$) was applied to control squash bugs and cucumber beetles as needed. Weeds were controlled early in the season by one application of glyphosate (18.6 $mL \cdot L^{-1}$ a.i.) in the row middles and hand-weeding during the rest of the season.

In 2012, the vines were turned once a week to make data collection easier. In 2013 high rainfall prevented turning the vines before data collection.

Data collection. Data were collected three times a week, for six weeks after transplanting, except for the first week when data were collected twice. For all pollenizers, data were collected on the number of open staminate flowers on that particular day for each plant, whereas the presence of open pistillate flowers was recorded for triploids and harvested pollenizers. Any hermaphroditic flowers were scored as pistillate flowers.

Statistical analysis. The number of days from transplanting to the first open flower and number of staminate flowers per flowering plant were analyzed using JMP Pro Version 10.0.1 (SAS Institute, Cary, NC). Analysis of variance was used to determine the significance of the cultivar and year main effects and their interactions. Tukey's honestly

Table 1. The triploid and pollenizer watermelon cultivars used in this study.

Cultivar	Company	Description	Flower data collected	
			Staminate	Pistillate
Accomplice	Harris Moran Seed Company	Non-harvested pollenizer	X	
Ace	Sakata	Non-harvested pollenizer	X	
ACR 10319DP	Bayer	Non-harvested pollenizer	X	
Affirmed	Sakata	Triploid		X
AU Producer	Hollar	Harvested pollenizer	X	X
Bold Ruler	Sakata	Triploid		X
Citation	Sakata	Triploid		X
Crimson Sweet	Seedway	Harvested pollenizer	X	X
Crunchy Red	Harris Moran Seed Company	Triploid		X
Declaration	Bayer	Triploid		X
Exclamation	Syngenta	Triploid		X
Extazy	Hazera Genetics	Triploid		X
Fascination	Syngenta	Triploid		X
Gladiator	Bayer	Non-harvested pollenizer	X	
Imagination	Syngenta Seeds, Inc.	Triploid		X
Jenny	Bayer	Non-harvested pollenizer	X	
Leopard	Hazera Genetics	Triploid		X
Liberty	Bayer	Triploid		X
Majestic	Monsanto Vegetable Seeds	Triploid		X
Melody	Syngenta Seeds, Inc.	Triploid		X
Mickylee	Hollar	Harvested pollenizer	X	X
Minipol	Hazera Genetics	Non-harvested pollenizer	X	
Nun01007	Bayer	Triploid		X
Nun01009	Bayer	Triploid		X
Polimax	Bayer	Non-harvested pollenizer	X	
Pollen Pro	Syngenta Seeds, Inc.	Non-harvested pollenizer	X	
Revolution	Bayer	Triploid		X
Serval	Hazera Genetics	Triploid		X
Side Kick	Seed Company	Non-harvested pollenizer	X	
SP-5	Syngenta Seeds, Inc.	Non-harvested pollenizer	X	
SP-6	Syngenta Seeds, Inc.	Non-harvested pollenizer	X	
SSX8585	Sakata	Harvested pollenizer	X	X
Starbrite	Monsanto Vegetable Seeds	Harvested pollenizer	X	X
StarGazer	Monsanto Vegetable Seeds	Harvested pollenizer	X	X
Sugar Coat	Syngenta Seeds, Inc.	Triploid		X
Sugar Heart	Syngenta Seeds, Inc.	Triploid		X
Summer Flavor 720	Bayer	Harvested pollenizer	X	X
Summer Flavor 790HQ	Bayer	Harvested pollenizer	X	X
Summer Flavor 800	Bayer	Harvested pollenizer	X	X
Summer Sweet 5244	Bayer	Triploid		X
SuperSeedless 6177 Plus	Bayer	Triploid		X
SuperSeedless 7197 HQ	Bayer	Triploid		X
SuperSeedless 9651 HQ	Bayer	Triploid		X
SuperSeedless 7167	Bayer	Triploid		X
SuperSeedless 7187HQ	Bayer	Triploid		X
Sweet Gem	Syngenta Seeds, Inc.	Triploid		X
SWT7829	Sakata	Triploid		X
Traveler	Harris Moran Seed Company	Triploid		X
Troubadour	Harris Moran Seed Company	Triploid		X
WT2527	Monsanto Vegetable Seeds	Harvested pollenizer	X	X

significant difference test was used to separate the least square means of significant effects.

K-means clustering of the weekly percentage of flowering plants for each cultivar was carried out using Euclidian distance with Cluster, Version 3.0 (de Hoon et al., 2004; Eisen et al., 1998). To determine the number of clusters, the sum of squared error was plotted for a number of cluster solutions in R (R Core Team, 2013) and the "elbow" point in the plot was used as a starting point. Flowering profiles and average cluster profiles for different numbers of clusters was then visually investigated for uniformity.

Results and Discussion

Data were collected 17 times during the 6-week period after transplanting in both years. In the first week, data were collected only two times and for all following weeks, data were collected three times a week. The only exception was in 2012 when data were collected twice in Week 3 and four times in Week 4.

To determine synchronized flowering patterns, we examined three traits for each cultivar: 1) the number of days from transplanting to the first staminate and/or pistillate flower; 2) the percentage of plants with staminate and/or pistillate flowers; and 3) the number of staminate flowers per flowering plant for pollenizers. There was a significant year effect for the traits (data not shown) and therefore data are presented separately for the 2 years.

The average number of DAT for the first staminate flower was between 5.3 d ('Ace') and 19.1 d ('Jenny') in 2012 and 9.7 d ('Ace' and 'Minipol') and 24.4 d ('SP 6') in 2013 (Table 2). For appearance of the first pistillate flower on triploids, the number of days to first flower was between 18.7 d ('Bold Ruler') and 27.6 d ('Fascination') in 2012 and 22.1 d ('Serval') and 32.7 d ('SuperSeedless 7197') in 2013 (Table 3). For several cultivars, the number of plants used for analysis was less than 10 (Tables 2 and 3). There were several reasons for this, including poor germination ('Bold Ruler', 2012), crows pulling out seedlings (2012), deer damage (2013), and flooding (2013). In some cases, plants were lost after data collection for the first staminate flower was completed, but not for the first pistillate flower, leading to different numbers of plants used for the two data sets (Tables 2 and 3). Pistillate flowering data were also collected for harvested pollenizers to compare natural flowering patterns on diploids.

Table 2. The average number of days after transplanting (DAT) to the appearance of the first staminate flowers and the percentage of flowering plants for pollenizer watermelon cultivars in 2012 and 2013.[z]

	2012								2013							
			Percentage of plants flowering								Percentage of plants flowering					
Cultivar	n	Mean (DAT)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	n	Mean (DAT)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Accomplice	9	12.0 abcdef[y]	0	89	100	100	100	100	6	18.2 ab	0	50	50	83	100	100
Ace	9	5.3 a	90	90	100	100	100	100	10	9.7 a	60	50	80	80	100	100
ACR 10319DP	10	13.7 bcdefg	10	50	90	90	100	100	—	—	—	—	—	—	—	—
AU Producer	9	16.3 efg	0	44	78	100	100	100	8	17.8 ab	0	0	67	67	100	100
Crimson Sweet	—	—	—	—	—	—	—	—	10	20.1 ab	0	71	71	43	100	100
Gladiator	—	—	—	—	—	—	—	—	9	15.8 ab	0	33	89	89	100	100
Jenny	8	19.1 g	0	25	50	88	100	100	10	16.5 ab	0	50	70	80	100	100
Mickylee	10	7.7 ab	60	90	100	100	100	100	8	12.4 ab	13	75	88	88	100	100
Minipol	8	7.5 abc	75	88	88	100	100	100	7	9.7 a	29	100	86	71	100	100
Polimax	9	17.2 efg	0	11	78	100	100	100	8	21.9 ab	0	38	50	63	88	100
Pollen Pro	10	8.2 abcd	30	100	100	100	100	100	9	16.7 ab	0	44	89	89	100	100
Summer Flavor *720*	8	17.8 fg	0	13	88	88	100	100	7	16.1 ab	0	57	71	71	100	100
Summer Flavor *790*	10	14.8 efg	10	30	60	100	100	90	10	21.9 ab	0	50	38	63	88	88
Summer Flavor *800*	10	14.4 defg	0	50	100	100	100	100	7	21.0 ab	0	60	20	0	100	100
Sidekick	10	14.4 defg	0	50	100	100	100	100	10	18.0 ab	0	30	90	90	100	100
SP 5	9	10.8 abcde	11	89	100	100	100	100	9	21.0 ab	0	11	56	78	100	100
SP 6	10	14.1 cdefg	0	60	100	100	100	100	9	24.4 b	0	0	33	78	100	100
SSX8585	—	—	—	—	—	—	—	—	6	22.5 ab	0	33	50	67	83	83
Starbrite	9	16.3 efg	11	11	89	100	100	100	9	20.9 ab	0	38	25	75	100	100
StarGazer	8	16.0 efg	0	50	75	100	100	100	9	20.3 ab	0	50	75	100	100	100
WT2527	—	—	—	—	—	—	—	—	8	14.8 ab	0	67	50	83	100	100

[z]Harvested pollenizers are indicated with italics.
[y]Values followed by the same letters within each year are not significantly different ($P < 0.05$) by Tukey's honestly significant difference test.

The earliest flowering (pistillate) harvested pollenizer was 'Mickylee' in 2012 (17.5 DAT) and 'AU Producer' (28.8 DAT) in 2013. In 2012 and 2013, the difference between the average appearance of the first staminate and pistillate flowers on harvested pollenizers ranged from 9.7 d ('AU Producer') to 17.5 d ('Summer Flavor 790' and 'Summer Flavor 800') and 6.8 d ('SSX8585') to 20.3 d, respectively (Tables 2 and 3). Harvested pollenizers generally tended to flower later than non-harvested pollenizers with 'Mickylee' being the notable exception. Flowers appeared significantly later in 2013 than 2012 (pistillate 4.81 d later; staminate 4.6 d later). There are many possible reasons for the delay in flowering in 2013, but the most obvious is the very high rainfall during the experimental period in 2013 (≈100 mm) compared with 2012 (≈350 mm) (Fig. 1).

In an effort to condense the data for the percentage of flowering plants for each cultivar into a form that is easier to interpret, we converted the daily data into weekly data (percentage of plants that flowered during a particular week for each cultivar). K-means clustering was then used to group cultivars with similar flowering patterns together (Figs. 2 and 3). Staminate flower patterns were clustered into four groups in both years (Figs. 2A–D and 3A–D), whereas pistillate flowering patterns were clustered into four groups in 2012 and five groups in 2013 (Figs. 2E–H and 3E–I). Flowering patterns for pollenizers generally showed a quick increase in the percentage of flowering plants early in the season until nearly all plants were flowering by Week 4 in 2012 and Week 5 in 2013. In 2013, the rate of increase of percentage flowering over time was slower than 2012. Interestingly, 'Crimson Sweet' and 'Summer Flavor 800' showed a dramatic decrease in percentage flowering plants from Week 2 to 4 in 2013. It is possible that these cultivars were more severely affected by the heavy rains during this period (Fig. 1) than the other cultivars. Together with the data from Dittmar et al. (2010) that showed decreased triploid yields when 'Summer Flavor 800' was used as a pollenizer, it suggests that this cultivar is probably not the optimum choice for pollenizer and should only be used when advantage can be taken of the diploid fruit it produces through a reliable market for seeded fruit (Dittmar et al., 2010).

Pistillate flowering percentages increased later in the season, reached its highest values at Weeks 4 and 5, and then declined. Flowering was later in 2013 and was still increasing at the end of the study period for cultivars in cluster 2013I (Fig. 3). To simplify the comparison of triploid and pollenizer flowering patterns, we plotted the averages for the individual clusters (Figs. 2 and 3) for staminate and pistillate flowers together (2012, Fig. 4A, and 2013, Fig. 4B). In both years flowering patterns show that most of the pollenizers reach high percentages of flowering well before the pistillate triploids and would make appropriate pollenizers. However, for clusters 2012E (Figs. 2E and 4A)

Table 3. The average number of days after transplanting (DAT) to the appearance of the first pistillate flowers and the percentage of flowering plants for triploid and harvested pollenizer (italics) watermelon cultivars in 2012 and 2013.

	2012								2013							
			Percentage of plants flowering								Percentage of plants flowering					
Cultivar	n	Mean (DAT)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	n	Mean (DAT)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Affirmed	10	24.0 abcdef[z]	0	0	20	80	80	70	9	24.1 abc	0	0	11	89	78	56
AU Producer	9	26.0 abcdef	0	11	0	56	89	33	6	28.8 abcd	0	0	0	50	67	17
Bold Ruler	3	18.7 abcd	0	0	67	100	67	67	9	23.4 ab	0	11	0	78	78	78
Citation	8	21.4 abcd	0	0	25	100	75	63	9	27.6 abcd	0	0	22	33	89	78
Crimson Sweet	—	—	—	—	—	—	—	—	7	33.7 bcd	0	0	0	29	43	86
Crunchy Red	9	26.8 bcdef	0	0	22	56	89	44	7	30.3 abcd	0	0	0	43	57	57
Declaration	—	—	—	—	—	—	—	—	10	29.2 abcd	0	0	0	50	60	50
Exclamation	—	—	—	—	—	—	—	—	8	32.6 bcd	0	0	0	38	63	63
Extazy	8	19.5 abc	0	13	50	100	100	75	9	29.9 abcd	0	0	11	22	89	56
Facination	10	27.6 cdef	0	0	0	70	90	30	8	32.5 bcd	0	0	0	38	75	50
Imagination	9	22.6 abcde	0	11	22	100	100	22	—	—	—	—	—	—	—	—
Leopard	—	—	—	—	—	—	—	—	10	29.8 abcd	0	0	0	60	80	80
Liberty	9	18.9 ab	0	20	70	70	70	50	6	28.7 abcd	0	0	17	33	83	17
Majestic	10	25.6 abcdef	0	0	10	50	100	50	10	30.3 abcd	0	0	0	50	80	40
Melody	10	22.0 abcd	0	10	40	100	100	40	9	25.0 abcd	0	0	0	89	89	44
Mickylee	10	17.5 a	0	40	30	100	70	40	8	31.9 bcd	0	0	0	13	75	63
Nun01007	—	—	—	—	—	—	—	—	6	29.5 abcd	0	0	0	50	67	17
Nun01009	—	—	—	—	—	—	—	—	9	29.0 abcd	0	0	11	44	89	0
Revolution	10	26.3 bcdef	0	0	20	60	80	70	7	30.4 abcd	0	0	0	43	100	43
Serval	—	—	—	—	—	—	—	—	10	22.1 a	10	20	30	80	90	20
Summer Flavor 720	8	31.5 ef	0	0	0	25	100	38	7	32.1 abcd	0	0	0	14	86	57
Summer Flavor 790	10	32.3 f	0	0	0	10	90	60	8	34.9 d	0	0	0	0	75	63
Summer Flavor 800	9	31.9 f	0	0	0	11	78	44	5	35.4 cd	0	0	0	0	40	80
Summer Sweet 5244	8	21.6 abcd	0	0	50	88	100	75	9	26.6 abcd	0	0	22	56	100	44
SuperSeedless 6177	—	—	—	—	—	—	—	—	8	30.8 abcd	0	0	0	25	88	50
SuperSeedless 7167	9	23.9 abcdef	0	0	22	67	89	22	7	30.0 abcd	0	0	0	57	43	43
SuperSeedless 7187	8	23.9 abcdef	0	0	25	50	100	50	9	28.7 abcd	0	0	11	44	78	44
SuperSeedless 7197	—	—	—	—	—	—	—	—	7	32.7 bcd	0	0	0	29	71	57
SuperSeedless 9651	—	—	—	—	—	—	—	—	10	30.0 abcd	0	0	0	40	80	50
SSX8585	—	—	—	—	—	—	—	—	6	29.3 abcd	0	0	17	67	50	50
Starbrite	9	30.3 def	0	0	0	44	78	33	8	31.0 abcd	0	0	0	25	88	25
StarGazer	8	25.9 abcdef	0	0	25	38	88	63	4	30.5 abcd	0	0	0	25	75	25
Sugar Coat	8	29.9 def	0	0	0	50	75	75	9	33.8 cd	0	0	0	0	78	78
Sugar Heart	10	22.2 abcd	0	20	10	80	90	80	6	31.0 abcd	0	0	0	33	100	33
Sweet Gem	—	—	—	—	—	—	—	—	7	27.4 abcd	0	0	14	57	100	29
SWT7829	—	—	—	—	—	—	—	—	6	28.5 abcd	0	0	17	50	50	17
Traveler	—	—	—	—	—	—	—	—	9	29.8 abcd	0	0	11	44	78	33
Troubadour	10	25.2 abcdef	0	0	10	70	100	40	10	26.6 abcd	0	0	10	70	100	30
WT2527	—	—	—	—	—	—	—	—	6	35.0 d	0	0	0	0	50	83

[z]Values followed by the same letters within each year are not significantly different ($P < 0.05$) by Tukey's honestly significant difference test.

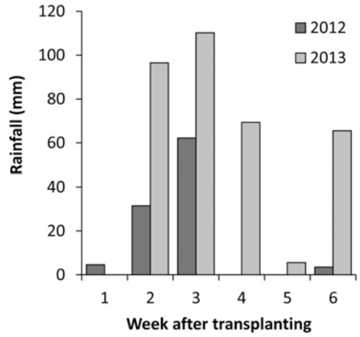

Fig. 1. The total weekly rainfall for the experimental period in 2012 and 2013.

and 2013E (Figs. 3E and 4B), pollenizers in clusters 2012D (Figs. 2D and 4A) and 2013C (Figs. 3C and 4B) would not be ideal. In an effort to evaluate the validity of recommendations made using this clustering methodology, we compared the staminate and pistillate flowering patterns of harvested pollenizers. If our interpretation is correct, we would expect harvested pollenizers with staminate flowers in cluster 2012D (Figs. 2D and 4A) to have staminate flowers in cluster 2012F (Fig. 2F), 2012G (Fig. 2G), or 2012H (Fig. 2H) (not group 2012E; Fig. 2E). Likewise, we would expect harvested pollenizers with staminate flowers in cluster 2013D (Fig. 3D) to have staminate flowers in clusters 2013G (Fig. 3G), 2013H (Fig. 3H), or 2013I (Fig. 3I) (not 2013E or 2013F; Figs. 3D and 3F).

Based on the clustering methodology for percentage of flowering plants, the following are early triploids cultivars where caution should be taken when choosing a pollenizer: Affirmed, Bold Ruler, Citation, Extazy, Imagination, Liberty, Melody, Serval, Summer Sweet 5244, Sweet Gem, and Troubadour. Appropriate pollenizers for early (2012E and 2013E; Figs. 2E and 3E) triploids are those that are clustered in 2012A (Fig. 2A), 2012B (Fig. 2B), or 2012C (Fig. 2C) and 2013A (Fig. 3A) or 2013B (Fig. 3B) (‘Ace’, ‘Mickylee’, ‘Minipol’, ‘Pollen Pro’, ‘Accomplice’, ‘Sidekick’, and ‘Stargazer’). ‘Gladiator’ and ‘WT2527’

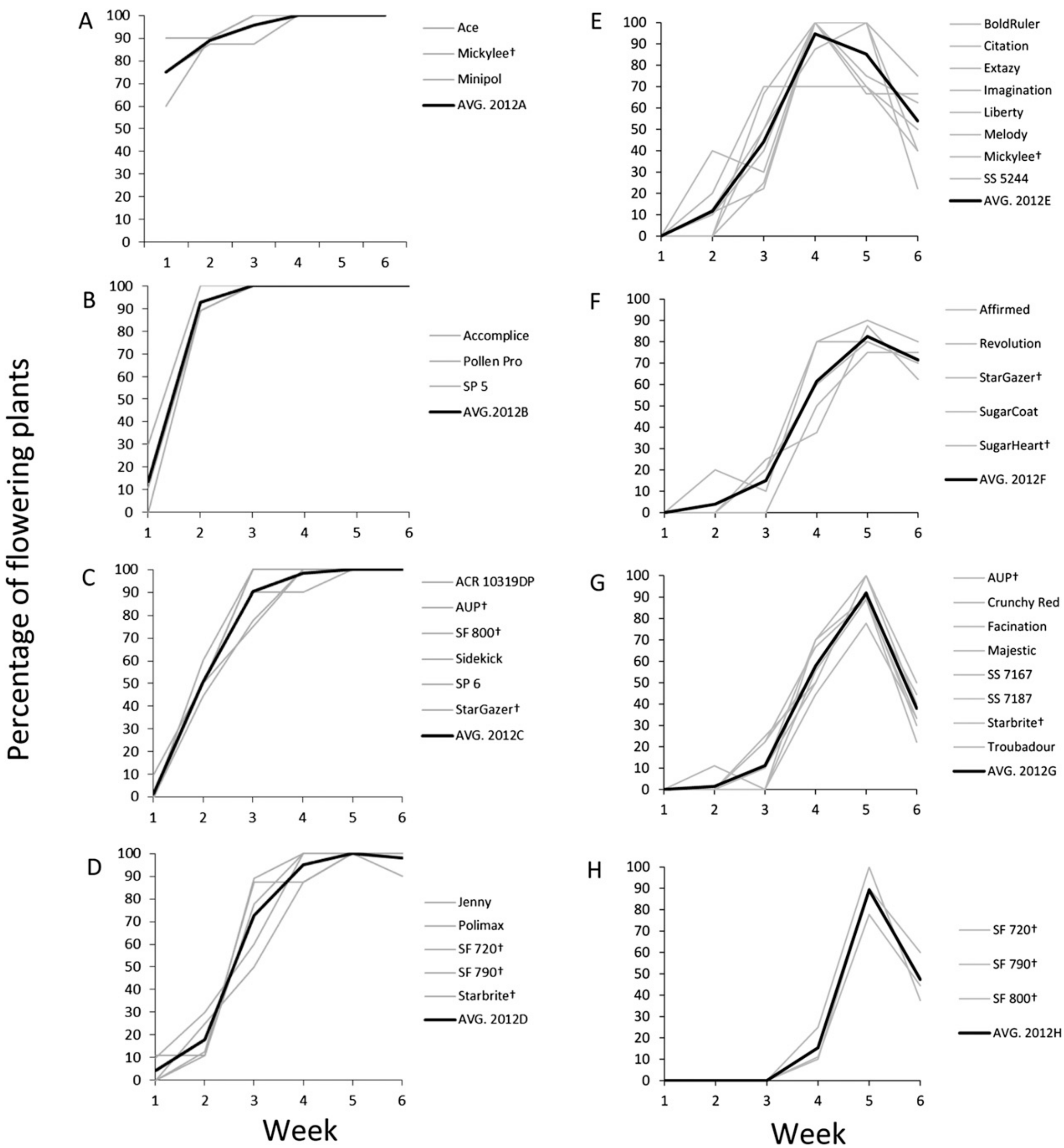

Fig. 2. K-Means clustering patterns for the weekly percentage of plants from each watermelon cultivar with staminate (**A–D**) and pistillate (**E–H**) flowers in 2012. Each graph represents cultivars with similar flowering patterns and the bold line indicates the average for cultivars in the particular cluster. †A harvested pollenizer.

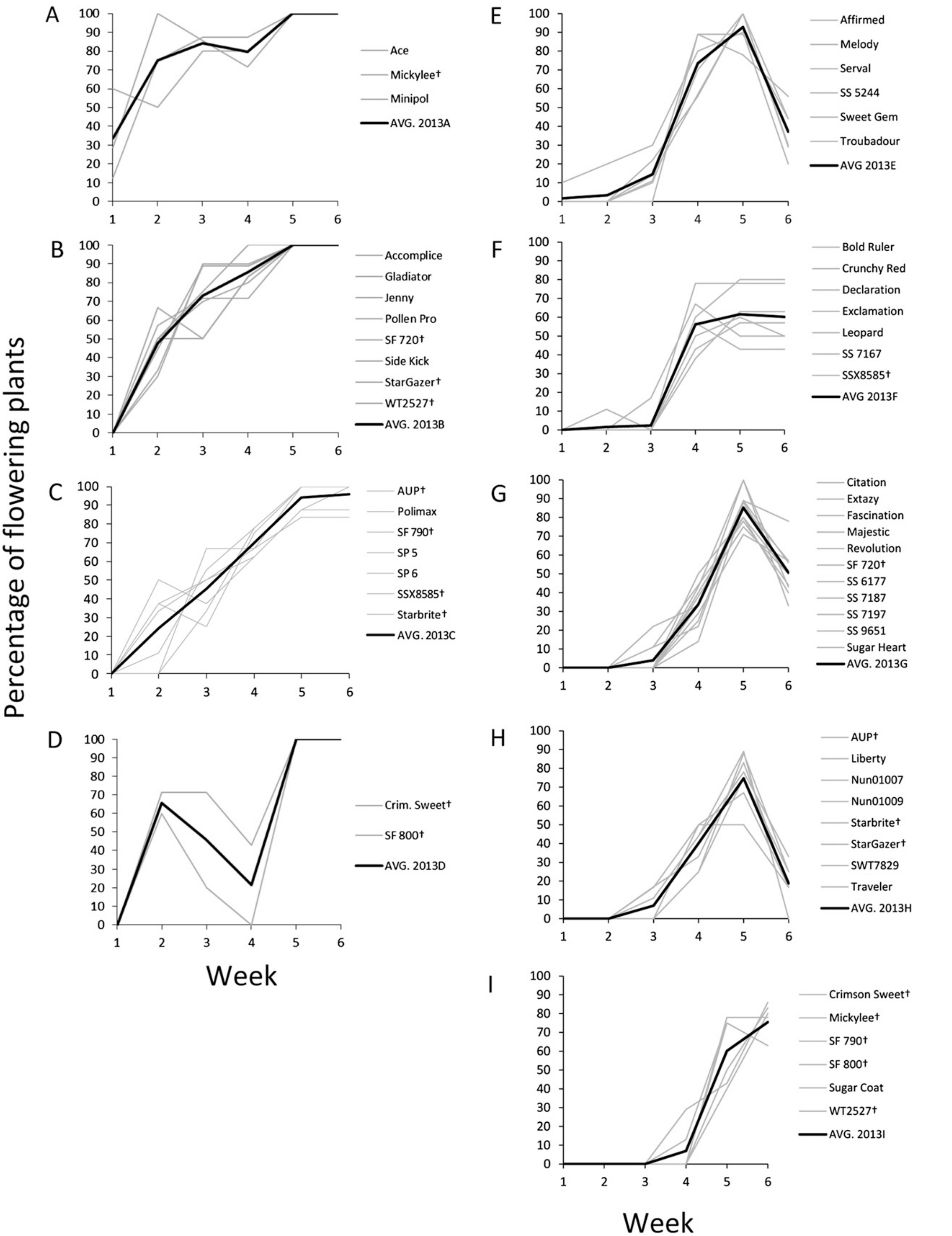

Fig. 3. K-Means clustering patterns for the weekly percentage of plants from each watermelon cultivar with staminate (**A–D**) and pistillate (**E–I**) flowers in 2013. Each graph represents cultivars with similar flowering patterns and the bold line indicates the average for cultivars in the particular cluster. †A harvested pollenizer.

might also be appropriate, but data were only available for 1 year for these two cultivars.

In addition to the percentage of flowering plants, we also calculated the average number of staminate flowers per flowering plant for each cultivar (Table 4). The number of staminate flowers per flowering plant shows a general increase from week to week over the duration of the study in 2012, but in 2013, several cultivars show a slight decline in Week 6. 'Pollen Pro' performed well in both years. The number of flowers per plant is lower in 2013 than 2012 except for 'Mickylee' that had a significantly lower number of flowers than the other cultivars in Weeks 5 and 6 in 2012. The lower number of flowers for 'Mickylee' might have been the result of disease pressure because downy mildew symptoms were observed in 2012. Freeman et al. (2007b) previously observed lower yields for triploids pollinated by 'Mickylee' compared with 'SP-1'. Although we can only speculate about the reason for the low number of staminate flowers per plant for this cultivar in 2012, it suggests that despite its favorable flowering pattern (Figs. 2A and 3A), it might not be the optimum pollenizer.

The number of flowers per plant shows a similar pattern as was observed in previous studies (Dittmar et al., 2009; Freeman and Olson, 2007a), although a lower absolute number of flowers was observed in the current study. The data for the number of pistillate flowers are not shown. Because the vast majority of plants usually have only one or two pistillate flowers at a time, these data add little to what is already reflected by the percentage of flowering plants.

The current study focused on early flowering and specifically aims to make recommendations for synchronization of pollenizer flowering patterns with the peak period of triploid pistillate flowering. However, growers may want to extend the length of the harvesting window and that would require pollenizer cultivars that flower consistently for a long period of time (Dittmar et al., 2009; Maynard and Elmstrom, 1992). At the end of our study at Week 6, most of the pollenizer plants were still flowering at a high level and other studies have shown that the number of flowers per plant is still increasing at this stage (Dittmar et al., 2009; Freeman and Olson, 2007a). Although we cannot make any recommendation that goes beyond the duration of our study, it should be noted that for most triploid cultivars, there is a decline in the number of flowering (pistillate) plants by Week 6 and thus the flowering pattern of the triploid cultivar might also play a role in the success of efforts to extend the harvesting season. Dittmar et al. (2010) observed higher yield for earlier harvests and the pistillate flowering patterns we observed provide one possible explanation for their observations.

In the present study, the number of plants used per cultivar was limited because our aim was to compare a large number of cultivars. Although we have shown that the genetic factors influencing flowering time can be determined using such an experimental design (McGregor et al., 2014), future studies comparing synchronized flowering patterns over time should endeavor to use a larger number of plants per cultivar. In addition,

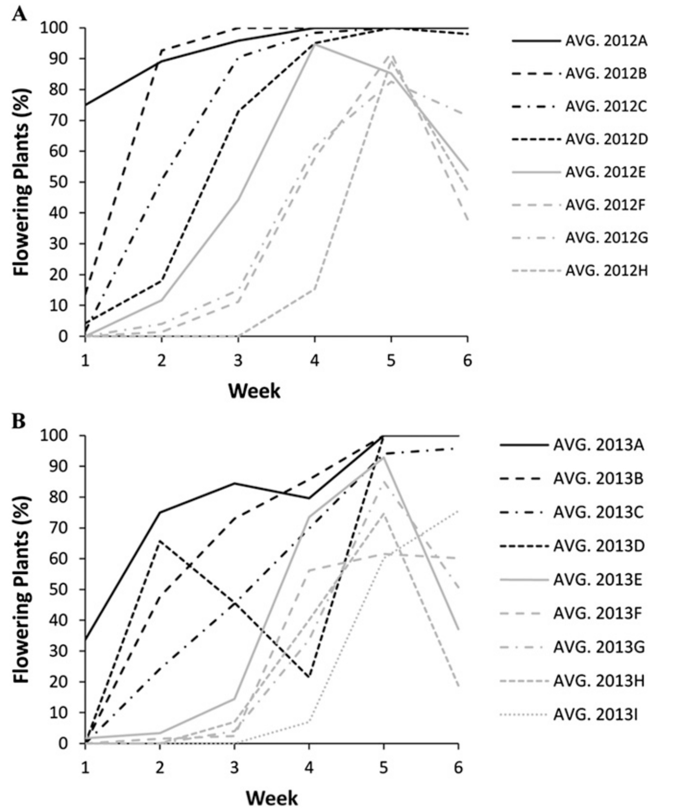

Fig. 4. The average plots of the K-means clusters (Figs. 2 and 3) for the weekly percentage of plants from each watermelon cultivar with staminate (black) and pistillate (gray) flowers in (**A**) 2012 and (**B**) (2013).

Table 4. The average number of staminate flowers per flowering plant for each of the pollenizer cultivars in 2012 and 2013.[z]

	2012						2013					
Cultivar	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Accomplice		1.1 a[y]	1.9 ab	7.9 a	11.9 ab	12.3 abc		1.0 a	1.7 ab	4.9 b	9.1 ab	11.3 a
Ace	1.0 a	1.1 a	1.6 ab	5.9 ab	9.0 bc	14.6 abc	1.3 a	1.0 a	1.2 b	4.4 b	6.2 b	5.8 cd
ACR 10319DP	1.0 a	1.0 a	1.4 ab	4.2 bcd	9.0 bc	13.9 abc						
AU Producer		1.0 a	1.5 ab	4.1 bcd	8.2 bc	15.2 abc			1.2 b	3.4 b	5.0 b	5.1 d
Crimson Sweet								1.1 a	1.0 b	4.5 ab	5.3 b	5.1 d
Gladiator								1.2 a	1.8 ab	3.2 b	5.7 b	4.3 d
Jenny		1.3 a	1.8 ab	5.2 abcd	9.3 abc	15.0 abc		1.0 a	1.3 b	4.1 b	5.9 b	5.6 d
Mickylee	1.0 a	1.0 a	1.8 ab	2.5 d	2.7 d	2.7 d	1.0 a	1.0 a	1.4 b	4.3 b	5.5 b	5.8 cd
Minipol	1.1 a	1.0 a	2.3 a	4.8 bcd	8.1 bc	14.5 abc	1.0 a	1.1 a	1.3 b	5.1 b	4.4 b	6.0 bcd
Polimax		1.0 a	1.4 ab	3.3 d	7.6 c	15.7 ab		1.0 a	2.0 ab	3.8 b	5.5 b	4.4 d
Pollen Pro	1.0 a	1.1 a	2.3 a	7.9 a	13.1 a	13.1 abc		1.0 a	2.8 a	10.0 a	13.2 a	8.9 abc
Summer Flavor *720*		1.0 a	1.4 ab	3.4 bcd	9.3 abc	15.6 ab		1.2 a	1.2 ab	2.6 b	5.9 b	4.7 d
Summer Flavor *790*	1.0 a	1.0 a	1.7 ab	3.1 cd	9.1 abc	15.2 abc		1.0 a	1.0 ab	3.5 b	4.3 b	4.2 d
Summer Flavor *800*		1.0 a	1.4 ab	2.9 d	9.0 abc	16.1 a		1.3 a	1.0 ab		3.4 b	3.8 d
Sidekick		1.2 a	1.6 ab	4.3 bcd	11.3 abc	12.0 bc		1.0 a	1.2 b	2.6 b	8.6 b	9.0 ab
SP 5	1.0 a	1.1 a	1.5 ab	5.8 abc	10.4 abc	11.5 c		1.5 a	1.0 b	3.6 b	5.8 b	9.5 a
SP 6		1.3 a	1.3 b	3.7 bcd	10.3 abc	13.8 abc			1.3 ab	2.9 b	6.0 b	6.0 cd
SSX8585								1.0 a	1.0 b	5.0 ab	4.1 b	2.9 d
Starbrite	1.0 a	1.0 a	1.3 b	2.9 d	8.9 bc	15.6 ab		1.0 a	1.0 ab	3.9 b	5.5 b	4.9 d
StarGazer		1.0 a	1.1 b	2.3 d	7.7 bc	14.0 abc		1.0 a	1.0 b	4.8 b	4.4 b	4.1 d
WT2527								1.2 a	1.0 b	2.6 b	5.0 b	5.6 cd

[z]Harvested pollenizers are indicated with italics.
[y]Values followed by the same letters within each column are not significantly different ($P < 0.05$) by Tukey's honestly significant difference test.

studies comparing yield of triploid cultivars pollinated by different pollenizers (Dittmar et al., 2010; Fiacchino and Walters, 2002; Freeman et al., 2007a) often use only one or two triploid cultivars. This is certainly understandable given the space and isolation requirement for such experiments. However, given the different clustering patterns (Figs. 2E–G and 3E–I) of the triploids, it would be prudent to use cultivars representing each of the pistillate flowering cluster patterns in such studies to limit the confounding effect of the triploid cultivar flowering pattern.

Although synchronized flowering of triploids and pollenizers is a fundamental requirement for fruit set (Dittmar et al., 2009), it is by no means the only factor that determines fruit set and ultimate yield. Freeman and Olson (2007b) showed that all pollenizers are not equally attractive to pollinators. So just because a pollenizer plant has open staminate flowers, it does not guarantee successful pollination and triploid fruit set.

Our data show that different pollenizers and triploid cultivars have specific flowering patterns both in the percentage of plants flowering and the number of (staminate) flowers per plant. A good pollenizer should have a high percentage of plants flowering and a high number of flowers per plant at the time that the triploid cultivar is producing pistillate flowers. Based on our results, certain combinations of triploids and pollenizers meet these criteria better than others. Growers have to be especially careful when choosing pollenizers for the early-flowering triploids and most harvested pollenizers are better suited to later flowering triploids or when growers want to extend their harvest season.

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