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Fruit Yield and Physicochemical Quality Evaluation of Hybrid and Grafted Field-Grown Muskmelon in Pennsylvania

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Abstract: Selecting vegetable cultivars suitable to local environmental conditions and with quality traits desired by the evolving market and consumer needs is an important production decision farmers face annually. As seed companies continue to expand their offerings of new cultivars and rootstocks, selecting the best cultivar and/or scion/rootstock combination can be challenging for farmers. Land-grant universities, through their integrated research and extension programs, can provide an unbiased, science-based evaluation of the available cultivar and rootstock options to assist farmers in making this important selection. A two-year study was conducted to evaluate 20 hybrid cultivars and two grafted entries of muskmelons at three locations in Pennsylvania in 2018 and 2019 to provide farmers with science-based recommendations focused on fruit yield and physicochemical quality characteristics. Most cultivars did not differ in fruit yields from the standard "Aphrodite". "Sugar Cube" produced more, smaller sized melons than "Aphrodite". However, the combination of the soluble solids concentration, flesh pH, and titratable acidity values was not as favorable, indicating that consumer preference may be lower for "Sugar Cube" than for other cultivars. Yield from grafted entries was not different from the non-grafted "Aphrodite"; although, biotic and abiotic stressors favoring the use of grafting were not present throughout the study. Physicochemical evaluation of the combination of "Aphrodite" scion and "Flexifort" rootstock was more favorable than "Aphrodite/RS841" and non-grafted "Aphrodite". This combination may be desirable even in the absence of yield stressors.

Keywords: vegetable variety; cultivar evaluation; vegetable grafting; rootstock selection; fruit quality; cantaloupe; *Cucumis melo*

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1. Introduction

Muskmelons (*Cucumis melo* L.) are a common component of diversified vegetable operations in Pennsylvania and are grown on about 14% of farms, primarily for fresh markets [1]. The increasing demand for local fresh high-quality produce is resulting in vegetable farmers in the northeastern U.S. diversifying their operations and increasing the seasonal availability of fresh fruits and vegetables [2]. Muskmelon and other cucurbits are an important rotational crop, primarily grown in the open-field during the spring–summer season using raised-bed plasticulture systems equipped with drip-irrigation. In the northeastern USA, the growing season for warm-season vegetables like muskmelon is relatively short, starting in mid-May or early-June and ending with harvest in July–August. Cultivar selection is critical for the success of this crop, especially considering the unpredictable weather conditions and rainfall patterns, changing from season to season. Numerous muskmelon cultivars are commercially available, and deciding which to grow is an important managerial decision. Additionally, this decision must be considered annually, as the market life cycle of individual cultivars is often short, and new ones are continuously added to the available offerings [3]. Vegetable and fruit farmers ranked cultivar selection as

third in importance from a list of vegetable production activities in a 2019 survey (n = 110), behind irrigation management and crop rotation [4].

Additionally, an increasing number of muskmelon farmers are considering the use of grafted plants. They need assistance determining whether grafting is a good fit for their farms and with selecting rootstocks from those currently available on the market. Over the last few decades, with the phase-out of methyl bromide, the use of vegetable grafting is becoming more common in the USA [5], as it is increasingly proposed as a biological solution for addressing diseases caused by soilborne pathogens, as well as for managing abiotic stressors, including cold, heat, flooding, salinity, and mineral excess, or the combination of multiple stressors [6–10]. Despite these benefits, the adoption of vegetable grafting is currently limited in Pennsylvania, especially for cucurbit crops. This may be partly due to the concern that vegetable grafting may delay maturity and negatively impact fruit quality [8,11,12], which is particularly important with muskmelon, especially for local markets. For muskmelons, flavor and texture are positively correlated with consumer preference [13]. Consumer preference and the overall eating quality of muskmelons have been linked to the physicochemical traits of the fruit [14]. There is a need to understand if there are new cultivars that produce higher yields and fruit quality, and if the use of grafted plants provides benefits or drawbacks in terms of fruit yield and quality under the pedoclimatic conditions typical of the U.S. mid-Atlantic region.

Through their research and extension programs, land-grant universities provide farmers an unbiased evaluation of cultivars and allied technologies, such as vegetable grafting. A reliable evaluation requires conducting field evaluations at multiple locations representative of the commercial production area, possibly repeated over a minimum of two seasons, while following the standard agronomic practices used by local farmers [15–19]. Using such protocols, it is possible to compare open-pollinated, hybrid, and/or grafted cultivars by measuring plant characteristics, yield performances, and/or quality of the harvested products, which are the main parameters farmers use for assessing the suitability of a cultivar or rootstock for their farms.

The goal of this research was to provide farmers with recommendations for commercially available muskmelon cultivars and grafted plant combinations by evaluating the yield components and physicochemical traits of the fruit across three locations representative of the main Pennsylvania vegetable production areas for two growing seasons. Funding and time constraints limit the number of cultivar evaluations scientists can conduct. In the mid-Atlantic, university Extension educators and faculty members from the University of Delaware, University of Maryland, Rutgers the State University of New Jersey, Pennsylvania State University, University of Virginia, and University of West Virginia post research-based recommendations for farmers in a commercial vegetable production guide [20] used in all six states. Recommendations from this evaluation were also intended to be included in that production guide.

2. Materials and Methods

A two-year field study was conducted to evaluate 20 cultivars of muskmelon and two grafted combinations (Table 1) in three locations representative of western, central, and southeastern Pennsylvania. Cultivars were selected based on conversations with farmers and seed company representatives. The two rootstocks evaluated were interspecific hybrids between *Cucurbita maxima* Duch. (winter squash) and *Cucurbita moschata* Duch. (pumpkin), and were selected for high and moderate vigor for RS841 and Flexifort, respectively. Both rootstocks had resistance to several soilborne pathogens and root-knot nematodes; however, these issues were not present in this study.

Table 1. Cultivars, rootstocks, and seed sources of muskmelons evaluated at three sites in Pennsylvania in 2018–2019.

Seed Companies and Headquarters							
Clifton Seed	**Rupp**	**Sakata**	**Seedway LLC**	**Seminis**	**Syngenta**	**Enza Zaden**	**De Ruiter Seeds**
Faison, NC	Wauseon, OH	Morgan Hill, CA	Mifflinburg, PA	St. Louis, MO	Greensboro, NC	Salinas, CA	Creve Coeur, MO
Muskmelon cultivars						Rootstocks [z]	
Carousel Lani Fiji	Ambassador Tirreno	Atlantis Avatar Infinite Gold	Afterglow Aphrodite Atlantis Goddess Minerva Shockwave Sugar Cube Verona	Sun Blushed	Accolade Aphrodite Ariel Astound Athena	Flexifort	RS841

[z] "Aphrodite" scions were grafted to rootstocks. Grafted plants were produced and provided by Tri-Hishtil LLC (Mills River, NC) a commercial nursery specialized in producing grafted plants for the USA market.

While the study had the same objective in all three locations, planting and harvesting dates, as well as crop management practices, varied by location, as reported in Table 2, and were determined based on what was optimal at each location. At all locations, experimental units contained six plants, and were arranged in a randomized complete block design with four replications.

Table 2. Sites, production protocols, and dates used in an evaluation of hybrids and grafted cultivars in Pennsylvania in 2018 and 2019.

Experimental Details	Western Site	Central Site	Southeastern Site
Location	Commercial farm, Indiana; lat. 40°39′30.9″ N 79°16′05.4″ W	Pennsylvania State University's Russell E. Larson Research Center, Pennsylvania Furnace; lat. 40°42′45.04″ N, long 77° 57′12.44″ W	Pennsylvania State University"s Southeast Research and Extension Center, Manheim; lat. 40° 07′05.11″ N, long. 76° 25′45.69″ W
Planting dates	30 May 2018; 27 May 2019	30 May 2018; 11 June 2019	15 May 2018; 06 June 2019
Nitrogen rate	128 kg/ha applied pre-plant	112 kg/ha applied; 60% applied pre-plant, 40% fertigated throughout the growing season	None applied pre-plant; 140 kg/ha fertigated throughout the growing season
Phosphorus and potassium fertility	54 kg/ha P applied pre-plant; 104 kg/ha K applied pre-plant	P and K were not applied based on soil test results	112 kg/ha applied pre-plant
In-row spacing	0.38 m	0.61 m	0.61 m
Row centers	3.7 m	3.7 m	3.7 m
Irrigation	Drip irrigation system installed, but not used	Drip irrigation used to supplement rainfall to provide ~103 m^3 to 155 m^3 of water weekly	Drip irrigation used to supplement rainfall to provide ~103 m^3 to 155 m^3 of water weekly
Harvest dates	31 July–28 August 2018; 30 July–19 August 2019	4–29 August 2018; 4 August–16 September 2019	13–July 13 August 2018; 5–30 August 2019

At all sites, four- or five-week-old transplants were planted into a plasticulture system with raised beds, a single drip irrigation line (T-Tape model 508-12-450, John Deere, Moline, IL, USA), and embossed black plastic mulch (1 mil, Wrap Bros., Chicago, IL, USA). Pest management practices followed the 2018 Commercial Vegetable Production Recommendation guide [20].

Melons were harvested, counted, and weighed as individual fruit reached the full slip stage, when fruit easily separated from the vine by hand, and were categorized as

marketable or unmarketable. Melons were considered marketable when they were full-sized, the rind had developed netting, they were a normal color for the cultivar, and they were free of cracks or other damage and disease.

At the central site only, postharvest physicochemical evaluations were conducted on the marketable fruit of 14 cultivars and the two grafted combinations. Within 48 h of harvest, two fruit per experimental unit were quartered, the placenta and rind were discarded, and the soluble solids concentration (SSC) was averaged from near the blossom and stem ends and the middle of the mesocarp with an analog handheld refractometer (Atago ATC-1, Bellevue, WA, USA). The fresh weight of ~125 g mesocarp samples was recorded. Samples were then oven-dried at ~66 °C for ~10 days until constant weight and reweighed to determine the fruit dry matter content. Fresh mesocarp subsamples (~100 g) were cut into cubes and stored at −20 °C until the analysis of flesh pH and titratable acidity (TA) was performed. Thawed tissue samples were juiced with 150 mL of distilled water and filtered through a coffee filter (6.35 × 8.25 cm; Wegmans; Rochester, NY, USA). Fruit pH was determined with a table-top meter (Mini-titrator HI84532; Hanna Instruments; Smithfield, OR). Titratable acidity was measured by titrating to pH 8.2 with 0.1 M NaOH and was reported as percent malic acid.

We were advised by a statistical consultant on the statistical analysis used in this research. Visual inspection of the yield data indicated a three-way interaction between site, year, and cultivar; therefore, data were analyzed by site. Yield and physicochemical properties data were analyzed using the mixed procedure and means were compared at $P < 0.05$ using the "PDIFF" option to compare all means and adjusted using Tukey's honestly significant difference for multiple comparisons among means (SAS 9.4; Cary, NC, USA). When year–cultivar interactions were significant, means were compared within each year (*P*-values available as Supplementary Tables S1 and S2).

3. Results and Discussion

3.1. Yield

Using a standard makes results more meaningful for farmers as it provides a reference point for comparison [21]. "Aphrodite" was used as the standard to which all other cultivars were compared because farmers told us this was the main cultivar they grow.

3.1.1. Western Site

In 2018, the mean number of marketable melons ranged from 0.00 to 1.92 per plant (Table 3). "Lani", "Shockwave", and "Fiji" produced fewer melons than "Aphrodite" (1.00 per plant). All other cultivars did not differ from "Aphrodite". In 2019, the range was similar at 0.00 to 1.88 per plant. "Sugar Cube", "Tirreno", "Carousel", "Astound", "Goddess", and "Athena" produced more melons than "Aphrodite" (0.29 per plant). All other cultivars did not differ from "Aphrodite".

In 2018, the mean weight of marketable melons ranged from 0.00 kg to 4.04 kg per plant (Table 3). Weights from "Infinite Gold" (0.20 kg per plant),"Fiji" (0.00 kg per plant), "Lani" (0.00 kg per plant), and "Shockwave" (0.00 kg per plant) were lower than from "Aphrodite" (2.62 kg per plant). All other cultivars did not differ from "Aphrodite". In 2019, the range was smaller, from 0.00 kg to 1.86 kg per plant. Mean weights from "Carousel" and "Tirreno" were higher than from "Aphrodite" (0.65 kg per plant). All other cultivars did not differ from "Aphrodite".

In 2018, the mean number of unmarketable melons ranged from 0.08 to 1.29 per plant (Table 4). All cultivars did not differ from "Aphrodite" (0.67 per plant). In 2019, the range was similar, at 0.00 to 1.21 per plant. "Shockwave" and "Infinite Gold" produced more unmarketable melons than "Aphrodite" (0.00 per plant). All other cultivars did not differ from "Aphrodite".

Table 3. Mean marketable fruit number [z] and weight per plant of 20 muskmelon cultivars and two grafted entries evaluated in western Pennsylvania in 2018 and 2019.

Cultivar	2018		2019	
	Number	Weight (kg)	Number	Weight (kg)
Accolade	0.75 b-f [y]	1.79 b-f	0.29 ef	0.78 c-h
Afterglow	1.29 a-d	2.66 a-d	0.21 f	0.37 e-h
Aphrodite	1.00 a-e	2.62 a-d	0.29 ef	0.65 c-h
Aphrodite/Flexifort	1.00 a-e	3.23 abc	0.46 c-f	0.93 b-h
Aphrodite/RS48	1.21 a-d	4.04 a	0.17 f	0.39 e-h
Ariel	1.08 a-e	2.62 a-d	0.50 c-f	0.98 b-h
Astound	1.46 ab	3.28 abc	0.96 bc	1.51 abc
Athena	0.63 b-f	1.43 b-f	0.84 bcd	1.50 a-d
Atlantis	1.17 a-d	2.67 a-d	0.75 b-e	1.35 a-e
Avatar	0.79 b-f	2.84 a-d	0.46 c-f	1.15 b-g
Carousel	1.33 ab	3.33 abc	1.21 b	2.20 a
Fiji	0.00 f	0.00 f	0.08 f	0.11 gh
Goddess	0.75 b-f	1.69 b-f	0.88 bc	1.61 abc
Infinite Gold	0.08 ef	0.20 ef	0.08 f	0.14 gh
Lani	0.00 f	0.00 f	0.00 f	0.00 h
Minerva	0.58 b-f	1.40 b-	0.29 ef	0.80 c-h
Shockwave	0.00 f	0.00 f	0.33 def	0.47 d-h
Sugar Cube	1.92 a	1.86 a-	1.88 a	1.19 a-f
Sun Blushed	0.38 def	0.86 de	0.17 f	0.29 fgh
Tirreno	1.17 a-d	2.51 a-e	1.25 b	1.86 ab
Verona	0.88 b-f	2.91 a-d	0.33 def	0.90 b-h

[z] Values are the mean of four replications; data were analyzed using the mixed procedure and means were separated using PDIFF; values followed by different letters within a column are significantly different at $P < 0.05$; "Aphrodite" was considered the standard. [y] Experimental units consisted of six plants.

Table 4. Mean unmarketable fruit number [z] and weight per plant of 20 muskmelon cultivars and two grafted entries evaluated in western Pennsylvania in 2018 and 2019.

Cultivar	2018		2019	
	Number	Weight (kg)	Number	Weight (kg)
Accolade	0.33 bc [y]	0.52 cde	0.13 b	0.09 b
Afterglow	0.54 abc	0.84 b-e	0.00 b	0.00 b
Aphrodite	0.67 abc	1.12 a-e	0.00 b	0.00 b
Aphrodite/Flexifort	0.42 bc	1.29 a-e	0.13 b	0.18 b
Aphrodite/RS48	0.25 bc	0.66 b-e	0.04 b	0.07 b
Ariel	0.38 bc	0.82 b-e	0.08 b	0.08 b
Astound	0.29 bc	0.46 cde	0.00 b	0.00 b
Athena	0.21 bc	0.35 de	0.04 b	0.03 b
Atlantis	0.08 c	0.21 e	0.00 b	0.00 b
Avatar	0.08 c	0.20 e	0.04 b	0.09 b
Carousel	0.38 bc	0.88 b-e	0.00 b	0.00 b
Fiji	1.29 a	2.09 ab	0.17 b	0.27 b
Goddess	0.33 bc	0.62 b-e	0.33 b	0.33 b
Infinite Gold	0.54 abc	0.91 a-e	1.17 a	2.01 a
Lani	0.54 abc	0.68 b-e	0.08 b	0.08 b
Minerva	0.17 c	0.34 de	0.21 b	0.24 b
Shockwave	0.46 abc	0.98 b-e	1.21 a	1.73 a
Sugar Cube	0.42 bc	0.38 cde	0.00 b	0.00 b
Sun Blushed	1.04 ab	1.89 abc	0.00 b	0.00 b
Tirreno	0.63 abc	1.02 a-e	0.04 b	0.02 b
Verona	0.29 bc	0.70 b-e	0.04 b	0.03 b

[z] Values are the mean of four replications; data were analyzed using the mixed procedure and means were separated using PDIFF; values followed by different letters within a column are significantly different at $P < 0.05$; "Aphrodite" was considered the standard. [y] Experimental units consisted of six plants.

In 2018, the mean weight of unmarketable melons ranged from 0.20 kg to 2.09 kg per plant (Table 4). All cultivars did not differ from "Aphrodite" (1.12 kg per plant). In 2019, the range was 0.00 kg to 2.01 kg per plant. Mean unmarketable weight from "Infinite Gold" and "Shockwave" was higher than from "Aphrodite" (0.00 kg per plant). All other cultivars did not differ from "Aphrodite".

3.1.2. Central Site

In 2018, the mean number of marketable melons ranged from 0.00 to 3.96 per plant (Table 5). "Lani" produced more melons (3.96 per plant) than "Aphrodite" (1.25 per plant). All other cultivars did not differ from "Aphrodite". In 2019, the range was similar at 0.29 to 3.54 per plant. "Sugar Cube" and "Lani" produced more and "Shockwave", "Infinite Gold", "Goddess", and "Fiji" fewer melons than "Aphrodite" (1.79 per plant). All other cultivars did not differ from "Aphrodite".

Table 5. Mean marketable number [z] and weight per plant of 20 muskmelon cultivars and two grafted entries evaluated in central Pennsylvania in 2018 and 2019.

Cultivar	2018		2019	
	Number	Weight (kg)	Number	Weight (kg)
Accolade	1.90 a-d [y]	4.76 abc	1.88 cde	3.53 a-d
Afterglow	3.08 ab	6.53 ab	2.33 bc	3.82 a-d
Aphrodite	1.25 bcd	3.38 a-d	1.79 cde	4.74 abc
Aphrodite/Flexifort	1.38 bcd	4.93 abc	1.25 d-g	3.35 a-d
Aphrodite/RS48	1.17 bcd	3.71 a-d	1.75 cde	5.26 a
Ariel	2.29 abc	6.07 ab	1.92 b-e	3.98 a-d
Astound	2.21 abc	5.99 ab	2.29 bcd	4.72 abc
Athena	2.71 ab	4.49 abc	1.79 cde	3.70 a-d
Atlantis	0.58 cd	1.32 cd	1.17 efg	2.71 cde
Avatar	1.63 bcd	5.91 ab	1.67 cde	4.97 ab
Carousel	1.75 bcd	4.16 a-d	1.38 c-f	3.45 a-d
Fiji	2.79 ab	5.73 ab	0.29 g	0.44 f
Goddess	2.21 abc	5.04 abc	0.42 fg	0.66 ef
Infinite Gold	0.00 d	0.00 d	0.43 fg	0.61 ef
Lani	3.96 a	4.04 a-d	2.96 ab	3.38 a-d
Minerva	1.67 bc	5.30 abc	1.83 cde	4.45 a-d
Shockwave	1.71 bcd	4.21 a-d	0.50 fg	0.69 ef
Sugar Cube	2.20 abc	2.47 bcd	3.54 a	3.29 a-d
Sun Blushed	1.96 a-d	5.09 abc	1.29 c-g	2.87 b-e
Tirreno	3.17 ab	6.72 a	1.38 c-f	2.23 def
Verona	1.54 bcd	4.81 abc	1.83 cde	5.44 a

[z] Values are the mean of four replications; data were analyzed using the mixed procedure and means were separated using PDIFF; values followed by different letters within a column are significantly different at $P < 0.05$; "Aphrodite" was considered the standard. [y] Experimental units consisted of six plants.

In 2018, the mean weight of marketable melons ranged from 0.00 kg to 6.72 kg per plant (Table 5). All cultivars did not differ from "Aphrodite" (3.38 kg per plant). In 2019, the range was 0.44 kg to 5.44 kg per plant. "Tirreno", "Shockwave", "Goddess", "Infinite Gold", and "Fiji" had lower marketable weights than "Aphrodite (4.74 kg per plant). All other cultivars did not differ from "Aphrodite".

In 2018, the mean number of unmarketable melons ranged from 0.00 to 1.17 per plant (Table 6). "Atlantis" produced more unmarketable melons than "Aphrodite" (0.50 per plant). All other cultivars did not differ from "Aphrodite". In 2019, the range was wider, at 0.00 to 2.17 per plant. "Fiji" and "Shockwave" produced more unmarketable melons than "Aphrodite" (0.08 per plant). All other cultivars did not differ from "Aphrodite".

Table 6. Mean unmarketable fruit number [z] and weight per plant of 20 muskmelon cultivars and two grafted entries evaluated in central Pennsylvania in 2018 and 2019.

Cultivar	2018		2019	
	Number	Weight (kg)	Number	Weight (kg)
Accolade	0.22 b [y]	0.63 b	0.79 bc	0.14 b
Afterglow	0.13 b	0.17 b	0.04 c	0.05 b
Aphrodite	0.50 b	1.32 ab	0.08 c	0.10 b
Aphrodite/Flexifort	0.38 b	0.55 b	0.04 c	0.18 b
Aphrodite/RS48	0.25 b	0.68 b	0.21 c	0.59 b
Ariel	0.04 b	0.11 b	0.00 c	0.00 b
Astound	0.00 b	0.00 b	0.13 c	0.13 b
Athena	0.08 b	0.15 b	0.13 c	0.20 b
Atlantis	1.17 a	2.81 a	0.00 c	0.00 b
Avatar	0.33 b	1.21 b	0.00 c	0.00 b
Carouse	0.08 b	0.27 b	0.38 c	0.84 b
Fiji	0.21 b	0.00 b	2.17 a	2.85 a
Goddess	0.50 b	0.98 b	0.38 c	0.55 b
Infinite Gold	0.00 b	0.00 b	0.78 bc	0.80 b
Lani	0.00 b	0.00 b	0.04 c	0.02 b
Minerva	0.33 b	0.92 b	0.00 c	0.00 b
Shockwave	0.00 b	0.00 b	1.75 ab	2.33 a
Sugar Cube	0.00 b	0.00 b	0.04 c	0.05 b
Sun Blushed	0.21 b	0.64 b	0.13 c	0.16 b
Tirreno	0.00 b	0.00 b	0.00 c	0.00 b
Verona	0.25 b	0.61 b	0.17 c	0.11 b

[z] Values are the mean of four replications; data were analyzed using the mixed procedure and means were separated using PDIFF; values followed by different letters within a column are significantly different at $P < 0.05$; "Aphrodite" was considered the standard. [y] Experimental units consisted of six plants.

In 2018, the mean weight of unmarketable melons ranged from 0.00 kg to 2.81 kg per plant (Table 6). All cultivars did not differ from "Aphrodite" (1.32 kg per plant). In 2019, it ranged from 0.00 kg to 2.85 kg per plant. "Fiji" and "Shockwave" produced a higher mean unmarketable weight than "Aphrodite" (0.10 kg per plant). All other cultivars did not differ from "Aphrodite".

3.1.3. Southeastern Site

In 2018, the mean number of marketable melons ranged from 0.04 to 2.50 per plant (Table 7). "Sugar Cube" produced more melons than "Aphrodite" (1.25 per plant) and "Shockwave", "Lani", "Fiji", and "Infinite Gold" produced fewer. All other cultivars did not differ from "Aphrodite". In 2019, the range was 0.08 to 2.75 per plant. "Sugar Cube", "Astound", "Atlantis", "Athena", and "Carousel" produced more, and "Fiji", fewer melons than "Aphrodite" (1.04 per plant). All other cultivars did not differ from "Aphrodite".

In 2018, the mean weight of marketable melons ranged from 0.07 kg to 5.82 kg per plant (Table 7). "Shockwave", "Lani", "Fiji", and "Infinite Gold" produced a lower weight than "Aphrodite" (4.26 kg per plant). All other cultivars did not differ from "Aphrodite". In 2019, the range was 0.21 kg to 5.93 kg per plant. "Shockwave", "Goddess", "Infinite Gold", "Lani", and "Fiji" produced a lower weight than "Aphrodite" (3.97 kg per plant). All other cultivars did not differ from "Aphrodite".

In 2018, the mean number of unmarketable melons ranged from 0.00 to 1.58 per plant (Table 8). "Goddess" produced more than "Aphrodite" (0.38 per plant). All other cultivars did not differ from "Aphrodite". In 2019, the range was 0.13 to 1.38 per plant. "Atlantis", "Infinite Gold", "Avatar", and "Fiji" produced fewer than "Aphrodite" (1.0 per plant). All other cultivars did not differ from "Aphrodite".

Table 7. Mean marketable number [z] and weight per plant of 20 muskmelon cultivars and two grafted entries evaluated in southeastern Pennsylvania in 2018 and 2019.

Cultivar	2018		2019	
	Number	Weight (kg)	Number	Weight (kg)
Accolade	1.50 bc [y]	4.55 a-d	1.63 b-e	4.29 a-d
Afterglow	1.46 bc	4.05 a-d	1.33 b-g	3.20 cde
Aphrodite	1.25 bc	4.26 a-d	1.04 e-i	3.97 a-d
Aphrodite/Flexifort	1.17 bc	5.11 abc	0.63 hij	2.33 de
Aphrodite/RS48	1.42 bc	5.49 ab	0.71 g-j	2.75 cde
Ariel	1.13 bc	3.48 bcd	1.25 c-h	4.20 a-d
Astound	1.58 bc	4.46 a-d	1.88 b	4.54 abc
Athena	1.75 b	4.96 a-d	1.75 bcd	4.47 abc
Atlantis	1.21 bc	3.78 bcd	1.83 bc	5.49 ab
Avatar	1.29 bc	5.82 a	1.42 b-f	5.66 ab
Carousel	1.29 bc	4.85 a-d	1.75 bcd	5.93 a
Fiji	0.08 d	0.18 e	0.08 j	0.21 f
Goddess	1.21 bc	3.21 cd	0.50 ij	1.52 ef
Infinite Gold	0.04 d	0.07 e	0.58 hij	1.42 ef
Lani	0.13 d	0.18 e	0.83 f-i	1.41 ef
Minerva	0.92 c	3.59 bcd	1.13 d-i	4.17 a-d
Shockwave	0.21 d	0.76 e	0.63 hij	1.59 ef
Sugar Cube	2.50 a	3.01 d	2.75 a	3.66 bcd
Sun Blushed	1.17 bc	3.22 cd	1.08 d-i	2.97 cde
Tirreno	1.33 bc	3.20 cd	1.58 b-e	3.86 a-d
Verona	1.08 bc	4.18 a-d	1.17 c-i	4.69 abc

[z] Values are the mean of four replications; data were analyzed using a mixed procedure and means were separated using PDIFF; values followed by different letters within a column are significantly different at $P < 0.05$; "Aphrodite" was considered the standard. [y] Experimental units consisted of six plants.

Table 8. Mean unmarketable number [z] and weight per plant of 20 muskmelon cultivars and two grafted entries evaluated in Southeastern Pennsylvania in 2018 and 2019.

Cultivar	2018		2019	
	Number	Weight (kg)	Number	Weight (kg)
Accolade	0.33 bcd [y]	0.98 b-f	0.54 d-h	1.47 def
Afterglow	0.38 bcd	0.98 b-f	0.46 fgh	1.15 def
Aphrodite	0.38 bcd	1.66 b-f	1.00 a-f	3.31 abc
Aphrodite/Flexifort	0.71 b	2.71 ab	1.13 abc	4.45 a
Aphrodite/RS48	0.46 bcd	1.96 bcd	1.04 a-e	4.42 a
Ariel	0.63 bc	2.30 abc	0.58 c-h	1.75 c-f
Astound	0.38 bcd	1.08 b-f	0.67 b-h	1.66 def
Athena	0.42 bcd	1.31 b-f	0.75 b-g	1.66 c-f
Atlantis	0.25 bcd	0.75 c-f	0.42 gh	1.09 def
Avatar	0.42 bcd	1.84 b-e	0.13 h	0.65 ef
Carousel	0.50 bcd	1.56 b-f	0.58 c-h	1.96 cde
Fiji	0.13 cd	0.11 ef	0.13 h	0.31 f
Goddess	1.58 a	3.97 a	1.38 a	3.70 ab
Infinite Gold	0.00 d	0.00 f	0.42 gh	1.14 def
Lani	0.17 bcd	0.28 def	0.79 b-g	1.27 def
Minerva	0.46 bcd	1.80 b-e	1.08 a-d	3.98 ab
Shockwave	0.29 bcd	0.86 c-f	0.79 b-g	2.05 cde
Sugar Cube	0.71 b	0.85 c-f	1.17 ab	1.58 def
Sun Blushed	0.58 bc	1.38 b-f	0.75 b-g	1.89 c-f
Tirreno	0.46 bcd	1.18 b-f	0.50 e-h	1.33 def
Verona	0.58 bc	2.42 abc	0.67 b-h	2.39 bcd

[z] Values are the mean of four replications; data were analyzed using the mixed procedure and means were separated using PDIFF; values followed by different letters within a column are significantly different at $P < 0.05$; "Aphrodite" was considered the standard. [y] Experimental units consisted of six plants.

In 2018, the mean weight of unmarketable melons ranged from 0.00 kg to 3.97 kg per plant (Table 8). "Goddess" produced a higher weight than "Aphrodite" (1.66 kg per plant). All other cultivars did not differ from "Aphrodite". In 2019, the range was 0.31 kg to 4.45 kg per plant. "Astound", "Sugar Cube", "Accolade", "Tirreno", "Lani", "Afterglow", "Infinite Gold", "Atlantis", "Avatar", and "Fiji" produced lower weights than "Aphrodite" (3.31 kg per plant). All other cultivars did not differ from "Aphrodite".

3.1.4. Yield Performance of Hybrid Cultivars

Yields from most cultivars did not differ from "Aphrodite" over the 2 years and were comparable to muskmelon yields in other Pennsylvania studies [22,23]. Given that most cultivars did not produce different yields than "Aphrodite", farmers could base cultivar selection on other criteria, including disease resistance and fruit quality, without sacrificing yield. The ability to select cultivars based on disease resistance without forfeiting yield may be particularly advantageous for low-input and organic farmers, who have fewer options for disease management than conventional farmers.

"Sugar Cube" produced more melons than "Aphrodite" in four site-years. Additionally, the mean marketable fruit weight from "Sugar Cube" was not different than "Aphrodite", indicating that melons were generally smaller, but the number produced was larger. "Sugar Cube" was bred to be small in size to reduce food waste [24]. Due to its smaller size, it may be a good option for selling separately from other cultivars. Indeed, we have observed this cultivar for sale individually by cultivar name at farmers' markets in Pennsylvania.

"Infinite Gold" produced fewer melons and had a lower mean marketable weight than "Aphrodite" in four site-years. Days to maturity were longer for "Infinite Gold" than "Aphrodite" (85 days and 72 days, respectively), and the growing season ended before several "Infinite Gold" fruit were harvestable. "Shockwave" and "Fiji" produced a lower mean marketable weight in four site-years, and "Lani" in three site-years. When high marketable weights are desired other cultivars may be better options.

3.1.5. Yield Performance of Grafted Cultivars

Grafted cultivars did not result in higher marketable yields by number or weight compared to non-grafted "Aphrodite" in all three locations for both growing seasons, regardless of the rootstock used (Tables 3, 5 and 7). Grafting has been increasingly proposed and used as a tool to overcome soilborne pests and diseases [5,25], to address abiotic stresses [9,26,27], and to increase yield [8,28]. "Flexifort" has a high resistance to *Fusarium oxysporum* f.sp. *melonis* (Fom) races 0, 1, 2, and 1.2, intermediate resistance to *Fusarium oxysporum* f. sp. *radicis-cucumerinum* (Forc), and a claimed tolerance to drought, heat, cold, and salinity stress, and, "RS841" has high resistance to *Fusarium oxysporum* f.sp. *cucumerinum* (Foc) races 1 and 2, Fom races 0, 1, 1.2, and 2, *Fusarium oxysporum* f.sp. *niveum* (Fon) races 1 and 2, and *Fusarium oxysporum* f. sp. *radicis-lycopersici* (For), as well as intermediate resistance to *Rhizoctonia solani*, and *Meloidogyne* sp. [29,30]. However, disease and pest pressure, and these abiotic stresses were low or absent throughout this study. Therefore, while these findings differ from previous studies [31–34], results from this study may be explained by the absence of soilborne pests and pathogens and specific abiotic stressors over the 2 years and at the three locations of this study. These results suggest that in the presence of low or no soilborne pests and pathogens and abiotic stress conditions there is no yield advantage to using grafted plants under the Pennsylvania pedoclimatic conditions.

3.2. Postharvest Fruit Physicochemical Properties

Soluble solids concentration (SSC) is highly correlated with sugar concentration and is used as a measure of marketability [14,35]. SSC ranged from 7.79% for "Astound" to 11.06% for "Aphrodite" (Table 9). It was not different between cultivars; however, it was higher in 2019, at 10.42%, than in 2018, at 8.58%. The U.S.D.A.'s protocols for muskmelons for shipping point and market inspection include methods for measuring SSC to determine

the internal quality [35]. Soluble solids concentration between 9% and 10.99% is reported as "good internal quality" and 11% or greater as "very good internal quality." Furthermore, SSC is reported to the "nearest half percent." Using these standards, melons had "good internal quality" in 2019, but not in 2018. Irrigation practices can influence muskmelon SSC, where applying higher amounts of water is correlated with lower values [36,37]. In our case, lower values in 2018 could be related to record high rainfall [38], particularly in July, August, and September, which likely lowered the sugar concentration (Table 10).

Table 9. Physiochemical quality properties of 14 muskmelon cultivars and two grafted entries evaluated in central Pennsylvania in 2018 and 2019.

Year	2018–2019	2018–2019	2018	2019	2018–2019	2018–2019
Fruit Quality Parameters	**SSC (soluble solids concentration) (%)**	**Flesh pH**	**TA (titratable acidity) [z] (%)**		**SSC/TA [y]**	**Juiciness (% Water Content)**
Cultivar						
Accolade	9.38 a [x]	7.00 a-d	0.02907 a	0.03408 bcd	357.53 a	91.94 bc
Afterglow	9.27 a	7.00 a-d	0.02533 a	0.03829 bcd	352.85 a	93.22 abc
Aphrodite	11.06 a	7.07 a-d	0.02357 a	0.03506 bcd	401.09 a	92.59 abc
Aphrodite/Flexifort	9.91 a	7.33 a	0.02356 a	0.02173 d	473.37 a	92.69 abc
Aphrodite/RS841	9.29 a	6.98 a-d	0.02093 a	0.03410 bcd	378.88 a	92.70 abc
Ariel	7.99 a	6.80 d	0.02809 a	0.03866 bcd	243.61 a	94.65 a
Astound	7.79 a	6.90 bcd	0.02050 a	0.03605 bcd	305.47 a	94.14 ab
Athena	9.59 a	6.93 bcd	0.03448 a	0.03385 bcd	285.55 a	91.28 c
Atlantis	9.38 a	6.97 a-d	0.02946 a	0.02776 cd	337.40 a	92.75 abc
Carousel	10.05 a	6.85 cd	0.03003 a	0.04660 b	262.06 a	92.33 abc
Minerva	9.37 a	7.07 a-d	0.01468 a	0.04412 bc	371.97 a	92.73 abc
Shockwave	9.29 a	7.22 abc	0.01929 a	0.03876 bcd	372.58 a	91.86 bc
Sugar Cube	9.38 a	6.78 d	0.02347 a	0.04849 b	331.34 a	92.20 bc
Sun Blushed	10.64 a	6.77 d	0.02746 a	0.08127 a	299.77 a	91.10 c
Tirreno	10.77 a	7.27 ab	0.01671 a	0.02855 cd	591.99 a	92.44 abc
Verona	8.89 a	6.98 a-d	0.02512 a	0.04021 bc	288.31 a	92.50 abc
Year	SSC (%)	Flesh pH	TA (%)		SSC/TA	Juiciness (% water content)
2018	8.58 b	7.22 a	0.02448 b		413.18 a	92.08 b
2019	10.42 a	6.76 b	0.03922 a		293.54 b	93.06 a

[z] TA calculated as percentage of malic acid. [y] SSC/TA is the ratio of soluble solids content to titratable acidity. [x] Values are the mean of four replications; data were analyzed using the mixed procedure and means were separated using PDIFF; values followed by different letters within a column are significantly different at $P < 0.05$; "Aphrodite" was considered the standard.

Table 10. Rainfall amount (centimeters) and temperature (degrees Celsius) at three sites of muskmelon cultivar evaluation in Pennsylvania.

	Central Pennsylvania [z]				**Southeastern Pennsylvania [y]**				**Western Pennsylvania [x]**			
	2018	**2019**	**Mean Rainfall**	**Mean Temp.**	**2018**	**2019**	**Mean Rainfall**	**Mean Temp.**	**2018**	**2019**	**Mean Rainfall**	**Mean Temp.**
May	10.59	15.80	8.79	15.28	13.08	16.94	10.21	16.50	13.92	22.12	11.07	14.50
June	13.72	9.17	10.44	20.17	12.24	13.18	10.26	21.56	17.73	10.90	11.66	19.11
July	23.80	6.38	8.94	22.28	24.71	13.59	11.81	23.44	21.84	10.24	12.47	21.28
Aug.	18.72	6.71	9.75	21.44	29.95	13.11	9.04	22.50	10.92	8.81	10.41	20.72
Sept.	22.83	4.75	9.07	17.06	missing	5.18	10.77	18.56	29.85	8.51	10.03	16.78

[z] Central site data collected from weather station 11.52 km from experimental plots in State College, PA [39]. [y] Southeastern site data collected from an on-site weather station in Manheim, PA [39]. [x] Western site data collected from weather station 15 km from experimental plots in Indiana, PA [40].

Low TA has been associated with high overall eating quality [14]. TA ranged between 0.01468% and 0.03448% in 2018 and between 0.02173% and 0.08127% in 2019 (Table 9). In 2018, no significant differences existed between cultivars. In 2019, "Aphrodite/Flexifort"

had a lower TA than "Carousel", "Minerva", "Sugar Cube", "Sun Blushed", and "Verona". All other cultivars did not differ from "Aphrodite/Flexifort". Additionally, TA was higher in 2019 than in 2018. Irrigation and fertility management practices affect TA [41]. Each year of our study these factors were uniform for all cultivars. However, the amount of water supplied varied between years, owing to excessive rainfall in 2018 (Table 10). In a review, Etieene et al. [41] reported that higher amounts of water resulted in lower pH in several experiments and higher pH in others; although, none of these experiments focused on muskmelon. Our study suggested that higher amounts of water may result in a lower TA for muskmelon. More research is needed to verify this theory.

Flesh pH has been positively correlated with overall eating quality [14]. It ranged from 6.77 for "Sun Blushed" to 7.33 for "Aphrodite/Flexifort" (Table 9). "Aphrodite/Flexifort" had higher pH than "Astound", "Athena", "Carousel", "Ariel", "Sugar Cube", and "Sun Blushed". Additionally, it was higher in 2018 than in 2019. For muskmelon, it has been observed that pH is inversely related to TA, considering that a higher content of organic acids has been generally associated with a lower pH and vice versa [14,42].

Soluble solids concentration alone is not a predictable measure of muskmelon quality as other factors are also contributors [43]. The ratio of SSC to TA (SSC/TA) has been more highly linked to consumer preference than SSC or TA alone [44]. In our study, SSC/TA ranged from 243.61 to 591.99 and was not different between cultivars (Table 9). It was higher in 2018 than in 2019. Considering the non-significant variation of the SSC between cultivars and the non-significant cultivar × year interaction, the variation of the SSC/TA ration over the two seasons was primarily due to the lower levels of TA observed in the first growing season, likely as a consequence of the high level of rainfall recorded in proximity of the harvest.

Consumer preference for muskmelon has been associated with high SSC and pH, and low TA [14]. "Tirreno" and "Atlantis" met these criteria, as well as "Sugar Cube" and "Sun Blushed", whereas "Ariel" did not perform as well (Table 9). "Aphrodite/Flexifort" also met these criteria. Interestingly, non-grafted "Aphrodite" and "Aphrodite/RS841" did not. Grafting has improved muskmelon fruit quality by increasing photosynthesis and carbohydrate metabolism [45] and extending post-harvest life [46]. However, the rootstock and scion should be deliberately selected as negative effects can also occur, as shown for some cucurbits [47]. "Aphrodite/Flexifort" may be a better combination of muskmelon compared to "Aphrodite/RS841" based on the physicochemical traits measured in this study. Including "Aphrodite/Flexifort", "Tirreno", and "Atlantis" in a taste panel would be a next step, to determine how well consumer preference is correlated with their SSC, pH, and TA values.

Percentage water content was recorded as a measure of juiciness. It ranged between 94.65% to 91.10% and was higher in 2019 (93.06%) than in 2018 (92.08%) (Table 9). The percent water content in "Ariel" was higher than "Accolade", "Shockwave", "Sugar Cube", "Athena", and "Sun Blushed". All other cultivars did not differ from "Ariel". Despite these differences between cultivars, the range was relatively small, indicating they may all have had suitable juiciness.

4. Conclusions

Most cultivars did not produce different yields than "Aphrodite". One exception was "Sugar Cube" which produced a larger number of smaller-sized fruit than "Aphrodite" in four site-years. In the physicochemical evaluation, "Sugar Cube's" values for SSC, pH, and TA combined considering all cultivars were inferior, indicating that consumer preference may be greater for other cultivars. Alternatively, the novelty of being a small-sized muskmelon may be more important to consumers than relative taste and could be further studied through consumer preference research.

"Infinite Gold", "Fuji", and "Shockwave" produced fruit with a lower mean marketable weight than "Aphrodite". Additionally, "Sun Blushed" and "Ariel" did not perform

as well as other cultivars for SSC, pH, and TA combined. "Aphrodite" may be preferred over these cultivars, depending on other factors, including market and farmer preference.

The yield between grafted and non-grafted "Aphrodite" was not different; however, biotic and abiotic stresses were minimal or absent throughout the study. Combined SSC, pH, and TA values indicated that "Aphrodite/Flexifort" may be preferred by consumers compared to "Aphrodite/RS841" and non-grafted "Aphrodite". The "Aphrodite/Flexifort" combination offers an advantage for grafting, even in the absence of environmental stressors. "Sugar Cube" produced a unique, small-sized fruit that lends it to niche marketing. Small-sized fruit may suit the preferences of small households, which constitute a growing market segment. However, this cultivar had inferior combined SSC, pH, and TA values compared to other cultivars. Evaluating "Sugar Cube" on a "Flexifort" rootstock may improve these physicochemical values.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/horticulturae7040069/s1, Table S1: *P*-values for cultivar, year, and the interaction between year and cultivar for fruit yield components measured in an evaluation of 20 hybrid cultivars and two grafted entries of muskmelon in 2018 and 2019 at three sites in Pennsylvania and Table S2: *P*-values for cultivar, year, and the interaction between year and cultivar for fruit physicochemical components measured in an evaluation of 14 hybrid cultivars and two grafted entries of muskmelon in 2018 and 2019 at the center site in Pennsylvania.

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