INVESTIGATION OF MANAGEMENT STRATEGIES
TO IMPROVE FRUIT SET
IN SEEDLESS WATERMELON
(CITRULLUS LANATUS VAR. LANATUS)

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Plant & Soil Sciences

Fall 2017

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ACKNOWLEDGMENTS

I would like to thank Dr. Gordon Johnson, my advisor, for the opportunity to perform this research. His wealth of knowledge and aid in navigating graduate school have been greatly appreciated. I would to thank my committee members as well: Dr. Harsh Bais, Dr. Deb Delaney, Dr. Sherry Kitto, and Dr. Richard Taylor.

I would like to also thank the fantastic individuals who aided me with plot maintenance and data collection in the sweltering Georgetown heat. Without their help, this work would not have been completed. Thank you, Kellie Blessing, Brianna Bryfogle, Melissa Bryfogle, Matthew Chaffinch, Hilary Ennis, Davey Peterson, Cody Stubbs, Danielle Vanderhei, Caleb Yatuzis, and Matthew Zoller. Each one of you was an indispensable set of hands and made long hours of “chucking watermelons” unforgettable. I would like to thank Jake Jones and Andrew Kness, at the time fellow graduate students, for their help. Data collection has never been so easy.

I would like to thank Brian Hearn for working with me to ensure the success of my crops. Without the weed and pest control, seven acres of watermelons quickly becomes unmanageable. In addition, I would like to thank Ward Harris for installing my drip irrigation systems.

Thank you to the Mar-Del Watermelon Association for helping to fund this research. I truly hope that my work can aid your future endeavors. Thank you to the College of Agriculture and Natural Resources, especially those that work in the Plant and Soil Science Department. You have been my home away from home and have supported me over countless hours.

Finally, I would be remiss to not thank my family and friends. Without their encouragement, this most certainly would have not been possible. My drive to succeed is a direct result of their love and support.

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ABSTRACT

Watermelon (*Citrullus lanatus*) is an economically important crop in the Delaware-Maryland region with over 5000 acres grown annually. Seedless watermelons account for over 80% of the acreage in Delaware, and diploid pollenizers are necessary to provide pollen for triploid seedless watermelon development. However, due to spring weather variability on the Delmarva Peninsula, growers often face challenges with early fruit set. Reasons for this include limited bee activity in cold, rainy weather conditions and poor transplant vigor under these conditions.

The goal of this research was to explore areas that could improve early and overall fruit set. These included examining flower timing and pollen viability of pollenizer cultivars, identifying the effects of application of plant growth regulators during crown set, and determining what links there might be between pollenizer and seedless cultivars when planted alongside one another. All research was conducted during the summers of 2014 and 2015 at the University of Delaware's Carvel Research and Education Center, Thurmond Adams Agricultural Research Farm located in Georgetown, Delaware.

Staminate flowers were counted and collected from 24 different pollenizers with two different planting dates per year. Pollen was removed from those flowers and stained to determine viability. Pollen was then stained using acetocarmine solution and counted under the microscope. Male flower counts were found to range from a low of 2.8 flowers in May to a high of 11.4 in June, showing a wide range of pollen

availability. Furthermore, pollen viability ranged from 76.12 to 81.04%, a difference of less than 5% between the pollenizer with the highest pollen viability and the lowest. This is valuable information for pollenizer selection by growers.

Plant growth regulator applications showed significant differences from the untreated controls in 2014 but not in 2015. Watermelons treated with Promalin had the highest yields in 2014 at 85184.65 Kg/Ha, and Radiate treated watermelons had the highest yields in 2015 at 45095.44 Kg/Ha. The Promalin watermelons in 2014 were significantly different than the untreated control, but the 2015 Radiate watermelons were not (P = 0.05). Weather conditions likely played a major role in these differences. More testing must be done on these compounds before effort should be made to get these products on-label for watermelon production in Delaware and Maryland.

Finally, certain pollenizers performed well across multiple cultivars of seedless watermelon. ‘Pollen Pro’ and ‘Premium’ are two modern pollenizer cultivars that could be recommended to area growers no matter which cultivar of seedless watermelon they wished to grow. ‘Pollen Pro’, when used as a pollenizer for cultivar 7187 in 2015, produced almost twice as many fruit as the lowest producing pollenizer (6100 vs. 3200). Furthermore, cv. 7187 plants planted alongside ‘Pollen Pro’ had the highest yields for that seedless cultivar. When used as a pollenizer, the cultivar ‘Premium’ produced yields that were in the upper half of all three seedless cultivars, even if these differences were not statistically significant (P = 0.05). However, this research would have benefited greatly from one more year of data collection due to the great differences in weather between 2014 and 2015.

Chapter 1

INTRODUCTION

1.1 Watermelon Production

The watermelon (*Citrullus lanatus*), a member of the family *Cucurbitaceae*, originating from southern Africa, has been actively cultivated for over 4000 years on the African continent (53). Its theorized genetic ancestor, *Citrullus colocynthis*, is small and bitter compared to the modern ideal of a large, sweet watermelon (83). The name *Citrullus* was first created in 1775, by Forskal. H. Schrader, however, was the first to classify the genus analytically and have it introduced into the *Nomida Conservanda* in 1954 (27) (57).

The seedless watermelon, especially when compared to the above time frame, is a new development, only just over 50 years old (2). A "seedless" watermelon is the product of breeding a male, seeded diploid (2N) parent with a female, tetraploid (4N) parent. The resulting cross is a triploid (3N), sterile product producing the "seedless" quality. Due to the low seed count produced from the tetraploid female, seed costs for seedless watermelon are higher than seeded varieties. Because of the increased startup costs and uniqueness of their sterility, seedless watermelons require unique management practices to produce economically feasible results (51).

American consumption of all melons is around 25 pounds per capita, and watermelon accounts for roughly half of that (12). Californian watermelons are the earliest available. American grown watermelons, available starting in mid-May, and American grown fruit are available until late October (8). For the remaining months, America imports its watermelons, mainly from Latin America, with roughly 91% coming from Mexico (4).

Due to the lucrative nature of watermelon in humid regions, such as Delmarva, irrigation of watermelon plants is an important consideration. Drip irrigation systems have been improving in efficiency and effectiveness. The University of Delaware in 2006 showed that over irrigating has been used as a form of risk management, and that the watermelons could produce comparable results with less water applied (54). Black plastic mulched beds are also common. Mulched beds have been shown to help improve both growth and yields (67). Research has been done on other colors of mulch, but no consistent results have been obtained (84).

Barring application of chemicals to induce fruit parthenocarpically, seedless watermelon plants are required to have pollenizer rows or pollenizers planted in row, to produce fruit. The amount of field space normally allowed for these fruit is roughly 33% of total field space (53) (54). Apomixis, when studied in fellow cucurbit, muskmelon (*Cucumis melo*), was unheard of, and the sterility of the pollen produced by a triploid watermelon would likely preclude the possibility of such an event occurring (49). A dedicated, diploid pollenizer produces sexually viable pollen which is then carried by pollinators, usually managed honey bees *(Apis mellifera*), to the female (pistillate) flowers of the triploid plants (51). Most the honey bees come from colonies that have been artificially placed around fields by a grower to ensure a large population of bees.

Research has shown that different pollenizers can cause statistically significant differences between pollinated triploid fruit yields and saleable qualities (20). However, work by Freeman at the University of Florida has shown that, from year to year, the above may not be true (24). While yields were shown to be significantly different between seedless cultivars in 2006 (which was not the case in 2005), soluble solid concentration and hollow heart incidence were not significantly affected by pollenizer choice.

Furthermore, number of male flowers and pollen viability are important considerations for diploid pollenizer cultivars (22). Without a high quantity of viable pollen in a given field, full fruit set will not be accomplished, and yields suffer. Physical deformities also begin to show themselves on fruit that have been insufficiently pollinated, such as pinched and lobed melons.

Fruit weight is affected by plant spacing and interplant competition, therefore spacing is a key factor during transplanting (81). A study at the University of Florida in 2006 showed that a more vigorous pollenizer planted in row, one that produces greater foliage, negatively impacted the yields of the seedless cultivars that it was planted alongside (25).

The fertilization of the ovary provides auxin and other plant growth regulators (PGRs) in small quantities that encourages fruit development and growth (72). The plant then uses these small initial quantities of PGRs as signaling factors to begin the numerous, interconnected processes of fruit growth and maturation.

1.2 Plant Hormones (Plant Growth Regulators) and Their Applications

Plant hormones are produced in various parts of the plant and each has a very specific use in affecting the physiology of a maturing plant. These hormones are not major nutrients required for plant health, but are nonetheless incredibly important to the maturation and success of an individual. The major categories of plant hormones include: auxins, brassinosteroids, cytokinins, gibberellins, ethylene, jasmonates, and abscisic acid (77). These chemicals will be referred to as PGRs for the rest of this paper.

Parthenocarpy, the production of fruit without fertilization of the ovules, was studied in the late 1930s by Felix G. Gustafson. He explored the use of lanolin based compounds mixed with plant growth hormones and applied directly to cut ovaries of summer squash, as well as a handful of other plants (34). His success in this was cited as an inspiration for Gardner and Marth to induce parthenocarpy by utilizing low levels of indole-3-acetic acid (IAA) sprayed on uncut flowers to produce fruit. Their success in using IAA led to further experimentation with 1-naphthaleneacetic acid (NAA) to obtain equivalent results, though the usage volumes chosen failed (28). However, despite that initial failure, NAA was used in low levels of application to successfully produce fruit in watermelon by Cheong-Yin Wong. (86) Gibberellic acid (GA) was shown to be effective in producing parthenocarpic fruit, as well (16). Further studies showed promising results in the use of the synthetic cytokinin CPPU (3).

CPPU was found to be an excellent agent to both induce parthenocarpy and improve the quality of fruit produced in this manner. Watermelons treated with CPPU, for example, when used with 4-chlorophenoxyacetic acid (4-CPA), were shown to have a much higher level of soluble solids than fruit treated with solely CPPU (87). Soluble solids refer to the sugars that are part of the flesh of the melon. Obviously, soluble solids have great impact on the sale and marketing of watermelons, due to taste being an important factor for consumers when purchasing melons. A 200 part per million application consisting solely of CPPU on pollinated watermelons has been shown to be a practical consideration, providing larger watermelons than the pollinated control with no decrease in soluble solid content (32).

1.3 Pollination

Pollination, the other major component of this research, is interesting because the focus of pollination research is not solely on the plants themselves, but also on the pollinators. Without pollinators, viable pollen means nothing, since animal pollination is indispensable to watermelon success (48). This is important to acknowledge since honey bee pollination is another monetary cost to consider when working with watermelons. Hives are usually rented and placed around fields at the expense of the grower, with anywhere between 1 to 5 hives placed per acre based on field size, and ensuring the efficiency of those hives is essential to economic success (13). Open pollinations systems (where there is no limit to the number of bee visits to flowers) have shown to significantly increase fruit set due to the increased number of bee visits per flower, and therefore the increased viable pollen available (30).

Because bees, both honey bees and bumblebees, either being excellent pollinators of watermelon, are affected by ambient temperature, temperature and weather patterns must be considered when discussing pollination management (76). Even though both species are capable of functioning at lower ambient temperatures than is ideal, they do so at an increased metabolic cost (78). As a result, the effectiveness of these pollinators is likely to be reduced, and managing this stress on the bees is essential to their well-being and continued pollination of fields.

Chapter 2

POLLEN VIABILITY AND FLOWER COUNTS IN POLLENIZERS

2.1 Abstract

Optimizing pollenizer-seedless combinations is important to maximize yield potential in a field. Pollen viability studies were conducted with 26 pollenizer cultivars in 2014 and 2015 in four studies at Georgetown, DE.   Pollenizer trialed were SF800, Edom, Estrella, 4030, Sangria, Stargazer, Accomplice, Vista, SP5, SP6, Polimax, Premium, Sidekick, 10319, Jadestar, 4290, 4370, Golden Pioneer, Red Delicious, Wild Card, Faerie, Mickylee, Ox, Boost, Ace, Adir and Wingman. Boost, Ace and Adir produced the most male flowers on average, while SF 800 and Estrella produced the fewest. Overall, Adir (the experimental line), Ace, Boost, Ox, and Mickylee, all produced the highest volumes of viable pollen, whereas Stargazer, Sangria, 4030, Edom, Estrella and SF800 all produced the lowest ($P < 0.0001$). The difference in pollen viability between pollenizer cultivars was less than 5%, with percent viability ranging from 76.12 to 81.04%. Flower counts increased greatly from early to mid-season, from 2.8 flowers in May to a high of 11.4 in June. Knowing when pollenizers are producing the greatest number of flowers and which pollenizer produces the most viable pollen is important for growers who want to estimate pollen availability within their fields.

2.2 Introduction

Watermelon (*Citrullus lanatus*) is an economically important crop in the Delaware-Maryland region with over 5000 acres grown annually. Because of their sterility, seedless (triploid) watermelons must be planted alongside seeded (diploid) pollenizers. Pollenizer choice is an important consideration for optimizing seedless watermelon production. Pollenizers are required to produce pollen for triploid (seedless) watermelon fruit development (18). These watermelons are chosen because they are not sterile like the seedless watermelons, and they can produce the viable pollen necessary for those triploid plants to bear fruit.

Pollination initiates fruit development, but fertilization of ovules in the triploid fruit does not occur due to differences in the ploidy of the parents, thus no mature seeds are produced (stenospermocarpy) (91). In each watermelon field, 25% to 33% of the plants will be diploid pollenizers, the remainder will be the triploid seedless types.

To maximize pollen production, breeders have selected plants that produce high numbers of male flowers and small, inedible fruit. These are called “special pollenizers”. Standard seeded types may also be used to pollinate fields, and these cultivars produce saleable fruit (62).

Watermelon fruit set is influenced by many factors; the amount of pollen available (the number of male flowers and the amount of pollen per flower) and the viability of that pollen are two key factors (76).

Pollen viability could be a determining factor in the performance of watermelon pollenizers. Pollen flow from a pollenizer would be of little value if the viability was low, because pollen tube growth and ovule fertilization are necessary for seedless fruit maturation (52) (66). Poor pollination in watermelon can affect fruit shape and thus its marketability, and may be a contributing factor to the physiological disorder termed hollow heart (21) (52).

Hollow heart is a physiological disorder of watermelon categorized by the incomplete formation of the flesh. The three carpels that are within the melon fail to properly expand, and in severe cases, a large cavity is formed. This hurts the salability of fruit and can result in entire lots being discarded. The pictures below show the hollow heart rating scale.

Figure 1. Hollow Heart Ratings from 1 to 3 – None, Carpel Separation Evident, One Large Gap Evident

Figure 2. Hollow Heart Rating 4 – 2 or More Large Gaps

Figure 3. Hollow Heart Rating 5 – Severe Hollow Heart

Without a high quantity of viable pollen in each field, full fruit set will not be accomplished, and yields will suffer. Physical deformities also begin to show themselves on fruit that have been insufficiently pollinated, such as pinched and lobed melons.

A Florida study looked at the pollen viability of four pollenizer cultivars, three special pollenizers and Mickylee, a standard seeded type. There were no significant differences between the pollen viability of the pollenizers and all produced greater than 95% viable pollen (25).

The number of flowers produced by different pollenizer cultivars was studied at two locations in a 2005 Florida study. Significant differences were found between the number of male flowers produced by pollenizers over a 64-day period (23).

This work builds on that study with testing of additional pollenizers over a 2-year period with information on pollen production and pollen viability under

Delmarva climate and growing conditions. The pollenizer cultivars chosen include special pollenizers of interest to industry; cultivars with unique market characteristics, and cultivars with unique rind characteristics, which may be of interest in niche markets.

2.3 Materials and Methods

A total of 4 field trials were performed on the University of Delaware's Carvel Research and Education Center Thurmond Adams Research Farm (UD REC) near Georgetown, DE in 2014 and 2015. In each year, there were early and late plantings. The 2014 trials were repeated in 2015 with slight modifications to the protocols. Pollenizers used in the trial are described in Table 1 below. Cultivars tested in 2014 are denoted with a 1, and those tested in 2015 are denoted with a 2.

Table 1. Pollenizer Cultivars Tested in 2014 and 2015, Georgetown, DE, Source and Pollenizer Type.

Special Pollenizers			**Standard (marketable) Seeded Pollenizers**	
Cultivar	**Source**		**Cultivar**	**Source**
4030 (1, 2)	Highmark Seed Co		Estrella (1, 2)	Syngenta
4290 (1, 2)	Nunhems		Faerie (1, 2)	Stokes Seed Co
4370 (1, 2	Nunhems		Golden Pioneer (2)	Known You Seed
10319 (1, 2)	Nunhems		Jadestar (1, 2)	Twilley Seeds
Accomplice (1, 2)	Harris Moran Seed Co		Mickylee (1, 2)	Seminis
Ace (1, 2)	Sakata, Siegers Seed Co		Premium (1, 2)	Nunhems
Adir (1, 2)	Origene Seeds		Red Delicious (1, 2)	Twilley Seeds
Boost (1, 2)	Highmark Seed Co		Sangria (2)	Seedway LLC, Twilley Seeds
Edom (1, 2)	Origene Seeds		SF 800 (1, 2)	Nunhems
Ox (2)	Origene Seeds		Stargazer (1, 2)	Seminis
Polimax (1, 2)	Nunhems		Vista (1, 2)	Twilley Seeds
Sidekick (1, 2)	Harris Moran Seed Co			
SP5 (1)	Syngenta			
SP6 (1, 2)	Syngenta			
SVX (Wingman) (1, 2)	Seminis			
Wild Card (1, 2)	Sakata Seed America Inc			

All pollenizers tested were started in the UD REC greenhouses. Seeds in 2014 were planted over the course of two days, March 31st and April 1st, for the early trial and then again on April 22nd and 23rd for the late trial. The early trial in 2015 was planted on March 24th and 25^{t}h, and the late trial was planted on April 24th. Transplants were grown in 72 cell plug trays (fitting a 1020 standard tray) using Pro-Mix BX™ growing media. One week before field planting, transplants were moved outside to harden off.

Pollenizer plants were field planted into raised beds covered by 1.0 mil black plastic mulch, 90 cm wide at the bed top with drip irrigation tape beneath (0.23 gph, 30 cm emitter spacing). In 2014, spacing between plants was 60 cm. In 2015, spacing between plants was reduced 45 cm due to field space limitations. Each trial consisted of 4 beds of pollenizer cultivars in a randomized, complete block design, each bed a block, and seven plants of each pollenizer planted contiguously per block, for a total of 28 plants per cultivar. Care was taken to replace any plants that died within the first week after transplanting, ensuring that all replications had the same number of pollenizers.

The soil type for all studies was a Pepperbox Series (Loamy, mixed, semiactive, mesic Auic Arenic Paleudults). Each trial received 134 kg ha^{-1} nitrogen as urea ammonium nitrate solution divided into 3 applications, at planting (broadcast prior to bed formation), and 3 and 6 weeks after planting (through the drip irrigation system). All trials were irrigated when soil moisture availability decline to 50% field capacity to limit moisture stress. Fungicide, insecticide, and miticide treatments were applied as recommended. (2016-2017 Mid-Atlantic Commercial Vegetable Production Recommendations)

The pollenizers were observed for anthesis of the male flowers. In 2014, 5 male flowers that were at anthesis were collected per block for each of the cultivars and kept in a cold storage environment. If 5 flowers were not available, all flowers that were open were collected. In 2015, flower collection was reduced to 3 flowers per cultivar in each block. Flower counts were taken in 2015 prior to the collection of flowers. All opened male flowers were recorded.

Collected flowers were placed into the bulbous ends of 0.1 mm pipettes, which had been cut to allow for the flower to rest in the opening. The pipette ends with the flowers inside them were shaken vigorously by hand for 3 to 5 minutes and then placed on a lab bench underneath a hood to allow for pollen to settle overnight. The next day the flowers were discarded.

The fallen pollen was stained with an acetocarmine stain and placed onto a microscope slide for counting. The pollen was given two drops of water with a surfactant (unscented liquid dish soap (Dawn Pure Essentials)) incorporated to prevent the pollen grains from sticking to one another and to allow for easier counting. The acetocarmine stain was used to stain the viable pollen by staining the chromosomes. Viable pollen and total pollen numbers were recorded. All the pollen was counted manually in 2014. A counting slide was used in 2015 and the pollen numbers were extrapolated by multiplying the subsample by the grid size on the counting slide. After 10 samples, a check using the 2014 method of manually counting was performed to ensure accuracy.

All data was analyzed using SAS software (SAS Institute Inc.). An analysis of variance was performed for viable pollen and flower counts and means were separated using Tukey's range test.

2.4 Results

In 2015, mean flower counts across all cultivars (Figure 4) were calculated. In the early study, mean flower number ranged from 2.8 flowers on May 20th to 11.4 flowers on June 4th, when the number of flowers reached a maximum. Flower numbers then dropped to 8.5 on June 9th, the last day that data was collected.

In the 2015 late study, mean flower counts ranged from 1.5 to 3.0 over the 8-day period from June 25 to July 3; thereafter, flower numbers rose to 4.5 on July 7 and finally to the high of 8.1 flowers on July 9.

Figure 4. Mean Flower Counts by Date Across All Pollenizer Cultivars Tested in 2015. University of Delaware, Georgetown, 2015.

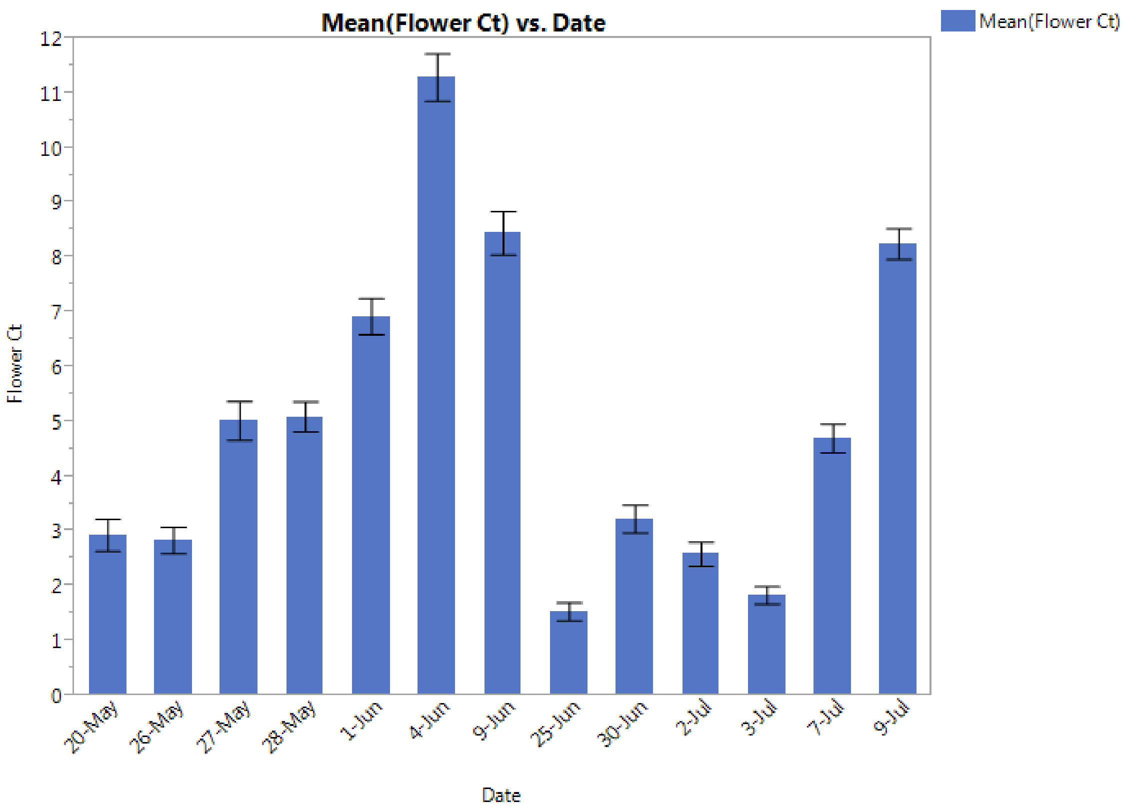
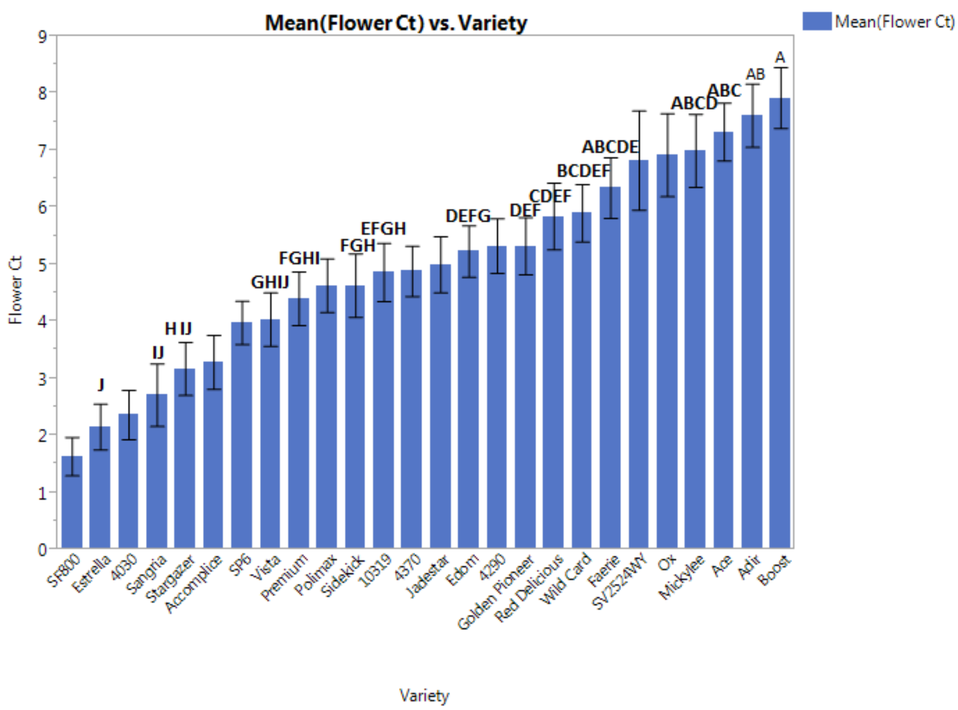


Figure 5 shows mean flower counts between cultivars. Boost, Adir, Ace, Mickylee, Ox, and SV2524WY formed the highest group, with means ranging from 7.9 to 6.8 flowers over the course of both studies. Sangria, 4030, Estrella, and SF800 form the lowest group, with means ranging from 2.7 to 1.6 flowers over the course of both studies.

Figure 5. Mean Flower Counts by Pollenizer Cultivar. University of Delaware, Georgetown, 2015.



Means followed by the same letter were not significantly different at p > 0.05 using Tukey's Range Test

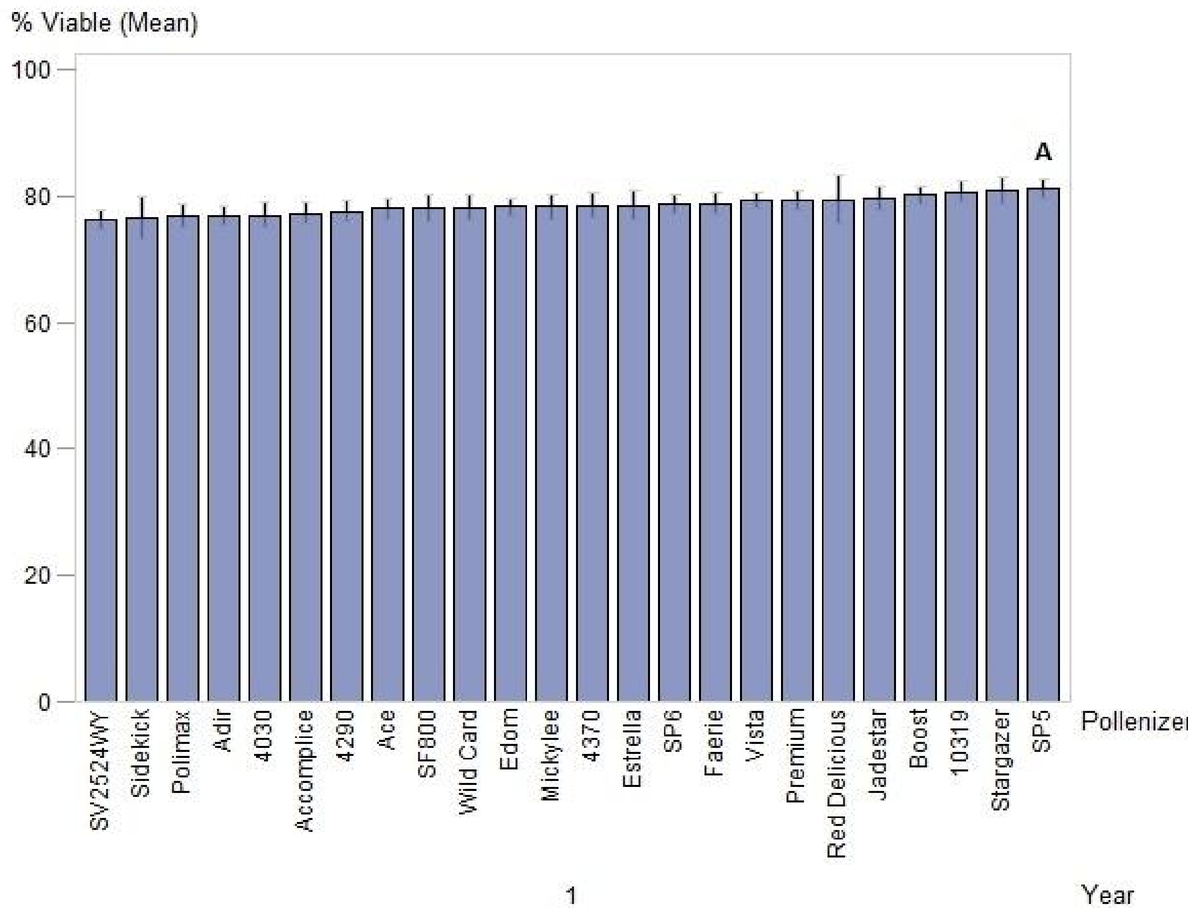
Tables 2 and 3 and Figure 4 show shows pollen viability results. In 2014, there were no statistical differences in pollen viability between cultivars which ranged from 76.18-81.04%. In 2015, cultivar 10319 (73.01%), Sangria (73.07%), and Golden Pioneer (73.98%) had significantly lower viability than Ace (77.52%) and 4290 (77.61%). Cultivar 4290 was also significantly different than SP6 (74.38%). In addition to Ace and 4290, Accomplice (77.40%), Mickylee (77.28%), Polimax (76.62%) Red Delicious (76.46%) and SVX (76.44%) all produced significantly higher mean percent viable pollen than Sangria and cultivar 10319. All other cultivars were not significantly different from one another.

Table 2. Mean Percent Viable Pollen by Pollenizer Cultivar Averaged Across 2014 and 2015. University of Delaware, Georgetown, 2014-2015.

Pollenizer	% Viable Pollen
Mickylee	78.50 a
Ace	78.17 ab
4290	78.05 ab
Red Delicious	77.81 ab
Accomplice	77.66 ab
Faerie	77.53 ab
Polimax	77.29 ab
Jadestar	77.23 abc
Boost	77.12 abc
Edom	77.02 abc
Ox	76.74 abc
Premium	76.79 abc
Estrella	76.41 abcd
4370	76.38 bcd
4030	76.35 bcd
Sidekick	76.33 bcd
10319	76.32 bcd
Adir	76.20 bcd
SF800	76.16 bcd
Golden Pioneer	75.25 cd
Sangria	74.34 d

Means followed by the same letter were not significantly different at $p > 0.05$ using Tukey's Range Test

Figure 6. Mean Percent Viable Pollen by Pollenizer Cultivar in 2014. University of Delaware, Georgetown, 2014.



Cultivars were not significantly different at p > 0.05 using Tukey's Range Test

Table 3. Mean Percent Viable Pollen by Pollenizer Cultivar in 2015. University of Delaware, Georgetown, 2015.

Pollenizer	Mean
4290	77.613 a
Ace	77.522 ab
Accomplice	77.396 abc
Mickylee	77.280 abc
Polimax	76.616 abcd
Red Delicious	76.460 abcd
SVX	76.438 abcd
Faerie	76.042 abcde
Wild Card	75.976 abcde
Edom	75.870 abcde
Vista	75.851 abcde
Ox	75.684 abcde
Adir	75.363 abcde
Boost	75.301 abcde
Estrella	75.131 abcde
Jadestar	75.028 abcde
Sidekick	74.919 abcde
Premium	74.898 abcde
SF800	74.842 abcde
4030	74.699 abcde
4370	74.535 abcde
Stargazer	74.498 bcde
SP6	74.379 cde
Golden Pioneer	73.975 de
Sangria	73.067 e
10319	73.012 e

Means followed by the same letter were not significantly different at $p > 0.05$ using Tukey's Range Test

Over both years, Sangria produced the least viable pollen by percentage at 74.3%, while Mickylee produced the greatest amount of viable pollen by percentage at 78.5%. All other cultivars produced similar percentages of viable pollen.

2.5 Discussion

It was suspected that early season pollen viability would be lower, due to the early season stress that we often see on the Delmarva Peninsula, but cultivars showed relatively little variability between early and late plantings in 2014 and 2015. Freeman, at the University of Florida, found similar results, but his overall pollen viability was much higher, not lower than 95% for any cultivar (26).

The differences in pollen viability seen between this study and Freeman's work could possibly be the effects of early season stress, but without performing a study to test pollen viability of these cultivars in optimal growing conditions (such as in a greenhouse or growth chamber) versus in the field, it is impossible to know for certain. A study that explores what differences may exist between those conditions would be very useful as preliminary work for future trials.

It is also possible that my technique for pollen removal was not optimal for watermelon. It has been shown that buzzing frequencies of bumblebees can affect pollen removal. A several hundred megahertz difference in vibration radically changed the volume of pollen removed in previous studies (38). The mechanical shaking of the flowers may not have dislodged all of the viable pollen on the stamen. Since watermelons are not generally pollinated by bumblebees, this was not considered when designing the experiment but determining what force is necessary to remove all the pollen from a watermelon flower could be very useful information in the future.

There is also the question of whether viable pollen indicates the ability of that pollen to successfully form pollen tubes/germinate. In this study, staining the pollen (specifically, staining chromosomes within the pollen) was used as a surrogate for actual germination. However, it would be highly beneficial for future studies to actually test pollen for the percentage of pollen tubes that are formed once viable pollen counts are recorded. This would provide a clearer picture as to whether or not staining pollen worked as an accurate surrogate for watermelon pollen germination.

Furthermore, in future studies, limiting the possible effects of pollinators on pollen counts would be useful. Bagging flowers the night prior to anthesis to prevent potential loss from early pollinator activity would be ideal. While every effort was made to collect flowers as they opened in the morning, there could still have been some pollen robbed by pollinators. Bagging the flowers the night before would help ensure that all pollen grains removed from the flowers once collected were the pollen grains easily accessible to pollinators, providing a better picture of what pollen viability and availability is in the field.

2.6 Conclusions

Pollen availability throughout a season is a function of the number of flowers that are produced by the pollenizer. Pollen viability in the pollenizers tested was relatively consistent across cultivars. Special pollenizers, specifically bred for the production of numerous male flowers, consistently outperformed standard seeded types in the total amount of effective pollen they were producing. Adir, Ace, Boost, and Ox were special pollenizers that were shown to produce consistently high amount of viable pollen in the Delaware trials. One specialty watermelon that was tested as a pollenizer, Faerie, produced a small fruit with a yellow rind but also had high amounts of effective pollen along with Mickylee, which has been used successfully as a pollenizer for many years. Larger fruited standard seeded cultivars produced much lower amounts of effective pollen in these trials.

Chapter 3

PLANT GROWTH REGULATORS AND THEIR APPLICATION

3.1 Introduction

Watermelon (*Citrullus lanatus*) is an important crop on the Delmarva Peninsula. Plant growth regulators (referred to from here on as PGRs) are chemicals that when applied mimic naturally occurring plant hormones. Some PGRs are, in fact, naturally occurring plant hormones made available for exogenous application, but others are synthesized from many sources. In Europe, Israel, and Asia, PGRs are commonly applied to watermelons with success to improve fruit set and fruit yield. By mimicking plant hormones that could be in short supply during early season pollination, PGR applications have the potential to increase fruit yields, if a successful regimen of application can be determined. Too little of a PGR and one may not see any change in yield, losing money with an application that had no effect. Too much of a PGR and one may see detrimental effects on the plants, resulting in lost yields from damaged fruit or other signs of phytotoxicity. Currently, PGRs are labeled for application on certain fruit crops in the US, but not on watermelons in Delaware. For PGRs to be put on-label in Delaware, more work must be done to prove that these applications are economically viable. California and Arizona have multiple commercial products labeled for use on watermelons.

PGRs are produced in various parts of the plant and each has different mechanisms for affecting the physiology of a maturing plant. These PGRs are important to the growth and development of an individual plant. In flowering plants, the fertilization of the ovary provides auxin and other hormones in small quantities that initiates fruit development and growth (72). Subsequently these small initial quantities of PGRs serve as signaling factors to begin the numerous, interconnected processes of fruit growth and maturation. The major categories of plant PGRs include: auxins, brassinosteroids, cytokinins, gibberellins, ethylene, jasmonates, and abscisic acid (77). In this research, the effect of exogenous applications of auxin, gibberellin, and cytokinin via commercially available products on watermelon development was studied.

Auxins are found in all parts of plant in various quantities, and it affects cell division and cell expansion, two functions vitally important regarding fruit production (26). The cell elongation that takes place to allow this elasticity is driven by the presence of auxins. Indole-3-acetic-acid (IAA), is the most common of all the naturally occurring auxins and has been the auxin the most rigorously studied (90). In this study, synthetic auxins such as 2,4-Dichlorophenoxyacetic acid (2,4-D) and α-Naphthalene acetic acid were used.

Cytokinins promote cytokinesis within plants, the division of cells. The two types of cytokinins are adenine-type cytokinins, examples of which are kinetin and 6-benzyladenine, and phenylurea-type cytokinins, of which CPPU (N-(2-Chloro-4-pyridyl)-N'-phenylurea) is an example (70).

Gibberellins were originally identified as secretions of a parasitic fungi, (*Gibberella fujikuroi*), in the 1920s in Japan and were named after the pathogen (72). Gibberellins encourage flower production, as well as seed dormancy and germination (47) (31) (74). Gibberellic acids (GAs) GA1, GA3, GA4, and GA7 are biologically active and are responsible for most of the actions that gibberellins are known for within plants (88). Today, there are over 110 GAs identified, and even though their chemical properties are similar with minor changes, they vary significantly in their bioactivity (72). GA3, in combination with CPPU, was found to increase berry quality in grapes in moderate quantities, while over application increased qualities that were detrimental to fruit quality (92).

Parthenocarpy, IAA, NAA and GA (3 PGRs useful for parthenocarpic fruit production and used in this study for their properties relating to fruit set) are all described on page 15 of this document. Furthermore, CPPU, another, more volatile PGR also used in this study, is also described on pages 15 and page 16. Refer to those pages for further information.

Pollenizer effectiveness and pollen availability are serious concerns for early fruit set during the variable springs of the Delmarva Peninsula. Other countries, such as Israel, Spain, and China, have found success using PGR applications to supplement any pollination that occurs in their fields (53) (83) (2) (51) (49). These applications are meant to ensure that cell division and expansion takes place within fruit that may not have fully matured with the plant hormones provided by these applications.

Using a PGR, or mix of PGRs, that can act to supplement poor early season pollination can improve fruit set. Phytotoxicity has been shown during the application process in the past (39). Foliar damage must be kept to a minimum to ensure that future harvests do not suffer at the cost of potential one harvest gains. As such, the PGRs used in this study were chosen and applied in amounts and using application methods to reduce phytotoxicity or fruit defects.

3.2 Materials and Methods

All trials were performed on the University of Delaware's Carvel Research and Education Center Thurmond G Adams research farm (UD REC) near Georgetown, DE. The 2014 trial was repeated in 2015 with slight modifications to the protocols.

All cultivars used were started from seed in the UD REC greenhouses. Seeds in 2014 were planted April 7th into trays. Seeds were planted April 2nd and 13th in 2015, for the early and late trials respectively. Transplants were grown in 72 cell plug trays (fitting a 1020 standard tray) using Pro-Mix BX™ growing media. One week before field planting transplants were moved outside to harden off. In 2014, the early trial was field planted on April 25th and the late trial was field planted on May 20th. In 2015, the early trial was planted on April 24th and the late trial was planted on May 22nd. Care was taken to replace any plants that died within the first week after transplanting, ensuring that all replications had the same number of pollenizers.

Plants were field planted into raised beds covered by 1.0 mil black plastic mulch, 90 cm wide at the bed top with drip irrigation tape beneath (0.23 gph, 30 cm emitter spacing). In 2014, spacing between plants was 60 cm. In 2015, spacing between plants was 45 cm. Spacing was changed due to limits on available field space. Each trial consisted of 4 beds of pollenizer cultivars in a randomized, complete block design, each bed a block, and seven plants of each pollenizer planted contiguously per block, for a total of 28 plants per cultivar.

A preliminary study performed in 2013 using Prestige (CPPU) and Maxcel (6-BA) in addition to hand pollination, showed promise for possible Delaware PGR applications when pollen sources were not present. These chemicals were applied directly to the ovaries on a small scale by hand, but some fruit were successfully set. This study gave cause to try these chemicals on a larger scale.

In 2014, the seedless watermelon cultivars planted were cultivar 7187, Crunchy Red, and Fascination. Maxcel, Prestige, Promalin and a water-application control were the experimental treatments. In 2015, Fascination, Liberty, and Melody were used as the seedless watermelon varieties. Maxcel, Prestige, Promalin and the water-application control were all used once again, with Radiate and a Promalin/Radiate mix being used as well.

Product Name	PGRs	Concentrations
Promalin	6-benzyladenine	1.8%
	Giberellins A4 & A7	1.8%
Prestige	N-(2-chloro-4-pyridinyl)-N'-phenyl urea	0.8%
Maxcel	6-benzyladenine	1.9%
Radiate	3-Indolebutyric acid	0.85%
	Kinetin	0.15%

The soil type for all studies was a Pepperbox Series (Loamy, mixed, semiactive, mesic Auic Arenic Paleudults). Each trial received 134 kg ha^{-1} nitrogen as urea ammonium nitrate solution divided into 3 applications, at planting (broadcast prior to bed formation), and 3 and 6 weeks after planting (through the drip irrigation system). All other nutrients and pH were in optimum range according to University of Delaware Soil Testing Laboratory analysis. All trials were irrigated on a regular basis to limit stress. Fungicide, insecticide, and miticide treatments were applied as needed per University of Delaware recommendations.

At the time when the first female flowers were observed in the field, PGR applications were prepared. Maxcel (6-BA), Promalin (6-BA, GA 4&7), Radiate (IBA, kinetin) and the Promalin/Radiate mix were tank mixed into 40 part per million solutions and were sprayed as a foliar application once a day for four days so that a total of 160 ppm of each PGR was applied. Prestige (CPPU) was tank mixed to a 200-ppm solution and was applied directly to the ovaries of female flowers using the wand of the backpack sprayer, to minimize foliar damage.

Watermelons were harvested twice per trial in both 2014 and 2015. In 2014, the first harvest took place on August 1st, and the second harvest took place on August 19th. The early PGR application trial was harvested on July 23rd and August 13th in 2015. The late PGR application trial was harvested on August 10th and August 26th in 2015.

The watermelons that were harvested were chosen based on industry standards. No watermelon smaller than 3.18 kg (7 lbs.) was harvested, and if a watermelon fell under that weight, it was discarded. Once weighed, watermelons were cut open. Hollow heart ratings were recorded on a 1 to 5 scale. A rating of 1 indicates no hollow heart is present, while a 5 indicates the presence of severe hollow heart, encompassing most of the flesh, which would render the fruit unsaleable. For ease of understanding, refer to Figures 1, 2 and 3. Soluble solids were measured by removing a piece of flesh from the melon, extracting the juice from that piece of flesh and using a handheld refractometer to measure degrees Brix from that juice. Fruit quality measurements were not collected for the August 26th, 2015 harvest of the late PGR trial, due to labor constraints.

All data was analyzed using SAS software (SAS Institute Inc.). Analysis of variance was performed and means were separated using Fisher's LSD, $P > 0.05$.

3.3 Results

Tables 4, 5, and 6 show the summary statistics (number of observations, mean, standard deviation and the sum) for the weight in lbs. for 2014 and 2015, early and late plantings.

Table 4. Early Planting in 2015 Mean Watermelon Fruit Weights in Lbs. and Kg by Cultivar and Treatment. University of Delaware, Georgetown, 2015.

PGR	Cultivar	Number of Observations	Mean Weight in Lbs.	Mean Weight in Kg	Standard Deviation	Sum
Control	Fascination	29	14.55 bc	6.59 bc	4.47	422.06
Control	Liberty	41	14.90 ab	6.75 ab	4.09	610.82
Control	Melody	42	14.95 ab	6.77 ab	4.01	627.92
Maxcel	Fascination	40	16.45 ab	7.45 ab	4.19	658.02
Maxcel	Liberty	39	14.95 ab	6.77 ab	3.46	583.20
Maxcel	Melody	36	14.51 ab	6.57 ab	3.99	522.24
Mix	Fascination	44	13.96 c	6.32 c	4.48	614.04
Mix	Liberty	55	14.19 bc	6.43 bc	3.80	780.68
Mix	Melody	43	14.80 abc	6.70 abc	4.62	636.20
Prestige	Fascination	39	14.91 ab	6.75 ab	3.56	581.46
Prestige	Liberty	33	13.96 bc	6.32 bc	2.89	460.78
Prestige	Melody	31	15.40 ab	6.98 ab	3.90	477.3
Promalin	Fascination	53	15.69 ab	7.11 ab	4.36	831.82
Promalin	Liberty	34	15.20 ab	6.89 ab	3.55	516.92
Promalin	Melody	44	14.24 bc	6.45 bc	3.94	626.68
Radiate	Fascination	50	14.60 ab	6.61 ab	4.07	730.10
Radiate	Liberty	41	17.00 a	7.70 a	4.16	696.90
Radiate	Melody	50	14.33 ab	6.49 ab	4.09	716.60

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

Table 5. Late Planting in 2015 Watermelon Fruit Weights in Lbs. and Kg in Kg by Cultivar and Treatment. University of Delaware, Georgetown, 2015.

PGR	Cultivar	Number of Observations	Mean Weight in Lbs. (Kg)	Mean Weight in Kg (Kg)	Standard Deviation	Sum (Kg)
Control	Fascination	48	7.02 bcde	7.02 bcde	4.43	743.63
Control	Liberty	44	6.91 e	6.91 e	3.93	671.48
Control	Melody	47	7.33 abcde	7.33 abcde	3.92	760.54
Maxcel	Fascination	59	7.29 abcde	7.29 abcde	4.01	950.12
Maxcel	Liberty	53	7.21 abcde	7.21 abcde	4.99	843.1
Maxcel	Melody	50	6.44 ab	6.44 ab	5.3	710.8
Mix	Fascination	47	7.97 a	7.97 a	5.29	827.34
Mix	Liberty	54	6.5 abc	6.50 abc	4.62	774.5
Mix	Melody	34	8.05 de	8.05 de	4.2	603.68
Prestige	Fascination	53	6.53 abcd	6.53 abcd	5.55	764.0
Prestige	Liberty	47	7.48 cde	7.48 cde	4.24	776.34
Prestige	Melody	53	6.41 a	6.41 a	3.88	750.48
Promalin	Fascination	50	7.74 ab	7.74 ab	5.09	854.56
Promalin	Liberty	49	6.94 abcde	6.94 abcde	4.3	750.16
Promalin	Melody	58	7.74 abcde	7.74 abcde	4.1	991.46
Radiate	Fascination	50	7.75 ab	7.75 ab	4.88	855.7
Radiate	Liberty	46	7.02 abcde	7.02 abcde	5.65	712.44
Radiate	Melody	62	6.57 abcde	6.57 abcde	4.16	899.02

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

In 2014, Maxcel and Promalin applied to Fascination produced significantly heavier watermelons than the Prestige application or the untreated control. Furthermore, Maxcel, Prestige and Promalin applied to cultivar 7187 all produced significantly heavier watermelons than the untreated control. None of the treatments differed significantly for the cultivar Crunchy Red. (Table 7)

Table 6. ANOVA Table. Comparison of Fruit Weights in Lbs. and Kg for Early Watermelon Planting by PGR Application and Cultivar, 2014. University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	66.32288	22.10763	1.04	0.3739
PGR	5	276.3265	55.26529	2.6	0.024
Cultivar	2	86.48071	43.24036	2.03	0.1313
PGR*Cultivar	10	789.023	78.9023	3.71	<.0001
Rep*Cultivar	6	172.1049	28.68414	1.35	0.2323

Table 7. Least Squares Means Comparison of Fruit Weights in Lbs. and Kg for Early Watermelon Planting by PGR Application and Cultivar, 2014. University of Delaware, Georgetown, 2014.

PGR	Cultivar	Mean Weight in Lbs.	Mean Weight in Kg
Maxcel	Fascination	13.59 a	6.17 a
Maxcel	7187	13.52 ab	6.14 ab
Promalin	Fascination	13.17 ab	5.98 ab
Promalin	7187	12.78 abc	5.80 abc
Prestige	7187	12.4 bcd	5.63 bcd
Prestige	Fascination	11.72 cde	5.32 cde
Promalin	Crunchy Red	11.45 de	5.20 de
Prestige	Crunchy Red	11.45 de	5.20 de
Maxcel	Crunchy Red	11.26 de	5.11 de
Control	Fascination	10.29 e	4.67 e
Control	7187	9.78 e	4.44 e
Control	Crunchy Red	8.11 e	3.68 e

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

In the early planting of 2015, Radiate + Liberty produced significantly heavier watermelons than the other varieties and applications (17.017 lbs). Radiate +

Fascination, Radiate + Melody, PGR Mix + Liberty, PGR Mix + Fascination, Promalin + Melody, and Prestige + Liberty performed worse than the untreated control, which performed similarly to the other treatments and cultivars. (Table 9)

Table 8. ANOVA Table for Fruit Weight for the Early Watermelon Planting and PGR Application, 2015. University of Delaware, Georgetown, 2015.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	88.43616	29.47872	1.84	0.1391
PGR	5	78.97176	15.79435	0.98	0.4265
Cultivar	2	17.83652	8.91826	0.56	0.5739
PGR*Cultivar	10	337.5322	33.75322	2.1	0.0222
Rep*Cultivar	6	127.107	21.18449	1.32	0.2457

Table 9. Least Squares Means Comparison of Fruit Weight in Lbs. and Kg in Lbs. and Kg for Early Watermelon Planting and PGR Application, 2015. University of Delaware, Georgetown, 2015.

Cultivar	PGR	Mean Weight in Lbs	Mean Weight in Kg
Radiate	Liberty	17.02 a	7.73 a
Maxcel	Fascination	16.28 ab	7.39 ab
Promalin	Fascination	15.64 abc	7.10 abc
Prestige	Melody	15.47 abc	7.02 abc
Promalin	Liberty	15.38 abc	6.98 abc
Control	Melody	15.03 bc	6.82 bc
Control	Liberty	15.00 bc	6.81 bc
Prestige	Fascination	14.90 bc	6.76 bc
Maxcel	Liberty	14.89 bc	6.76 bc
Maxcel	Melody	14.71 bc	6.68 bc
Mix	Melody	14.71 bc	6.68 bc
Control	Fascination	14.68 bc	6.66 bc
Radiate	Fascination	14.54 bc	6.60 bc
Radiate	Melody	14.23 c	6.46 c
Mix	Liberty	14.19 c	6.44 c
Mix	Fascination	14.17 c	6.43 c
Promalin	Melody	14.12 c	6.41 c
Prestige	Liberty	13.88 c	6.30 c

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

In 2015, the control treatment on cv. 7187 produced the highest hollow heart ratings (HHR) (Mean: 2.01) overall. This was significantly higher than Maxcel applied to Crunchy Red (Mean: 1.45), the lowest mean HHR. Promalin, Prestige and Maxcel applied to cultivar 7187 (1.98, 1.94, and 1.93) were also significantly higher than Maxcel applied to Crunchy Red. (Table 10)

Table 10. Least Squares Means Comparison for Hollow Heart Ratings by PGR and Cultivar, 2014. University of Delaware, Georgetown, 2014.

PGR	Cultivar	Mean Hollow Heart Rating
Control	7187	2.01 a
Promalin	7187	1.98 a
Prestige	7187	1.94 a
Maxcel	7187	1.93 a
Control	Crunchy Red	1.90 ab
Control	Fascination	1.71 ab
Promalin	Crunchy Red	1.75 ab
Maxcel	Fascination	1.68 ab
Prestige	Fascination	1.60 ab
Prestige	Crunchy Red	1.58 ab
Promalin	Fascination	1.58 ab
Maxcel	Crunchy Red	1.45 b

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

For the late planting in 2015, the PGR Mix + Troubadour and the PGR Mix + Fascination produced significantly heavier watermelons than any other cultivar and application combination (17.78 and 17.54 lbs). Prestige + Troubadour produced the lightest melons (13.202 lbs). Every other combination of application and cultivar was not statistically significant. (Table 11)

Table 11. Least Squares Means Comparison for Weight in Lbs. and Kg and Kg, Late Watermelon Planting and PGR Application, 2015. University of Delaware, Georgetown, 2015.

Variety	PGR	Mean Weight in Lbs.	Mean Weight in Kg
Troubadour	Mix	17.78 a	8.07 a
Fascination	Mix	17.54 a	7.96 a
Troubadour	Promalin	17.15 ab	7.79 ab
Fascination	Promalin	17.13 ab	7.78 ab
Fascination	Radiate	16.90 abc	7.67 abc
Melody	Prestige	16.55 abc	7.51 abc
Troubadour	Control	16.21 abcd	7.36 abcd
Fascination	Maxcel	16.08 abcde	7.30 abcde
Melody	Maxcel	16.02 abcdef	7.27 abcdef
Melody	Radiate	15.62 bcdef	7.09 bcdef
Fascination	Control	15.52 bcdefg	7.05 bcdefg
Melody	Promalin	15.46 bcdefg	7.02 bcdefg
Melody	Control	15.23 cdefg	6.91 cdefg
Troubadour	Radiate	14.50 defg	6.58 defg
Fascination	Prestige	14.46 defg	6.56 defg
Melody	Mix	14.37 efg	6.52 efg
Troubadour	Maxcel	14.25 fg	6.47 fg
Troubadour	Prestige	14.20 g	6.45 g

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

The PGR Mix applied to Liberty showed the highest hollow heart ratings in the early planting of 2014 (1.25). This was significantly higher than the control treatment on Melody, the PGR Mix on Melody and Radiate on Melody (1.02, 1.01 and 1.01, respectively). All other treatments were not significantly different. (Table 12)

Table 12. Least Squares Means Comparison for Hollow Heart Ratings by PGR and Cultivar, 2014. University of Delaware, Georgetown, 2014.

PGR	Cultivar	Mean Hollow Heart Rating
Control	7187	2.01 a
Promalin	7187	1.98 a
Prestige	7187	1.94 a
Maxcel	7187	1.93 a
Control	Crunchy Red	1.90 ab
Control	Fascination	1.71 ab
Promalin	Crunchy Red	1.75 ab
Maxcel	Fascination	1.68 ab
Prestige	Fascination	1.60 ab
Prestige	Crunchy Red	1.58 ab
Promalin	Fascination	1.58 ab
Maxcel	Crunchy Red	1.45 b

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

In 2015, the PGR Mix applied to Liberty produced the highest hollow heart ratings (1.25) while the control treatment applied to Fascination produced the lowest (1.05). This was the only significant interaction amongst the treatments and cultivars.

Table 13. Least Squares Means Comparison for Hollow Heart Ratings by PGR and Cultivar for 2015 Early Planting. University of Delaware, Georgetown, 2014.

PGR	Cultivar	Mean Hollow Heart Rating
Mix	Liberty	1.25 a
Promalin	Liberty	1.24 ab
Prestige	Fascination	1.22 ab
Control	Fascination	1.22 ab
Prestige	Melody	1.19 ab
Maxcel	Liberty	1.18 ab
Radiate	Liberty	1.18 ab
Control	Liberty	1.17 ab
Promalin	Fascination	1.16 ab
Maxcel	Melody	1.14 ab
Mix	Fascination	1.13 ab
Promalin	Melody	1.11 ab
Radiate	Fascination	1.08 ab
Maxcel	Fascination	1.05 ab
Prestige	Liberty	1.02 ab
Control	Melody	1.02 b
Mix	Melody	1.01 b
Radiate	Melody	1.01 b

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

In the late planting of 2015, Prestige applied to Melody produced the highest hollow heart ratings (1.92). This was significantly different, and higher, than all other treatment and cultivar combinations. (Table 14)

Table 14. Least Squares Means Comparison for Hollow Heart Ratings by PGR and Cultivar, 2015 Late Planting. University of Delaware, Georgetown, 2015.

PGR	Cultivar	Mean Hollow Heart Rating
Prestige	Melody	1.92 a
Mix	Fascination	1.43 b
Promalin	Fascination	1.40 b
Control	Melody	1.34 b
Radiate	Melody	1.30 b
Radiate	Troubadour	1.26 b
Mix	Melody	1.26 b
Control	Fascination	1.24 b
Prestige	Fascination	1.24 b
Maxcel	Troubadour	1.21 b
Maxcel	Fascination	1.17 b
Control	Troubadour	1.16 b
Maxcel	Melody	1.13 b
Promalin	Troubadour	1.12 b
Promalin	Melody	1.09 b
Radiate	Fascination	1.04 b
Prestige	Troubadour	1.01 b
Mix	Troubadour	1.01 b

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

Tables 15 and 16 show summary statistics (number of observations, mean, standard deviation, minimums and maximums) for 2015 soluble solid content.

Table 15. Summary Statistics Table for Early Trial Soluble Solid Content in Degrees Brix by Cultivar and PGR, 2015. University of Delaware, Georgetown, 2015.

Cultivar	PGR	N Obs	Mean	Std Dev	Min	Max
7187	Control	9	11.01	0.99	9.40	12.60
7187	Maxcel	22	10.96	1.47	7.70	12.70
7187	Prestige	46	11.25	1.07	7.00	12.70
7187	Promalin	34	11.51	1.06	9.60	13.10
Crunchy Red	Control	2	10.70	0.42	10.40	11.00
Crunchy Red	Maxcel	19	10.69	0.86	9.50	13.40
Crunchy Red	Prestige	31	11.11	1.20	7.40	13.40
Crunchy Red	Promalin	41	11.43	0.84	9.20	13.10
Fascination	Control	48	10.72	0.98	8.60	12.60
Fascination	Maxcel	73	10.55	1.03	8.00	12.60
Fascination	Mix	44	10.37	0.90	6.20	12.00
Fascination	Prestige	76	10.73	1.16	7.20	13.10
Fascination	Promalin	97	10.64	0.82	7.80	12.70
Fascination	Radiate	50	10.12	0.90	7.00	11.80
Liberty	Control	41	10.51	0.94	8.00	12.40
Liberty	Maxcel	39	10.22	0.61	8.20	11.20
Liberty	Mix	55	10.38	0.76	8.40	12.20
Liberty	Prestige	33	10.27	0.77	8.80	12.00
Liberty	Promalin	34	10.51	0.77	8.80	12.40
Liberty	Radiate	41	10.33	1.00	7.40	12.00
Melody	Control	42	1033	0.73	8.40	11.60
Melody	Maxcel	36	10.01	0.73	8.80	11.60
Melody	Mix	43	10.40	0.80	8.00	12.20
Melody	Prestige	31	10.02	0.89	7.40	11.00
Melody	Promalin	44	10.60	1.19	7.00	12.80
Melody	Radiate	50	10.39	0.90	8.00	12.00

Table 16. Mean Late Trial Soluble Solid Content in Degrees Brix by Cultivar and PGR, 2015. University of Delaware, Georgetown, 2015.

Cultivar	PGR	N Obs	Mean	Std Dev	Min	Max
Fascination	Control	48	10.28	0.70	8.80	11.80
Fascination	Maxcel	59	10.66	0.71	8.80	12.20
Fascination	Mix	47	9.95	0.81	8.20	12.00
Fascination	Prestige	53	10.52	0.68	8.80	11.60
Fascination	Promalin	50	10.50	0.57	9.40	11.80
Fascination	Radiate	50	10.22	0.65	8.60	11.80
Melody	Control	44	10.51	0.69	8.80	12.00
Melody	Maxcel	53	10.32	0.83	7.00	11.40
Melody	Mix	54	10.19	0.74	8.60	11.80
Melody	Prestige	47	10.62	1.07	8.80	14.00
Melody	Promalin	49	10.28	0.59	9.00	11.60
Melody	Radiate	46	10.45	0.73	9.00	11.80
Troubadour	Control	47	10.27	0.56	9.00	11.80
Troubadour	Maxcel	50	10.53	0.63	9.20	11.60
Troubadour	Mix	34	10.32	0.53	9.00	11.20
Troubadour	Prestige	53	10.32	0.64	9.00	11.80
Troubadour	Promalin	58	10.31	0.59	9.00	12.00
Troubadour	Radiate	62	10.24	0.67	8.60	11.60

Table 17 shows that in the early trial in 2015 only one application and cultivar (Promalin + Melody) produced significantly higher soluble solid content than the untreated control for that cultivar (10.61 Brix vs. 10.31). The rest of the treatments produced similar or lower results than the untreated control.

Table 17. Least Squares Means Comparison for Early Soluble Solid Content in Degrees Brix by Cultivar and PGR, 2015. University of Delaware, Georgetown, 2015.

Cultivar	PGR	Mean Soluble Solids
Melody	Promalin	10.61 a
Fascination	Control	10.58 ab
Liberty	Promalin	10.56 ab
Liberty	Control	10.54 ab
Fascination	Prestige	10.53 ab
Fascination	Mix	10.48 ab
Fascination	Promalin	10.46 ab
Liberty	Mix	10.43 abc
Melody	Radiate	10.42 abc
Melody	Mix	10.34 abcd
Melody	Control	10.31 abcd
Liberty	Radiate	10.29 abcd
Liberty	Prestige	10.28 abcd
Fascination	Maxcel	10.22 bcd
Liberty	Maxcel	10.22 bcd
Fascination	Radiate	10.11 cd
Melody	Prestige	10.04 cd
Melody	Maxcel	10.00 d

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

In Table 18, we can see that none of the cultivars produced soluble solid contents significantly higher than the untreated controls, but Fascination + PGR Mix produced far fewer soluble solids than Melody + Prestige and Fascination + Maxcel (9.951 vs 10.616 and 10.585). This is lower than the industry acceptable standard of 10 degrees Brix soluble solid content for “Very Good Internal Quality” and was the only cultivar plus application that failed to meet that standard.

Table 18. Least Squares Means Comparison for Late Soluble Solid Content in Degrees Brix by Cultivar and PGR, 2015. University of Delaware, Georgetown, 2015.

Cultivar	PGR	Mean Soluble Solids
Melody	Prestige	10.62 a
Fascination	Maxcel	10.58 a
Troubadour	Maxcel	10.56 ab
Melody	Radiate	10.56 ab
Melody	Control	10.53 ab
Fascination	Prestige	10.48 ab
Fascination	Promalin	10.45 ab
Melody	Maxcel	10.37 ab
Troubadour	Mix	10.34 ab
Melody	Promalin	10.33 ab
Troubadour	Prestige	10.32 ab
Troubadour	Promalin	10.31 ab
Troubadour	Control	10.28 abc
Fascination	Control	10.28 abc
Troubadour	Radiate	10.24 bc
Fascination	Radiate	10.17 bc
Melody	Mix	10.15 bc
Fascination	Mix	9.95 d

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

Table 19 provides the ANOVA table for Table 20. Table 20 shows yields in lbs per acre and Kg/hectare for the July 23 harvest for 2015, the first harvest. Radiate applied to Liberty produced the highest Kg/hectare (35278.85 Kg/Ha), and this was significantly different than the control Fascination treatment, the PGR Mix applied to Liberty, Prestige applied to Liberty, Promalin applied to Melody and the PGR Mix applied to Fascination, which produced the lowest yield (14594.98 Kg/Ha). Furthermore, 11 treatments produced significantly higher yields than the PGR Mix/Fascination combination.

Table 19. ANOVA Table for Yield of Seedless Watermelon Fruits in Lbs/Acre and Kg/Hectare for July 23, 2015 by PGR and Cultivar. University of Delaware, Georgetown, 2015.

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	2	9.5288706	4.7644353	0.32	0.7286
Rep	5	60.2410580	12.0482116	0.80	0.5493
PGR	5	304.8594409	60.9718882	4.05	0.0013
PGR*Cultivar	10	200.6160524	20.0616052	1.33	0.2101

Table 20. Yield of Seedless Watermelon Fruits in Lbs/Acre and Kg/Hectare for July 23, 2015 by PGR and Cultivar. University of Delaware, Georgetown, 2015.

Cultivar	PGR	Lbs/Acre	Kg/Hectare
Liberty	Radiate	31470.88 a	35278.85
Melody	Prestige	30500.21 ab	34190.73
Fascination	Maxcel	30321.87 ab	33990.82
Melody	Control	29241.61 ab	32779.84
Liberty	Maxcel	27248.81 ab	30545.91
Fascination	Radiate	24938.79 ab	27956.39
Fascination	Promalin	22299.40 ab	24997.63
Melody	Radiate	21679.50 ab	24302.72
Liberty	Promalin	21402.58 ab	23992.29
Melody	Maxcel	19907.59 ab	22316.40
Liberty	Control	19348.24 ab	21689.37
Fascination	Prestige	16095.06 ab	18042.56
Melody	Mix	15816.83 abc	17730.67
Fascination	Control	14060.27 bc	15761.56
Liberty	Mix	13496.57 bc	15129.66
Liberty	Prestige	13397.40 bc	15018.48
Melody	Promalin	13237.14 bc	14838.83
Fascination	Mix	13019.61 c	14594.98

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

Table 21. ANOVA Table for Yield of Seedless Watermelon Fruits in Lbs/Acre and Kg/Hectare for August 10, 2015 by PGR and Cultivar. University of Delaware, Georgetown, 2015.

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cultivar	2	66.0012069	33.0006034	2.25	0.1065
Rep	5	201.7525811	40.3505162	2.75	0.0183
PGR	5	102.7292012	20.5458402	1.40	0.2224
PGR*Cultivar	10	262.7655031	26.2765503	1.79	0.0594

Table 22. Yield of Seedless Watermelon Fruits in Lbs/Acre and Kg/Hectare for August 10, 2015 by PGR and Cultivar. University of Delaware, Georgetown, 2015.

Cultivar	PGR	Lbs/Acre	Kg/Hectare
Fascination	Maxcel	44539.01 abcde	49883.69
Troubadour	Promalin	41129.61 abcde	46065.16
Fascination	Radiate	38387.88 ab	42994.43
Melody	Maxcel	37187.30 ab	41649.78
Melody	Prestige	34690.59 a	38853.46
Fascination	Promalin	34581.56 ab	38731.35
Fascination	Mix	33159.24 a	37138.35
Melody	Mix	31147.66 de	34885.38
Troubadour	Radiate	30628.23 abcde	34303.61
Troubadour	Prestige	29553.83 cde	33100.29
Fascination	Control	29256.75 bcde	32767.56
Troubadour	Mix	29076.05 abc	32565.17
Fascination	Prestige	27931.82 abcd	31283.64
Melody	Promalin	26777.80 abcde	29991.13
Troubadour	Control	26678.57 e	29880.00
Melody	Control	24347.24 abcde	27268.91
Melody	Radiate	22690.93 abcde	25413.84
Troubadour	Maxcel	18241.44 abcde	20430.41

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

Finally, Tables 23 and 24 provide the number of fruit produced across all cultivars, all year long, affected by each plant growth regulator. In 2014, Promalin plots produced the most fruit and yielded the greatest weights (77440.59 lbs/acre or 85184.65 Kg/hectare). This was significantly different than both Maxcel plots (48948.25 lbs/acre or 53843.07 Kg/hectare) and the control plots (16113.84 lbs/acre or 17725.22 Kg/hectare). Prestige plots also produced significant differences when compared to the control plots.

In 2015, Radiate plots produced the most fruit (299 watermelons) and yielded the highest weights (40233.25 lbs/acre or 45095.44 Kg/hectare). This was significantly higher than Prestige plots which produced not the fewest fruit (256 vs. the control treatments 251) but produced the lowest yields in weight (32551 lbs/acre or 36485.07 Kg/hectare).

Table 23. Mean Yields across All Cultivars by PGR in Kg/Ha in 2014. University of Delaware, Georgetown, 2014.

PGR	Number of Fruit	Mean Lbs./acre	Mean Kg/Ha
Promalin	118 a	75999.97 a	85184.65 a
Prestige	113 a	68975.25 ab	77310.99 ab
Maxcel	73 bc	48037.66 bc	53843.07 bc
Control	30 c	15814.07 c	17725.22 c

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

Table 24. Mean Yields across All Cultivars by PGR in Kg/Hectare in 2015. University of Delaware, Georgetown, 2015.

PGR	Number of Fruit	Mean Lbs./acre	Mean Kg/ha
Radiate	299	40233.21 a	45095.44 a
Promalin	288	39411.71 ab	44174.66 ab
Mix	277	36436.96 ab	40840.41 ab
Maxcel	277	36050.96 ab	40407.76 ab
Control	251	33758.21 ab	37837.93 ab
Prestige	256	32551.22 b	36485.07 b

Mean separation by Least Significant Difference. Means followed by the same letter were not significantly different at $p > 0.05$

3.4 Discussion

PGRs were shown to have very different effects from year to year. In 2014, significant yield increases were shown in comparison to the untreated control, but this was not the case in 2015. However, one major variable that was impossible to control for was weather conditions after application. Whereas the temperature in 2014 was relatively mild post-application, the summer became hot, quickly post-application in 2015. Also in 2015, replants were common, which increased variability. Replants are not typically used in production but are necessary for research plots. Phytotoxicity was observed in 2015, and even though the plants recovered and managed to produce melons, it is very likely that this damage caused yields to be affected. Another year of data collection would be very useful for future studies of this type, with three years of data hopefully providing enough similarities between two of the three years to draw conclusions.

Since the chemicals tested in this study were commercially available in on crops in other states, we tested rates that are applied on those other crops with the hope that we may have been able to provide data that could be used to encourage companies to apply for an on-label application in Delaware. Future studies with this goal should continue to test products on-label in other states. PGR studies with a more exploratory function should focus on rate studies for these compounds, examining a range of application rates and their effects. It would also be beneficial to perform smaller tests in a controlled environment.

When examining PGRs in the future, it will be important to continue to take internal quality measurements when recording data. Research has shown the ability of PGRs to negatively impact the formation of sugars and soluble solids in muskmelons, which was partially explained by delayed maturity, even though the applications used did not change the flowering dates of these plants. (64)

An interesting study would be to examine the level of plant hormones within ovaries and determine a time scale for watermelons, which could possibly help optimize exogenous applications of PGRs. This study could be performed on a small scale, using hand pollination, to ensure that the fruits (or, at the least, the fertilized ovaries) were collected at the exact time frame that the researcher wanted to examine. It is likely that gas chromatography or thin layer chromatography of these tissues could be used to determine the PGR levels within (41). This research could also be very valuable for the study of the origin of hollow heart and could possibly determine when hollow heart is first visible within a maturing watermelon.

3.5 Conclusions

Despite initial concerns about the over application of plant growth regulators, there was little in the data to show that the applications in 2014 and 2015 caused any significant changes in the growth of the watermelons or phytotoxicity; however, Troubadour performed worse when Prestige was applied in both the early and late plantings in 2015.

Perhaps the most interesting interpretation of the data comes from the aforementioned hollow heart severity increase that was recorded in Melody when Prestige was applied. The causes of hollow heart as a morphological condition are still not completely understood. Johnson at the University of Delaware has performed numerous studies on the condition and has proposed that the cause relates to inadequate pollination, specifically that improper cell division and expansion occurs in these poorly pollinated fruit, causing the deformation to occur.

Fruit set, as presented in the 2015 table showing total numbers of fruit, was not significantly different between the different PGR treatments, with the sole exception of Radiate versus Prestige. However, there were significant benefits to yields with the application of some of the PGRs used in this trial. Radiate and Promalin produced over 5000 lbs. more than the untreated control in the plots studied. Promalin application had no effect on yield when applied to most varieties, but when applied to Fascination, yields were significantly better than the untreated control. Promalin also produced significantly higher yields when applied to Troubadour in comparison to Maxcel.

The 2014 growing season produced very different results from the 2015 growing season. The number of fruit produced, and the total weights per hectare, were greater than the control in two Promalin and Prestige treatments.

Even with replication over multiple years, it is difficult to draw conclusions from these studies. While select plant growth regulators appeared to improve watermelon fruit set and weights in 2014, this was not the case in 2015. It is possible that due to the increased temperatures in 2015 post-PGR application the increased phytotoxicity of the chemicals negatively affected the plants' yields. This would at least partially explain why the untreated control yields were not significantly different than the yields of the treated watermelons.

More research must be done to examine the effect that PGR applications have based on which cultivar they are applied to. It would also be beneficial to study the effects that temperature conditions have on the plant responses to the various PGR applications. Furthering this line of research could provide great insight to the proper timing and regimen of PGRs that would benefit the Delmarva region the most.

Chapter 4

POLLENIZER CULTIVAR TRIAL

4.1 Introduction

To produce seedless watermelons, diploid pollenizers are necessary to provide adequate viable pollen to the field. These pollenizers are specially bred to produce large numbers of staminate flowers while the seedless cultivars produce a large quantity of pistillate flowers. While most of these special pollenizers do not produce saleable fruit, a few do. The University of Florida and Clemson University have conducted research that compares different pollenizer cultivars for their effectiveness (23). High relative humidity and temperatures have been shown to affect pollen vigor and viability (72).

A study published in 2014 examined the flower production patterns of several pollenizer cultivars to determine when different pollenizers produced the largest number of staminate flowers (55). It was determined that a successful pollenizer cultivar 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.” It was also found that due to flowering clustering, growers must take care to select pollenizers with similar growth habits, and that harvested pollenizers are better suited for planting alongside late flowering triploids. However, pollen grain production, a critical component when choosing pollenizer cultivars, not only varied between cultivars, but between years and even between days within years (79).

Seedless watermelon growers are increasingly interested in pollenizer effectiveness with growing numbers of special pollenizers. In addition, there is a need for additional information on how special pollenizers compare with standard and specialty seeded types in providing pollen and setting fruit.

Special pollenizers are a type of watermelon plant bred to produce large numbers of male flowers, having small fruit that are not harvested, and providing limited competition to triploids when interplanted (52). Growers have questioned the value of special pollenizers that were significantly more expensive than standard seeded cultivars and perceived as having lower vigor. Furthermore, initially, the use of dedicated rows of pollenizers allowed for production of both standard seeded cultivars and seedless watermelons while providing adequate pollen (52). However, with increased demand for seedless watermelon and reduced demand for seeded watermelon, there was an industry wide move towards in-row pollenizers to maximize seedless production. Their less competitive nature and abundance of male flowers make them the common choice for many growers currently.

Even with the use of black plastic mulch to improve plant health and proper use of spacing to maximize yields, pollenizer efficacy is imperative to crop success (67) (60). Testing pollenizers against one another is important to provide growers with information to determine pollenizer choices for their production fields.

Fruit development and growth is controlled by photosynthesis, specifically by carbon dioxide fixation in the leaves and transport of organic compounds throughout the plant (43). Light levels affect how carbon is metabolized within a plant, with sucrose synthases and other enzymes fluctuating based on quantity of the light received by the plant (33). For growers, this means that fruit weight is affected by plant spacing and interplant competition; therefore, spacing is an important factor during transplanting (80). A study at the University of Florida in 2006 showed that a more vigorous pollenizer, one that produces greater foliage, planted in rows negatively impacted the yields of the seedless cultivars that it was planted alongside (25). In non-seedless fruit, ripening occurs after seed maturation. However, despite being seedless, the seedless watermelon is still influenced by the influx of plant growth hormones that leads to carotenoid development that occurs during ripening (29).

Research has shown that different pollenizers can cause statistically significant differences between pollinated triploid fruit yields and saleable qualities (20). Research in Florida and South Carolina by Freeman has shown that yields were significantly different between seedless cultivars in 2006 (which was not the case in 2005). This shows that yields can vary greatly between years even in a controlled setting. Soluble solid concentration and hollow heart incidence were not significantly affected by pollenizer choice (24). Watermelons must be above 8% soluble solid content to meet the “good internal quality” standard and above 10% to meet the “very good internal quality” standard (4).

4.2 Materials and Methods

All trials were performed on the University of Delaware’s Carvel Research and Education Center Thurmond Adams Research Farm (UD REC) in Georgetown, DE in 2014 and 2015.

All cultivars used were started from seed in the UD REC greenhouses. Seeds in 2014 were seeded from March 31st to April 2nd in 2014 and from March 30th to April 1st in 2015.

All transplants were grown in 72 cell plug trays (fitting a 1020 standard tray) using Pro-Mix BX™ growing media. The pollenizer cultivars used in this study are listed in Table 25:

Table 25. List of Pollenizer Culitvars, Pollenizer Types and Producers.

Pollenizer	Pollenizer Type	Producer
4030	Special Pollenizer	Highmark Seed Co
4290	Special Pollenizer	Nunhems
4370	Special Pollenizer	Nunhems
10319	Special Pollenizer	Nunhems
Accomplice	Special Pollenizer	Harris Moran Seed Co
Ace	Special Pollenizer	Sakata, Siegers Seed Co
Adir	Special Pollenizer	Origene Seeds
Boost	Special Pollenizer	Highmark Seed Co
Edom	Special Pollenizer	Origene Seeds
Estrella	Standard Seeded	Syngenta
Faerie	Small Saleable	Stokes Seed Co
Jadestar	Small Saleable	Twilley Seeds
Liberty	Standard Seeded	Nunhems
Mickylee	Small Saleable	Seminis
Polimax	Special Pollenizer	Nunhems
Pollen Pro	Special Pollenizer	Siegers Seed Co
Premium	Special Pollenizer	Nunhems
Red Delicious	Small Saleable	Twilley Seeds
Sangria	Standard Seeded	Seedway LLC, Twilley Seeds
SF800	Standard Seeded	Nunhems
Sidekick	Special Pollenizer	Harris Moran Seed Co
SP5	Special Pollenizer	Syngenta
SP6	Special Pollenizer	Syngenta
Stargazer	Standard Seeded	Seminis
Vista	Special Pollenizer	Twilley Seeds
Wild Card	Special Pollenizer	Sakata Seed America Inc
Wingman (SV2524WY)	Special Pollenizer	Seminis

The seedless cultivars that they were tested alongside were cultivar 7187 (Nunhems), cultivar 9651 (Nunhems), Fascination (Syngenta), and Revolution (Nunhems) in 2014. In 2015, Revolution, Melody (Syngenta) and cultivar 7187 were used.

One week before field planting transplants were moved outside to harden off. The seedlings were transplanted into the field on May 16th in 2014 and May 18th in 2015. Six beds were used in 2014 for each replication. These were planted in sets of three, roughly 110 meters in length, with another two beds on either side of each set of three used for isolation. In 2015, two beds roughly 200 meters in length were used for each replication, with two beds on either side of each row planted for isolation. The isolation rows were planted using sweet corn to act as a physical barrier and windbreak. In 2015, rye windbreaks were planted between the rows in addition to the corn.

In 2014, 4 meters of seedless watermelons (4 plants) of the cultivar 7187 were planted in between treatments to act as a buffer against cross pollination. In 2015, 4 meters of parthenocarpic cucumbers, were used in the same manner. These cucumbers produce male and female flowers, and are attractive to pollinators, but do not produce viable pollen. The pollinators visit these plants and through natural pollen deposition clean themselves of the pollen they carried from the previous plot. Therefore, these cucumbers would act as pollen “traps” for pollinators moving down the row. Care was taken to replace any plants that died within the first two weeks to ensure that all replications contained the same number of plants. Figures 1 and 2 provide the plot layouts for 2014 and 2015 respectively.

Plants were field planted into raised beds covered by 1.0 mil black plastic mulch, 90 cm wide at the bed top with drip irrigation tape beneath (0.23 gph, 30 cm emitter spacing). Spacing between triploid plants was 90 cm. In 2015, spacing between plants was 45 cm. Spacing was changed due to limited space availability. Each trial consisted of 4 beds of pollenizer cultivars in a randomized, complete block design, each bed a block, and seven plants of each pollenizer planted contiguously per block, for a total of 28 plants per cultivar. Care was taken to replace any plants that died within the first week after transplanting, ensuring that all replications had the same number of pollenizers.

The soil type for all studies was a Pepperbox Series (Loamy, mixed, semiactive, mesic Auic Arenic Paleudults). Each trial received 134 kg ha^{-1} nitrogen as urea ammonium nitrate solution divided into 3 applications, at planting (broadcast prior to bed formation), and 3 and 6 weeks after planting (through the drip irrigation system). All other nutrients and pH were in optimum range per University of Delaware Soil Testing Laboratory analysis. All trials were irrigated on a regular basis to limit stress. Fungicide, insecticide, and miticide treatments were applied as needed per University of Delaware recommendations.

Table 26. Example Plot Layout for 2014 Cultivar Trial Plots

Revolution (Rev.)	Rev.	Rev.	Rev.	Rev.	Rev.
7187 + Pollenizer A	Fascination + Pollenizer A	7187	7187 + Pollenizer B	Fascination + Pollenizer B	7187
9651	9651	9651	9651	9651	9651

Table 27. Example Plot Layout for 2015 Cultivar Trial Plots

Corn	Corn	Corn	Corn	Corn	Corn	Corn	Corn	Corn	Corn
Rye	Rye	Rye	Rye	Rye	Rye	Rye	Rye	Rye	Rye
Revolution + Pollenizer A	Melody + Pollenizer A	7187 + Pollenizer A	Parthenocarpic Cucumbers	Revolution + Pollenizer B	Melody + Pollenizer B	7187 + Pollenizer B	Revolution + Pollenizer A	Melody + Pollenizer A	7187 + Pollenizer A
Rye	Rye	Rye	Rye	Rye	Rye	Rye	Rye	Rye	Rye
Corn	Corn	Corn	Corn	Corn	Corn	Corn	Corn	Corn	Corn

Watermelons were harvested on the following dates in 2014: First harvest August 4th-August 7th, second harvest August 30th-September 2nd, and third harvest September 16th. In 2015, the harvest dates were August 3rd-August 5th for the first harvest and August 26th for the second harvest.

The watermelons that were harvested were chosen based on industry standards. No watermelon smaller than 3.18 kg (7 lbs.) was harvested. If a watermelon was underweight, it was discarded and no data was recorded. Because melons were harvested only with the reasonable assumption that the melon was ripe, the amount of discarded melons was not recorded. Once weighed, watermelons were cut open. Hollow heart ratings were recorded on a 1 to 5 scale. A rating of 1 indicates no hollow heart is present, while a 5 indicates the presence severe hollow heart, encompassing the majority of the flesh, which would render the fruit unsaleable. Soluble solids were measured by removing a piece of flesh from the melon, extracting the juice from that piece of flesh and using a handheld refractometer to measure degrees Brix from that juice. For the last harvest of each season (September 16th, 2014 and August 26th, 2015), no fruit quality measurements were taken (soluble solids and hollow heart ratings), only the weight of each harvested watermelon.

4.3 Results

Tables 28 and 29 show the ANOVA information for weight in lbs. and Kg between the pollenizers for seedless cultivars 7187 and 9651. That information is presented in Table 30.

Table 28. ANOVA Table for Cultivar 7187 Weight in Lbs. and Kg University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	580.358487	193.452829	14.29	<.0001
Pollenizer	23	699.356038	30.406784	2.25	0.0007
Rep*Pollenizer	69	1275.835579	18.490371	1.37	0.0296

Table 29. ANOVA Table for Cultivar 9651 Weight in Lbs. and Kg University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	266.455906	88.818635	7.68	<.0001
Pollenizer	23	511.083461	22.221020	1.92	0.0060
Rep*Pollenizer	69	1087.215166	15.756742	1.36	0.0313

The pollenizer Premium produced the highest average weight (14.46 lbs.), which was significantly different from cultivar 10319 and Adir (11.24 lbs. and 10.96 lbs.). For cultivar 9651, watermelons pollinated by Wild Card weighed the most (17.82 lbs.) This was significantly higher than the watermelons pollinated using cultivar 10319 and SP6 (14.46 lbs and 13.88 lbs.). Also, Faerie (17.08 lbs.) was significantly higher than SP6. All other pollenizers showed no significant differences in mean weights for 9651 in 2014. In the following tables, special pollenizers are denoted with an SP, standard seeded types with an SS, and small saleable watermelons with an SM. (Table 30)

Table 30. Mean Weights of Cultivar 7187 and 9651 Triploid in Lbs. and Kg by Pollenizer for 2014. University of Delaware, Georgetown, 2014.

Pollenizer	Pollenizer Type	Cv. 7187 Mean Wt. in Lbs.	Cv. 7187 Mean Wt. in KgCultivar 7187 Mean Weights in Kg	Cv.7187 Number of Obs.	Cv. 9651 Mean Wt. in Lbs.	Cv. 9651 Mean Wt. in KgCultivar 9651 Mean Weights in Kg	Cv. 9651 Number of Obs.
Premium	SP	14.46 a	6.56 a	38	15.86 abc	7.20 abc	41
Boost	SP	13.88 ab	6.30 ab	40	16.27 abc	7.39 abc	62
Wild Card	SP	13.65 ab	6.20 ab	40	17.83 a	8.09 a	44
Estrella	SS	13.56 ab	6.16 ab	37	15.97 abc	7.25 abc	59
SF800	SS	13.26 ab	6.02 ab	39	15.38 abc	6.98 abc	57
Vista	SP	13.18 ab	5.98 ab	51	16.51 abc	7.50 abc	38
Stargazer	SS	13.11 ab	5.95 ab	40	15.95 abc	7.24 abc	65
4290	SP	13.02 ab	5.91 ab	40	15.92 abc	7.23 abc	72
Mickylee	SM	12.84 ab	5.83 ab	38	16.28 abc	7.39 abc	39
Jadestar	SP	12.53 ab	5.69 ab	34	16.41 abc	7.45 abc	50
Ace	SP	12.50 ab	5.68 ab	35	15.17 abc	6.89 abc	56
Wingman (SV2524WY)	SP	12.47 ab	5.66 ab	36	14.93 abc	6.78 abc	66
Polimax	SP	12.47 ab	5.66 ab	40	15.26 abc	6.93 abc	56
Sangria	SS	12.36 ab	5.61 ab	26	15.79 abc	7.17 abc	52
Faerie	SM	12.35 ab	5.61 ab	45	17.08 ab	7.75 ab	47
Edom	SP	12.28 ab	5.58 ab	40	16.61 abc	7.54 abc	35
Sidekick	SP	12.24 ab	5.56 ab	38	15.13 abc	6.87 abc	72
4030	SP	12.17 ab	5.53 ab	38	16.72 abc	7.59 abc	72
Accomplice	SP	11.93 ab	5.42 ab	41	15.19 abc	6.90 abc	94
Red Delicious	SP	11.84 ab	5.38 ab	37	15.28 abc	6.94 abc	38
4370	SP	11.80 ab	5.36 ab	43	16.84 abc	7.65 abc	69
SP6	SP	11.28 ab	5.12 ab	39	13.88 c	6.30 c	41
10319	SP	11.24 b	5.10 b	35	14.46 bc	6.56 bc	60
Adir	SP	10.96 b	4.98 b	33	15.71 abc	7.13 abc	35

NOTE. − SM: small saleable, SP: special pollenizer, SS: standard seeded
Means followed by the same letter were not significantly different at p > 0.05 using Duncan’s Multiple Range Test.

Tables 31 and 32 show the ANOVA information for weight in lbs. and kg. between the pollenizers for seedless cultivars 7187 and 9651, which is shown on table 33.

Table 31. ANOVA Table for Fascination Weight in Lbs. and Kg for Seedless Cultivar Fascination. University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	266.455906	88.818635	7.68	<.0001
Pollenizer	23	511.083461	22.221020	1.92	0.0060
Rep*Pollenizer	69	1087.215166	15.756742	1.36	0.0313

Table 32. ANOVA Table for Weight in Lbs. and Kg for Seedless Cultivar Revolution. University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	1515.246479	505.082160	19.99	<.0001
Pollenizer	23	1300.531553	56.544850	2.24	0.0007
Rep*Pollenizer	68	2792.208006	41.061882	1.63	0.0011

The Fascination watermelons pollinated by SF800 (14.08 lbs.) and Boost (14.02 lbs.) were significantly higher than Accomplice (10.90 lbs.) This was the only significant interaction between all pollenizer cultivars for SF800. In 2014, Wild Card

(19.10 lbs.) and Edom (19.01 lbs.) produced Revolution watermelons that were significantly heavier than cultivar 10319 (15.99 lbs.). No other cultivar was significantly different than the others (Table 33).

Table 33. Mean Weights of Fascination and Revolution Triploid by Pollenizer for 2014. University of Delaware, Georgetown, 2014.

Pollenizer	Pollenizer Type	Fascination Mean Wt. in Lbs.	Fascination Mean Wt. in Kg	Fascination Number of Observations	Revolution Mean Wt. in Lbs.	Revolution Mean Wt. in Kg	Revolution Number of Observations
SF800	SS	14.08 a	6.39 a	35	18.00 ab	7.82 ab	114
Boost	SP	14.02 a	6.37 a	43	17.47 ab	7.60 ab	113
Faerie	SM	13.33 ab	6.05 ab	34	17.09 ab	7.65 ab	95
4030	SP	13.21 ab	6.00 ab	31	17.33 ab	7.87 ab	105
Vista	SP	13.14 ab	5.97 ab	27	17.90 ab	8.03 ab	105
Sangria	SS	13.09 ab	5.94 ab	35	17.35 ab	8.30 ab	90
Polimax	SP	12.94 ab	5.87 ab	32	17.22 ab	7.528 ab	95
Sidekick	SP	12.92 ab	5.87 ab	44	16.74 ab	8.63 a	92
Stargazer	SS	12.68 ab	5.76 ab	37	16.85 ab	7.72 ab	109
4370	SP	12.62 ab	5.73 ab	39	17.24 ab	7.266 b	157
Estrella	SP	12.60 ab	5.72 ab	35	17.69 ab	7.46 ab	110
Premium	SP	12.57 ab	5.71 ab	42	18.29 ab	8.46 ab	77
Ace	SP	12.36 ab	5.61 ab	29	16.57 ab	8.43 ab	95
Edom	SP	12.31 ab	5.59 ab	31	19.01 a	8.33 ab	85
4290	SP	12.31 ab	5.59 ab	35	17.01 ab	8.67 a	119
10319	SP	12.29 ab	5.58 ab	36	15.99 b	7.72 ab	104
Mickylee	SM	12.20 ab	5.54 ab	30	16.43 ab	8.30 ab	102
Red Delicious	SM	12.14 ab	5.51 ab	32	18.63 ab	7.45 ab	63
Wingman (SV2524WY)	SP	12.13 ab	5.51 ab	41	18.57 ab	7.82 ab	79
Jadestar	SM	11.98 ab	5.44 ab	37	18.34 ab	7.60 ab	64

NOTE. − SM: small saleable, SP: special pollenizer, SS: standard seeded
Means followed by the same letter were not significantly different at p > 0.05 using Duncan's Multiple Range Test.

In 2015, there were no significant differences in weight in lbs. between any pollenizer when providing pollen for 7187. Faerie (18.51 lbs.), Mickylee (18.13 lbs.), and Sangria (17.96 lbs.) were all significantly different than Stargazer (13.89 lbs.) for the triploid 'Melody'. There were no other significant differences between the pollenizers (Table 42). Sangria (22.18 lbs.) produced significantly higher weights than Sidekick (16.90 lbs.), Wild Card (16.44 lbs.), and Boost (15.41 lbs.). Faerie (21.18 lbs.) was also higher than Wild Card and Boost. Adir (20.85 lbs.), Polimax (20.75 lbs.), Premium (20.55 lbs.), Stargazer (20.38 lbs.), Edom (20.37 lbs.), and Pollen Pro (20.19 lbs.) were significantly heavier than Boost, as well. All other pollenizers were not significantly different than one another. The number of observations recorded for the untreated control is much lower than with the pollenizer treatments. While some pollination did occur, the amount of watermelons harvested was between a quarter to a half of the total number of seedless watermelons harvested from each of the other pollenizers. (Table 37)

Table 34. ANOVA Table for Weight in Lbs. for Seedless Cultivar 7187. University of Delaware, Georgetown, 2015.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	63.071640	21.023880	0.89	0.4472
Pollenizer	22	871.550090	39.615913	1.67	0.0272
Rep*Pollenizer	64	2629.775579	41.090243	1.73	0.0005

Table 35. ANOVA Table for Weight in Lbs. for Seedless Cultivar Melody. University of Delaware, Georgetown, 2015.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	65.430885	21.810295	1.10	0.3468
Pollenizer	22	846.506461	38.477566	1.95	0.0059
Rep*Pollenizer	64	2102.381667	32.849714	1.66	0.0013

Table 36. ANOVA Table for Weight in Lbs. for Seedless Cultivar Revolution. University of Delaware, Georgetown, 2015.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	799.295463	266.431821	10.71	<.0001
Pollenizer	22	1483.437799	67.428991	2.71	<.0001
Rep*Pollenizer	65	3263.334944	50.205153	2.02	<.0001

Table 37. Mean Weights of Cultivar 7187, Melody and Revolution Triploid by Pollenizer in 2015. University of Delaware, Georgetown, 2015.

Pollenizer	Pollenizer Type	Cv. 7187 Mean Wt. in Lbs.	Cv. 7187 Mean Wt. in KgCultivar 7187 Mean Weights in Kg	Melody Mean Wt. in Lbs.	Melody Mean Wt. in KgMelody Mean Weights in Kg	Revolution Mean Wt. in Lbs.	Revolution Mean Wt. in KgRevolution Mean Weights in Kg
Mickylee	SM	20.01 a	9.08 a	18.13 a	7.24 ab	18.02 abcd	8.18 abcd
Adir	SP	19.36	8.79	14.82 ab	8.4 a	20.85 abc	9.47 abc
Ace	SP	19.13	8.69	14.76 ab	7.69 ab	19.95 abcd	9.06 abcd
Sangria	SS	19.13	8.69	17.96 a	7.69 a	22.18 a	10.07 a
Polimax	SP	19.01	8.63	15.94 ab	6.66 ab	20.75 abc	9.42 abc
Faerie	SM	18.96	8.61	18.51 a	7.14 ab	21.18 ab	9.62 ab
Wingman (SV2524WY)	SP	18.86	8.56	16.93 ab	7.05 ab	18.63 abcd	8.46 abcd
Accomplice	SP	18.84	8.55	16.93 ab	6.79 ab	18.46 abcd	8.38 abcd
Jadestar	SP	18.80	8.54	14.68 ab	6.3 ab	19.95 abcd	9.06 abcd
4370	SP	18.68	8.48	15.73 ab	6.95 ab	18.55 abcd	8.42 abcd
Pollen Pro	SP	18.55	8.42	15.52 ab	7.33 b	20.19 abcd	9.17 abcd
10319	SP	18.41	8.36	14.95 ab	6.97 ab	18.20 abcd	8.26 abcd
Stargazer	SS	18.38	8.34	13.87 b	7.39 ab	20.38 abc	9.25 abc
Premium	SP	18.23	8.28	15.31 ab	7.28 ab	20.55 abc	9.33 abc
SP6	SP	18.20	8.26	16.15 ab	7.38 ab	18.69 abcd	8.49 abcd
Control	N/A	18.20	8.26	15.35 ab	7.18 ab	18.67 abcd	8.48 abcd
Edom	SP	18.14	8.24	16.27 ab	6.72 ab	20.37 abcd	9.25 abcd
Wild Card	SP	18.05	8.19	16.04 ab	6.92 ab	16.44 cd	7.46 cd
4030	SP	17.77	8.07	16.25 ab	7.39 ab	17.74 abcd	8.05 abcd
Sidekick	SP	17.61	7.99	15.82 ab	6.92 ab	16.90 bcd	7.67 bcd

NOTE. − SM: small saleable, SP: special pollenizer, SS: standard seeded
Means followed by the same letter were not significantly different at p > 0.05 using Duncan's Multiple Range Test.

There were no differences between pollenizers when measuring soluble solid content for cultivar 9651 in 2014. All pollenizers and seedless varieties produced soluble solid contents at or above 10 degrees Brix. This measurement is the industry standard for “very good internal quality.” Any rating above 8 degrees Brix qualifies as “good internal quality.” Cultivar 4370 produced the highest soluble solid contents when used to pollinate cultivar 9651 at (11.20 degrees Brix). This was significantly higher than cultivar 9651 melons pollinated by Ace (9.63) and Sidekick (9.32) . Boost (11.15), Accomplice (11.10), Adir (11.07), Polimax (10.98) and cultivar 4030 (10.96) were also significantly different from Sidekick. Sangria pollinated Fascination produced the highest soluble solids for that cultivar in 2014 (11.53 degrees Brix). This was significantly different than Sidekick (10.08), Mickylee (10.00), Accomplice (9.90), Red Delicious (9.85), and Adir (9.84). No other cultivars were significantly different. Finally, for 2014, Revolution pollinated by Edom had the highest mean soluble solid content at 11.55 degrees Brix. This was significantly different than SF800 and Premium, with 10.21 and 10.18 degrees Brix mean soluble solid contents. All other cultivars were not significantly different.

Table 38. ANOVA Table for Soluble Solids for Seedless Cultivar 7187. University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	51.3379666	17.1126555	9.93	<.0001
Pollenizer	23	41.0293863	1.7838864	1.03	0.4181
Rep*Pollenizer	69	186.7810260	2.7069714	1.57	0.0035

Table 39. ANOVA Table for Soluble Solids for Seedless Cultivar 9651. University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	37.97266233	12.65755411	18.11	<.0001
Pollenizer	23	49.30854236	2.14384967	3.07	<.0001
Rep*Pollenizer	58	84.63484528	1.45922147	2.09	0.0003

Table 40. ANOVA Table for Soluble Solids for Seedless Cultivar Fascination. University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	14.3906566	4.7968855	2.99	0.0306
0	23	76.1914558	3.3126720	2.07	0.0027
Rep*Pollenizer	68	172.0669192	2.5303959	1.58	0.0036

Table 41. ANOVA Table for fSoluble Solids for Seedless Cultivar Revolution. University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	41.08861982	13.69620661	20.82	<.0001
Pollenizer	23	26.84571959	1.16720520	1.77	0.0210
Rep*Pollenizer	66	96.65146923	1.46441620	2.23	<.0001

Table 42. Means Comparison for Soluble Solids for Cultivars 7187, 9651, Fascination and Revolution by Pollenizer in 2014. University of Delaware, Georgetown, 2014.

Pollenizer	Pollenizer Type	Cultivar 7187 Soluble Solids	Cultivar 9651 Soluble Solids	Fascination Soluble Solids	Revolution Soluble Solids
Sangria	SS	11.13 a	9.75 abc	11.53 a	10.89 ab
Polimax	SP	11.08	10.98 ab	10.67 ab	11.10 ab
Premium	SP	11.06	9.65 abc	10.78 ab	10.18 b
4290	SP	11.04	9.71 abc	10.65 ab	10.62 ab
Boost	SP	10.91	11.15 ab	10.71 ab	11.19 ab
Vista	SP	10.88	10.80 ab	10.58 ab	11.18 ab
Red Delicious	SS	10.80	10.26 abc	9.85 b	10.97 ab
Wingman (SV2542WY)	SP	10.79	9.98 abc	10.79 ab	10.95 ab
Stargazer	SS	10.79	10.68 abc	10.95 ab	11.02 ab
4370	SP	10.77	11.20 a	10.75 ab	11.38 ab
4030	SP	10.76	10.96 ab	10.79 ab	10.90 ab
SP6	SP	10.75	10.19 abc	10.46 ab	11.08 ab
Accomplice	SP	10.73	11.10 ab	9.90 b	10.57 ab
Jadestar	SM	10.69	10.51 abc	10.51 ab	11.28 ab
Mickylee	SM	10.64	10.14 abc	10.00 b	10.76 ab
SF800	SM	10.61	10.47 abc	10.39 ab	10.21 b
10319	SM	10.60	10.30 abc	10.65 ab	10.61 ab
Wild Card	SM	10.51	10.29 abc	10.55 ab	10.57 ab
Ace	SP	10.47	9.63 bc	10.63 ab	10.76 ab
Edom	SP	10.36	9.93 abc	10.30 ab	11.55 a
Sidekick	SP	10.34	9.32 c	10.08 b	10.68 ab
Faerie	SM	10.34	10.34 abc	10.17 ab	10.55 ab
Estrella	SS	10.33	10.52 abc	10.19 ab	10.88 ab
Adir	SP	10.00	11.07 ab	9.84 b	11.21 ab

NOTE. − SM: small saleable, SP: special pollenizer, SS: standard seeded
Means followed by the same letter were not significantly different at $p > 0.05$ using Duncan's Multiple Range Test.

Estrella and Premium used to pollinate Revolution produced the highest mean soluble solid contents (11.34 and 11.33 degrees Brix) in 2015. SP6 pollinizing Melody and cultivar 7187 produced the lowest soluble solids (9.92 and 9.88 degrees Brix). These two combinations of pollinizer and seedless watermelons fail to meet the "Very Good Internal Quality" standard set by the industry but are over the threshold required for "Good Internal Quality." Furthermore, the non-pollinated control and Melody plots produced melons with 11.14 degrees Brix, significantly higher than twelve other pollenizer combinations. Nine of those twelve were also of the seedless cultivar Melody. (Table 44)

Table 43. ANOVA Table for for Soluble Solids Across All Seedless Cultivars. University of Delaware, Georgetown, 2014.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	3	69.79114158	23.26371386	35.43	<.0001
Seedless	2	21.39489814	10.69744907	16.29	<.0001
Pollenizer	22	27.36315254	1.24377966	1.89	0.0077
Seedless*Pollenizer	44	34.70775948	0.78881272	1.20	0.1760

Table 44. Means Comparison for Soluble Solids across All Cultivars and Pollenizers in 2015. University of Delaware, Georgetown, 2015.

Pollenizer	Pollenizer Type	Seedless	Mean Soluble Solids	Pollenizer	Pollenizer Type	Seedless	Mean Soluble Solids
Estrella	SS	Revolution	11.34 a	Mickylee	SM	Melody	10.61 bcdef
Premium	SP	Revolution	11.33 a	Sidekick	SP	7187	10.60 bcdef
4370	SP	7187	11.23 ab	4030	SP	7187	10.59 bcdef
Control	None	Melody	11.14 ab	Jadestar	SM	7187	10.59 bcdef
Ace	SP	7187	11.09 abc	Faerie	SM	Melody	10.59 bcdef
Adir	SP	7187	11.05 abc	Edom	SP	Revolution	10.58 bcdef
Premium	SP	7187	11.03 abc	SF800	SS	7187	10.57 bcdef
Sangria	SS	Revolution	11.03 abc	Adir	SP	Melody	10.57 bcdef
Pollen Pro	SM	Revolution	11.02 abc	Polimax	SP	7187	10.55 bcdef
10319	SP	Revolution	10.89 abc	Pollen Pro	SM	7187	10.51 bcdef
Adir	SP	Revolution	10.86 abc	SV2524WY (Wingman)	SP	Melody	10.50 bcdef
Boost	SP	7187	10.85 abc	Accomplice	SP	Revolution	10.48 bcdefg
Wild Card	SP	Revolution	10.83 abc	SP6	SP	Revolution	10.48 bcdefg
Faerie	SM	7187	10.83 abc	Sidekick	SP	Melody	10.47 bcdefg
SV2524WY (Wingman)	SP	Revolution	10.82 abc	4370	SP	Melody	10.43 bcdefg
Mickylee	SM	7187	10.80 abc	Sidekick	SP	Revolution	10.42 bcdefg
Mickylee	SM	Revolution	10.79 abc	Premium	SP	Melody	10.42 bcdefg
Ace	SP	Revolution	10.78 abc	Wild Card	SP	Melody	10.40 bcdefg
Jadestar	SM	Revolution	10.77 abcd	4030	SP	Melody	10.39 bcdefg
Accomplice	SP	7187	10.76 abcd	Sangria	SS	Melody	10.38 bcdefg
Polimax	SP	Revolution	10.75 abcde	Control	None	7187	10.37 bcdefg
SV2524WY (Wingman)	SP	7187	10.74 abcde	Control	None	Revolution	10.37 bcdefg
Wild Card	SP	7187	10.74 abcde	4370	SP	Revolution	10.34 cdefg
Boost	SP	Revolution	10.72 abcde	Ace	SP	Melody	10.30 cdefg
SF800	SS	Melody	10.70 bcdef	Estrella	SS	Melody	10.24 defg
Sangria	SS	7187	10.69 bcdef	Jadestar	SM	Melody	10.23 defg
4030	SP	Revolution	10.69 bcdef	10319	SP	7187	10.20 defg
Stargazer	SS	Revolution	10.69 bcdef	Edom	SP	Melody	10.20 efg
Stargazer	SS	Melody	10.68 bcdef	Pollen Pro	SM	Melody	10.16 fg
Faerie	SM	Revolution	10.68 bcdef	Polimax	SP	Melody	10.15 fg
SF800	SS	Revolution	10.67 bcdef	Accomplice	SP	Melody	10.14 fg
Edom	SP	7187	10.67 bcdef	10319	SP	Melody	10.07 fg
Stargazer	SS	7187	10.66 bcdef	SP6	SP	Melody	9.92 g
Estrella	SS	7187	10.66 bcdef	SP6	SP	7187	9.88 g
Boost	SP	Melody	10.64 bcdef				

NOTE. − SM: small saleable, SP: special pollenizer, SS: standard seeded
Means followed by the same letter were not significantly different at $p > 0.05$ using Duncan's Multiple Range Test.

All pollenizer cultivars produced average hollow heart ratings between 1 and 2 (except Faerie/cultivar 7187 at 2.07), meaning that very little hollow heart was present. However, the hollow heart ratings of the non-pollinated controls were significantly higher than all other pollinizer cultivars. Hollow heart was present in the majority of watermelons that were harvested from the control plots (70.3%). In a pollen limited environment, it has been previously shown that hollow heart is more likely to occur. The hollow heart ratings of the non-pollinated controls were significantly higher than all other pollinizer cultivars.

Three pollenizer cultivars produced mean hollow heart ratings of 1.00 for cultivar 7187: Ace, SP6, and Boost. 10319, Edom, 4030, Ace, Polimax, SF800, SP6, 4370, Jadestar, Sidekick, Adir, and Boost produced mean hollow heart ratings of 1.00 for Melody, and Adir, Stargazer and Edom produced 1.00 mean hollow heart ratings for Revolution. This is important to notice because this means that there was no hollow heart present in any of the samples taken for these pollenizer/seedless watermelon combinations. (Table 45)

Table 45. Mean Hollow Heart Ratings for Cultivar 7187, Melody and Revolution in 2015 by Pollenizer. University of Delaware, Georgetown, 2015.

Pollenizer	Pollenizer Type	Cv. 7187 Hollow Heart Ratings	Cv. 7187 Number of Obs.	Melody Hollow Heart Ratings	Melody Number of Obs.	Revolution Hollow Heart Ratings	Revolution Number of Obs.
Control	N/A	3.50 a	4	4.00 a	4	3.75 a	4
Faerie	SM	2.07 b	15	1.37 b	10	1.84 b	19
4370	SP	1.70 b	10	1.00 b	20	1.27 b	15
Jadestar	SM	1.55 b	20	1.00 b	16	1.41 b	17
10319	SP	1.54 b	13	1.00 b	20	1.25 b	12
Wild Card	SP	1.47 b	17	1.13 b	20	1.15 b	13
Premium	SP	1.46 b	13	1.16 b	17	1.11 b	18
Pollen Pro	SM	1.41 b	17	1.21 b	17	1.41 b	17
Adir	SP	1.40 b	20	1.00 b	12	1.00 b	13
Sidekick	SP	1.36 b	14	1.00 b	14	1.67 b	12
Accomplice	SP	1.30 b	20	1.38 b	15	1.13 b	15
Sangria	SS	1.30 b	20	1.28 b	20	1.14 b	14
Mickylee	SM	1.22 b	18	1.15 b	20	1.24 b	17
Estrella	SS	1.13 b	15	1.17 b	13	1.14 b	14
Edom	SP	1.13 b	15	1.00 b	18	1.00 b	13
Stargazer	SS	1.13 b	16	1.24 b	13	1.00 b	14
SF800	SS	1.12 b	17	1.00 b	17	1.35 b	17
4030	SP	1.11 b	18	1.00 b	15	1.13 b	16
Polimax	SP	1.10 b	20	1.00 b	16	1.38 b	13
Wingman (SV2524WY)	SP	1.06 b	16	1.15 b	14	1.80 b	20
Ace	SP	1.00 b	14	1.00 b	15	1.11 b	19
SP6	SP	1.00 b	12	1.00 b	18	1.58 b	12
Boost	SP	1.00 b	19	1.00 b	19	1.13 b	15

NOTE. − SM: small saleable, SP: special pollenizer, SS: standard seeded
Means followed by the same letter were not significantly different at $p > 0.05$ using Duncan's Multiple Range Test.

In 2014, 7187 produced the highest yields when pollinated by Faerie and the lowest when pollinated by Sangria and Adir. Cultivar 9651 had the highest yields when pollinated by Accomplice and the lowest yields when pollinated by Adir and SP6. Fascination had the highest yields pollinated by Boost and the lowest yields pollinated by Wild Card and Adir. Revolution pollinated by cultivar 4370 produced the most Kg/Ha and the least when pollinated by Adir. (Table 46)

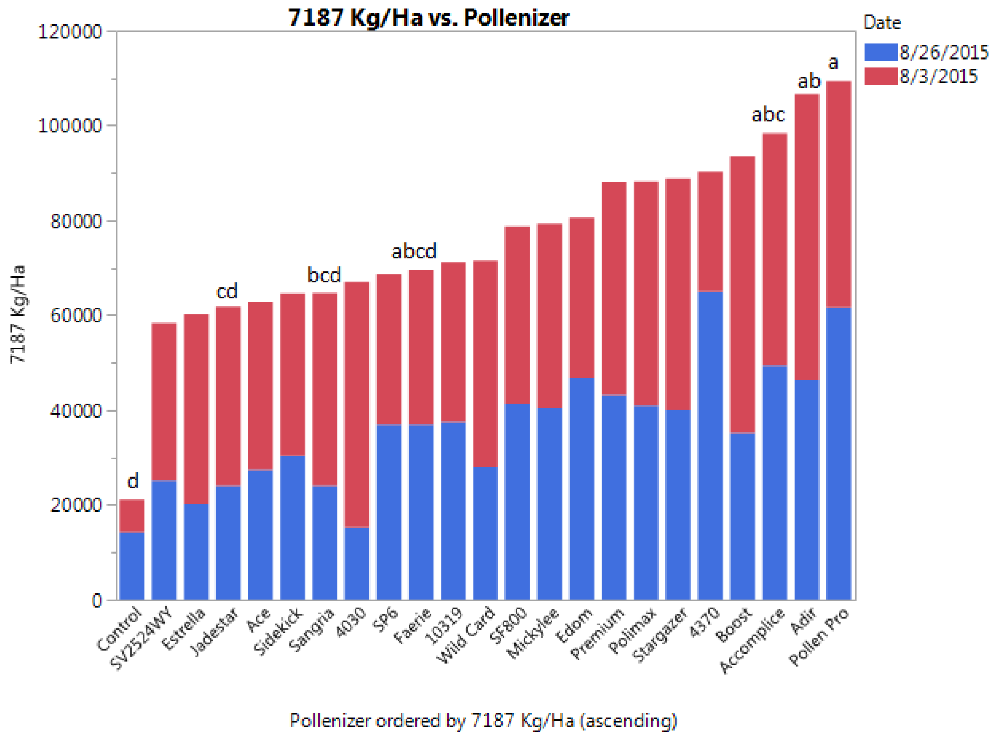
Table 46. 2014 Harvest Data in Kg/Ha and Number of Fruit per Hectare Across All Seedless Cultivars and Pollenizers. University of Delaware, Georgetown, 2014.

Pollenizer	Cv. 7187 Kg/Ha	Cv. 7187 No/Ha	Cv. 9651 Kg/Ha	Cv. 9651 No/Ha	Melody Kg/Ha	Melody No/Ha	Revolution Kg/Ha	Revolution No/Ha
Faerie	28274 a	5040 a	40849 ab	5264 ab	23065b	3808 a	82638 ab	10640 abc
Boost	28251	4480	51352 ab	6944 ab	30689 a	4816	100466 ab	12656 abc
Premium	27975	4256	33092 ab	4592 b	26864 ab	4704	71682 b	8624 bc
Wild Card	27794	4480	39917 ab	4928 b	17449 b	3248	86500 ab	9968 bc
Vista	27498	4592	31932 ab	4256 b	18056 ab	3024	95653 ab	11760 abc
Stargazer	26703	4480	53761 ab	7280 ab	23877 ab	4144	93490 ab	12208 abc
4290	26515	4480	58342 ab	8064 ab	21937 ab	3920	103011 ab	13328 ab
SF800	26318	4368	44613 ab	6384 ab	25085 ab	3920	104442 ab	12768 abc
4370	25826	4816	59146 ab	7728 ab	25053 ab	4368	137745 a	17584 a
Estrella	25546	4144	47947 ab	6608 ab	22442 ab	3920	99027 ab	12320 abc
Polimax	25377	4480	43503 ab	6272 ab	21047 ab	3584	83257 ab	10640 abc
Edom	25004	4480	29590 ab	3920 b	19424 ab	3472	82255 ab	9520 bc
Accomplice	24896	4592	72661 a	10528 a	25518 ab	5152	76823 ab	10304 abc
Mickylee	24822	4256	32315 ab	4368 b	18628 ab	3360	85322 ab	11424 abc
Sidekick	23671	4256	55439 ab	8064 ab	28947 ab	4928	78421 ab	10304 abc
4030	23542	4256	61264 ab	8064 ab	20852 ab	3472	92629 ab	11760 abc
SV2524WY (Wingman)	22842	4032	50177 ab	7392 ab	25302 ab	4592	74667 ab	8848 bc
SP6	22397	4368	28955 ab	4592 b	22817 ab	4256	98728 ab	12768 abc
Red Delicious	22309	4144	29545 ab	4256 b	19765 ab	3248	59748 b	7056 bc
Ace	22277	3920	43241 ab	6272 ab	18239 ab	3248	80104 ab	10640 abc
Jadestar	21676	3808	41754 ab	5600 ab	22564 ab	4144	59729 b	7168 bc
10319	20010	3920	44153 ab	6720 ab	22512 ab	4032	84623 ab	11648 abc
Adir	18408	3696	27982 b	3920 n	17961 ab	3584	46543 b	5600 c
Sangria	16355	2912	41789 ab	5824 ab	23315 ab	3920	79483 ab	10080 abc

Means followed by the same letter were not significantly different at p > 0.05 using Duncan's Multiple Range Test.

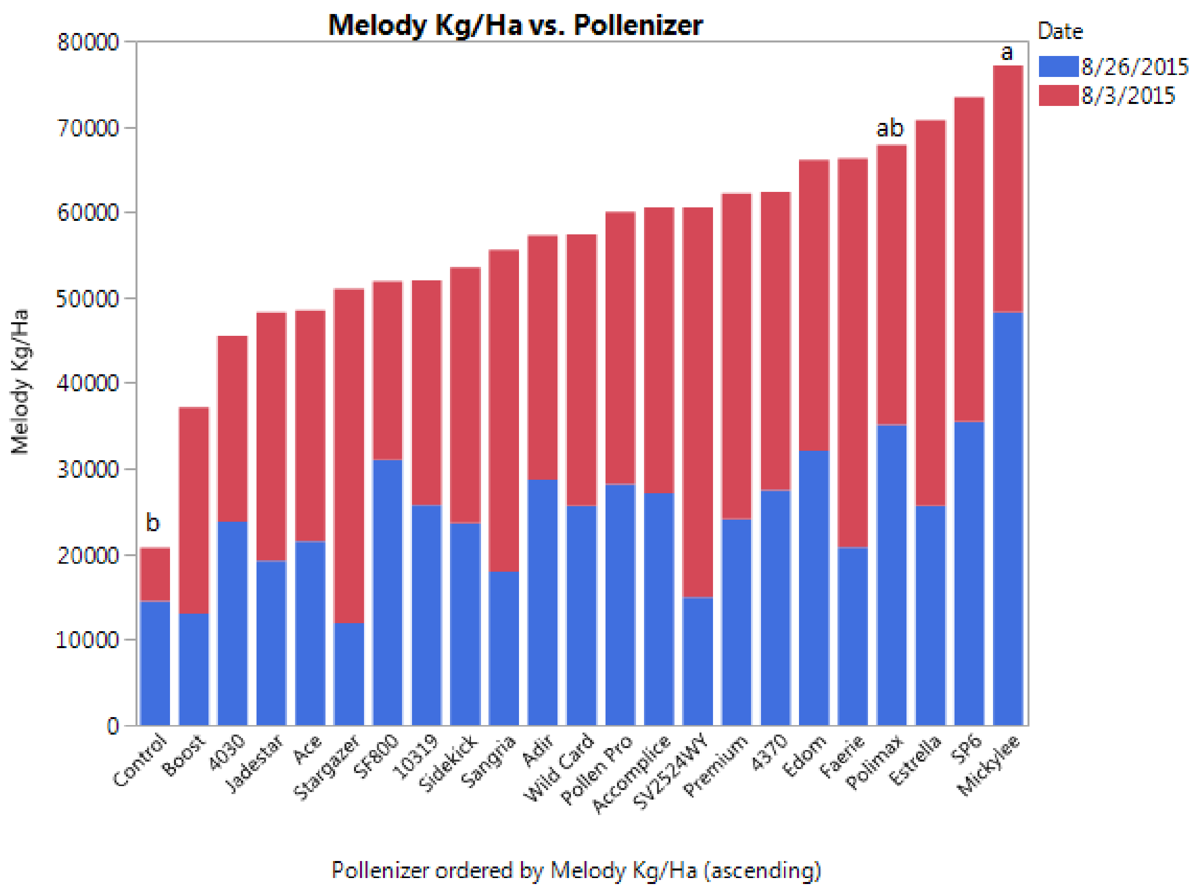
In 2015, cultivar 7187 when pollinized by Pollen Pro produced the highest Kg/Ha, while the non-pollinated Control had the lowest. Except for the control treatment, Wingman (SV2524WY) had the lowest yields. Mickylee produced the highest yields, while the non-pollinated control again produced the lowest yields. Boost was the lowest yielding pollenizer. Finally, Revolution pollinated by Ace had the highest yields for that cultivar, and Adir had the lowest pollinated yields, excluding the control group. (Figures 7, 8, 9**)**

Figure 7. 2015 Harvest Data of Seedless Watermelon Cultivar 7187 Yields in Kg/Ha by Pollenizer. University of Delaware, Georgetown, 2015.



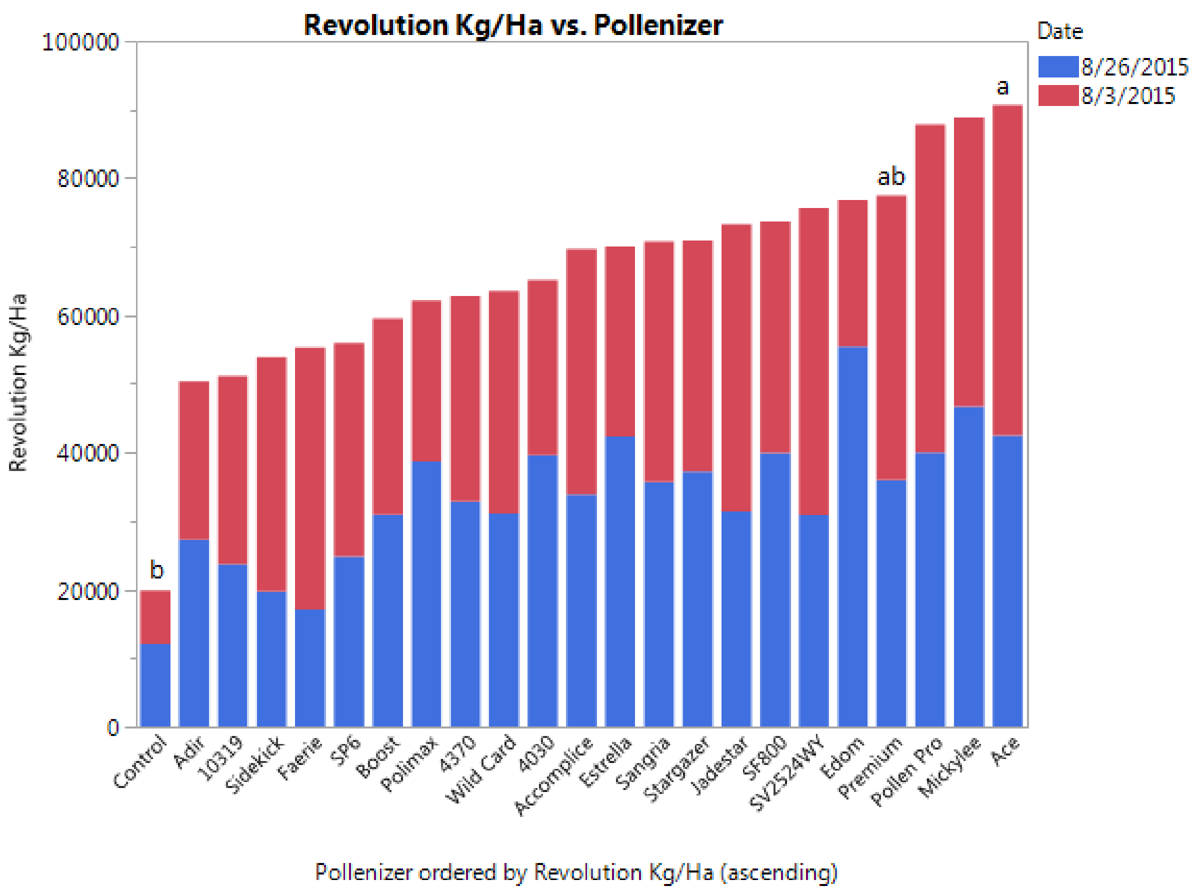
Means followed by the same letter were not significantly different at $p > 0.05$ using Duncan's Multiple Range Test.

Figure 8. 2015 Harvest Data of Seedless Watermelon Melody Yields in Kg/Ha by Pollenizer. University of Delaware, Georgetown, 2015.



Means followed by the same letter were not significantly different at p > 0.05 using Duncan's Multiple Range Test.

Figure 9. 2015 Harvest Data of Seedless Watermelon Revolution Yields in Kg/Ha by Pollenizer. University of Delaware, Georgetown, 2015.



Means followed by the same letter were not significantly different at p > 0.05 using Duncan's Multiple Range Test.

Table 47. 2015 Number of Fruit per Hectare Across All Seedless Cultivars and Pollenizers. University of Delaware, Georgetown, 2015.

Pollenizer	Cv. 7187 No/Ha	Melody No/Ha	Revolution No/Ha
Pollen Pro	6100 a	4000 ab	4500 a
Adir	5700 ab	4000 ab	2500 ab
Boost	5600 ab	3467 ab	4000 ab
Accomplice	5400 ab	3700 ab	3900 ab
SF800	5100 ab	3300 ab	4200 ab
Estrella	5067 ab	4800 a	3700 ab
4370	5000 ab	4100 ab	3500 ab
Premium	5000 ab	4200 ab	3900 ab
Stargazer	5000 ab	3800 ab	3600 ab
Polimax	4800 ab	4400 ab	3100 ab
Edom	4600 ab	4200 ab	3900 ab
Mickylee	4100 abc	4400 ab	5100 a
Wild Card	4100 abc	3700 ab	4000 ab
10319	4000 abc	3600 ab	2900 ab
4030	3900 abc	2900 ab	3800 ab
SP6	3900 abc	4700 a	3100 ab
Sidekick	3800 abc	3500 ab	3300 ab
Faerie	3800 abc	3700 ab	2700 ab
Sangria	3500 abc	3200 ab	3300 ab
Jadestar	3400 bc	3400 ab	3800 ab
Ace	3400 bc	3400 ab	4700 a
SV2524WY (Wingman)	3200 bc	3700 ab	4200 ab
Control	1600 c	1867 b	1467 b

Means followed by the same letter were not significantly different at $p > 0.05$ using Duncan's Multiple Range Test.

4.4 Discussion

Of all the studies performed, this was physically the largest by far and, as such, was the most difficult to manage. An ideal set-up for this study would have been even larger, however. Complete isolation of each of the cultivars, the separation of the plots by enormous stretches of land, would have ensured that no pollen movement would take place between plots. However, that ideal scenario is impossible given the limited time, space and funds that always constrain projects. Pollen movement has been tracked moving up to 6 km by pollinators in other studies and attempting to place that distance between plots is unfeasible. (65)

On the five acres available for this study, there was some movement of pollen up and down the rows, evidenced by the formation of watermelons in the non-pollinated control plots. Since there were significantly fewer melons in the control plots than those planted with pollenizers, the experimental design was at least partially successful in its goal of isolation. This also implies that there was some pollen mixing within plots, though it is impossible to quantify how much pollen was moved from one plot to the next.

The variability of yields between years can be partially explained through the difference in experimental designs, with the new design in 2015 producing a greater number of significant differences between yields using the different pollenizers. This could suggest that the 2015 design helped reduce pollen mixing between pollenizer cultivars. Another year of data using this design would have been very useful.

Another variable to consider when looking at the yield data is the competitiveness of the in-row pollenizers. Standard seeded types are not specifically bred for use as in-row pollenizers and crowd the seedless cultivars they are planted alongside, whereas the small saleable melons and special pollenizers are less aggressive in their vine production. Work has been done that quantifies yield lost from competitive pollenizer cultivars, but only a few cultivars are tested. (26) If growers want to pursue using small saleable melons and standard seeded types as their pollenizers so that they can have salable pollenizers, it would be interesting to perform a similar experiment using a larger number of cultivars.

Furthermore, it would be interesting for future research to compare seedless cultivars that are known for producing melons of different size classes and how fruit set of those cultivars are affected by pollinator choice. Are seedless cultivars known to produce more 36 count melons (18 to 22 lb fruit), for example, more vigorous and competitive in-row than cultivars that produce smaller fruit? If so, what pollenizer cultivar ensures the best conditions for fruit set for melons of each of those sizes? Some clues to the answers to these questions could possibly be extrapolated from the data of this research.

As always, it is important to discuss the effects that weather has on field studies, and 2014 and 2015 were very different in their conditions. A third year of data would have helped mitigate this variability.

4.5 Conclusions

The untreated controls in 2015 showed significant hollow heart and produced far fewer fruit than the pollinated sections of the study.

Determining which seedless cultivars a grower wishes to plant is the first step for any grower. Once that decision is made pollenizers can be matched to these seedless cultivars using the information from the collected data. It is impossible to suggest as to which cultivar of pollenizer is the “best” on the Delmarva Peninsula since every grower has different demands. As pointed out above, if adequate pollen is made available within a field, whatever the number and size of the set fruit, these fruits will be saleable produce when taken to market. Steps taken towards the prevention of hollow heart will pay dividends.

Certain pollenizers performed well across multiple cultivars of seedless watermelon. If such trends continue, it is possible to conclude that these pollenizers will continue to produce reliable results and should be strongly considered for use by growers. Pollen Pro pollinated melons were, at worst, in the upper half of yields in 2015, no matter the cultivar. They were the best overall yield producer for cultivar 7187 and third highest for Revolution. Accomplice performed similarly, producing the third highest yields in 2015 for cutivar7187 and yields better than roughly half of the other cultivars for the other two seedless cultivars. Mickylee, despite being an older cultivar that has since fallen out of favor, performed quite well, producing the highest yields for Melody and the second highest for Revolution. Premium produced good overall results, managing to produce yields in the upper third of pollenizers from all three seedless cultivars.

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Appendix A

WEATHER SUMMARY FOR 2014 AT GEORGETOWN, DE

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
5/1/2014	69.2	75.9 (16:35)	65.3 (00:05)	0.01
5/2/2014	60.9	67.9 (16:40)	50.8 (23:50)	0.03
5/3/2014	58.5	70.5 (17:15)	45.9 (05:00)	0
5/4/2014	59.9	74.7 (14:20)	45.4 (06:45)	0
5/5/2014	56.2	64.4 (17:45)	46.0 (05:15)	0
5/6/2014	58.6	70.7 (16:10)	50.1 (23:55)	0
5/7/2014	54.3	63.0 (12:10)	45.1 (06:05)	0.13
5/8/2014	65.6	81.2 (17:40)	55.3 (00:55)	0
5/9/2014	60.8	71.7 (15:25)	54.8 (02:25)	0
5/10/2014	71.6	78.6 (14:15)	62.1 (00:05)	0
5/11/2014	69	78.5 (17:20)	56.6 (23:50)	0
5/12/2014	72.1	85.8 (14:45)	55.0 (02:45)	0.11
5/13/2014	66.6	84.4 (12:15)	54.5 (21:55)	0
5/14/2014	58.5	62.9 (16:15)	54.9 (00:05)	0.02
5/15/2014	70.7	80.3 (13:50)	59.7 (00:10)	0
5/16/2014	65.3	70.3 (04:45)	56.4 (22:50)	1.51
5/17/2014	59.5	66.9 (16:35)	50.7 (23:50)	0
5/18/2014	57.5	66.6 (15:30)	49.0 (01:35)	0
5/19/2014	58.4	70.5 (17:25)	42.6 (06:10)	0
5/20/2014	63.7	74.4 (15:00)	48.0 (06:10)	0
5/21/2014	66.6	76.2 (15:10)	60.3 (06:25)	0.01
5/22/2014	68	81.7 (14:50)	61.4 (05:10)	0.06
5/23/2014	66.7	74.0 (15:35)	57.9 (06:30)	0
5/24/2014	63.5	73.1 (18:05)	53.9 (06:20)	0
5/25/2014	66	79.7 (16:25)	51.3 (06:10)	0
5/26/2014	72.7	84.7 (16:20)	58.9 (06:00)	0
5/27/2014	76.3	87.7 (14:10)	67.0 (05:50)	0.15
5/28/2014	67.2	78.4 (12:30)	55.7 (24:00)	0
5/29/2014	54.8	55.9 (15:00)	53.4 (23:30)	0.11
5/30/2014	59	68.7 (18:50)	53.1 (04:20)	0.02
5/31/2014	63.2	74.4 (14:35)	52.8 (24:00)	0

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
6/3/2014	71.5	86.1 (13:40)	57.0 (04:25)	0
6/4/2014	74.7	87.9 (15:20)	64.4 (05:50)	0.06
6/5/2014	69.1	75.1 (18:15)	61.8 (24:00)	0.54
6/6/2014	67.2	76.0 (17:20)	58.3 (05:50)	0
6/7/2014	68.8	81.3 (17:00)	53.9 (05:45)	0
6/8/2014	70.5	83.0 (15:40)	56.8 (04:50)	0
6/9/2014	74.8	84.1 (14:50)	67.4 (01:35)	0
6/10/2014	75.5	84.8 (13:50)	71.0 (07:45)	0.23
6/11/2014	69.8	76.7 (12:50)	67.4 (20:20)	0.39
6/12/2014	70.6	74.4 (13:50)	66.7 (01:05)	0.04
6/13/2014	75.7	85.5 (15:20)	69.8 (04:55)	0
6/14/2014	69.9	75.2 (14:15)	60.3 (24:00)	0
6/15/2014	67.1	79.0 (17:55)	53.7 (05:35)	0
6/16/2014	72.9	86.2 (14:10)	57.1 (06:10)	0
6/17/2014	80.9	92.6 (16:30)	68.3 (05:45)	0
6/18/2014	84.3	94.3 (14:35)	74.8 (06:15)	0
6/19/2014	75.8	86.2 (13:10)	66.3 (24:00)	0.05
6/20/2014	71	81.1 (16:00)	62.1 (05:10)	0
6/21/2014	69	75.5 (14:10)	63.1 (01:20)	0.03
6/22/2014	71.1	79.1 (14:05)	63.1 (24:00)	0
6/23/2014	69.9	80.9 (13:30)	56.9 (06:00)	0
6/24/2014	72.5	86.4 (15:15)	59.4 (06:00)	0
6/25/2014	76.9	86.4 (12:30)	69.5 (00:05)	0.26
6/26/2014	76.7	84.2 (16:30)	69.3 (23:35)	0.06
6/27/2014	70.9	78.0 (16:15)	60.7 (24:00)	0
6/28/2014	70.9	82.8 (16:15)	56.7 (03:55)	0
6/29/2014	70.3	83.2 (16:10)	54.0 (06:10)	0
6/30/2014	74.1	86.2 (15:55)	60.5 (04:45)	0

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
7/1/2014	79.1	90.1 (15:50)	69.6 (04:45)	0
7/2/2014	82.8	93.3 (13:50)	72.8 (03:25)	0
7/3/2014	81.6	92.5 (16:55)	71.2 (05:20)	0
7/4/2014	71.3	77.9 (17:20)	62.3 (23:55)	2.76
7/5/2014	69.2	81.0 (16:35)	57.9 (05:40)	0
7/6/2014	71.4	82.1 (15:45)	57.9 (05:05)	0
7/7/2014	78.6	88.6 (14:50)	67.3 (01:40)	0
7/8/2014	83	90.6 (17:20)	74.0 (24:00)	0
7/9/2014	78.2	87.1 (16:15)	71.3 (22:10)	0.14
7/10/2014	73.2	81.5 (13:00)	67.7 (17:40)	1.2
7/11/2014	73.2	82.3 (15:55)	66.6 (24:00)	0
7/12/2014	72.8	84.5 (15:20)	62.4 (05:40)	0.01
7/13/2014	77.4	88.0 (15:00)	67.9 (01:15)	0
7/14/2014	80.5	91.0 (15:05)	72.5 (23:00)	0.11
7/15/2014	77.6	89.9 (15:00)	71.1 (22:55)	1.02
7/16/2014	73.9	82.0 (16:25)	67.0 (24:00)	0.04
7/17/2014	70.8	81.4 (16:15)	59.6 (05:45)	0
7/18/2014	70.4	82.0 (16:30)	57.9 (06:05)	0
7/19/2014	70.1	76.5 (12:15)	62.7 (05:20)	0
7/20/2014	70.3	75.1 (16:10)	63.4 (24:00)	0.07
7/21/2014	71.2	80.3 (16:05)	61.9 (01:25)	0
7/22/2014	73.5	84.9 (15:25)	61.6 (04:40)	0
7/23/2014	77.7	88.4 (16:35)	65.1 (02:50)	0.23
7/24/2014	72.1	77.9 (16:45)	68.6 (24:00)	0.09
7/25/2014	70.6	82.4 (17:20)	59.5 (06:20)	0
7/26/2014	70.2	81.1 (12:30)	59.3 (04:05)	0.45
7/27/2014	75.2	83.0 (16:25)	68.7 (00:45)	0
7/28/2014	77.5	84.1 (16:10)	70.0 (24:00)	0
7/29/2014	67.8	77.7 (14:35)	57.3 (23:50)	0
7/30/2014	66.4	78.8 (17:20)	55.6 (03:05)	0
7/31/2014	70.8	83.2 (15:15)	55.7 (03:35)	0

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
8/1/2014	71.7	78.2 (14:30)	66.4 (06:40)	0.18
8/2/2014	67.5	73.1 (14:35)	61.2 (01:45)	1.35
8/3/2014	71	78.2 (16:30)	66.9 (05:00)	1.6
8/4/2014	73.4	85.3 (16:25)	65.0 (05:10)	0
8/5/2014	74.3	85.9 (15:20)	64.1 (03:20)	0.01
8/6/2014	73.1	82.4 (14:10)	65.4 (06:35)	0
8/7/2014	70.9	81.4 (14:55)	62.3 (06:00)	0
8/8/2014	68.5	79.3 (14:30)	57.5 (06:10)	0
8/9/2014	69.9	83.9 (15:00)	56.5 (06:25)	0
8/10/2014	71.1	84.0 (15:20)	57.9 (06:05)	0
8/11/2014	69.4	81.1 (15:25)	54.8 (06:30)	0
8/12/2014	73.3	78.2 (12:45)	69.4 (01:10)	1.67
8/13/2014	73.4	81.2 (15:30)	67.2 (06:20)	0
8/14/2014	69	78.9 (15:05)	57.3 (06:30)	0
8/15/2014	65.7	75.6 (17:20)	54.8 (06:50)	0
8/16/2014	70.1	82.5 (16:00)	58.7 (00:15)	0.01
8/17/2014	71.6	83.5 (17:05)	59.1 (01:40)	0
8/18/2014	70.2	80.4 (15:40)	59.4 (06:35)	0
8/19/2014	72.8	80.7 (13:50)	63.9 (24:00)	0.01
8/20/2014	70.5	81.0 (14:15)	58.6 (06:15)	0
8/21/2014	71.8	83.7 (14:10)	62.8 (03:55)	0.19
8/22/2014	70.6	77.6 (11:35)	64.7 (06:00)	1.25
8/23/2014	67.1	75.3 (11:55)	59.8 (06:40)	0.07
8/24/2014	67	76.2 (16:20)	58.7 (06:35)	0
8/25/2014	66.2	78.2 (15:40)	54.4 (06:20)	0
8/26/2014	67.6	81.2 (15:20)	55.1 (06:15)	0
8/27/2014	69.2	86.3 (17:45)	54.3 (06:20)	0
8/28/2014	71.1	81.2 (16:15)	59.3 (23:45)	0
8/29/2014	64.9	77.3 (16:05)	52.1 (06:05)	0
8/30/2014	68.2	81.9 (16:20)	55.7 (04:55)	0
8/31/2014	76.7	86.5 (15:15)	68.1 (00:45)	0

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
9/1/2014	77.6	87.3 (16:25)	70.8 (23:50)	0.08
9/2/2014	79.5	90.6 (14:50)	69.9 (03:50)	0.04
9/3/2014	74.2	84.5 (15:50)	64.8 (23:40)	0.08
9/4/2014	71.5	82.6 (16:35)	60.0 (06:00)	0
9/5/2014	74.7	85.0 (14:15)	64.7 (05:40)	0
9/6/2014	77.3	87.1 (15:20)	68.7 (24:00)	0.65
9/7/2014	68.4	76.4 (16:25)	62.0 (24:00)	0.06
9/8/2014	65.2	71.0 (09:50)	61.0 (01:00)	0.2
9/9/2014	69.5	73.7 (15:55)	65.5 (01:00)	0
9/10/2014	68.5	78.9 (13:50)	61.3 (07:05)	0
9/11/2014	72.4	81.5 (17:25)	62.1 (01:00)	0
9/12/2014	68.5	75.4 (14:50)	58.1 (24:00)	0
9/13/2014	63.1	73.8 (12:05)	55.8 (03:15)	0.13
9/14/2014	58.7	68.0 (15:25)	51.2 (07:10)	0
9/15/2014	59.4	72.9 (16:10)	45.2 (07:05)	0
9/16/2014	65	76.3 (15:50)	55.1 (23:40)	0.03
9/17/2014	60.8	74.2 (16:05)	50.5 (06:55)	0
9/18/2014	60.6	75.6 (13:20)	45.3 (06:55)	0
9/19/2014	61.2	71.4 (11:45)	48.6 (07:15)	0
9/20/2014	64.3	76.1 (15:35)	51.7 (04:35)	0
9/21/2014	68.8	77.8 (17:10)	64.3 (00:10)	0
9/22/2014	65.4	72.3 (16:45)	53.9 (24:00)	0
9/23/2014	54.5	64.1 (14:30)	44.3 (07:05)	0
9/24/2014	61.7	69.8 (12:35)	50.0 (03:25)	0.35
9/25/2014	63.6	68.1 (10:55)	57.8 (24:00)	2.63
9/26/2014	60.2	70.4 (15:50)	51.6 (07:05)	0
9/27/2014	61.3	76.3 (15:25)	48.2 (06:25)	0
9/28/2014	63.1	79.8 (15:25)	47.9 (06:35)	0
9/29/2014	63.3	71.5 (15:40)	56.6 (05:50)	0.05
9/30/2014	63.4	73.8 (15:30)	57.0 (06:50)	0.05

Appendix B

WEATHER SUMMARY FOR 2015 AT GEORGETOWN, DE

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
5/1/2015	50.2	52.9 (14:25)	41.7 (23:50)	0.25
5/2/2015	54.1	70.7 (17:10)	39.9 (01:55)	0
5/3/2015	62	79.4 (16:45)	44.5 (04:55)	0
5/4/2015	67.9	82.7 (15:55)	50.5 (06:00)	0
5/5/2015	72.7	84.5 (16:50)	63.3 (06:20)	0
5/6/2015	65.1	78.0 (11:40)	54.9 (23:10)	0
5/7/2015	63.2	75.5 (16:20)	52.4 (05:45)	0
5/8/2015	65.2	79.8 (14:50)	55.1 (05:20)	0
5/9/2015	70.2	80.5 (16:10)	63.7 (00:45)	0
5/10/2015	73.5	84.8 (15:40)	64.7 (00:10)	0.01
5/11/2015	71	77.5 (12:05)	66.4 (05:10)	0
5/12/2015	77.7	88.8 (16:05)	64.5 (04:05)	0
5/13/2015	65	75.6 (00:15)	54.8 (23:50)	0
5/14/2015	58.6	69.1 (17:15)	48.7 (06:25)	0
5/15/2015	60.9	74.4 (15:20)	48.2 (06:10)	0
5/16/2015	71.4	84.1 (16:00)	59.3 (04:10)	0.09
5/17/2015	73.9	83.5 (17:25)	67.8 (00:30)	0.02
5/18/2015	73.7	87.2 (12:40)	67.1 (23:35)	0.83
5/19/2015	73.2	83.0 (18:30)	66.4 (06:30)	0.48
5/20/2015	65.1	72.4 (00:10)	53.9 (23:15)	0
5/21/2015	52.3	55.9 (10:10)	49.1 (02:35)	0.79
5/22/2015	60.8	72.2 (17:35)	48.1 (03:35)	0
5/23/2015	59.8	70.0 (17:30)	48.2 (06:05)	0
5/24/2015	64.1	78.3 (16:35)	48.3 (05:25)	0
5/25/2015	70.3	81.0 (16:00)	59.2 (05:05)	0
5/26/2015	73	84.6 (14:50)	62.7 (04:40)	0
5/27/2015	75.4	86.3 (15:15)	68.4 (03:15)	0
5/28/2015	75.6	85.1 (16:05)	68.2 (04:45)	0
5/29/2015	73.5	83.6 (13:30)	65.7 (04:55)	0
5/30/2015	74	84.9 (13:50)	65.9 (05:30)	0
5/31/2015	76.3	87.5 (15:45)	67.1 (04:30)	0

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
6/1/2015	77.3	88.7 (15:25)	69.3 (23:20)	0.27
6/2/2015	61.8	69.5 (00:05)	56.2 (21:10)	0.65
6/3/2015	56.7	58.4 (15:05)	55.2 (06:30)	1.1
6/4/2015	58.2	60.4 (11:35)	57.0 (19:55)	0.14
6/5/2015	61.4	65.9 (17:25)	57.6 (00:15)	0.01
6/6/2015	66.6	76.2 (14:20)	58.2 (24:00)	0.04
6/7/2015	64.6	74.4 (15:25)	53.9 (05:00)	0
6/8/2015	71.4	83.0 (16:40)	57.4 (03:15)	0
6/9/2015	76.3	85.3 (16:25)	69.1 (05:30)	0.02
6/10/2015	73.3	83.0 (16:30)	61.2 (05:50)	0
6/11/2015	78.3	91.3 (15:10)	64.6 (03:05)	0
6/12/2015	82.3	92.4 (15:35)	72.8 (02:20)	0
6/13/2015	81.9	88.7 (16:15)	74.8 (06:05)	0
6/14/2015	77.1	87.9 (13:45)	72.0 (06:45)	0.14
6/15/2015	80	88.1 (18:25)	72.9 (03:15)	0
6/16/2015	82.8	92.8 (13:50)	73.1 (04:40)	0.01
6/17/2015	73.6	80.4 (11:25)	66.1 (05:10)	0
6/18/2015	74.6	85.8 (17:50)	68.5 (05:00)	0.59
6/19/2015	77.4	86.3 (16:30)	69.5 (02:40)	0.1
6/20/2015	78.7	87.4 (14:20)	71.7 (02:45)	0.14
6/21/2015	79.6	88.4 (17:25)	71.0 (01:00)	0.97
6/22/2015	80.7	88.5 (17:15)	72.3 (06:10)	0
6/23/2015	81.7	93.1 (16:30)	70.4 (22:30)	0.41
6/24/2015	74.5	81.5 (17:20)	65.7 (24:00)	0
6/25/2015	73.8	84.5 (14:50)	61.4 (05:50)	0.18
6/26/2015	69.8	75.9 (15:00)	64.7 (23:40)	0.65
6/27/2015	70.3	75.8 (17:40)	63.4 (01:30)	0.35
6/28/2015	74.3	79.8 (14:40)	67.6 (24:00)	0.11
6/29/2015	71.2	80.9 (16:40)	60.9 (06:00)	0
6/30/2015	75.4	85.5 (14:20)	65.0 (03:20)	0.02

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
7/1/2015	77.2	85.4 (16:10)	68.3 (06:15)	0
7/2/2015	69.6	73.3 (00:05)	65.3 (24:00)	0.89
7/3/2015	70.9	80.7 (14:40)	60.6 (05:30)	0
7/4/2015	73.1	80.0 (17:20)	68.7 (24:00)	0.04
7/5/2015	74	83.6 (15:10)	66.1 (04:40)	0
7/6/2015	77.8	87.8 (15:55)	70.8 (01:35)	0.1
7/7/2015	80.3	87.9 (15:25)	73.6 (06:05)	0
7/8/2015	80.4	88.3 (15:25)	74.6 (24:00)	0.06
7/9/2015	81	89.1 (16:25)	73.1 (03:20)	0
7/10/2015	78.6	83.8 (16:25)	70.4 (24:00)	0
7/11/2015	73.4	80.8 (16:45)	66.4 (24:00)	0.02
7/12/2015	73.8	84.6 (14:45)	62.2 (04:45)	0
7/13/2015	74	84.3 (13:35)	65.6 (06:00)	0.07
7/14/2015	76.5	83.8 (17:50)	71.7 (00:30)	0.13
7/15/2015	75.1	78.9 (11:50)	71.1 (24:00)	0.03
7/16/2015	70.5	77.8 (17:25)	63.2 (23:50)	0
7/17/2015	71.4	82.3 (15:55)	58.6 (06:15)	0
7/18/2015	78.4	87.8 (15:40)	67.9 (00:05)	0
7/19/2015	82	93.2 (15:50)	71.5 (04:55)	0
7/20/2015	84.1	94.3 (15:55)	76.4 (03:35)	0
7/21/2015	79.5	89.6 (13:25)	74.7 (04:20)	0.39
7/22/2015	75.7	84.1 (16:00)	67.5 (23:45)	0
7/23/2015	73.2	82.5 (15:45)	63.3 (24:00)	0
7/24/2015	72.2	84.2 (16:30)	57.9 (06:10)	0
7/25/2015	73.3	86.3 (14:35)	58.7 (06:25)	0
7/26/2015	76.4	87.6 (14:40)	66.0 (01:00)	0
7/27/2015	75	84.2 (17:10)	69.4 (07:45)	1.17
7/28/2015	77.7	91.1 (15:05)	69.3 (06:35)	0.03
7/29/2015	79.1	87.6 (15:20)	69.6 (06:05)	0
7/30/2015	79.8	89.2 (15:40)	74.0 (04:45)	0.01
7/31/2015	78.6	88.2 (15:40)	68.5 (24:00)	0.01

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
8/1/2015	78.4	90.3 (16:05)	66.0 (04:40)	0.15
8/2/2015	76.5	88.3 (14:30)	65.9 (06:15)	0
8/3/2015	78.4	89.1 (15:25)	64.9 (04:55)	0
8/4/2015	81.4	90.8 (15:55)	71.0 (24:00)	0.79
8/5/2015	76.6	87.6 (15:35)	67.4 (06:05)	0.64
8/6/2015	74.6	82.2 (15:20)	66.8 (04:15)	0
8/7/2015	72.3	74.8 (17:00)	69.0 (05:25)	0.04
8/8/2015	71.4	76.6 (18:10)	62.5 (23:40)	0
8/9/2015	70.7	83.3 (16:05)	59.7 (06:25)	0
8/10/2015	70.5	75.8 (16:55)	63.1 (05:05)	0.02
8/11/2015	73.4	84.5 (17:00)	68.7 (21:20)	1.17
8/12/2015	73.8	82.5 (15:15)	65.3 (23:40)	0.06
8/13/2015	71.2	82.1 (16:05)	61.2 (05:30)	0
8/14/2015	71.5	84.7 (16:15)	58.1 (06:10)	0
8/15/2015	72.9	85.7 (15:35)	60.0 (06:00)	0
8/16/2015	74.2	87.6 (15:35)	61.6 (06:40)	0
8/17/2015	75.6	89.4 (15:15)	61.6 (06:40)	0
8/18/2015	76.3	86.7 (13:45)	66.2 (06:10)	0
8/19/2015	78.1	86.1 (14:30)	71.1 (05:20)	0
8/20/2015	77.2	84.6 (13:50)	72.9 (05:20)	0.31
8/21/2015	77.4	85.3 (15:05)	70.2 (24:00)	0.07
8/22/2015	72.4	82.9 (15:50)	61.6 (24:00)	0
8/23/2015	69.8	83.6 (15:45)	56.2 (06:50)	0
8/24/2015	74.1	87.3 (14:45)	60.3 (05:50)	0
8/25/2015	75.6	84.7 (16:00)	65.7 (24:00)	0
8/26/2015	70.2	82.2 (16:05)	58.0 (06:30)	0
8/27/2015	67.8	80.9 (15:45)	57.2 (06:15)	0
8/28/2015	68.5	82.7 (17:35)	55.6 (06:40)	0
8/29/2015	70.3	84.9 (15:30)	55.9 (06:30)	0
8/30/2015	73.7	86.1 (16:10)	60.4 (06:40)	0
8/31/2015	77.1	85.5 (12:35)	71.0 (24:00)	0

Day	Avg Temp (°F)	Max Temp (°F)	Min Temp (°F)	Rainfall (in)
9/1/2015	74.7	90.6 (13:30)	64.7 (06:20)	0.23
9/2/2015	77.2	90.3 (15:05)	67.1 (06:45)	0
9/3/2015	78.4	92.9 (16:05)	68.2 (06:50)	0
9/4/2015	77.3	88.1 (14:30)	67.8 (05:35)	0
9/5/2015	73.5	79.7 (14:25)	62.2 (23:45)	0
9/6/2015	70.8	84.0 (15:15)	59.7 (04:45)	0
9/7/2015	74.2	88.5 (15:30)	61.0 (06:55)	0
9/8/2015	77.2	90.6 (15:55)	65.1 (05:05)	0
9/9/2015	81.1	92.5 (15:00)	73.4 (04:40)	0
9/10/2015	75.4	81.7 (12:20)	70.4 (24:00)	0.65
9/11/2015	71.2	79.7 (18:00)	65.2 (23:25)	0
9/12/2015	69.3	76.6 (11:50)	63.9 (02:10)	1.11
9/13/2015	65.8	71.1 (17:15)	58.2 (24:00)	0
9/14/2015	63.5	75.5 (17:05)	52.5 (04:10)	0
9/15/2015	65.8	82.7 (16:25)	51.0 (06:55)	0
9/16/2015	68.4	85.4 (16:40)	53.2 (06:05)	0
9/17/2015	69.1	83.5 (15:25)	57.4 (07:10)	0
9/18/2015	69	83.2 (15:35)	55.7 (07:15)	0
9/19/2015	71.6	85.8 (15:05)	59.0 (06:40)	0
9/20/2015	68	74.1 (14:10)	62.3 (06:15)	0
9/21/2015	66.9	71.6 (13:25)	62.2 (02:35)	0
9/22/2015	67.9	73.3 (12:25)	63.7 (02:35)	0
9/23/2015	66	75.4 (15:05)	55.7 (23:40)	0
9/24/2015	65	76.4 (13:30)	53.3 (03:10)	0
9/25/2015	69	74.9 (11:50)	62.6 (00:45)	0
9/26/2015	68.3	71.7 (11:55)	66.2 (19:50)	0
9/27/2015	69.3	75.0 (15:45)	65.5 (07:05)	0
9/28/2015	73	82.7 (13:45)	66.3 (02:45)	0
9/29/2015	75.3	84.5 (12:25)	68.1 (03:45)	0.83
9/30/2015	74.8	81.6 (14:40)	67.1 (24:00)	0.55