MISSION MELON: IMPROVING QUANTITATIVE TRAITS IN *CUCUMIS MELO* USING PHENOMICS

A Thesis

by

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ABSTRACT

Cucumis melo var. reticulatus is a diploid, andromonoecious species in the Cucurbitaceae family with origins in India. Muskmelon has robust cultivation growth over the last century due to its culinary appeal and health benefits. The U.S. ranks fifth internationally for production with a three-hundred-million-dollar market, following countries such as China, Turkey, and Spain. Among the states that cultivate melons, California grows 60 percent (1 million tons/year) of the total U.S. market from June to October. In the off-season, melons are imported from Costa Rica, Guatemala, and Mexico. A decline in production can be attributed to the increase cost of production and a lack of adapted cultivars. The objective of this experiment is to address producer and consumer needs' in a dynamic market by developing and identifying cultivars adapted to the Texas environment, with enhanced fruit quality and yield potential.

Andromonoecious breeding lines were used as the six maternal parents and six paternal parents in a North Carolina II factorial design to produce thirty-four F1 hybrids. Field evaluations were conducted in Uvalde, Texas during the spring of 2019 to determine high-parent heterosis and narrow-sense heritability of the F1 hybrids within this population. Evaluation parameters for the traits of interest include netting height, width, and coverage; weight (lbs.), shape and size (cm.); colorimeter values (CIE **L*, **a*, **b*); penetrometer (N); Brix (TSS); abscission size; cavity fill percentage and physiological defects present. The assumptions made about narrow sense heritability estimates of the quantitative traits in this population only pertain to these specific hybrid

varieties. However, they could hold true for other muskmelons if the underlying, additive genes are the same, which may likely be true. Genetic diversity leads to a higher chance of discovering useful heterosis within a population. Therefore, in future experiments, additional combinations and families will be evaluated. Identification of 15 hybrids that qualify for further field testing were 19 x 65, 26 x 96 and 52 x 96. Continuing to improve phenotyping methodology and protocol efficiency will lead to enhanced fruit quality and straightforward selection of useful hybrids in future trials.

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NOMENCLATURE

B/CS	Bryan/College Station
UV	Uvalde
TSS	Total Soluble Solids
FM	Female
M	Male
CMV	Cucumber Mosaic Virus
IPM	Integrated pest management
IU	International unit (fat soluble vitamins)
g	Grams
Mg	Milligram
G	Gallon
cm.	Centimeters
Lbs.	Pounds
VWC	Volumetric water content
N	Newton (SI unit for force)
**L*	Lightness from black (0) to white (100)
**a*	Shade of green (-) to red (+)
**b*	Shade of blue (-) to yellow (+)
GCA	General combining ability
SCA	Specific combining ability

H^2	Broad sense heritability
BSH	Broad sense heritability
h^2	Narrow sense heritability
NSH	Narrow sense heritability
MS	Mean Squares
RCBD	Randomized complete block design
V_P	Phenotypic variance
V_G	Genotypic variance
hp Heterosis	High parent Heterosis
m	Male
f	Female
MS	Mean Squares
df	Degrees of Freedom
Netting H.	Netting Height
Netting C.	Netting Coverage
Netting W.	Netting Width

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CHAPTER 1

INTRODUCTION

Cucumis melo var. reticulatus, muskmelon, is an economically important fruit that is consumed worldwide for its high nutritional value, health benefits and culinary usages. Imported to North America in the sixteenth century from Africa and India, the United States has become one of the largest producers of this crop, ranking fifth in total overall production worldwide (Pitrat, 2008). Overwhelming pest and disease pressures, relatively low cost to import muskmelon from countries such as Guatemala and Costa Rica, and numerous incidents of food-borne illnesses from contaminated fresh-cut produce have caused the melon industry to steadily decline in areas like Texas, who once dominated the industry (Bowen et al., 2006, McCollum et al., 2013, Del Rosario and Beuchat, 1995). According to the USDA, overall production has declined in the United States over the last decade. Economic gross fell from $325 million in 2012 to $261 million in 2015, while the total acreage produced decreased from 66, 350 acres to 51,600 acres (USDA, 2018).

Breeding efforts in muskmelon production are geared towards reducing the relative risk of food-borne illness contamination, as well as improving the overall quality of fruit and reducing the labor input requirements. Fruit quality and yield potential of hybrid varieties are the two pertinent factors under consideration when deciphering which lines are most adequate to commercialize, total soluble solids (TSS) being the number one factor influencing customer preference (Yamaguchi et al., 1977). A phenotypic analysis is used to analyze which varieties meet the market standards and are

adapted to specific growing regions. Evaluation parameters for the phenotypic traits of interest include netting height, width, and coverage; weight (lbs.), shape and size (cm.); colorimeter values (CIE *L, *a, *b); firmness measured by penetrometer (N); sugar content measured in Brix (TSS); abscission size; cavity fill percentage and physiological defects present.

Phenotypic data collected with these evaluation parameters are used to determine heterosis, narrow-sense heritability, correlation of traits and the general combining ability of hybrid genotypes within the generated population. These phenotypic traits are highly influenced by environmental factors and genotype x environment interactions. This valuable information allows breeders the ability to enhance the efficiency of their selection of appropriate genotypes adapted to an environment. The objectives of this study focus on a) the improvement of phenotypic quantitative traits in hybrid muskmelon varieties that address producer and consumer demands in a dynamic market, and b) organic greenhouse hybrid production, coupled with field trials in Uvalde, Texas, c) produce and identify varieties with improved fruit quality and yield potential, with a focus on reducing the netting presence and increasing the percentage of total soluble solids.

CHAPTER II

LITERATURE REVIEW

Plant Description

Muskmelon is a diploid (*Cucumis melo* var. reticulatus L., 2n = 2x = 24), andromonoecious, warm season annual species in the Cucurbitaceae (gourd) family with its origins in India. The cucurbitaceae family contains 98 genera and over 1,000 different species, which consist of numerous different fruits and vegetables such as squash, pumpkin, cucumber, zucchini, and a watermelon (USDA, 2018). This family typically produces fruit with an edible, fleshy pericarp that can be sweet or starchy (Lester, 1997). *Cucumis melo* var. reticulatus is commonly referred to as muskmelon, cantaloupe, honeydew, or melon. Reticulatus varieties are trailing and vining plants with tendrils, grown for their long shelf-life, sweet, medium to large, netted fruits that are salmon-fleshed to white-green-fleshed in color (J, 2016). Well-drained, sandy-loam and clay-loam soils are preferred in production areas during the main-season due to a greater water-holding capacity and ability to resist water logging, which favors a prolonged harvesting period. Muskmelon vines can grow upwards of 9.8 ft. in length, sprawling across the beds and in between the rows. The leaves of a muskmelon vine are simple, orbicular to ovate and shallowly lobed, arranged in an alternate pattern around the stem. Yellow flowers are produced during the flowering phase of the muskmelon lifecycle. These yellow flowers are 1.2–3.0 cm. (0.5–1.2 in) in diameter, female flowers being identified by their enlarged ovary at the base of the petals. Each staminate flower

contains five sepals and three carpels and will cluster together, while each pistillate flower contains up to five anthers on a short pedicel (J, 2016). Pollination is influenced by bee populations and weather conditions (cold, rain, wind, and prolonged cloud coverage). Insufficient bee populations and unfavorable weather conditions can reduce viable pollination and fruit set (Hartz et al., 2008). Optimal growth occurs in the temperature range of 85° to 95°F (30° to 35°C), growth can begin to slow in temperatures below 60°F (16°C). Some genotypes can tolerate temperatures in excess of 104°F (40°C) (Hartz et al., 2008).

Economic importance and Health benefits

Phytochemicals of interest

For centuries, muskmelon has been one of the most economically important cucurbits cultivated primarily for its numerous culinary usages and various health benefits (J, 2016). Muskmelon is known for having high levels of water content, antioxidant, and pro-vitamin A (beta-carotene), Vitamin B6, Vitamin C and Vitamin K (Lester, 1997). Consumption of muskmelon has been linked to healthy skin, hair, lungs, heart, and eyes, decreases stress and anxiety, strengthens the immune system, reduces the risk of arthritis and cancer, aids in weight loss and managing side effects of diabetes, and the treatment of kidney stones. A single serving size (1 cup of diced fruit) of muskmelon has the following nutritional values: Water (90.15 g), Calories (53), Fat (.3 g), No cholesterol, No saturated fat, Carbohydrate (12 g), Protein (1 g), Sugar (11 g), Dietary fiber (1 g), Sodium (25 mg), Vitamin A (5276 IU), Folic acid (22 mg), Niacin

(1mg), Vitamin C (57 mg), Calcium (14 mg), Magnesium (19 mg), Potassium (417 mg), Iron (.21 mg) and Carotenoids (3.2 g) (Parnell et al., 2003).

Beta-carotene is a carotenoid pigment that gives fruits and vegetables their orange, red, and yellow color and converts into vitamin A which is important for eye health, immune system functioning, production of healthy red blood cells and acts as a powerful antioxidant to fight free radicals that attack cells in the body. Beta-carotene has been linked to decreased asthma, reduced risk of cancer, heart disease, cataracts, age-related macular degeneration, night blindness, chronic fatigue, psoriasis, cataracts, depression, epilepsy, high blood pressure, skin disorders and more (Kader et al., 2004, Burton and Ingold, 1984). Muskmelon, according to the USDA, has more beta carotene than oranges, mangoes, and grapefruit; one study shows that orange-fleshed melons contain the same amounts of beta-carotene as carrots (Fleshman, 2011).

Vitamin C is an essential antioxidant for growth and development that has been labeled one of the 'most effective' nutrients by experts because of its extensive usages (Laur and Tian, 2011). Benefits of vitamin C include immune system protection, collagen production, reduce the risk of cardiovascular disease and scurvy, promote prenatal health, wound healing, bone maintenance and repair, eye disease prevention and more (Kader et al., 2004). 1 cup of muskmelon contains 100 percent of the recommended daily value (DV) of vitamin C, according to the USDA.

Muskmelon is thought to have been imported to North America in the sixteenth century from Africa and India. Today, the United States ranks 5th internationally for melon production, following China, Turkey, Iran, and Spain (Pitrat, 2008). Among the

states that produce melons, California grows over 60 percent (1 million tons, or 907,000 metric tons, per year) of the total U.S. market from June to October. In the off-season from November to May, melons are imported from Costa Rica, Guatemala, Honduras, and Mexico (Parnell et al., 2003). On average, the average U.S consumer ate around 11.1 pounds of muskmelon in 2000. By 2009 the average per capita consumption decreased to 9 pounds per consumer of muskmelon per year. Melon consumption has remained high for a variety of reasons, including the health consciousness of consumers and year-round availability but the decline has come from the increase in the cost of production and decline in overall consumer acceptability. According to the USDA, U.S muskmelon production fell from $325 million in 2012 to $261 million in 2015 (USDA, 2018). The U.S. muskmelon acreage decreased from 66,350 acres in 2012 to 51,600 acres in 2015. The rising cost of production in the United States, increasing disease and pest pressures along with competition from Central America, has resulted in a major decline in melon production in states like Texas, where the growing area is now small and newly adapted hybrid cultivars are needed to address the current problems being faced in the industry.

Common Pests

A. Western Flower Thrips- *Frankliniella occidentalis*

A small (1.5 mm), slender insect with four fringed wings ranging in color from translucent white to blackish brown. Thrips feed on the flowers of plants in large groups, causing damage through rasping mouthparts and pollen removal making fertilization inviable (Bessin, 2007). In high enough populations, leaves of the plant may become

distorted, covered in stippling damage on the leaves left from feeding and speckled with black frass.

B. Silverleaf Whitefly- *Bemisia tabaci*

A small (.8 mm), a yellow-green powdery white bodied moth-like insect with transparent white wings that fold over the body during rest. To scout for this pest, slightly disturbing the leaves will produce movement from the colonies on the underside of the leaves (Bessin, 2007). These pests use their piercing-sucking mouthparts to extract nutrients from the plant, causing defoliation of leaves, stunting of growth and reduced fruit yields. Honeydew sap is excreted by the Whiteflies during feeding which can initiate the growth of black sooty mold on the leaf surface, leading to an extended number of problems such as ants (Webb, 2013).

C. Aphid- *Aphis gossypii*

A small (1-2 mm), yellow-greenish wingless soft-bodied insect, typically found on the underside of a plant leaf. These pests have been nicknamed plant lice (Bessin, 2007). These sucking insects extract nutrients from the plant stems and reproductively multiply rapidly. Heavily infested aphid populations may cause the leaves or stems of the plant to yellow, curl and become distorted, brown necrotic spots may begin to form and shoots to stunt (Webb, 2013). Honeydew sap is excreted by aphids during feeding which can initiate the growth of black sooty mold on the leaf surface, leading to an extended number of problems such as ants.

D. Mealybugs- *Phenacoccus solenopsis*

A small (2-5 mm), soft-bodied white insect distinguished by the powdery, waxy secretion and six pairs of transverse, dark bands covering the pro-thoracic and meta-thoracic segment and the waxy filaments protruding around the margin of the body. Mealybugs damage the plant by extracting sap with their sucking mouth parts. This stresses the plant, eventually becoming chlorotic and causing the leaves to shed over time. Mealybug infestations can also cause fruiting body abortion and reduced yields. Honeydew sap is excreted by mealybugs during feeding which can initiate the growth of black sooty mold on the leaf surface, leading to an extended number of problems such as ants (Bessin, 2007).

E. Spotted Cucumber Beetle- Diabrotica undecimpunctata

A small (6.4 mm), yellow-greenish beetle with 12 black spots arranged symmetrically on the elytra (forewings). Spotted Cucumber beetles overwinter during their adult stage and become active when temperatures reach above 15-20°C. These beetles begin feeding on cotyledons first, then move on to roots, seedlings, flowers, and foliage. They serve as a vector for Bacterial Wilt and cause mostly cosmetic injury in fruit. Heavy infestations and high feeding injury on melon plants can result in wilting of the leaves and reduced fruit yields (Webb, 2013).

Common Diseases

A. Powdery Mildew- *Podosphaera xanthii*

A powdery, white fungal growth classified as ‘colonies’ on the upper surfaces of leaves and stems. This pathogen thrives in dense foliage areas with high relative

humidity and warm temperatures. Infected areas can become stunted and distorted, spreading very quickly through sporulation. If the infection becomes severe enough, plants may begin to senesce. This pathogen can also infect the underside of leaves, causing yellow spots to form (Shankar et al.). Powdery mildew is currently one of the most serious diseases affecting muskmelon production around the world, with an extremely high severity at the time of fruit maturity making the fruit undesirable (Abdel-Kader et al., 2012).

B. Anthracnose, Leaf spot, Fruit rot- *Colletotrichum orbiculare*

A fungal pathogen that induces brown rounded spindle-shaped leaf spots and rounded lesions on the fruit leading to sunken rotten spots (Shankar et al.). This pathogen favors warm, wet conditions and moisture is required for the pathogen to inoculate. Symptoms of this pathogen will begin to develop 4 days following initial exposure. Race 1 favors cucumber, whereas Race 2 favors muskmelon.

C. Charcoal Rot- *Macrophomina phaseolina*

A fungal root disease found in the soil that attacks roots, stems, and fruits of cucurbits. This pathogen causes yellowing of the top leaves, basal cankers that girdle the stem, premature leaf drop, water-soaked lesions and amber gummy oozing at the stem baseline and eventually plant senescence (Shankar et al.). This pathogen favors hot, dry conditions with plants under water stress and can persist in the soil for 3 to 12 years (Turini).

D. Downy Mildew- *Pseudoperonospora cubensis*

An obligate fungal parasite that causes angular, chlorotic lesions on the foliage of the plant. This pathogen first appears as small yellow water-soaked lesions on the topside of the leaf surface that may appear greasy without a distinct border (Shankar et al.). On the underside of leaves, a gray-brown-purplish 'downy' growth can be observed. This pathogen thrives under cool, moist, humid conditions. Symptoms appear 4 – 12 days after infection and range from leaf spots and leaf curling to reduced fruit yields and a greater proportion of misshapen sun-scalded fruit.

E. Gummy Stem Blight- *Didymella bryoniae*

A fungal seed-borne disease commonly known as 'Black rot' causes circular brown or tan spots at the leaf margin which subsequently spread out the leaves rapidly. The earliest symptom of gummy stem blight is an indefinite shaped lesion on the leaves or stem surrounded by an area of chlorosis with minute ridges. Closer inspection of the infection with a 10x hand lens will expose pycnidia, reproductive fungal structures, a common characteristic of this disease (Shankar et al.). Other symptoms of this pathogen include vine wilting, sudden stem death, water-soaked lesions on the hypocotyls and fruit, and production of a gummy-brown exudate at the stem base.

F. Monosporascus Vine Decline- *Monosporascus cannonballus*

A soilborne ascomycete that causes root rot and vine decline. Symptoms caused by Monosporascus include stunted foliar and root growth, older growth turning chlorotic, and within 10 days of infection most of the canopy will have defoliated

leading to vine collapse. This pathogen is highly adapted to hot and dry areas and plant stress is required for initiation of the pathogen (Turini).

G. Cucumber Mosaic Virus- *(CMV)*

A virus that disturbs the normal activity of a plant cell and quickly multiples inside the host. CMV can spread with ease from infected plants to healthy plants by uneducated laborers, aphid/cucumber beetle feeding and improperly sanitized equipment. Symptoms of this pathogen include crinkled and deformed leaves with the presence of a mosaic pattern of light yellow and dark green leaves, stunting, ring-spots on leaves and fruit and the yellowing of stems (Shankar et al.).

Phenomics in Plant breeding

The major challenge of the 21st century is the ability of global agriculture to ensure global food security. The ability for plant breeders to produce high-yielding crops adapted to future climates and to predict the performance of a genotype as a function of genetic architecture (Furbank and Tester, 2011, White et al., 2012). To be able to harness the wealth of genomic information, it must be carefully and comprehensively linked to phenotype in reference to a particular environment (Furbank and Tester, 2011). The labor-intensive and costly nature of conventional phenotyping means that many crop breeding programs make a single measurement for final yield in replicated trials in contrasting environments over multiple growing seasons. Phenomics is an area of biology focused on high-throughput and high-dimensional phenotyping of a set of phenotypes (physical and biochemical traits) expressed by a genotype, and how that genotypes' phenome responds to environmental influences and genetic mutations. The

study of phenomics is the acquisition of high-dimensional data on an organism-wide scale and allows for an understanding of dynamic phenotypes and predictions of how a certain genotype will react in a particular environment (Houle et al., 2010), as well as allows for predictions of how that genotype will react in specific environmental conditions. Phenomic data is the necessary complement to genomics; the dimensionality of phenomes is high, therefore, analysis of phenomic data will require new conceptual techniques (Houle et al., 2010). This emerging field of research is trying to improve the capacity, both qualitatively and quantitatively, to measure phenomes by developing new measurement systems in collaboration between scientists with diverse expertise to create a high-throughput multi-dimensional data analysis. The clear goal of phenomics is to bridge the gap between agricultural traits, plant functions, and genomics.

Breeding in the commercial industry

Muskmelon has long been established as an American staple during the summer, but the fluctuation in quality, price, and availability cause a lack of popularity (Blinn, 1908). Breeding efforts are geared towards preventing poor quality by controlling the effects of the environment, disease pressure and pest incidence. Hybrid varieties dominate the commercial muskmelon production market across the United States because they hold a far higher economic value in the market due to their superior quality (Hartz et al., 2008, Goldman, 2002). Hybridization allows the breeder to combine the most desirable qualities from two selections. Breeding programs identify hybrid varieties, through selection, that are chosen based on earliness, high yield under stressful environments, high sugar content, and attractiveness, among other marketable

quantitative traits (Blinn, 1908). Commercial breeding efforts in hybrid varieties are aimed at identifying a hybrid with an attractive round/spherical fruit shape; thick flesh with orange/green color; small seed cavity with large percentage of cavity fill; sweet, juicy, musky flavorsome fruit; Total Soluble Solids (TSS) no less than 10 %; minimal amount of tough netted skin; uniform earliness and total marketable yield; resistance to common diseases (powdery mildew, downy mildew, virus, fusarium wilt, gummy stem blight) and important insect-pests (aphid and leaf miner) (J, 2016).

Hybrid vigor, the theory that progeny will exceed or outperform their parental lines in the expression of a trait, is the driving factor in breeding programs (Lippert and Hall, 1972). There are 96 genes reported in melon that can be classified into six different trait influencing categories: (1) plant, 24, (2) flower, 16, (3) fruit, 19, (4) disease resistance, 22, (5) insect resistance, 5, and (6) isozyme, 14 (McCreight et al., 1993). The biggest genetic challenge faced by breeders is the differing sex expressions of the plant. Different forms of expression have been reported including andromonoecious, hermaphroditic, gynomonoecious and monoecious; the environment and interaction among genes can cause alternative forms of sex expression (J, 2016, Singh et al., 2011). These 96 genes will interact with each other and the environment to express the phenotype that is conditioned by each genotype.

'Modern' melon breeding and the study of genetically controlling the phenotypic expression of traits started at the beginning of the twentieth century, with preliminary research being published in the early nineteenth century (Sageret, 1825, Blinn, 1908). Published articles covering the topic of melon genetics include Robinson and Whitaker

(1974), McCreight et al. (1993), Robinson and Decker-Walters (1997). Published reviews on modern melon biotechnology include Guis et al. (1998) and Pech et al. (2007) (USDA, 2018).

Commercially used hybrids include Gold Rush, Navigator, Gold Express, Oro Rico, Archer Classic, Gold Star, Imperial 4-50, Mission, Summit, and Durango (Motes et al., 2006, Hartz et al., 2008, Norton, 1971). The TAM-Dew improved cultivar (95 days) is round-shaped and is resistant to powdery mildew and downy mildew. The TAM-Dew fruit rind is white in color, smooth rind with no ribs at maturity and the flesh is lime green in color. The Golden Beauty variety (105 days) is globe-shaped, pointed at the stem with yellow fruit with corrugations but has no netting present on the rind. The fruit flesh is white, thick, juicy, and sweet with a considerably long shelf-life. The Crenshaw variety (110 days) is acorn-shaped, pointed at the blossom end and the fruit rind is yellow to green, rough, corrugated, with no netting present. The fruit flesh of the Crenshaw is salmon colored, crisp, juicy, and sweet (Motes et al., 2006).

CHAPTER III

GREENHOUSE HYBRID PRODUCTION

Rising costs of hybrid seed production coupled with the increasing pest and disease pressures in the last decade have created a need for more efficient cultivation techniques in a controlled greenhouse environment. Controlling the presence of pests that feed on pollen is a primary challenge faced by breeding programs producing hybrid seed. Toxicity of chemical pesticide applications, emerging resistance from pest species and the prospect of crop damage due to improper application led to the need for an alternative pest control method. Specialists in biological control agents anticipated in the 1980s that the use of biological control would be necessary for a greenhouse setting when growing ornamental and vegetable crops. Employing natural enemies in these situations to keep pest populations below the economic threshold is crucial because growing in a protected environment produces a high-value crop and damage from pests is not tolerated (Van Lenteren, 1988). Due to the isolation provided by a greenhouse, only a limited number of pest species will affect the crop during the growing season, as opposed to field production where there is no barrier between the crop and the environment. Therefore, biological control in a greenhouse is more realistic and applicable in most situations because the climate is managed within certain ranges, making a prediction of the population development of pest and natural enemy establishment easy and more reliable than in a field situation (Van Lenteren, 1988).

Integrated pest management (IPM) programs incorporate the use of crop specific pesticides and natural enemies to reduce pest populations below the economic threshold. Knowledge of crop specific pests, their natural enemies and the interaction between these insects and pesticides are crucial pieces of information needed in order to establish the proper application schedule. Greenhouse biological control is focused on the suppression of host numbers below the economic threshold while maintaining the quality of the product, rather than focused on the long-term stability of natural enemies.

Materials and Methods

Plant Materials

Hybrid muskmelon seeds were direct seeded into 72-cell count plastic flat trays. One seed was inserted into each cell .5-inch-deep and covered with a mixture of potting soil, vermiculite, and perlite. The soil mixture used was slightly acidic to neutral in pH, comprised by mixing two bags of 3.8 cu ft Premier Horticulture Pro-Mix planting soil, one bag of vermiculite, one bag of perlite, and one bag of 15-9-12 Scotts Osmocote Plus (BWI Companies, Inc., Nash, TX.). Planted flats were set in the greenhouse and hand watered using a garden watering hose with an attached water breaker nozzle for approximately three weeks, or until the first true leaves developed. Seedlings began to germinate and emerge 5-7 days after planting, depending on the temperature of the soil. When the first set of true leaves fully emerged, seedlings were then hand transplanted into 5-gallon (G) plastic pots that contained the previously mentioned soil mix. Every 5-G pot was planted with one muskmelon transplant and then two drip irrigation emitters were inserted at the base of each transplant. The drip irrigation system was equipped

with a Dosatron D25F (11 GPM) (Dosatron International, Inc., Clearwater, FL.), this system continuously injected Peat Lite Peters' Pro Plant Starter 10-30-20 (BWI Companies, Inc., Nash, TX.) into the watering system, delivering rainwater to each of the 5-G pots.

Muskmelon plants do not thrive at field capacity water (21 % VWC) conditions or at their permanent wilting point (11 % VWC); therefore, soil moisture levels were monitored using a plant soil moisture meter throughout the growing season and kept below levels of 4 to 7. The numbering system indicates that 1 to 3 is a dry pot (wilting), 4 to 7 is moist (ideal) and 8 to 10 is wet (waterlogged). As the muskmelon plants began to grow and the vines sprawled, a string was used to trellis the vines up vertically. This is typically done in a greenhouse production system, as compared to allowing them to grow horizontally along the floor, which is common in commercial production systems. Trellising the vines upward allows for easier maintenance, prevents fruit damage caused when there is contact between the fruit and the floor, and allows for ease when scouting for pest and pesticide applications.

Greenhouse preparations and Environmental conditions

Prior to planting, the greenhouse was emptied and sanitized with Floral Life DCD (2 oz/G) (Smithers-Oasis Company, Kent, OH.) to eliminate any preexisting pest and disease populations. Using a pressure washer, Floral Life DCD was added to a 50-G tank and allowed to agitate for approximately five minutes. A pressurized disinfectant was then sprayed onto all the surfaces of the greenhouse and allowed to sit for ten minutes prior to rinsing it off completely. After this ten-minute period, rainwater was

used to flush the sprayer and then it was filled again so that the pressure washer could be used to rinse the walls and floor of the greenhouse.

A warm-season annual, muskmelon requires copious amounts of light for flower production, relatively high temperatures, low humidity and adequate water drainage for optimal growth. Greenhouse temperatures and humidity were adjusted using an automated computer programing system Link4 iGrow 1800 Greenhouse Control (Link4 Greenhouse Controls, Anaheim, CA.) with the LinkConn 1800 software. Ideal growth temperatures for muskmelon produced in a greenhouse range between 30 and 35°C (85–95°F) during the day and temperatures of 16°C (60°F) at night (Hartz et al., 2008). Muskmelon has an ideal relatively low humidity requirement. Early in the growing season, heating mats were used during the germination phase as supplemental heating to ensure that the soil temperatures remained in the optimal range. Hanging sensors in the center of the greenhouse monitored the temperature and relative humidity, while a light meter on the rooftop of the greenhouse monitors light intensity emitted by the sun. Greenhouse climate data is collected and stored in an external drive for analysis and review.

Pest control methods

Pest Scouting and identification

Pest populations in the greenhouses were monitored using several different techniques. Daily scouting was conducted by checking each plant individually for the presence of pests. To scout, the leaves of each plant were turned over to check for the presence of pests such as mealy bugs, aphids and whiteflies. To scout for thrips, several

flowers were removed from each plant and inspected in the corolla for pest populations. Pest Wizard Yellow & Blue Sticky Card Traps (ARBICO Organics, Oro Valley, AZ.) were placed at three different heights: base of the plant, mid-height up the vine and at the top of the trellis and checked daily for pest populations. ARBICO recommends 1 trap per 1,000 square feet for monitoring and 1 trap per 20-25 square feet for trapping of pests. The blue side of the trap will attract mostly thrips, while the yellow side of the trap will attract a wider array of pests including thrips, whitefly and aphids. Optiroll Blue SUPER (Russell IPM, Deeside, Flintshire) glue traps were used as part of this integrated pest management system, along with the sticky cards and biological control, to keep pest populations below the threshold. When used as part of an IPM program, Optiroll Blue SUPER is highly attractive to thirps with its specific wavelength, high tack adhesive layer and patented 'bullseye' design.

Biological Control

Pest infestations can induce yield losses upwards of thirty percent in protected cultivation vegetable production, therefore IPM is required to keep pest populations below the economic threshold (Abdel-Kader et al., 2012). While pesticides are efficient and important for use in managing greenhouse pests, the potential for toxic exposure to workers, from the active ingredient chemical, during application is extremely high in a confined, enclosed space (Bessin, 2007). Biological control stems from the need for alternative methods of pest control that are safe for the environment, non-toxic to humans, animals, and bees and are rapidly biodegradable in the environment with no chemical residue (Abdel-Kader et al., 2012). Natural pest enemies were used for the

control of greenhouse pest in this research project such as the western flower thrips, spider mites, aphids, mealybugs, fungus gnats, and the silverleaf whitefly. The natural enemies used to control these pests were beneficial nematodes (*Steinernema feltiae, Heterorhabditis bacteriophora),* beneficial mites (*Phytoseiulus persimilis, Neoseiulus fallacis, Stratiolaelaps scimitus, Amblyseius cucumeris),* and predatory wasps (Trichogramma). All the biological products used for this experiment were purchased from BioLine AgroSciences Ltd. (BioLine AgroSciences Ltd., Telstar Nursery, Little Clacton, Essex, U.K.) and ARBICO Organics (ARBICO Organics, Oro Valley, AZ.). Both biological companies are nationwide suppliers of biological control agents and organic growing supplies.

Natural enemies require a longer time period to bring pest populations below the threshold compared to chemical applications but once a substantial population of beneficial insects is acquired, if environmental conditions are conducive, pest populations should remain below the threshold due to established natural enemy populations (Bessin, 2007). Applications of natural enemies were timed on a two to four-week release cycle, depending on the stage and level infestation. Natural enemies were applied to the foliage of the plant using a 50-G agitation tank sprayer or were soil drenched using a watering can or by incorporating them into the irrigation system (Abdel-Kader et al., 2012).

Organic Control

A recent study of organic farming compared to conventional farming techniques showed that organic fields have five times more plant species diversity, and almost

twenty times more pollinator species diversity as compared to conventional field production techniques. Shockingly, there was over one-hundred percent more pollinator abundance in the organic field as compared to the conventional field (Krauss et al., 2011). Traditional pesticide measures have been replaced with alternative, non-toxic organic versions. Spinosad (*Saccharopolyspora spinosa)* is used as a broad-spectrum insecticide produced from soil bacterium that is toxic to an insect's central nervous system. Spinosad is labeled for use on pests that include thrips, spider mites, leaf miners and ants. M-Pede is a broad-spectrum formulation of potassium salts naturally derived from fatty acids that acts as an insecticide, miticide, and fungicide. M-Pede is labeled for use on aphids, whiteflies, thrips and powdery mildew. BotaniGard ES (*Beauveria bassiana)* functions as a mycoinsecticide that penetrates through the pores of an insect's cuticle. BotaniGard ES is labeled for use on soft-bodied insects such as aphids, thrips and whiteflies. SuffOil-X is a mineral oil applied to plants as a miticide, fungicide, and insecticide that suffocates soft-bodied insects. SuffOil-X is labeled for use on mealybugs, whitefly, aphids and leafhopper. Cease (*Bacillus subtilis)* is an organic copper based biofungicide used to combat fungal and bacterial infections. Cease is labeled for use on angular leaf spot, powdery mildew, downy mildew, leaf spot, blight, *Botrytis*, and *Xanthomonas*. It is important to maximize the effectiveness of insecticides and miticides by applying the proper rate of the active ingredient when the pest is present. When applying fungicides and insecticides, rotation of active ingredients was used in a cycle to prevent pest resistance and ensure sufficient application timing, pressure, and coverage (Bessin, 2007).

Breeding methods in the greenhouse

Figure 1 (Top-R) Female flower closed the day prior to pollination (day 1) with a zip-tie (A. Fix, 2018)

Figure 2 (Top-L) Four days after pollination, crossing I.D tag and pollination flag (A. Fix, 2018)

Figure 3 (Bottom-R) Two weeks after pollination, size of softball (A. Fix, 2018)

Figure 4 (Bottom-L) Six weeks after pollination, yellow 'melon hammock' (A. Fix, 2018)

In this experiment, muskmelon plants were treated as andromonoecious, or hermaphroditic, with staminate flowers. This is the most common form of sexual

expression for muskmelon used in commercial breeding programs. For hybrid production of muskmelon, hand pollination of the extremely delicate flowers is necessary. For the andromonoecious types, cross-pollination is a two-step, two-day process. For step one, on the day prior to anthesis (day 1), the hermaphroditic immature flower to be used as the female is closed around the corolla using a zip-tie to ensure and prevent pollination or cross-contamination from pest or unsterile equipment (Figure 1) (J, 2016). Female flowers can be identified by the swollen ovary at the base of the corolla. On the morning of day 2, the zip-tie and corolla are removed from around the stigma so that anthers from a different cultivar might be used to transfer pollen. Perfect flowers are emasculated by removing the pre-anthesis anthers with fingernails/tweezers before the corolla opens. After a flower is emasculated, pollen from the male parent is transferred onto the stigma of the female parent by treating the anthers as a paintbrush and gently causing a pollen transfer (Goldman, 2002). Pollination is done by hand early in the morning, between 6:00 a.m. – 9:00 a.m. to ensure that this process is efficient. Pollen will become saturated in the afternoon, which can lead to unfavorable crossing conditions. Pollen is unlikely to shed on rainy days where there is a substantial amount of cloud cover, therefore full sun mornings are preferred for hybrid production.

For step two, once a female flower is hand pollinated, a gel capsule is placed over the stigma to prevent any further contamination. A white crossing tag is attached to the base of the pedicel with the hybrid cross-identification (I.D) number and a bright colored pollination flag is attached directly above the I.D tag to allow for ease when trying to find the fruit during harvest (Figure 2). In between every pair of parents during

the crossing process, all equipment is sterilized with alcohol to prevent cross-contamination of pollen or diseases. After several days, the gel capsule will fall off on their own as the ovary begins to swell. Once the melons reached a softball size (Figure 3), they were placed into yellow Bootstrap Farmer 'melon hammocks' (Bootstrap Farmer, Craven County, NC.) (Amazon.com, Inc.) (Figure 4) which help to prevent the fruit from slipping off the vine, as well as preventing an all-together vine breakage which can happen when there are multiple heavy fruits on a single vine.

Muskmelon Harvest

Muskmelons are ready to be harvested roughly thirty days following anthesis when the surface of the rind has become fully netted, the color underneath the rind changes from a shade of green to light yellow/white and the subtending leaves senesce (Cantwell, Goldman, 2002). A crack will appear in the peduncle where the fruit attaches to the vine, this is also a sign of the fruit being ripe. 'Slipping' or 'full-slip' is the key sign that a melon is mature and at the stage where they are ready to be harvested (Hartz et al., 2008). 'Slipping' is a term used to describe when the fruit can be easily separated from the vine with a slight pressure of the thumb, at the base of the fruit, where it is attached to the peduncle. This is due to formation of an ethylene induced abscission layer where the peduncle attaches to the fruit. Depending on the rate of pollination, plots may require multiple daily harvests over a two-week period. In commercial muskmelon production settings, the fruit is sized mechanically or by sight directly in the field and are packed into 9, 12, 15, 18, or 23 per carton based on their size (Hartz et al., 2008).

According to James D. McCreight at the USDA, the flavor is a complex interaction among sugars, texture, pH and volatile compounds. Vine-ripened melons harvested at the right time do not have much of a carbohydrate reserve; thus, melons cannot convert anything else into sugar and will never be as sweet as they are at the time of harvest (Goldman, 2002). To maximize the postharvest life of muskmelon, rapid removal of field heat is required and is typically done using the forced-air (pressure convection cooling) approach. With the forced-air approach, fans will circulate air around the produce causing cold air to sink and warm air to rise. Once the melons have been properly cooled, storage can be prolonged for two weeks at temperatures of 34° to 40°F (1° to 4°C) (Hartz et al., 2008). Proper handling of the melons, along with maintaining high humidity during storage can reduce water loss and physical damage.

Seed collection and storage

Production of hybrid seed is the primary goal of many breeding programs. Seeds were saved from every fruit that was processed during these trials for data collection. Mature, ripe fruit once harvested, was stored in a walk-in produce cooler with temperatures ranging from 36º to 41ºF (2.2º to 5ºC) and optimal relative humidity of 95 to 100 percent which can help to prevent drying. Data was collected once the fruit reached ambient temperatures. Allowing the produce to cool prior to collecting data can help to reduce error in firmness readings made by the penetrometer (Parnell et al., 2003). Melons were then cut open across the transverse plane and the seeds were removed using a metal spoon and placed into a zip-lock bag. Zip-lock bags containing melons flesh and seeds were placed into a cool, dry room on racks so that the seeds could

ferment for four days. At four days, the contents of the bag were transferred into a sieve and pressure rinsed under warm water. This process of washing will cause any debris to detach before the seeds are allowed air-dry at room temperature for as little as a week (Goldman, 2002). A commercial dehumidifier (Dayton SEAJ8, Dayton Electric Manufacturing Inc., Niles, IL.) was placed in the room to reduce ambient humidity. After seeds have completed drying, they were then packaged into manila seed envelopes that were labeled with the breeding pedigree, hybrid cross, date of cross, date of harvest, and location. These seed packets were filed in racks by their year of harvest, harvest location and plot number before and put into the seed storage cooler for further long-term storage. Melon seeds that are cured and stored properly can remain viable for up to five years (Goldman, 2002).

CHAPTER IV

BROAD SENSE HERITABILITY ANALYSIS

Heritability is a measure of the proportion of genetics versus environmental factors that have an influence on the variation of a trait (phenotype) expressed by a cultivar to compare the expected gains from selection. Heritability can vary among populations and family structures, which can be a useful tool in deciphering which base population will have the highest gains from selection. Broad-sense heritability is the variance of a phenotype that is due to total genetic effects (Holland et al., 2003), otherwise written as $H^2 = V_G / V_P$, where $V_P=V_G+V_E$ is the variance due to phenotype. Estimates are based on the entire population, not an individual plant, and measure the proportion of the phenotypic variance as the result of genetic factors. Broad-sense heritability estimates for the quantitative traits measured for individual plants within the F1 family were calculated using the formula H^2: $\sigma_{family} / \sigma_{family} + \sigma_{family\ x\ environment} + \sigma_{error}$, where σ_{family} is the variance due to genotype, $\sigma_{family\ x\ environment}$ is the variation caused by the interaction of the genotype by the environment and σ_{error} is variation in a sample due to natural error.

Materials and Methods

Plant Materials

Nineteen F1 hybrids, derived from cross-pollinating twenty-three elite inbred cultivars were evaluated in Uvalde, Texas in the spring of 2018 (Table 1). Cultivars used to produce the hybrids for this trial were provided by Dr. Kevin Crosby. The hybrids

were produced in a greenhouse under organic agriculture practices and evaluated under a replicated two treatment field trial: irrigated under normal agricultural practices (control) and drought conditions which received a 50% water deficit. Phenotypic quantitative traits evaluated under these conditions included a visual rating of rind and flesh color, flesh color (a*, b* and L*) with a colorimeter, weight and shape, Brix (TSS) with a refractometer, flesh firmness with a penetrometer, rind netting, days to maturity and fruit yield.

Field Planting

Muskmelon transplants were produced in a greenhouse located in College Station, Texas, and transported by truck three weeks after germination, in their flats, to the field in Uvalde, TX. Three replications of each genotype were hand planted into two treatments, in a randomized complete block design (RCBD) (Petersen, 1994). RCBD is the standard design for agriculture field experiments where blocks or replicates are used to group similar experimental units. Blocking into groups is done to control experimental variation by accounting for spatial effects due to the field and so observed differences are due to true differences between experimental treatments. Each treatment contained replications of equal size with all genotypes represented. Row beds had been previously tilled, fitted with drip irrigation, and covered with white plastic mulch which helps to conserve moisture, maintain soil temperatures and eliminate nutrient competition from weeds. The spacing used in-between planting rows was approximately 3 ft., the spacing between the plants within the rows was approximately 2 ft. and the planting depth was approximately 1 ½ in. (or until the root ball is completely submerged in the soil).

Muskmelon require a steady supply of fertilized irrigation water during growth to initiate blooming and for fruit set; sub-surface irrigation was periodically used to supplement lack of rainfall.

Table 1 Field Trial Planting List Uvalde, TX, spring 2018

(F 39 X 24-2) F1	BL 37 x BL 109	BL 61
(F 39 x BL 30) F1	BL 37 X BL 136	BL 61 X BL 40
(HD 1129 x MG55) F1	BL 37 x BL 40	BL 65
(M 26 x MF 9) F1	BL 40	BL 70
(MF 9 x F 39) F1	BL 40 X BL 61	BL 70 X BL 81
BL 109	BL 40 X BL 70	BL 81
BL 110	BL 51	BL 96
BL 110 X BL 109	BL 51 X BL 37	F39
BL 136	BL 51 X BL 65	HD 1129
BL 155	BL 52	HD 150
BL 155 X BL 70	BL 52 X BL 136	M 26
BL 2	BL 52 X BL 96	MF9
BL 24-2	BL 53	Mg 55
BL 30	BL 53 X BL 2	OC 164

Phenotypic Evaluation

Phenotypic Measurements

Figure 5 AgTec Fruit Penetrometer FHP-802

A. Penetrometer- Digital Fruit Firmness Tester (General Fruit)

Measuring the firmness of fruit is one of the most accurate ways to test for fruit maturity and quality. In muskmelon, firm-fleshed melons are desired for their crisp texture and long shelf-life. The FHP-802 (Figure 5) (AgTec, LLC., Phillips, ME.) penetrometer is a handheld, highly convenient device used to take firmness readings in Newton (N) (1 N = 4.45 pound-force) on a range of fruits weighing from 1-33 lbs. (Cantwell). Muskmelon should all be at the same temperature when sampling (Mitcham et al., 1996). At least five samples were randomly chosen from each genotype and cut open along the transverse plane. All measurements should be taken by a single person to reduce sampling error. Two puncture tests are made by inserting the tip of the penetrometer into the flesh of the fruit, producing an average firmness for that specific sample (Mitcham et al., 1996).

Figure 6 WR-10 FRU Portable Colorimeter

B. Colorimeter- WR-10 FRU

Flesh color is an important trait to consider when it comes to desirability and marketability to consumers. Orange-fleshed fruit in indicative of the presence of carotenoids and green-fleshed fruit suggest the presence of chlorophyll (Cantwell). A colorimeter is a light-sensitive tool used to measure the absorbance of wavelengths of light for any individual sample (Staff, 2018). Flesh color (CIE *L*, a*, b*)* (Abbott, 1999) is measured using a WR-10 FRU (Figure 6) (Shenzhen Threenh Technology Co., Ltd., Shenzhen, P.R. China) handheld colorimeter that came calibrated from the manufacturer. An imaging sensor is placed firmly against the exposed flesh of the muskmelon and a measurement is taken by pressing a 'Test' button. Results are expressed automatically and digitally as intensity values of lightness *(L*),* Chroma $(C^*=[(a^*)^2+(b^*)^2]^{0.5})$, and hue angle ($h_{ab}=tan^{-1}[(b^*)(a^*)^{-1}]$) (Saftner and Lester, 2009, Saftner et al., 2006). A colorimeter provides less variability in color measurements and can accurately identify small differences in color between genotypes (Mitcham et al., 1996).

Figure 7 ATAGO BRIX 3810

C. Refractometer - ATAGO BRIX 3810

Soluble solids content (SSC) or total soluble solids percentage (TSS) is indicative of the sweetness, ripeness, or quality of muskmelon (Kleinhenz and Bumgarner, 2012). A refractometer provides an objective, relatively inexpensive and straightforward measurement of a fruit's sweetness (sugar content or the total soluble solids percent), which is measured in degrees Brix, present in a solution. The Brix scale measures the percentage of total soluble solids present in a 100-gram sample. When obtained and applied properly, Brix values can aid a breeder in variety selection, harvest scheduling, and post-harvest management (Kleinhenz and Bumgarner, 2012). A cubed piece of muskmelon is wrapped in cheesecloth and inserted into a stainless-steel garlic press. Pressure is applied at the handle and a solution of muskmelon juice is excreted. This juice solution is placed into the well of the ATAGO BRIX 3810 refractometer (Figure 7) (ATAGO U.S.A., Inc., Bellevue, WA.) which uses light emitters and a prism to analyze the Brix content present in the sample. High-quality marketable melons will typically have a Brix of 10% or higher (Lester and Shellie, 2002, Goldman, 2002).

Size and Weight of fruit

Uniform size and shape of commercial muskmelon are critical quality characteristics considered by the consumer when purchasing products. Consumers tend to view larger fruit as being of higher quality and more mature in growth (Mitcham et al., 1996). Muskmelon is commercially packed in thirty lbs. crates with 4, 5, 6, 8, 9, 10, or 12 count per pack size (Lester and Shellie, 2002). According to the USDA and industry standard, 9 and 12 count crates are commercially the most popular with consumers because of their medium size. Every hybrid had five individual fruit used for sampling and data collection. Size of each sample was calculated in centimeters (cm) using a tape measure and the weight was calculated using an analog fruit scale in pounds (lbs.). The population of hybrids were analyzed for their consistency of size and weight.

Shape of fruit

Table 2 Fruit Shape rating scale

R	Round
O	Oval
R O	Round Oval – Blocky
S	Sutures

Fruit shape is an indicative characteristic for a high-quality melon free of any physiological damage and is one of the most important qualities. A major economic loss experiences is caused by misshapen fruit being discarded for not meeting consumer demands (Keshavarzpour, 2013). Classification of fruit shape is vital to evaluating

produce in cultivar registration and consumer preference, meeting quality standards and maintaining market value (Keshavarzpour, 2013). A rating scale was used to classify the shape of each hybrid (Table 2). Round melons were classified as ‘R’. Oval melons were classified as ‘O’. Blocky melons that squared off at the edges were classified as ‘R O’. Melons with sutures, or ribs, which have large vein tracks running vertically across the rind were classified as ‘S’. Genotypes were analyzed for their consistency in shape.

Rind color

Table 3 Rind Color rating scale

LY	Light Yellow
Y	Yellow
LG	Light Green
G	Green
DG	Dark Green
B	Brown

Rind color is a visual physical indicator that a melon has reached maturity and is ready to be harvested when the rind has reached a golden color. At the time of harvest, a visual rind color observation is collected. A rating scale was used to classify the rind color at the time of harvest (Table 3). ‘LY’ represents a muskmelon that has reached maturity and has a light-yellow rind. ‘Y’ represents a muskmelon that has reached maturity and has a yellow rind. ‘LG’ represents a considered honeydew melon, or it can represent a muskmelon that was harvested immature. All honeydew melons have a light

green to whitish rind color at the time of harvest. ‘G’ represents a muskmelon that was harvested ‘green’ or immature. ‘DG’ (Dark Green) and ‘B’ (Brown) represent melon varieties that have been harvested past maturity and further data should not be collected.

Flesh color

Table 4 Flesh Color rating scale

1	White/Green
2	Green/Orange
3	Orange
4	Deep Orange
5	Orange/Red

Flesh color is an indicator that a melon is of high quality. At the time of harvest, a visual flesh color rating observation is collected. A rating scale was used to classify the flesh color at the time of harvest (Table 4). A flesh color rating of ‘1’ represents a honeydew melon with white to green flesh and is indicative of good flavor or an unripe muskmelon. A rating of a ‘2’ represents a muskmelon variety with yellow flesh, indicating low carotenoids. A rating of a ‘3’ represents a muskmelon with light orange flesh and moderate carotenoid levels or an unripe muskmelon. A rating of a ‘4’ represents a muskmelon with deep-orange flesh harvested mature that has a high level of carotenoids. Ratings of a ‘5’ are given to muskmelon varieties with orange to red flesh and typically have very high carotenoid content. Consumers prefer a flesh color rating of ‘4’ or ‘5’ for muskmelon varieties and a rating of ‘1’ for honeydew varieties.

Visual Rating of rind netting coverage, height and width

Rind netting coverage

Table 5 Netting Coverage rating scale

1	None, 0% covered
2	Some, 30% Covered
3	Half, 50% Covered
4	Substantial 80% Covered
5	Full, 100% Covered

A major objective is to identify a hybrid variety that has a reduced netting coverage on the rind. The netting, vein like structures on the outside of the rind, can be an ideal environment for pathogens to harbor on the surface (Parnell et al., 2003). Netting coverage represents the total amount of rind covered by netting, this is composed of the height of rind and the width of rind. By reducing the netting present, the idea is to reduce the likelihood of foodborne illness caused by fresh-cut muskmelon products. A rating scale from 1 – 5 is used to identify the level of netting present on the rind at the time of harvest (Table 5). A rating of a '1' represent a honeydew variety with no netting present. A rating of a '5' represents a muskmelon variety with almost no rind visible through the netting that is present. Desired hybrid varieties have a rating of a '3'.

Rind netting height

Table 6 Netting Height rating scale

1	None
2	Short
3	Medium
4	Tall
5	Extra-Tall

The height of the netting on a rind is described how tall the netting is raised off the rind surface. A rating scale was used to classify the height of each individual hybrid (Table 6). A rating of a '1' represents a rind that has no netting present. A rating of a '3' represents netting that is only slightly raised off the surface of the melon. A rating of a '5' represents netting that is extremely raised off the surface of melons and can be felt by running fingertips across the rind surface.

Rind netting width

Table 7 Netting Width rating scale

1	None
2	Skinny
3	Medium
4	Thick
5	Extra-Thick

Netting width refers to the thickness of the netting on the surface of the rind. A rating scale was used to classify the width of each individual hybrid (Table 7). A rating of a '1' represents a melon with no netting present on the surface of the rind. A rating of '2' represents a netting that is very thin and minimal in width. A rating of a '5' represents a melon that has a rind width that is very thick, the rind is almost not visible because the netting is so close to each other due to width. Desired hybrids will have a netting width rating of '3' – '4'.

Other traits of interest

Abscission size

Table 8 Abscission Size rating scale

1	Small
2	Medium
3	Large
4	Extra-Large

The abscission zone is where the fruit separates from the peduncle (Copes, 2005), this is known as 'slipping'. 'Slipping' occurs when fruit reach maturity. This separation results in a scar zone that can range in size from small (<10 mm), medium (10 - 15 mm), large (15 - 20 mm) and extra-large (>20 mm) (Copes, 2005). A rating scale was used to classify the abscission size (Table 8). A rating of a '1' describes a small (<10 mm) abscission, a '2' describes a medium (10 - 15 mm) abscission, a '3' describes a large (15 - 20 mm) abscission and a '4' describes an extra-large (>20 mm) abscission.

Cavity fill

Table 9 Cavity Fill % rating scale

100%	No Cavity, Ideal
90%	Some Cavity
80%	Partial Cavity
50%	Half Cavity
30%	Over Half Cavity

Cavity fill percentage refers to hollow cavity at the center of the melon that houses the seeds and how much pore space is present between the seeds and the flesh of the melon. A rating scale was used to classify the cavity fill percentage of each hybrid (Table 8). A cavity fill percentage of 100 % represents a melon variety that has no cavity space present in between the seeds and the flesh of the melon. A cavity fill percentage of 50 % represents a melon variety that is over half cavity, meaning there is a large pore space between the seeds and flesh of the melon. A solidly filled, 100 % seed cavity, is desired for marketing purposes (Blinn, 1908).

Defects present at harvest

Table 10 Defects rating scale

0	None, 0% Defect
1	Some, 30% Defect
2	Half, 50% Defect
3	Substantial, 80% Defect
4	Extreme, 100% Defect

Muskmelon genotypes chosen for commercialization should be evaluated for the presence of defects. Common post-harvest defects include harvest immature or overripe, chilling injury, brown blotch, decay, internal breakdown caused from dropping, sunken areas on the surface from water loss, discolored surface area from sunburn, and soft ground spot (Cantwell, 1996). Genotypes chosen should be more tolerant of bruising and physiological injury, chilling injury, and physiological disorders (Mitcham et al., 1996). A rating system (0= none, 1= slight, 2=moderate, 3= severe, 4= extreme) (Table 10) can be used to describe the level and severity of defects present in a particular genotype (Mitcham et al., 1996).

Statistical Analysis

JMP Pro 13.0.0 (SAS Institute Inc., Cary, N.C., 2018) was used to analyze the quantitative phenotypic data collected in this experiment, using the REML Model = $\sigma_{family} + \sigma_{environment} + \sigma_{rep[environment]} + \sigma_{family\ x\ environment} + \sigma_{error}$ to calculate the variances with a two-way ANOVA for unbalanced data sets. The primary purpose of a two-way ANOVA is to understand the interaction between two independent variables on a specific

dependent variable. This interaction gives insight on the effect of one independent variable on the dependent variable, and if it has the same interaction with each independent variable. These variances were then used to calculate broad-sense heritability of the population of hybrids. The broad-sense heritability estimates for the quantitative traits measured were calculated using the formula: $\sigma_{family} / (\sigma_{family} + \sigma_{family\ x\ environment}) + \sigma_{error}$. High parent heterosis was determined using the formula: $[(\mu^{Hybrid\ F1} - \mu^{High\ Parent})/\mu^{High\ Parent}] \times 100$ (2015). Statistical analysis of this data was provided with assistance from Jeekin Lau.

Broad Sense Heritability Estimates

Broad-sense heritability estimates (H^2) (Table 11) of this population of hybrids were calculated as the ratio of the phenotypic variance (V_P) to the genotypic variance (V_G). Additive variance, dominance variance and variance due to error were considered when calculating broad-sense heritability (Feyzian, E., et al, 2009). Dominance effects are measured as the deviations between genotypic values and breeding values. Dominance genetic variance ($(2pqd)^2$) involves the functional dominant effects caused by a gene (Falconer and Mackay, 1996, Xiang, Tao, et al., 2018). Additive genetic variance measures the variation caused by functional additive and dominant effects ($2pqa^2$) (Falconer and Mackay, 1996, Xiang, Tao, et al., 2018). The broad-sense heritability estimates for the quantitative traits measured were calculated using the formula: $\sigma_{family} / (\sigma_{family} + \sigma_{family\ x\ environment}) + \sigma_{error}$.

Table 11 Broad Sense Heritability Estimates, Field trial; Uvalde, TX, spring 2018

Weight (lbs.)	0.2513
Size (Circumference, cm.)	0.2204
L*	0.0803
a*	0.4584
b*	0.2506
Flesh Firmness (N)	0.0315
TSS	-0.0079
Cavity Fill %	0.0649
Flesh Color	0.2454
Netting Height	0.0186
Netting Width	0.0787
Netting Coverage	0.1388
Abscission Size	0.0488

Evaluation of Traits

Heterosis refers to the tendency of a F1 hybrid individual to exhibit phenotypic qualities that is observed in progenies when mating diverse individuals by maximizing heterozygosity, also referred to as hybrid vigor. Heterosis is a tool useful in plant breeding used to further enhance selection practices. There are two models to consider when referring to heterosis. The “dominance” model and the “overdominance” model (Birchler, James A., et al., 2010. The “dominance” model references recessive alleles at different loci that complement within the hybrid (Birchler, James A., et al., 2010. The “overdominance” model references an interaction between differing alleles that lead to hybrid vigor (Birchler, James A., et al., 2010). Heterosis is quantified on a population basis as the difference in performance of a hybrid relative to the average of the more vigorous parent (Kaeppler, Shawn, 2012). High parent heterosis measures the phenotypic dependent superiority of an individual hybrid relative to the outperforming

parent. High parent heterosis was determined for the hybrid population using the formula: $[(\mu^{\text{Hybrid F1}} - \mu^{\text{High Parent}})/\mu^{\text{High Parent}}] \times 100$ (2015). Heterosis of phenotypic quantitative traits were determined for the control treatment (Table 12), as well as the drought treatment (Table 13).

Table 12 High Parent Heterosis for Quantitative traits in Hybrid muskmelon varieties, Control treatment; Uvalde, TX, spring 2018

Pedigree (C)	Netting Coverage	Weight (lbs.)	Size (cm.)	Flesh Color (1-5)	Firmness (N)	TSS
BL 110 X BL 109	0.000	0.351	9.331	33.333	-26.117	7.296
BL 155 X BL 70	10.811	-28.387	-14.270	-3.333	3.941	8.882
BL 40 X BL 61	20.000	-38.652	-13.279	6.667	-55.079	-2.026
BL 51 X BL 65	-19.865	-23.171	-3.535	-15.152	0.908	16.830
BL 52 X BL 96	-17.241	-13.021	-6.111	-18.182	-1.205	-19.621
BL 53 X BL 2	-33.333	6.472	5.038	1.190	-14.630	-3.959
BL 61 X BL 40	10.000	-21.418	-5.246	0.000	-39.603	3.965
BL 70 X BL 81	10.000	-18.272	-5.482	-33.333	-18.224	-4.129
F 39 X BL 24-2	-3.846	-35.417	-18.266	-5.000	-9.099	-3.797
F 39 X BL 30	-80.000	6.548	-4.486	-57.143	-17.703	-13.549
M 26 X MF 9	-11.429	-51.772	-22.222	-12.088	-24.833	-35.768
MF 9 X F 39	-10.000	-35.417	-22.213	-7.692	-16.511	-29.323

Table 13 High Parent Heterosis for Quantitative traits in Hybrid muskmelon varieties, Drought treatment; Uvalde, TX, spring 2018

Pedigree (D)	Netting Coverage	Weight (lbs.)	Size (cm.)	Flesh Color (1-5)	Firmness (N)	TSS
BL 110 X BL 109	-6.553	7.193	3.725	8.642	-4.272	8.187
BL 155 X BL 70	-10.784	25.610	2.628	0.000	-29.346	-1.458
BL 40 X BL 70	-6.667	11.066	2.509	-20.455	-13.418	-13.947
BL 51 X BL 65	-12.500	-6.531	0.544	-12.727	-33.408	14.947
BL 52 X BL 96	-18.750	6.906	1.285	9.524	-1.417	18.677
BL 61 X BL 40	-22.857	-5.577	-2.186	14.286	-29.089	-1.335
BL 70 X BL 81	2.941	-39.552	-19.623	0.862	-16.137	-13.445
F 39 X BL 24-2	-15.000	-57.627	-25.403	-16.667	-55.294	-6.764
F 39 X BL 30	-4.396	21.842	5.778	-1.429	19.454	-0.725
M 26 X MF 9	-5.814	-25.995	-10.987	-20.000	-38.058	-6.954
MF 9 X F 39	-11.047	-11.671	-4.650	-25.000	-33.032	-16.168

Results and Discussion

Quantitative traits: weight (lbs.), firmness (N), and percent total soluble solids (TSS) ranged from 1.8 – 14.2 lbs., 17.3 – 134 N, and 4.8 – 15.6 % TSS under the control treatment (Table 3); and 2.1 – 14.3 lbs., 11 - 131 N, and 6.7 – 15.1 % TSS under the

drought treatment; showing very little difference between quantitative trait ranges in the two treatments. Netting coverage had a high parent (hp) heterosis value of 20.0 for the hybrid BL 40 x BL 61 (Control) (Table 12), which was 2x higher than any other hybrid in either treatment. Hybrid BL 110 x BL 109 (Control) has a flesh color hp heterosis value of 33.33, higher than any other hybrid in either treatment (Table 12). BL 115 x BL 70 (Drought) had a weight hp heterosis value of 25.6. F 39 x BL 30 (Drought) had a weight hp heterosis value of 21.84 and a firmness hp heterosis value of 19.45 (Table 13).

The broad-sense heritability estimates (Table 11) for the quantitative traits measured were relatively low: weight, 0.25; size, 0.22; L*, 0.08; a*, 0.46; b*, 0.25; firmness, 0.03; TSS %, -0.01; % cavity fill, 0.06; flesh color, 0.25; netting height, 0.02; netting width, 0.79; netting coverage, 0.14; and abscission size, 0.05. Heritability estimates close to zero, like abscission size, firmness and L*(Table 11), indicates that all variability in a trait is influenced very little by genetic differences but mainly due to environmental factors (Dempster, E.R. and Lerner, I.M., 1950). Estimates in the middle range suggest that variability is due to a combination of environmental factors and genetic influence, such as a*(Table 11) (Dempster, E.R. and Lerner, I.M., 1950). Heritability estimates close to one, like netting width (Table 11), indicate that variances in a trait are influenced by genetic differences with little effects from environmental factors (Dempster, E.R. and Lerner, I.M., 1950).

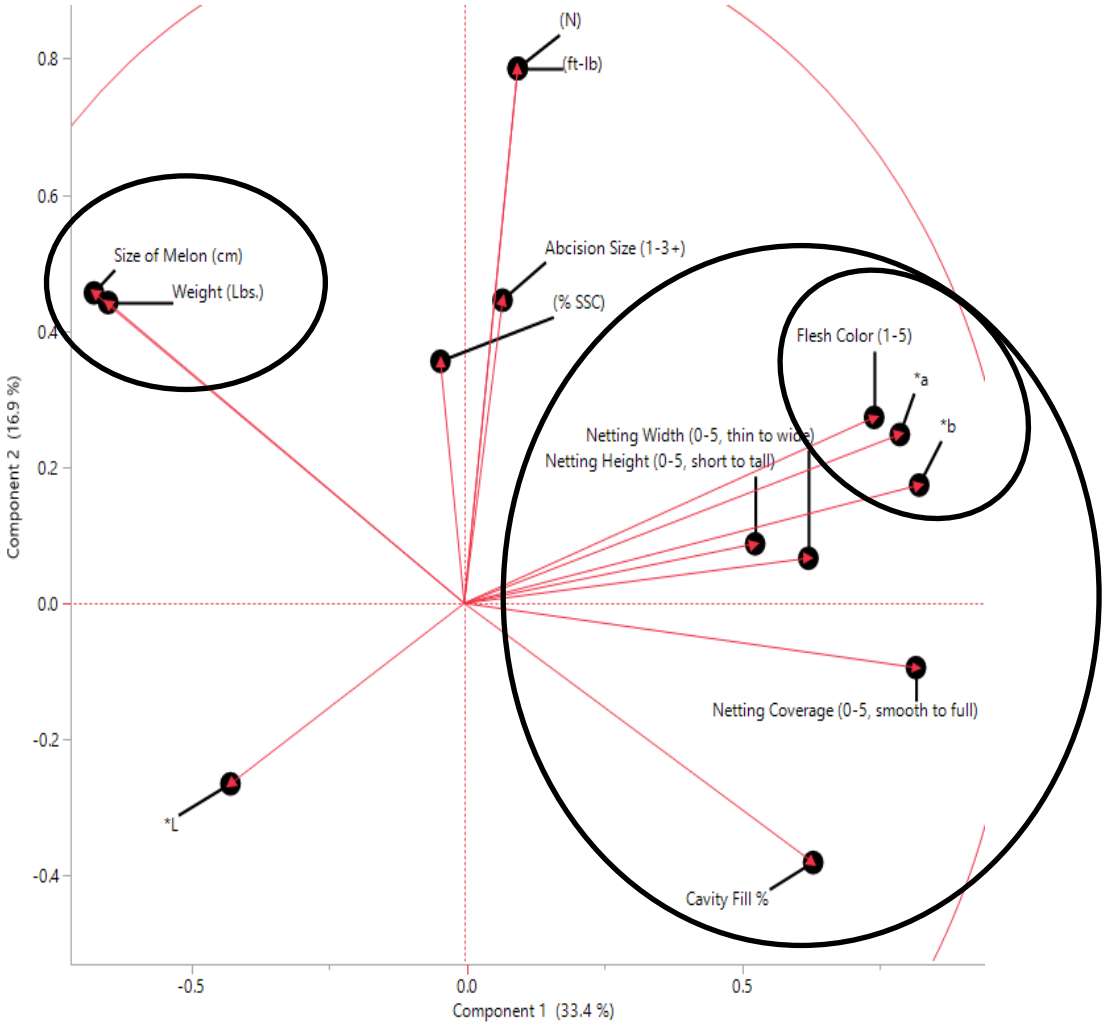

Figure 8 Principle Component Analysis for Quantitative traits in Melon

Phenotypic Correlation

A principal component analysis (Figure 8) determined that there is a biological explanation for the positive correlations in the quantitative traits examined among the hybrids. It was determined that there is a strong positive correlation between the size and shape of a melon. There is a correlation between the flesh color values of a* and b* and there is a correlation between the netting coverage amount and the flesh color. Orange-fleshed melons will have netting present on the rind and a large cavity fill

percentage. White-greenish-fleshed melons will have minimal to no netting present on their rind and a small cavity fill percentage.

Conclusion

Genetic diversity leads to a higher chance of discovering useful heterosis within a breeding population. Therefore, in future experiments, additional combinations and families will be evaluated. In this experiment, the lack of a complete factorial mating design for the trial resulted in the specific combining ability being undeterminable. In future experiments, a North Carolina Design II mating design will be used to establish a complete family (Nduwumuremyi et al., 2013). A complete family will provide narrow-sense heritability estimates, as well as combining ability and heterosis. The large amount of flexibility in broad-sense H^2 makes estimating its value without making strong assumptions almost impossible.

This experiment identified hybrid BL 110 x BL 109 as a potentially useful commercial hybrid that will be tested further for more phenotypic data. Continuing to improve phenotyping methodology and protocol efficiency will lead to enhanced fruit quality and straightforward selection of useful hybrids in future trials. Biological control in the greenhouse leads to increased plant vigor and superior fruit quality. The use of biological control will be continued in hybrid greenhouse production.

CHAPTER V

NORTH CAROLINA DESIGN II ANALYSIS

The North Carolina II factorial mating design is used in plant breeding programs for identification and selection of testcross performance individuals and parental breeding lines to be used in future hybrid production. The North Carolina II design, proposed by Comstock and Robinson in 1952 (Gardner et al., 1953), is a form of the diallel cross that is used to evaluate a randomly chosen set of inbred lines for their specific and general combining ability and heterosis, which can be calculated from the means of the hybrids compared against their parental breeding lines (Kitroongruang et al., 1992, Gardner, 1963). A set of males' '*m'* and a set of females' '*f'* are selected and an F1 population of hybrids are produced. Each '*m'* is crossed with every '*f'* in that set, thus producing a population of *mf* full-sib families.

This mating design is used in a two-way ANOVA analysis in which the variation may be partitioned into the difference between the interaction of males, females, and the environment (Nduwumuremyi et al., 2013). In this experiment, six female breeding lines are crossed with six independent male breeding lines. Breeding lines 19, 26, 37, 40, 46 and 52 were randomly chosen from elite inbred lines to act as females during this experiment. Breeding lines 61, 65, 70, 96, 109, and 136 were randomly chosen from elite inbred lines to act as males during this experiment. An unbalanced population of thirty-four full-sib F1 hybrids were produced.

Narrow Sense Heritability

Narrow-sense heritability simplifies the way we think about heritability as the total variance due to genetics as a combination of the additive effects, the dominant/recessive effects, and the interaction effects between the different variants. The formula $\sigma^2_G = \sigma^2_A + \sigma^2_D + \sigma^2_I$ is given to describe this interaction. σ^2_A are the additive effects within and between loci, σ^2_D are the difference due to simple dominance at a locus, and σ^2_I are the epistatic interactions between loci. The variance explained by additive genetics are simple interactions and are the largest and most immediately useful portion of the total genetic variance σ^2_G. The formula for narrow sense heritability is defined as $h^2 = (\sigma^2_A / \sigma^2_P)$, where σ^2_P represents the total phenotypic variance within the population. Narrow sense heritability defines the relationship between two individuals and what the probability is of an identified trait being similar for both individuals.

Materials and Methods

Plant Materials

Thirty-four F1 hybrids, derived from a North Carolina II mating design, and their twelve parental breeding lines (Table 14) were produced organically in the greenhouse and planted in a field trial in Uvalde, TX, in the spring of 2019. Breeding efforts began in Texas in 1955 with the Cooperative Muskmelon Breeding Program whose primary goal was to identify melon cultivars adapted to the West Texas growing environment. Uvalde, Texas was selected for this trial because it historically serves as the capital of muskmelon production in West Texas, with a steady decline observed over recent years.

Parents used to produce the hybrids for this trial were provided by Dr. Kevin Crosby. These genotypes were planted and maintained under typical agricultural practices for a field trial evaluation of phenotypic quantitative traits. Three replications of each genotype were planted in a single treatment randomized complete block design (RCBD) (Petersen, 1994). Phenotypic quantitative traits evaluated under these conditions included rind and flesh color measured with a colorimeter (a*, b* and L*), weight and shape, Brix (TSS) measured with a refractometer, flesh firmness measured with a penetrometer, rind netting, days to maturity and fruit yield. Narrow-sense heritability and high-parent heterosis were evaluated and determined for each genotype, with the objective being the identification of a superior F1 hybrid.

Randomized Complete Block Design

Muskmelon transplants for the 2019 field trial were produced in a greenhouse located in College Station, Texas, and transported in their flats to the field in Uvalde, Texas, by a truck. Three replications of each genotype were planted in a RCBD (Table 15) (Petersen, 1994). RCBD is the standard design for agriculture field experiments where blocks or replicates are used to group similar experimental units. Blocking into groups is done to control experimental variation by accounting for spatial effects due to the field and so observed differences are due to true differences between experimental treatments. The three replications were of equal size with all genotypes represented. At least three weeks following planting, once the first set of true leaves developed, transplants were placed into the field in Uvalde, TX. Row beds had previously been tilled, fitted with drip irrigation, and covered with white plastic mulch which helps to

conserve moisture, maintain soil temperatures and eliminate nutrient competition from weeds. The spacing in-between planting rows is approximately 3 ft., the spacing between the plants is approximately 2 ft. and the planting depth is approximately 1 ½ in. or until the root ball is covered with soil. Muskmelon requires a steady supply of fertilized irrigation water while they are growing, to initiate blooming and for fruit set; sub-surface irrigation is used as a supplement to rainfall.

Muskmelon Harvest

Muskmelons are harvested after roughly thirty days when the surface of the rind has become fully netted and the color underneath the rind changes from a shade of green to light yellow/white and the subtending leaves senesce (Cantwell, Goldman, 2002). 'Slipping' or 'full-slip' signals that a melon is mature and at the stage where they should be harvested (Hartz et al., 2008). 'Slipping' describes when the fruit can be easily separated from the vine with a slight pressure of the thumb, at the base of the fruit, where it is attached to the peduncle. This is due to formation of an ethylene induced abscission layer where the peduncle attaches to the fruit. Commercial muskmelon production fruit are typically sized by sight and packaged into 9, 12, 15, 18, or 23 per carton based on their size (Hartz et al., 2008). To maximize the postharvest life of muskmelon, rapid removal of field heat is required. Proper handling of the melons, along with maintaining high humidity during storage can reduce water loss and prevent physical damage.

Table 14 Carolina II Mating Design, Planting list for field trial; Uvalde, TX, spring 2019

Female	Male					
	BL 61	BL 65	BL 70	BL 96	BL 109	BL 136
BL 19	19 X 61	19 X 65	19 X 70	19 X 96	19 X 109	19 X 136
BL 26	26 X 61	26 X 65	26 X 70	26 X 96	26 X 109	26 X 136
BL 37	*MISSING*	37 X 65	37 X 70	37 X 96	37 X 109	37 X 136
BL 40	40 X 61	40 X 65	40 X 70	40 X 96	40 X 109	40 X 136
BL 46	46 X 61	46 X 65	46 X 70	*MISSING*	46 X 109	46 X 136
BL 52	52 X 61	52 X 65	52 X 70	52 X 96	52 X 109	52 X 136

Table 15 Randomized Complete Block Design, Planting design for field trial; Uvalde, TX, spring 2019

Row 1	Row 2	Row 3	Row 4	Row 5	Row 6	
42	5	4	21			
41	27	22	13	15	23	
34	7	10	2	19	1	
36	30	45	9	28	32	**Replication 3**
11	43	18	39	29	33	
3	6	46	37	17	25	
14	12	44	16	24	20	
26	35	8	31	40	38	
45	30	6	1			
10	3	5	19	8	12	
46	36	14	13	2	33	
21	34	25	42	17	11	
35	23	15	31	27	39	**Replication 2**
20	18	7	41	38	24	
16	37	4	9	22	28	
43	32	40	26	44	29	
43	44	45	46			
37	38	39	40	41	42	
31	32	33	34	35	36	
25	26	27	28	29	30	
19	20	21	22	23	24	**Replication 1**
13	14	15	16	17	18	
7	8	9	10	11	12	
1	2	3	4	5	6	

Phenotypic Evaluation

Phenotypic Measurements

Size and Weight of fruit

Uniform size and shape of commercial muskmelon are critical quality characteristics considered by the consumer when purchasing products. Consumers tend to view larger fruit as being of higher quality and more mature in growth (Mitcham et al., 1996). Muskmelon is commercially packed in thirty lbs. crates with 4, 5, 6, 8, 9, 10, or 12 count per pack size (Lester and Shellie, 2002). According to the USDA and industry standard, 9 and 12 count crates are commercially the most popular with consumers because of their medium size. Every hybrid had five individual fruit used for sampling and data collection. Size of each sample was calculated in centimeters (cm) using a tape measure and the weight was calculated using an analog fruit scale in pounds (lbs.). The population of hybrids were analyzed for their consistency of size and weight.

Shape of fruit

Table 16 Fruit Shape rating scale, 2019

R	Round
O	Oval
R O	Round Oval – Blocky
S	Sutures

Fruit shape is an indicative characteristic for a high-quality melon free of any physiological damage and is one of the most important qualities. A major economic loss

experiences is caused by misshapen fruit being discarded for not meeting consumer demands (Keshavarzpour, 2013). Classification of fruit shape is vital to evaluating produce in cultivar registration and consumer preference, meeting quality standards and maintaining market value (Keshavarzpour, 2013). A rating scale was used to classify the shape of each hybrid (Table 16). Round melons were classified as ‘R’. Oval melons were classified as ‘O’. Blocky melons that squared off at the edges were classified as ‘R O’. Melons with sutures, or ribs, which have large vein tracks running vertically across the rind were classified as ‘S’. Genotypes were analyzed for their consistency in shape.

Rind color

Table 17 Rind Color rating scale, 2019

LY	Light Yellow
Y	Yellow
LG	Light Green
G	Green
DG	Dark Green
B	Brown

Rind color is a visual physical indicator that a melon has reached maturity and is ready to be harvested when the rind has reached a golden color. At the time of harvest, a visual rind color observation is collected. A rating scale was used to classify the rind color at the time of harvest (Table 17). ‘LY’ represents a muskmelon that has reached maturity and has a light-yellow rind. ‘Y’ represents a muskmelon that has reached

maturity and has a yellow rind. ‘LG’ represents a considered honeydew melon, or it can represent a muskmelon that was harvested immature. All honeydew melons have a light green to whitish rind color at the time of harvest. ‘G’ represents a muskmelon that was harvested ‘green’ or immature. ‘DG’ (Dark Green) and ‘B’ (Brown) represent melon varieties that have been harvested past maturity and further data should not be collected.

Flesh color

Table 18 Flesh Color rating scale, 2019

1	White/Green
2	Green/Orange
3	Orange
4	Deep Orange
5	Orange/Red

Flesh color is an indicator that a melon is of high quality. At the time of harvest, a visual flesh color rating observation is collected. A rating scale was used to classify the flesh color at the time of harvest (Table 18). A flesh color rating of ‘1’ represents a honeydew melon with white to green flesh and is indicative of good flavor or an unripe muskmelon. A rating of a ‘2’ represents a muskmelon variety with yellow flesh, indicating low carotenoids. A rating of a ‘3’ represents a muskmelon with light orange flesh and moderate carotenoid levels or an unripe muskmelon. A rating of a ‘4’ represents a muskmelon with deep-orange flesh harvested mature that has a high level of carotenoids. Ratings of a ‘5’ are given to muskmelon varieties with orange to red flesh

and typically have very high carotenoid content. Consumers prefer a flesh color rating of ‘4’ or ‘5’ for muskmelon varieties and a rating of ‘1’ for honeydew varieties.

Visual Rating of rind netting coverage, height and width

Rind netting coverage

Table 19 Netting Coverage rating scale, 2019

0	None, 0% covered
1	Some, 30% Covered
2	Half, 50% Covered
3	Substantial 80% Covered
4	Full, 100% Covered

A major objective is to identify a hybrid variety that has a reduced netting coverage on the rind. The netting, vein like structures on the outside of the rind, can be an ideal environment for pathogens to harbor on the surface (Parnell et al., 2003). Netting coverage represents the total amount of rind covered by netting, this is composed of the height of rind and the width of rind. By reducing the netting present, the idea is to reduce the likelihood of foodborne illness caused by fresh-cut muskmelon products. A rating scale from 0 – 4 is used to identify the level of netting present on the rind at the time of harvest (Table 19). A rating of a ‘0’ represent a honeydew variety with no netting present. A rating of a ‘4’ represents a muskmelon variety with almost no rind visible through the netting that is present. Desired hybrid varieties have a rating of a ‘2’.

Rind netting height

Table 20 Netting Height rating scale, 2019

0	None
1	Short
2	Medium
3	Tall
4	Extra-Tall

The height of the netting on a rind is described how tall the netting is raised off the rind surface. A rating scale was used to classify the height of each individual hybrid (Table 20). A rating of a '0' represents a rind that has no netting present. A rating of a '1' represents netting that is only slightly raised off the surface of the melon. A rating of a '4' represents netting that is extremely raised off the surface of melons and can be felt by running fingertips across the rind surface.

Rind netting width

Table 21 Netting Width rating scale, 2019

0	None
1	Skinny
2	Medium
3	Thick
4	Extra-Thick

Netting width refers to the thickness of the netting on the surface of the rind. A rating scale was used to classify the width of each individual hybrid (Table 21). A rating of a '0' represents a melon with no netting present on the surface of the rind. A rating of '1' represents a netting that is very thin and minimal in width. A rating of a '4' represents a melon that has a rind width that is very thick, the rind is almost not visible because the netting is so close to each other due to width. Desired hybrids will have a netting width rating of '2' – '3'.

Other traits of interest

Abscission size

Table 22 Abscission Size rating scale, 2019

1	Small
2	Medium
3	Large
4	Extra-Large

The abscission zone is where the fruit separates from the peduncle (Copes, 2005), this is known as 'slipping'. 'Slipping' occurs when fruit reach maturity. This separation results in a scar zone that can range in size from small (<10 mm), medium (10 - 15 mm), large (15 - 20 mm) and extra-large (>20 mm) (Copes, 2005). A rating scale was used to classify the abscission size (Table 22). A rating of a '1' describes a small (<10 mm) abscission, a '2' describes a medium (10 - 15 mm) abscission, a '3' describes a large (15 - 20 mm) abscission and a '4' describes an extra-large (>20 mm) abscission.

Cavity fill

Table 23 Cavity fill % rating scale, 2019

100%	No Cavity, Ideal
90%	Some Cavity
80%	Partial Cavity
50%	Half Cavity
30%	Over Half Cavity

Cavity fill percentage refers to hollow cavity at the center of the melon that houses the seeds and how much pore space is present between the seeds and the flesh of the melon. A rating scale was used to classify the cavity fill percentage of each hybrid (Table 23). A cavity fill percentage of 100 % represents a melon variety that has no cavity space present in between the seeds and the flesh of the melon. A cavity fill percentage of 50 % represents a melon variety that is over half cavity, meaning there is a large pore space between the seeds and flesh of the melon. A solidly filled, 100 % seed cavity, is desired for marketing purposes (Blinn, 1908).

Defects present at harvest

Table 24 Defects rating scale, 2019

0	None, 0% Defect
1	Some, 30% Defect
2	Half, 50% Defect
3	Substantial, 80% Defect
4	Extreme, 100% Defect

Muskmelon genotypes chosen for commercialization should be evaluated for the presence of defects. Common post-harvest defects include harvest immature or overripe, chilling injury, brown blotch, decay, internal breakdown caused from dropping, sunken areas on the surface from water loss, discolored surface area from sunburn, and soft ground spot (Cantwell, 1996). Genotypes chosen should be more tolerant of bruising and physiological injury, chilling injury, and physiological disorders (Mitcham et al., 1996). A rating system (0= none, 1= slight, 2=moderate, 3= severe, 4= extreme) (Table 24) can be used to describe the level and severity of defects present in a particular genotype (Mitcham et al., 1996).

Statistical Analysis

JMP Pro 14.0.0 (SAS Institute Inc., Cary, N.C., 2019) was used to analyze the quantitative phenotypic data collected in this experiment, using the REML Model = ($Y_{ijk} = \mu + f_i + m_j + mf_k + e_{ijk}$) to calculate the variances with a two-way ANOVA (Table 29) for an unbalanced data set. The primary purpose of a two-way ANOVA is to

understand the interaction between two independent variables on a specific dependent variable. This interaction gives insight on the effect of one independent variable on the dependent variable, and if it has the same interaction with each independent variable. These variances were then used to calculate broad-sense heritability of the population of hybrids. The narrow-sense heritability estimates for the quantitative traits measured were calculated using the formula: $h^2 = (\sigma^2_A / \sigma^2_P)$ where $\sigma^2_G = \sigma^2_A + \sigma^2_D + \sigma^2_I$. High parent heterosis was determined using the formula: $[(\mu_{\text{Hybrid F1}} - \mu_{\text{High Parent}})/\mu_{\text{High Parent}}] \times 100$ (2015). Statistical analysis for this data was provided with assistance from Dr. Kevin Crosby and Sixto Marquez.

Evaluation of traits

The average, or mean, of each of the individual quantitative traits were calculated in Office Excel (Microsoft Office, Redmond, W.A., 2019). The population mean represents the average of a group characteristic or trait. The formula for calculating the mean of a specific set of data points is $\mu = (\Sigma * X)/ N$, where Σ means "the sum of", X = all the individual items in the group, and N = the number of items in the group. The calculated means of this population were used to determine useful heterosis and narrow-sense heritability.

Table 25 Means for Quantitative traits in Muskmelon, Trait set 1

Pedigree	Netting H.	Netting W.	Netting C.	Weight (Lbs.)	Size of Melon (cm.)	Abscission Size (1-4)
FEMALE						
19	2.17	1.50	2.83	1.49	35.42	1.00
26	1.00	1.67	2.83	3.54	47.25	1.67
37	1.17	2.17	2.67	2.62	42.33	1.83
40	1.33	1.67	3.17	3.19	46.33	1.17
46	2.00	1.33	1.67	4.65	56.17	2.00
52	1.83	1.50	2.50	2.41	40.67	1.83
MALE						
61	1.67	1.33	3.67	4.28	51.83	2.00
65	1.50	2.00	3.67	5.28	51.83	1.83
70	1.17	1.17	2.67	2.69	42.67	1.50
96	1.50	1.33	2.67	4.18	50.75	2.67
109	1.17	1.17	2.83	2.36	39.08	1.83
136	1.33	1.67	3.00	1.86	37.33	1.17
HYBRID						
19 x 61	1.33	1.33	2.17	2.43	42.17	1.33
26 x 61	1.17	1.50	2.50	4.42	50.92	2.50
40 x 61	1.67	1.83	4.00	3.22	47.75	1.67
46 x 61	1.00	2.00	3.00	3.04	45.92	1.00
52 X 61	1.33	1.50	2.17	5.02	53.63	1.67
19 x 65	1.83	1.33	3.17	2.11	40.17	1.00
26 x 65	2.17	2.00	3.00	4.72	53.00	2.33
37 x 65	2.00	2.17	2.67	3.68	47.75	2.00
40 x 65	2.00	1.83	3.00	3.33	46.25	1.67
46 x 65	1.50	1.83	3.00	2.40	41.83	1.50
52 x 65	2.50	1.83	2.67	2.63	42.92	1.50
19 x 70	1.67	1.50	3.00	2.90	44.50	2.00
26 x 70	1.50	1.67	2.83	3.97	48.83	2.67
37 x 70	1.67	2.00	2.67	2.30	41.33	1.33
40 x 70	1.83	1.83	2.83	3.52	47.42	2.00
46 x 70	1.33	1.33	3.17	2.63	42.83	1.33
52 x 70	1.83	2.00	2.67	3.90	48.83	1.83

Table 25 Continued

Pedigree	Netting H.	Netting W.	Netting C.	Weight (Lbs.)	Size of Melon (cm.)	Abscission Size (1-4)
19 x 96	1.50	1.33	2.17	3.10	45.33	2.83
26 x 96	1.67	1.83	3.00	2.97	44.50	2.33
37 x 96	1.50	2.00	2.33	3.43	46.67	2.17
40 x 96	1.83	2.00	3.00	2.65	42.52	2.17
52 x 96	2.00	1.83	2.83	3.48	46.73	2.17
19 x 109	2.17	2.00	3.00	3.06	44.17	2.17
26 x 109	1.83	1.83	3.00	3.12	44.75	1.83
37 x 109	1.50	1.67	3.00	2.58	42.83	1.67
40 x 109	1.50	1.67	3.00	2.39	44.08	1.50
46 x 109	1.50	1.67	3.00	2.52	43.33	1.67
52 x 109	1.67	2.00	2.83	2.98	46.42	1.83
19 x 136	1.67	2.33	3.00	2.66	44.67	1.33
26 x 136	2.00	2.17	3.00	3.38	46.33	1.83
37 x 136	1.67	2.00	3.00	2.63	42.67	1.33
40 x 136	1.50	1.83	2.83	2.62	43.08	1.50
46 x 136	1.17	1.67	3.00	2.32	34.45	1.00
52 x 136	2.17	2.00	3.00	3.26	45.50	1.50

Table 26 Means for Quantitative traits in Muskmelon, Trait set 2

Pedigree	Flesh Color	*L	*a	*b	(N)	(TSS)	Defects	Cavity Fill
FEMALE								
19	2.83	54.48	8.54	24.19	56.00	9.93	0.00	100.00
26	3.00	53.70	9.30	22.93	57.75	10.03	0.00	85.00
37	3.00	36.50	8.85	22.86	66.60	11.02	0.50	96.67
40	1.50	55.51	0.39	16.68	61.18	10.53	0.00	98.33
46	3.00	51.15	7.69	20.74	58.63	10.73	0.33	100.00
52	3.17	57.02	8.76	24.07	53.50	9.83	0.50	83.33
MALE								
61	2.67	55.05	7.29	20.46	66.38	11.08	0.67	88.33
65	3.17	49.65	8.65	20.33	86.52	9.10	0.00	96.67
70	3.00	52.25	7.42	22.11	66.35	9.82	0.33	100.00

Table 26 Continued

Pedigree	Flesh Color	*L	*a	*b	(N)	(TSS)	Defects	Cavity Fill
96	2.83	55.71	7.98	23.56	68.35	11.50	0.33	73.33
109	3.00	53.05	7.36	22.20	57.98	8.38	0.00	95.83
136	3.17	52.59	8.52	21.19	20.25	9.82	0.67	100.00
HYBRID								
19 x 61	2.83	52.73	8.62	18.70	43.85	9.68	0.33	100.00
26 x 61	3.50	53.28	10.0	23.91	68.25	11.12	0.00	81.67
40 x 61	3.33	54.44	8.10	21.54	52.78	9.63	0.00	98.33
46 x 61	3.33	49.60	8.47	20.40	39.45	10.03	0.33	100.00
52 X 61	3.00	53.96	7.41	20.42	54.37	9.72	0.33	66.67
19 x 65	3.33	52.60	9.39	24.43	77.27	11.55	0.00	98.33
26 x 65	3.33	50.50	7.62	19.01	61.77	11.25	0.17	93.33
37 x 65	3.17	54.15	7.93	20.70	44.13	9.80	0.33	75.00
40 x 65	3.00	52.13	8.09	22.18	60.75	10.57	0.00	95.00
46 x 65	3.17	51.82	8.02	20.82	46.47	9.68	0.17	95.00
52 x 65	3.33	51.67	7.34	19.79	59.42	10.97	0.33	98.33
19 x 70	3.00	51.81	7.46	20.35	62.85	10.48	0.00	100.00
26 x 70	3.00	50.56	7.01	18.70	42.65	9.17	0.00	93.33
37 x 70	3.00	54.93	9.43	23.64	68.57	9.43	0.00	100.00
40 x 70	3.00	53.11	4.98	21.15	72.55	10.23	0.00	91.67
46 x 70	3.00	51.97	9.20	22.56	46.82	9.70	0.67	98.33
52 x 70	3.17	50.44	7.70	20.44	67.00	10.85	0.00	98.33
19 x 96	3.00	53.37	6.96	20.71	54.43	11.03	0.00	98.33
26 x 96	3.17	54.10	8.28	21.80	91.38	11.43	0.00	93.33
37 x 96	2.83	54.61	7.61	21.75	47.12	8.77	0.17	83.33
40 x 96	3.17	54.61	7.70	21.60	46.57	9.35	0.33	86.67
52 x 96	3.17	52.03	7.43	22.11	56.62	11.33	0.00	98.33
19 x 109	3.67	50.51	8.76	21.07	50.57	10.58	0.00	100.00
26 x 109	3.33	49.92	7.45	19.32	62.85	11.08	0.00	96.67
37 x 109	3.67	51.54	8.67	21.47	52.17	10.07	0.00	98.33

Table 26 Continued

Pedigree	Flesh Color	*L	*a	*b	(N)	(TSS)	Defects	Cavity Fill
40 x 109	3.67	52.54	9.13	22.27	44.93	9.97	0.00	100.00
46 x 109	3.33	53.09	9.39	22.96	53.03	8.05	0.00	90.00
52 x 109	3.00	52.52	7.64	20.53	65.43	10.43	0.00	98.33
19 x 136	3.00	50.78	8.40	21.70	36.00	10.25	0.00	100.00
26 x 136	3.00	51.04	8.94	22.92	55.38	11.15	0.33	100.00
37 x 136	3.17	54.13	7.95	20.03	42.53	10.28	0.00	100.00
40 x 136	2.67	54.85	7.87	21.81	33.20	9.60	0.33	98.33
46 x 136	3.17	53.33	8.78	21.88	35.37	10.52	0.17	96.67
52 x 136	3.17	52.92	8.42	21.35	71.43	10.85	0.00	96.67

Heterosis

Heterosis is the superiority of an F1 progeny's ability to outperform its parental lines in one or more traits. Desirable heterosis can be positive in cases of yield, quality and disease resistance; heterosis can be negative in cases of plant height and days until maturity. Heritability is used by plant breeders to quantify the precision of a field trial and is defined as the proportion of phenotypic variance due to heritable genetic effects in a population (Piepho and Möhring, 2007). Heterosis is quantified on a population basis as the difference in performance of a hybrid relative to the average of the more vigorous parent (Kaeppler, Shawn, 2012). High parent heterosis measures the phenotypic dependent superiority of an individual hybrid relative to the outperforming parent. High parent heterosis was determined for the hybrid population using the formula: $[(\mu^{\text{Hybrid F1}} - \mu^{\text{High Parent}})/\mu^{\text{High Parent}}] \times 100$ (2015). Heterosis of phenotypic quantitative traits were determined for this treatment (Table 27, Table 28).

Table 27 High Parent Heterosis for Quantitative traits in Hybrid muskmelon varieties; Trait set 1, Uvalde, TX, spring 2019

Pedigree	Netting Height	Netting Width	Netting Coverage	Weight (Lbs.)	Size (cm.)	Abscission Size
HYBRID						
19 x 61	-38.46	-11.11	-40.91	-43.19	-18.65	-33.33
26 x 61	-30.00	-10.00	-31.82	3.11	-1.77	25.00
40 x 61	0.00	10.00	9.09	-24.90	-7.88	-16.67
46 x 61	-50.00	50.00	-18.18	-34.59	-18.25	-50.00
52 X 61	-27.27	0.00	-40.91	17.12	3.46	-16.67
19 x 65	-15.38	-33.33	-13.64	-60.09	-22.51	-45.45
26 x 65	44.44	0.00	-18.18	-10.73	2.25	27.27
37 x 65	71.43	0.00	-27.27	-30.28	-7.88	9.09
40 x 65	33.33	-8.33	-18.18	-36.91	-10.77	-9.09
46 x 65	-25.00	-8.33	-18.18	-54.57	-25.52	-25.00
52 x 65	36.36	-8.33	-27.27	-50.16	-17.20	-18.18
19 x 70	-23.08	0.00	5.88	7.74	4.30	33.33
26 x 70	28.57	0.00	0.00	12.00	3.35	60.00
37 x 70	42.86	-7.69	0.00	-12.10	-3.12	-27.27
40 x 70	37.50	10.00	-10.53	10.18	2.34	33.33
46 x 70	-33.33	0.00	18.75	-43.37	-23.74	-33.33
52 x 70	0.00	33.33	0.00	44.89	14.45	0.00
19 x 96	-30.77	-11.11	-23.53	-25.90	-10.67	6.25
26 x 96	11.11	10.00	5.88	-29.08	-12.32	-12.50
37 x 96	0.00	-7.69	-12.50	-17.93	-8.05	-18.75
40 x 96	22.22	20.00	-5.26	-36.65	-16.22	-18.75
52 x 96	9.09	22.22	6.25	-16.73	-7.91	-18.75

Table 27 Continued

Pedigree	Netting Height	Netting Width	Netting Coverage	Weight (Lbs.)	Size (cm.)	Abscission Size
19 x 109	0.00	33.33	5.88	29.68	13.01	18.18
26 x 109	57.14	10.00	5.88	-12.00	-5.29	0.00
37 x 109	28.57	-23.08	12.50	-1.59	1.18	-9.09
40 x 109	12.50	0.00	-5.26	-25.07	-4.86	-18.18
46 x 109	-25.00	25.00	5.88	-45.88	-22.85	-16.67
52 x 109	-9.09	33.33	0.00	23.88	14.14	0.00
19 x 136	-23.08	40.00	0.00	43.14	19.64	14.29
26 x 136	50.00	30.00	0.00	-4.47	-1.94	10.00
37 x 136	25.00	-7.69	0.00	0.32	0.79	-27.27
40 x 136	12.50	10.00	-10.53	-18.02	-7.01	28.57
46 x 136	-41.67	0.00	0.00	-50.18	-38.66	-50.00
52 x 136	18.18	20.00	0.00	35.29	11.89	-18.18

Table 28 High Parent Heterosis for Quantitative traits in Hybrid muskmelon varieties; Trait set 2, Uvalde, TX, spring 2019

Pedigree	Flesh Color	*L	*a	*b	(N)	TSS	Defects	Cavity Fill
HYBRID								
19 x 61	0.00	-4.21	0.92	-22.71	-33.95	-12.63	-50.00	0.00
26 x 61	16.67	-3.21	8.32	4.26	2.81	0.30	-100.00	-3.92
40 x 61	25.00	-1.92	11.07	5.30	-20.49	-13.08	-100.00	0.00
46 x 61	11.11	-9.91	10.17	-1.66	-40.57	-9.47	-50.00	0.00
52 X 61	-5.26	-5.38	-15.47	-15.16	-18.10	-12.33	-50.00	-24.53
19 x 65	5.26	-3.45	8.64	0.99	-10.69	16.28	0.00	-1.67

Table 28 Continued

Pedigree	Flesh Color	*L	*a	*b	(N)	TSS	Defects	Cavity Fill
26 x 65	5.26	-5.95	-18.04	-17.09	-28.61	12.13	0.00	-3.45
37 x 65	0.00	9.05	-10.40	-9.43	-48.99	-11.04	-33.33	-22.41
40 x 65	-5.26	-6.09	-6.48	9.08	-29.78	0.32	0.00	-3.39
46 x 65	0.00	1.30	-7.21	0.37	-46.29	-9.78	-50.00	-5.00
52 x 65	5.26	-100.00	-16.26	-17.76	-31.32	11.53	-33.33	1.72
19 x 70	0.00	-4.90	-12.72	-15.89	-5.28	5.54	-100.00	0.00
26 x 70	0.00	-5.84	-24.55	-18.43	-35.72	-8.64	-100.00	-6.67
37 x 70	0.00	5.14	6.57	-7.50	-35.96	-14.37	-100.00	0.00
40 x 70	0.00	-4.33	-32.85	-4.38	9.34	-2.85	-100.00	-8.33
46 x 70	0.00	-0.52	19.74	2.03	-29.44	-9.63	100.00	-1.67
52 x 70	0.00	-11.55	-12.15	-15.07	0.98	10.34	-100.00	-1.67
19 x 96	5.88	-4.21	-18.55	-14.40	-20.37	-4.06	-100.00	-1.67
26 x 96	5.56	-2.89	-10.92	-7.49	33.70	-0.58	-100.00	9.80
37 x 96	-5.56	-1.98	-14.00	-7.68	-31.07	-23.77	-66.67	-13.79
40 x 96	11.76	-1.97	-3.47	-8.33	-31.87	-18.70	0.00	-11.86
52 x 96	0.00	-8.75	-15.18	-8.12	-17.17	-1.45	-100.00	18.00
19 x 109	22.22	-7.29	2.52	-12.93	-9.70	6.54	0.00	0.00
26 x 109	11.11	-7.05	-19.81	-15.74	8.39	10.47	0.00	0.87
37 x 109	22.22	-2.84	-2.00	-6.08	-10.03	-8.62	-100.00	3.45
40 x 109	22.22	-5.35	24.08	0.35	-26.56	-5.38	0.00	1.69
46 x 109	11.11	0.08	22.19	3.45	-9.55	-25.00	-100.00	-10.00
52 x 109	-5.26	-7.89	-12.80	-14.70	12.85	6.10	-100.00	2.61

Table 28 Continued

Pedigree	Flesh Color	*L	*a	*b	(N)	TSS	Defects	Cavity Fill
19 x 136	-5.26	-6.79	-1.68	-10.31	-35.71	3.19	-100.00	0.00
26 x 136	-5.26	-4.95	-3.86	-0.05	-4.10	11.13	-50.00	0.00
37 x 136	0.00	2.93	-10.21	-12.37	-36.14	-6.66	-100.00	0.00
40 x 136	-15.79	-1.19	-7.63	2.93	-45.74	-8.86	-50.00	-1.67
46 x 136	0.00	1.41	2.99	3.30	-39.68	-2.02	-75.00	-3.33
52 x 136	0.00	-7.19	-3.97	-11.30	33.52	10.34	-100.00	-3.33

Table 29 ANOVA Mean Squares for Quantitative traits in Hybrid muskmelon varieties

	Weight	Size	Cavity	Abs.	TSS	N	Color	N. C.	N. W.	N. H.
Males	10.7	273.4	630.6	1.53	8.32	2919.4	0.22	1.32	0.64	0.24
Females	6.99	298.4	351.2	0.98	1.40	124.15	2.32	1.58	0.49	1.38
Hybrids	3.82	104.6	473	1.7	5.24	1358.3	0.44	0.92	0.53	0.84
Error	3.32	103.26	443.47	1.484	9.74	2137	0.92	1.035	0.672	1.174

*N.H. = Netting Height, N.W. = Netting Width, N.C. = Netting Coverage

Table 30 Narrow sense heritability for Quantitative traits in Hybrid muskmelon varieties

	Weight	Size	Cavity	Abs.	TSS	N	Color	N. H.	N. W.	N. C.
h^2M	0.46	0.51	0.16	-0.05	-0.33	0.45	0.14	0.71	0.42	0.32
h^2F	0.28	0.54	-0.17	0.24	0.24	-1.76	3.63	1.83	-0.36	0.43

Table 31 ANOVA Sum of Squares for Quantitative traits in Hybrid muskmelon varieties

	Weight	Size	Cavity	Abs.	TSS	N	Color	N. C.	N. W.	N. H.
Males	53.4	1367.4	3153.5	7.66	41.6	14596	1.14	6.6	3.22	1.22
Females	34.9	1492.2	1755.6	4.92	7	621	11.58	7.9	2.47	6.92
Hybrids	95.5	2614.5	11826	42.3	131	33958	11	22.9	13.2	21.2
Error	232.4	7228	31043	103.9	681.8	96665	62.25	72.5	47.1	82.2

*N.H. = Netting Height, N.W. = Netting Width, N.C. = Netting Coverage

Table 32 F values for Quantitative traits in Hybrid muskmelon varieties

	Weight	Size	Cavity	Abs.	TSS	N	Color	N. H.	N. W.	N. C.
Males	3.223	2.648	1.422	1.031	0.854	2.114	0.247	0.204	0.951	1.274
Females	2.105	2.889	0.791	0.660	0.144	0.899	2.609	1.175	0.728	1.526
Error	1.151	1.013	1.066	1.145	0.538	0.984	0.495	0.715	0.787	0.888
Males	**	*	ns	ns	ns	ns	ns	ns	ns	ns
Females	*	*	ns	ns	ns	ns	*	ns	ns	ns
Error	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*N.H. = Netting Height, N.W. = Netting Width, N.C. = Netting Coverage

Narrow Sense Heritability Estimates

Heritability relates to the amount of transmissible genetic variation to total variation within a population and determines how to optimize response from selection (Janghel, A., *et al.*, 2018). Heritability estimates close to zero, like *f*TSS, *m*Cavity and *m*Color (Table 30), indicates that all variability in a trait is influenced very little by genetic differences but mainly due to environmental factors (Dempster, E.R. and Lerner, I.M., 1950). Estimates in the middle range suggest that variability is due to a combination of environmental factors and genetic influence (both additive and dominant), such as *m*N, *m*TSS, *f*Size and *m*Netting Width and Coverage (Table 30) (Dempster, E.R. and Lerner, I.M., 1950). Heritability estimates close to one, like *f*Netting Height, *m*Netting Height and *f*color (Table 30), indicate that variances in a trait are influenced by additive gene action with little effect from environmental factors (Dempster, E.R. and Lerner, I.M., 1950).

Conclusion

Analysis of variance determined a mean square (MS) for weight of 10.7 for the male population, MS of 6.99 for the female population and a MS value for the hybrid population of 3.82. A similar experiment conducted by Mahmoud Akrami and Ahmad Arzani had a MS value for general combining ability of weight at 3.38 which was significant at $P < 0.01$, meaning that genotypes differed significantly in this trial which indicates genetic variability among genotypes (Akrami, M. and Arzani, A., 2019). Very few F values were significant, suggesting that there was too much variability within the experiment, even with taking into consideration genotype and replications.

Similar heritability estimates of fruit weight were observed between this study at 0.46 for the h^2 male value which was significant at $P < 0.05$ or $P < 0.01$ and Akrami and Arzani's study where an h^2 value of 0.69 was not significant at $P < 0.05$ or $P < 0.01$ (Akrami, M. and Arzani, A., 2019). Another similar experiment by, Janghel, A., *et al*, 2018, recorded an h^2 value for fruit weight of 0.60, like the male h^2 estimate for total weight recorded in this study of 0.46. Different heritability estimates for TSS were observed between this study at h^2 males = -0.33 and Akrami and Arzani's study where an $h^2 = 0.51$ but neither was significant at $P < 0.05$ or $P < 0.01$ (Akrami, M. and Arzani, A., 2019).

In comparison to a study conducted by B.P.K Reddy, *et al.* which shows a heritability estimate of TSS as $h^2 = 0.11$ (Reddy, B.P. K., *et al.,* 2013), this study exhibited a similar but slightly higher value of TSS h^2 female = 0.24. In contrast, the study by Reddy, B.P.K., et al. shows a heritability estimate for average fruit weight as $h^2 = 0.90$ (Reddy, B.P. K., *et al.,* 2013), this study exhibited a similar but slightly lower

value of TSS h^2 male = 0.46 and TSS h^2 female = 0.28. Reddy, B. P. K., *et al.* reports that TSS ranges from 6.00 - 9.10 BRIX in their study compared to the 9 - 11.5 BRIX range exhibited in this study.

Genetic diversity leads to a higher chance of discovering useful heterosis within a breeding population. Therefore, in future experiments, additional combinations and families will be evaluated. The assumptions made about narrow sense heritability estimates of the quantitative traits in this population only pertain to these specific hybrid varieties. However, they could hold true for other muskmelons if the underlying, additive genes are the same, which may likely be true.

Identification of 15 hybrid varieties that qualify for further field testing, in a process towards commercialization: 19 X 65, 26 X 96, 52 X 96, 26 X 65, 26 X 136, 26 X 61, 26 X 109, 19 X 96, 52 X 65, 52 X 136, 52 X 70, 19 X 109, 40 X 65, 52 X 109, and 37 X 136. Hybrid varieties 19 x 65, 26 x 96 and 52 x 96 were among the top 3 varieties in this experiment. Female parents 19, 26 and 52 were the most vigorous. Male parents 65, 96, and 109 were the most vigorous. Continuing to improve phenotyping methodology and protocol efficiency will lead to enhanced fruit quality and straightforward selection of useful hybrids in future trials.

CHAPTER VI

SUMMARY

Genetic diversity leads to a higher chance of discovering useful heterosis within a breeding population. In future experiments, additional combinations and families will be evaluated to find useful heterosis and heritability to be used to further the selection process. In this first experiment, the lack of a complete factorial mating design for the trial resulted in the specific combining ability being undeterminable. It was determined that in future experiments, a North Carolina Design II mating design will be used to establish a complete family (Nduwumuremyi et al., 2013). A complete family would provide narrow-sense heritability estimates, as well as combining ability and heterosis. The large amount of flexibility in broad-sense H^2 makes estimating without making strong assumptions almost impossible. In the second experiment, the assumptions made about narrow sense heritability estimates of the quantitative traits in this population only pertain to these specific hybrid varieties. These assumptions could hold true for other muskmelon populations if the underlying, additive genes are the same, which may likely be true.

Heritability is often used to aid in artificial selection to determine which traits are the most likely to be successfully selected each generation. A major component to remember when discussing narrow sense heritability values which are moderate or high (close to 1.0 or 1%) is that these genes are responsible for the variation present and the environment is not a factor. Narrow sense heritability values which are low (0.0 or 0.2%) indicate that environmental effects are the source of variation. A

heritability estimate of 0.0 indicates that the genes have been fixed through selection and there is no variation in the genes. An explanation for the variation present between heritability estimates within this population, some exhibiting very low values, (some exhibiting high values and very different between male and female estimates), may be due to: maternal effects on the gene or trait, negative alleles being contributed from one of the parents, greater sensitivity of one of the parents to environmental factors such as drought, heat, fertility, one or more of the parents is strongly dominant, or the parents may have different alleles or genes responsible for the same trait.

This first experiment identified hybrid BL 110 x BL 109 as a potentially useful commercial hybrid that will be tested further for more phenotypic data. The second experiment identified 15 hybrid varieties that qualify for further field testing, in a process towards commercialization: 19 X 65, 26 X 96, 52 X 96, 26 X 65, 26 X 136, 26 X 61, 26 X 109, 19 X 96, 52 X 65, 52 X 136, 52 X 70, 19 X 109, 40 X 65, 52 X 109, and 37 X 136. Hybrid varieties 19 x 65, 26 x 96 and 52 x 96 were among the top 3 varieties in this experiment. Female parents 19, 26 and 52 were the most vigorous. Male parents 65, 96, and 109 were the most vigorous. Breeding line 109 was a top performer from both experiments and should be used in future for useful hybrid vigor and heritability.

Continuing to improve phenotyping methodology and protocol efficiency will lead to enhanced fruit quality and straightforward selection of useful hybrids in future trials. Uniform phenotypic protocols remove error from the experiment and allows for an objective data collection. Biological control in the greenhouse lead to increased plant

vigor and superior fruit quality. The use of biological control will be continued in hybrid greenhouse production as it is safer for the environment, applicator and plant. Biological control provided a safe, economical alternative to common agriculture pesticide practices.

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