ABSTRACT

PATEL, TAKSHAY KISHORBHAI. Studies on Anthracnose Resistance in Watermelon Germplasm. (Under the direction of Dr. Todd Wehner and Dr. Hamid Ashrafi).

Anthracnose, caused by the pathogen *Colletotrichum orbiculare*, is a significant disease of cucurbits around the world. Anthracnose has been a major challenge in the USA for watermelon (*Citrullus lanatus*) production since the early 19th century. Anthracnose is particularly destructive in the southeast region of the USA, where summer rains favor disease infection. Four races cause anthracnose in watermelon, but commercial cultivars are resistant to only three.

Many studies identified anthracnose resistant accessions by screening subsets of the watermelon germplasm, with the last in 1994. No new resistant sources have been reported for 25 years. From 2016 to 2018 we screened the watermelon germplasm collection of 1408 PI accessions and ten commercial cultivars, using anthracnose race 1 and 2. Plants were screened in the greenhouse, field and growth chamber. For race 1 there were four replications in the greenhouse, two replications in field and two replications in the chamber. For the race 2 screening there were two replications in the greenhouse. Predicted means were estimated using mixed models for each environment. We identified resistant accessions for both races. We also observed that race 2 is more virulent than race 1. Further, subsets of the most resistant and susceptible accessions were retested for both races. The most resistant accessions to race 1 were PI635712 (*C. lanatus*), PI385964 (*C. lanatus*), PI186489 (*C. mucosospermus*), PI482251 (*C. lanatus*) and PI482250 (*C. lanatus*). The most resistant accessions to race 2 were PI500303 (*C. amarus*), PI482293 (*C. amarus*), PI482333 (*C. amarus*), PI244018 (*C. amarus*) and PI494817 (*C. amarus).*

We studied the inheritance of resistance using biparental cross populations. We developed two populations from the crosses of ‘Charleston gray’ x ‘New Hampshire Midget’ (For race 1 resistance) and PI189225 x ‘New Hampshire Midget’ (For race 2 resistance). We screen six

generations from each cross: Parent 1, Parent 2, F1, F2, Backcross Parent 1 and Backcross Parent 2. Resistance against both races is dominant over susceptibility and segregates as a single gene.

We estimated heritabilities from two types of populations, 1) the designed biparental cross population, and 2) the germplasm with unaccounted population structure. In the biparental cross, the narrow-sense (h^2) and broad-sense (H^2) heritability for race 1 resistance were 0.639 and 0.885, respectively. While the h^2 and H^2 for race 2 were 0.545 and 0.802, respectively. Due to the lack of a population structure, we only estimated H^2 from the germplasm data. The H^2 for race 1 resistance in greenhouse and chambers were 0.3405 and 0.146, respectively. The H^2 for race 2 resistance in the greenhouse was 0.3743.

Studies on Anthracnose Resistance in Watermelon Germplasm

by
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A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Horticultural Science

Raleigh, North Carolina
2019

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DEDICATION

I dedicate my work to Bhagwan Krishna, whose words encouraged the best in me. I dedicate it to my wife Snehal, who has happily sacrificed countlessly for this achievement. My parents Kishor and Leela for their constant support.

BIOGRAPHY

I was born on November 7, 1988, in Gujarat, India. I am the elder son of Kishor and Leela Patel. I am the loving brother of Rutika, my younger sister. I was raised in Nashik, Maharashtra, where my father runs a real estate business and mother is a caring housewife. During my middle school years with more liking towards Mathematics, I had never planned to be a plant scientist.

On the contrary, I was fascinated with biotechnology during my high school and graduated in 2009 from Pune University with a Bachelor of Science in Biotechnology. I further completed my Bachelor of Science in Plant Biotechnology at Pune University in 2010. During my undergrad in biotechnology, I was fascinated by plant sciences and their global impact. I realized my passion is in applying science to address practical challenges I decided to pursue a career as a science researcher.

In 2011, I met Snehal, my wife through family friends. We had a long-distance relationship for three years as I moved to the USA shortly after to pursue higher education. In 2012, I started MS program in Horticultural Science at North Carolina State University. During my MS I learned the meaning of research and researcher. I worked on GMOs, learning plant molecular biology and plant pathology. Although it was intellectually stimulating, the project ended only with publications and no real-life applications. That is when I realized that plant breeding is the perfect way to pursue my passion for applying research and technology to real-life problems. This awareness led me to my Ph.D. in plant breeding.

In late 2014, I got married to Snehal, and we started our new life in the USA. I decided to study plant breeding for my Ph.D. In 2015, I met Dr. Wehner, who at that time was looking for a technician for his program. I interviewed for the technician position, but we agreed on me starting as his Ph.D. student. In fall 2015, I started my Ph.D. at the Horticultural Science Department, North Carolina State University. During my Ph.D. I learned genetics and statistics in details and became more confident in my choice of being a plant breeder. I also learn the non-scientific aspects like management and organization from Dr. Wehner.

We had our first child here in Raleigh. Karmanya Takshay Patel, our boy, was born on August 8, 2018. Now feeding the world population begins at home.

Next, as a plant breeder, I look forward to delivering solutions to growers and seeing my work making an impact. Although not my original plan, I see myself as a satisfied scientist in the shoes of a plant breeder.

ACKNOWLEDGMENTS

I express my sincere gratitude to Dr. Todd Wehner, my advisor, for his invaluable support for my research and sharing his plant breeding knowledge. My confidence for being a successful breeder is the direct result of Dr. Wehner's training and teachings. I would like to thanks Dr. Amnon Levi for suggesting this project. I would also like to thank my committee members for the support and assistance with my experiments: Dr. Ashrafi, Dr. Quesada and Dr. Balint-Kurti. I also thank Dr. Holland for his help on data analysis. As large experiment requires large teams, I thank my fellow students and staff at NCSU: James Daley, Brandon Huber, Luis Rivera, Emily Silvermen, Jordan Hartman, Lauren Arteman, Dessteen Plaza, Nicholas Noel. Finally, I would not had been able to complete this without the loving support of my wife, Snehal, who supported me in more ways than I asked.

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INTRODUCTION

Watermelon is an important crop grown worldwide with 100 million megatons produced in 2011 (FOA, 2016). In the United States (US), the crop has a total economic value of $500 million per year (USDA National Agriculture Statistic Services, 2017). Watermelons are grown in most US states, but the majority of the production occurs in Florida, Georgia, California, and Texas where the growing seasons are warmer and longer (Wehner, 2008). The introduction of seedless varieties has increased the per capita consumption of watermelon by 37% since 1980 (Wehner, 2008). As the watermelon industry grew, challenges related to fruit quality, yield, and production methods emerged. As is the case with many crops, disease and pest management is a significant limitation to watermelon production. Diseases, in particular, are a major priority for watermelon producers since new races of pathogens continue to break down host resistance and develop insensitivity to fungicides. The major diseases of watermelons are Fusarium wilt, Anthracnose, Gummy stem blight, Powdery mildew, Phytophthora, Bacterial fruit blotch, and viruses. While Fusarium wilt and Phytophthora are considered the most devastating diseases to watermelon when fields become infested, foliar diseases such as anthracnose, gummy stem blight, and powdery mildew infect the crop on a yearly basis forcing growers to make significant investments in cultural practices and crop protection to manage these diseases (Keinath, 2017).

HISTORY OF WATERMELON ANTHRACNOSE

Anthracnose has been a major problem in watermelons worldwide at least since the 19th century, and it occurs wherever cucurbits are grown in a humid climate. Passerini in Italy first observed anthracnose on Calabash/bottle gourd in 1867 (Layton, 1937). In 1875, Passerini reported anthracnose on watermelon and cantaloupe, which is the first known scientific report of anthracnose on watermelon. More reports came from Europe during the late 19th century. In the USA, Dr. Eckfeldt (Philadelphia) and Prof. A. B. Seymour (Wisconsin) noted anthracnose on gourds and watermelons, respectively in 1885. In 1889, Galloway reported melon anthracnose in New Jersey, Virginia, and North Carolina. Substantial losses of cantaloupes, cucumbers, and watermelons due to anthracnose epidemics started during 1904 in Nebraska, Indiana, New Jersey, West Virginia, North Carolina, South Carolina, Wisconsin, and Ohio. Anthracnose became a major plant disease during the late 19th century, and by early 20th century, many US states started focusing on anthracnose as an important watermelon pathogen (Gardner, 1918).

THE PATHOGEN

The Causal Agent: *Colletotrichum orbiculare*

The genus *Colletotrichum* is economically and scientifically important as it contains the highest number of plant pathogenic fungi infecting a wide range of crops, which include row crops, fruits, flowers, and vegetables. Almost every domesticated crop is a host of a species belonging to the genus *Colletotrichum* (Dean et al., 2012). *Colletotrichum spp.* infects all the aerial parts of its host including stems, leaves, fruits, and flowers. *Colletotrichum spp.* are also a significant challenge as postharvest pathogens since spores from foliar infections during field growth can cause a dormant infection that progresses postharvest during transport or on the market shelves resulting in complete loss of the crop (Prusky, 1996). When the plant pathogen species were defined based on host specificity, *Colletotrichum* consisted of almost 700 species. Later, Von Arx reclassified these species in 1957 to 11 taxa based on morphological traits (Arx, 1957, 1970). *Colletotrichum* has been used as a model system for biochemical, physiological and genetic studies. The concept of pathogen races was initially recognized in *Colletotrichum lindemuthianum* (Barrus, 1911). Many of the studies that laid the foundation for the concept of systemic acquired resistance were done in the *Colletotrichum orbiculare*- cucumber model (Durrant & Dong, 2004).

Colletotrichum orbiculare [(Berk. & Mont.) Arx] is an important pathogen of cucurbits including cucumbers, muskmelons, watermelons, squash, gourd, pumpkin, cantaloupe, honeydew, and Luffa spp. (Wasilwa, Correll, Morelock, & McNew, 1993). *C. orbiculare* can also infect tobacco species (Shen et al., 2001). Anthracnose can cause severe damage in the field and postharvest and is one of the top research priorities for watermelons in US (Kousik, Brusca, & Turechek, 2016). In the field, *C. orbiculare* infects all the above ground parts of plants including leaves, stems, flowers, and fruits (Gardner, 1918; Layton, 1937; Wehner, 2008) Infections on any of these plant parts have direct effects on yield. The pathogen also infects at all growing stages of the plant, from the seedling stage to mature fruit bearing plants. Defoliation will leave the plant with poor photosynthetic capacity, stunt fruit development, and expose the mature fruit to direct sunlight, leading to sunburn. Infection on both growing and mature plant leads to unmarketable produce.

Taxonomy

Colletotrichum orbiculare belongs to the Kingdom Fungi, Phylum Ascomycota, Class Sordariomycetes, Order Glomerellales , Family Glomerelllaceae, Genus Colletotrichum (Kirk, 2018).

Earlier when plant pathogenic fungi taxonomic classification was based on plant disease specificity, *C. orbiculare* was named and identified multiple times by different researchers around the world (Table 1.1) Cucurbit and bean anthracnose were assumed to be caused by the same fungus, which was named as *Colletotrichum lagenarium* (Gardner, 1918). This assumption was discarded in a comparative study of anthracnose fungi, in which bean anthracnose was named as *Volutella citrulli*. Based on modern molecular tests *C. orbiculare* is recognized as a species complex with *C. lindemuthianum, C. malvarum, C. orbiculare,* and *C. trifolii* as distinct species (Liu et al., 2007). Currently, the isolates causing watermelon anthracnose are classified as a subspecies in *C. orbiculare* species group. Researchers still have difference of opinion in classifying this pathogen (Damm et al., 2013).

Fungal Morphology

Gardner (1918) first reported the morphologic characteristics of *C. orbiculare*, the latest descriptions were added by Damm et al. (2013). The mycelium at first is colorless, thin walled, septate, and uniformly cylindrical. Many of the cells later increase in diameter up to threefold, becoming thick walled and dark brown in color (Damm et al., 2013; Gardner, 1918). On culture media, mycelium is first colorless, then pink and black at the end. Pink coloration is sometimes observed in host tissues with blackening of mycelium being common in fruit lesions. Acervuli, anthracnose mycelium aggregates, branch and get intertwined to send out a layer of short colorless conidiophores (Gardner, 1918). From the tip of the conidiophores, spores bud off apically one at a time piling up to form a pink slimy cluster on top on acervuli. Spores are surrounded by a sticky water-soluble matrix and are single celled, clear, oblong or ovate and vaguely pointed at one end (Gardner, 1918). Spore size varies from 13 to 19 µm by 4 to 6 µm and masses are pink in color. Acervuli have 2-3 long setae scattered among the conidiophores, which are brown, thick-walled bristles about 90-120 µm in length (Damm et al., 2013; Gardner, 1918). The number of setae in a single acervulus varies and can be up to 36. Spores form heaps as high as setae, with setae supporting the spore mass. Sclerotial bodies are typically observed more on media and fruit lesions, and are formed due to the further development of the stromata or acervuli's bases, where the whole mass is enlarged and black in color(Gardner, 1918) . On media the spore mass may dry and remain as a part of sclerotial bodies, whereas in fruit lesions the spores are washed away, and the black stroma remains that forms the black spots on fruits (Gardner, 1918).

Germinating spores form an appressorium at the tip of each germ tube, which are brown, melaninized, thick-walled, and ovoid to spherical in shape. Appressoria are slightly tapered at one end and flattened on the side of contact with the host (Gardner, 1918). Melanization of appressoria is important for pathogenicity. Melanin deficient mutants have reduced pathogenicity, and melanization is supposed to resist the high turgor pressure within the appressorium and direct the force on the leaf epidermis for penetration (Kubo & Furusawa, 1991). Melanization in fungal spores is also assumed to provide protection under adverse conditions like oxygen radicals, high temperatures, irradiation, or lysis by other microbes (Bell & Wheeler, 1986).

Life and Disease Cycle

Colletotrichum orbiculare is the asexual form of the cucurbit anthracnose pathogen and propagates through conidia. Normally it exits in the asexual stage and it rarely goes under sexual stage (Damm et al., 2013; Jenkins & Winstead, 1961). There has been no defined complete life cycle for *C. orbiculare* and only few reports of the sexual stage of *C. orbiculare*. The sexual stage of *C. orbiculare* was reported as a species o*f Glomerella* but was not classified (Jenkins & Winstead, 1961). Ascospores are produced in abundance when paired with other isolates of *C. orbiculare*, but few ascospores develop when isolates are selfed (Jenkins & Winstead, 1961).

There is a close relation between *C. orbiculare* spread and wet weather conditions like rain, morning due, and overhead irrigation. Conidia are mainly dispersed by rain splashing, but also by wind, instruments, and workers (Keinath, 2017). Spore heaps in acervuli are surrounded by sticky water-soluble matrix (Damm et al., 2013; Gardner, 1918), explaining the need of moisture for spread. The importance of moisture for *C. orbiculare* was observed and established in the early 20th century when anthracnose epidemics were alarmingly new. A wetness period of 16hrs or more shows maximum disease development (Thompson & Jenkins, 1985). Further, temperatures from 18^{o} to 27^{o} C (65^{o} to 80^{o} F) are idle for establishment and growth of *C. orbiculare* on watermelon (Monroe, Santini, & Latin, 1997). *C. orbiculare* over-winters by surviving on the debris of infected plants. Cucurbit anthracnose was more severe on fields that had melons as previous crops (Sheldon, 1904). Sheldon documented spread of *C. orbiculare* by the transportation of diseased fruit and contaminated seeds. Overall, *C. orbiculare* spreads by rain, irrigation, seeds, fruits, and overwintering, and survives between seasons on infected plant debris, volunteer plants, in and on seeds from infected fruits (Keinath, 2017).

Infection Process

Colletotrichum orbiculare is a hemi biotrophic fungus, so that during the initial stage of infection it behaves as a biotrophic pathogen keeping the host cells alive, and later takes nutrients from dead host cells switching to the necrotrophic stage (Gan et al., 2013). *C. orbiculare* penetrates host leaves using two entry modes; turgor-mediated invasion (TMI) via melanized appressoria and hyphal tip-based entry (HTE). During TMI turgor-mediated invasion, *C. orbiculare* penetrates the adaxial epidermis (Gardner, 1918). Anderson and Walker (1962), Perfect et al. (1999) and Gan et. al (2012) have described the TMI infection process. After landing, the spores adhere to the plant surface. Then germinate to produce germ tubes and further form melanized appressoria. The appressoria penetrates plant epidermal cells directly through cuticle and cell wall. The epidermal cell wall below the appressorium swells, mostly due to cell wall degrading enzymes secreted by *C. orbiculare*. After penetration, biotrophic intracellular hyphae develop inside the host cells, infecting via intracellular colonization at the cellular level. The intracellular hypha is surrounded by an intact host cell plasma membrane, growing within the plant cell lumen i.e., between the plant plasma membrane and plant cell walls. The infection then proceeds to necrotrophic phase where the secondary necrotrophic hyphae arise from the intracellular hyphae, obtaining nutrients from dead host cells. HTE works independent of the melanized appressoria and is a morphogenic response at wound sites. Existence of these two invasive strategies imply a sensing system to induce the respective morphogenesis response on wound sites and intact leaf tissue for pathogenesis.

In watermelon fruits, the hyphae grow throughout the rind and acervuli are formed after 4 to 5 days of infection. Conidiophores form conidia masses rupturing the rind epidermis. In resistant watermelon plants, the appressorium entry during foliar disease is the same as in a susceptible plant but the hyphae are only able to infect few cells around the penetration site (Anderson, J.L; Walker, 1962). Plant cells around infected leaf sites elongate, divide and form a raised compact mass to resist fungal growth (Anderson, J.L; Walker, 1962), most likely cell through lignification. Fruits from resistant plants develop raised areas that are greener as compared to the surrounding rind and remain darker even when the remaining rind starts to bleach (Anderson, J.L; Walker, 1962). Like leaves of resistant plants, *C. orbiculare* only infects 1 to 2 epidermal cells in the fruit rind after penetration (Anderson, J.L; Walker, 1962).

Disease Symptoms

Colletotrichum orbiculare causes anthracnose on all cucurbits and the symptoms on each of the species vary. All the above ground parts of plants are susceptible to anthracnose. The photosynthetic cells are more susceptible than non-photosynthetic tissue (Anderson, J.L; Walker, 1962). Lesions gradually increase in size with abundant acervuli formation (acervuli are conidiophore producing mycelium aggregates). Gardner first reported the symptoms described here in 1918, latest descriptions were added by Keinath (2017). On watermelon leaves, anthracnose produces blackish brown lesions (Fig:1. A). Centers of older lesions on leaves fall out giving it a ‘shot-hole’ appearance. Petioles and stems show sunken and dark color spindled shape lesions, which penetrate deeply and finally grid the stem (Fig: 1. D). Infected young fruits show aborted growth or are abnormal. Lesions on young fruit are small, black depressed spots. On mature fruits, lesions start as yellow translucent centered elevated pimples, which later turn into flat-topped, circular, water-soaked elevations (Fig: 1. B, E). Lesions on mature fruit further sink and show pink spore masses on a black or cream-colored background. The black lesions are the result of black stroma left behind after washing of spores, whereas the pink masses are like the spore masses found in culture media.

Pathogenesis Genes and Effectors

The average genome size of *Colletrotrichum* species is 40 Mb, but *C. orbiculare* has a surprisingly large genome of 90 Mb (Gan et al., 2013). *C. orbiculare* expresses a large arsenal of sequences during the infection process including 287 protease-encoding sequences, 327 plant cell wall degrading enzymes, 700 small secreted proteins (SSPs), and many secondary metabolite backbone-forming proteins (Gan et al., 2013). All of these are expressed at a higher level than other species such as *C. graminicola* and *C. higginsianum*. SSPs and secondary metabolite synthesis genes are upregulated during the initial biotrophic stage of infection, whereas degrading enzymes are upregulated during the later necrotrophic stage of infection. The upregulation of SSP genes during early infection in *C. orbiculare* suggests their importance in maintaining biotrophy during infection. As *C. orbiculare* is a hemi biotroph, there is an orchestrated expression of the effector genes during the shift from biotrophy to necrotrophy (Irieda & Takano, 2016b).

Although through genomic and transcriptomic studies it is known that *C. orbiculare* expresses an arsenal of genes involved in pathogenesis, only a few effectors and pathogenic pathways are known yet. *C. orbiculare* has 3 well characterized effectors; NIS1 (Necrosis inducing secreted protein 1), DN3, and MC69 (Irieda & Takano, 2016b). NIS1 induces cell death and is expressed in bulbous biotrophic primary hyphae but its activity reduces in the necrotrophic hyphae. Homologs of NIS1 are present in other species like *C. higginsianum*, *C. graminicola*, and *Magnoporthe oryzae*, suggesting it as a conserved sequence in *Colletrotrichum* species. Although the NIS1-knockout mutants are virulent on tobacco (Yoshino et al., 2012), the transgenic expression of NIS1 in Arabidopsis made the plant susceptible to *C. orbiculare* (Kubo & Takano, 2013). Intuitively, the expression of cell-death inducing NIS1 during biotrophic phase suggests it as a recognized avirulence (AVR) protein, but it seems that NIS1 has an unknown role in impairing plant immune responses. DN3 suppresses NIS1-triggered HR-like cell death (Yoshino et al., 2012). MC69 is the third characterized effector in *C. orbiculare*. Although the MC69 mutants of *C. orbiculare* had normal colony morphology and conidiogenesis, they had reduced lesion development on cucumber and tobacco (Saitoh et al., 2012). *C. orbiculare* expresses MC69 predominantly during the biotrophic phase of infection.

Few signaling infection-related morphogenesis and pathogenesis pathways have been identified in *C. orbiculare*. *C. orbiculare* has three cascades important for virulence CMK1, MAF1, and RPK1. The CMK1 cascade is involved in conidial germination, infection, growth, and appressorium maturation. The MAF1 cascade is required for appressorium differentiation, whereas the RPK1 pathway is essential for vegetative growth and conidiation. Melanization of appressoria is important for normal function of *C. orbiculare* (Kubo & Furusawa, 1991), and three melanin biosynthesis enzyme genes, PKS1, SCD1, and THR1 and one regulatory gene CMR1 have been characterized (Kubo et al., 1996; Perpetua, Kubo, Yasuda, Takano, & Furusawa, 1996; Takano et al., 1995; Tsuji et al., 2000, 2003). Mutants of melanin-related genes showed defects in melanization of appressorium and penetration ability. Further, fatty acid oxidation of peroxisomes is also required for melanization and metabolic processes involved in turgor generation for penetration (Kubo & Takano, 2013).

Plants have receptors that recognize pathogen associated molecular patterns (PAMPs). An example of PAMP is chitin, a major cell wall component in filamentous fungi. *C. orbiculare* has the SSD1 gene involved in cell wall integrity. Mutants of *ssd1* were not virulent and induced host defense response along with papillae formation. *ssd1* mutants had increased induction of salicylic acid-induced protein kinase (SIPK) and wound induced-protein kinase (WIPK) activity as compared to the wildtype. The effector secretion mechanism has also been studied. *C. orbiculare* shows a strong ring-like signal of the effectors around the primary biotrophic hyphae. The ring signal is present in the interfacial region between the host and *C. orbiculare*, and not inside *C. orbiculare* (Irieda et al., 2014; Irieda & Takano, 2016a). *C. orbiculare* continuously secretes effectors towards the interfacial region. Effectors are also secreted in single-dot fashion at the bottom of the appressoria and at putative interfaces on the hyphal surface.

Pathogen Races

The first commercial watermelon anthracnose resistant varieties were released in 1949 and were widely used to manage the rampant anthracnose outbreaks at that time. Since then, *C. orbiculare* have emerged and overcome host resistance. In 1958, severe anthracnose symptoms on resistant watermelon varieties were observed in North Carolina (Goode, 1958). Pathogen isolates from the new symptoms were observed to be undistinguishable from earlier *C. orbiculare* isolates. Isolates were defined into races based on the differential host reactions on different cucurbit varieties. Most isolates before 1954 were defined as race 1. Isolates found in 1954 and 1955 were defined race 2 and were highly pathogenic on all cucurbit varieties of that time. Some isolates were defined as race 3. The difference between race 1 and race 3 was pathogenicity on squash varieties. The new isolates had no morphological and cultural differences, and were considered as different races (Goode, 1958). Race 4 (Dutta et al. 1960) and races 5, 6, and 7 (Jenkins et al. 1964) were also identified later.

Overall from 1954 to 1964 seven pathological races of *C. orbiculare* were identified based on differential host reactions. The seven races were based on virulence difference on different cucurbit species and varieties. Race diversity was reevaluated and the 7 races of *C. orbiculare* were combined into 3 Vegetative Compatibility Groups (VCG) by using 92 isolates from the US (Wasilwa et al., 1993). Based on vegetative compatibility (phenomenon where fungi with certain genetically similarity can fuse together to form a single heterokaryon) 11 VCG were formed among the 92 *C. orbiculare* isolates. Out of the 11 VCGs, only three were pathogenic on cucurbits and included VCGs 1, 2, and 3. VCGs 1 and 3 showed virulence on similar hosts. The watermelon variety 'Charleston Gray' was resistant to both VCG 1 and 3, but susceptible to VCG 2. Similar resistance was shown by cucumber varieties Poinsett-76 and GY14. VCG 1 and 3 were classified as race 1 virulence phenotype, and VCG 2 as race 2 virulence phenotype. A race 2B has also been somewhat characterized through vegetative compatibility and virulence (Wasilwa et al. 1996). Race 2B has been found on watermelon, bottle gourd, and muskmelon, and belongs to VCG 2 (Keinath, 2017).

DISEASE MANAGEMENT

Field management practices for anthracnose include planting disease free seed material, deep plowing of crop residue immediately after harvest, crop rotation with non-cucurbit crops for minimum 1 year (2 to 3 years is optimum), avoiding usage of farm machinery among field when the foliage is wet, fungicide applications, and resistant plant varieties (Keinath, 2017). To reduce fruit damage by anthracnose, growers are recommended to avoid mechanical injury to fruits, inspect for infected fruits during harvest and discard them, disinfect the fruit surface with chlorinated water, and refrigerate the fruit after harvest to prevent or delay anthracnose development postharvest (Keinath, 2017).

Host Resistance

In 1937, Layton started breeding for anthracnose resistance and identified sources of resistance to develop commercial varieties. Five varieties from Africa with high resistance to anthracnose were identified, out of which 3 had edible fruit and desired horticultural traits (Layton, 1937). The three varieties where named as Africa 8, 9 and 13, and were further used as parents. Homozygous anthracnose resistant selections from Africa 8, 9 and 13 were crossed with commercial varieties Iowa Belle, Iowa King, and a few other varieties (Layton, 1937). The commercial Iowa varieties were wilt resistant, large fruited and crisp fleshed. The first widely accepted anthracnose resistant watermelon varieties were ‘Congo’ (1949), ‘Fairfax’ (1953), and ‘Charleston Gray’ (1955), released by Andrus (Winstead et al. 1959). Charleston Gray, Congo and

Fairfax are resistant to races 1 and 3, but susceptible to race 2 (Goode, 1958). Varieties resistance to race 1 were also resistant to race 3 (Jenkins et al., 1964; Winstead et al., 1959a).

Resistance to race 2 was first found in a citron W695, which was also resistant to race 1 and 3 (Winstead et al. 1959). PI 326515 was the first PI reported to have resistance only to race 2 (Suvanprakorn & Norton, 1980). More resistance sources to race 2 including PI 189225, 271775, and 271778, 512385 were identified (Boyhan et al. 1994; Sowell et al. 1980). Resistance to anthracnose race 2 was also identified in *Citrullus colocynthis*, designated as R309 (Love & Rhodes, 1988). Interestingly, two studies found that resistance in *Citrullus colocynthis*, R309 did not followed the single gene inheritance, and was suggested to be multigenic (Love & Rhodes, 1988). These studies suggested that a dominant single gene confers major resistance, but there are other genes contributing to the phenotype. R309 has been the only source of multigenic resistance, no more such multigenic resistance sources are reported yet.

The first inheritance work on anthracnose resistance was done in 1937 (Layton, 1937). Resistance to race 1 is dominant over susceptibility, and segregates as a single gene. Resistance to race 1 and 3 is controlled by the same gene, *Ar-1* (Winstead et al., 1959a). Inheritance of race 2 resistance is like race 1 resistance, dominant and segregates as a single gene (Suvanprakorn & Norton, 1980).

Even today anthracnose is a problem and a major research priority in watermelon (Kousik et al., 2016). Most of the current commercial varieties with anthracnose resistance were developed by private industry (Table 1.2). These commercial varieties claim to have intermediate to high level of resistance to anthracnose race 1, and some varieties don’t specify the race. Hybrid watermelon cultivars are resistant to races 1 and 2B, and susceptible to race 2 (Keinath, 2017).

Crop Protection

Growers typically will use fungicide applications to manage watermelon anthracnose throughout the growing season. Fungicides can be applied preventatively if cost-effective or application should be started with the occurrence of the symptoms in a 5 to 10 day interval. If diseases severity if high or environmental conditions are conducive for disease (wet weather), growers will use the shorter application interval. Effective fungicide active ingredients to manage watermelon anthracnose include compounds in group 11: trifloxystrobin, azoxystrobin, pyraclostrobin, fluoxastrobin; group 7: boscalid, fluxapyroxad; group 3: difenoconazole; group M05: chlorothalonil; group M03: mancozeb (FRAC, 2018; Lina Quesada-Ocampo, 2018). Group 11 fungicides correspond to the Quinone outside Inhibitors (Qol), group 7 to the Succinate dehydrogenase inhibitors (SDHI), group 3 to the Demethylation inhibitors (DMI), and M05, M03 have multi-site contact activity. Products commonly recommended for watermelon anthracnose control include 'Kocide 3000'(Copper Hydroxide), 'Pristine' (pyraclostrobin, boscalid), 'Cabrio' (pyraclostrobin), 'Quadris Top' (azoxystrobin, difenoconazole), 'Bravo WeatherStik' (chlorothalonil), 'TopGuard EQ' (azoxystrobin) (Egel & Marchino, 2018; Everts & Korir, 2017, 2018; FRAC, 2018).

FUTURE PROSPECTS AND CHALLENGES

Although anthracnose has been an important watermelon disease for around a century, there are still many unanswered questions regarding pathogen biology and disease management. Anthracnose races have been identified for over 60 years now, but the genetic bases of those races remain unknown, forcing researchers to rely on differential phenotypic responses for race identification. Additional genomic studies like Gan et al. (2013) are needed to clarify race structure in *C. orbiculare* and determine if there are other unidentified genetic and physiological factors besides Avr-R genes that may give rise to different races and strains of *C. orbiculare*.

Many genomic resources have been developed for cucurbit crops and watermelon in particular (Huang et al., 2009; Jordi Garcia-Mas et al., 2012; Shaogui Guo et al., 2013). Nonetheless, genetic determinants of anthracnose resistance have not been clearly identified. Cucurbit breeders still rely on genetic maps, loci, and quantitative trait loci (QTL) to describe genetic resistance for conventional breeding, but specific resistance genes and the mechanism of anthracnose resistance have not been characterized. Genomic-driven technologies such as genotyping by sequencing in combination with genome wide association mapping, offer the opportunity to identify genes responsible for the anthracnose resistant phenotype, however, these approaches are sensitive to noise from phenotyping and genotyping and do not always result in a clear candidate gene. The occurrence of races in *C. orbiculare* is an indication that pyramiding resistance will be required to ensure durability of the trait and minimize the risk of new isolates overcoming individual resistance genes as has occurred with other cucurbit diseases (Goode, 1958; Holmes, Ojiambo, Hausbeck, Quesada-Ocampo, & Keinath, 2015). Establishing the resistance gene repertoire in watermelon and characterizing the interactions of such proteins with pathogen proteins that result in a resistant phenotype will be needed to achieve durable anthracnose resistance in watermelon. Likewise, continued identification of new and improved resistance sources will remain a priority for breeding anthracnose resistance.

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FIGURES



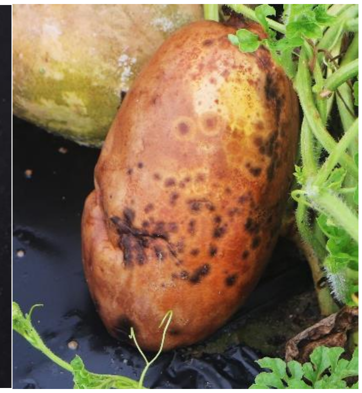

Figure 1.A Figure 1.B Figure 1.C


Figure 1.D Figure 1.E


Figure 1.F Figure 1.G

Figure 1.1: Anthracnose Symptoms on watermelon. A: Leaf; B-C: Fruits; D: Stem; E-G: Foliar & Canopy

TABLES

Table 1.1: Former classifications of *C. orbiculare* (Arx, 1970).

Name	Year	Source
Gloeosporium orbiculare	1853	Plant. Portug. Welw. p. 7
Myxosporium orbiculare	1860	Outl. Brit. Fungi p.324
Fusarium lagenarium	1868	Erb. Critt. Ital. 2, no.148
Gloeosporium lagenarium	1880	Sacc. & Roum.- Rev. Mycol. 2:201
Colletotrichum lagenarium	1893	Ellis & Halst. – Bull. Torrey bot. Cl. 20:250
Colletotrichum bryoniane	1917	Maire- Bull. Soc. Hist. nat. Afr. Nord. p. 183
Gloeosporium cucurbitarium	1882	Berk. & Br. -Trans. Linn. Soc. Lond. 2, 2:68
Colletotrichum oligochaetum	1889	Cav. -Rev. Mycol. 11: 173
Gloeosporium reticulatum	1880	Roum. -Rev. Mycol. 2:169
Macrophoma sheldonii	1928	Morbi. Plant. Leningr. 17: 153

Table 1.2: Commercial Anthracnose resistance varieties

Cultivar	Level of Resistance	Race	Company
SSX8585	High	1	Sakata
Valentino	High	1	Sakata
Belmont	Intermediate	1	Sakata
Sweet Treasure	Intermediate	1	Sakata
Fascination	Intermediate	1	Syngenta
Melody	Intermediate	1	Syngenta
Excursion	Intermediate	1	Syngenta
Captivation	Intermediate	1	Syngenta
Cooperstown	High	1	Seminis
Majestic	High	?	Seminis
Road Trip	High	?	Seminis
Santa Matilde	High	1	Seminis
HMX 1925	Intermediate	1	HM Clause
Maistros F1	High	1	HM Clause
Accomplice	High	1	HM Clause
Millenniem	High	1	HM Clause

Chapter 2

NEW SOURCES OF RESISTANCE TO ANTHRACNOSE RACE 1 AND RACE 2 IN THE USDA WATERMELON GERMPLASM COLLECTION

INTRODUCTION

Watermelon *Citrullus lanatus* [Thunb.] Matsum. & Nakai is an economically important crop, with 117 million tonnes production in 2016 (FOA, UN, 2016). Watermelon production was 17 million tonnes in 1961 (FOA, UN, 2016), and increased by 100 million tonnes in 60 years. In the USA, watermelon is a $500 million crop (USDA National Agricultural Statistics Service, 2017). Most of the states grow watermelon, with Florida, Georgia, California, and Texas being the primary producers (Wehner, 2008). The introduction of seedless cultivars has increased the per capita consumption of watermelon by 37% since 1980 (Wehner, 2008). As any other agricultural crop watermelon also has limiting factors with diseases being an important one. Diseases are a significant limiting factor for agricultural production of watermelon. The important diseases of watermelon are *Fusarium* wilt, anthracnose, gummy stem blight, powdery mildew, *Phytophthora*, bacterial fruit blotch and more than ten virus diseases. Although *Fusarium* wilt and *Phytophthora* are considered the most critical diseases of watermelon, infections of foliar diseases like anthracnose, gummy stem blight, and powdery mildew are observed every year. Farmers make a significant investment in cultural practices and crop protection because of diseases. In a recent survey, the top 8 out of 10 research priorities for watermelon research were diseases (Kousik et al., 2016).

Anthracnose caused by *Colletotrichum orbiculare* [(Berk. & Mont.) Arx] (former *Colletotrichum lagenarium*) infects the cucurbit crops including cucumber, melon, watermelon, squash, pumpkin, and *Luffa* spp. (Wasilwa et al., 1993). Literature suggests anthracnose as a significant watermelon disease worldwide since the 19th century, but it may have been present before that. Passerini in Italy first observed anthracnose on calabash/bottle gourd in 1867 (Layton, 1937). In 1875, Passerini reported anthracnose on watermelon and melon, which is the first known scientific report of anthracnose on watermelon. In the USA, Dr. Eckfeldt (Philadelphia) and Prof. A. B. Seymour (Wisconsin) noted anthracnose on gourds and watermelons, respectively in 1885. In 1889, Galloway reported melon anthracnose in New Jersey, Virginia and North Carolina. Substantial losses of melons, cucumbers, and watermelons due to anthracnose epidemics started during 1904 in Nebraska, Indiana, New Jersey, West Virginia, North Carolina, South Carolina, Wisconsin, and Ohio. Anthracnose became a major plant disease during the late 19th century. By early 20th century, many USA states started focusing on anthracnose as an important cucurbit pathogen (Gardner, 1918).

C. orbiculare is a hemibiotrophic fungus. *C. orbiculare* infect all the above-ground parts of watermelon including leaves, stem, flowers, and fruits (Gardner, 1918; Layton, 1937; Wehner, 2008). *C. orbiculare* causes disease at both preharvest and postharvest period, besides infecting watermelon at all growing stages from seedling to mature plants. All the above-ground parts of plants are susceptible to anthracnose. Severe infections during preharvest, i.e., growing season lead to a decrease in yield and unmarketable produce. Anthracnose produces blackish brown lesions on leaves, which at later stage fall out giving a ‘shot-hole’ appearance. Petiole and stem show sunken and dark color spindled shape lesions, which penetrate deeply and finally grids the stem. Infected young fruits show aborted growth or are abnormal. Lesions on young fruit are small, black depressed spots. On mature fruits, lesions start as yellow translucent centered elevated pimples, which later turn flat-topped, circular, water-soaked elevations. Lesions on mature fruit further sunk and show pink spore masses on a black or cream-colored background. The black lesions are the result of black stroma left behind after washing of spores.

C. orbiculare spreads widely in wet weather conditions like rain, morning due and overhead irrigation. Conidia are mainly dispersed by rain splashing, but also by wind, instruments, and workers (Keinath, 2017). A wetness period of 16hrs or more shows maximum disease development (Thompson & Jenkins, 1985). In fields, 2-3 hours of wetness period is enough for anthracnose to cause infection. Further, temperatures from 18^o to 27^o C (65^o to 80^o F) are idle for establishment and growth of *C. orbiculare* on watermelon (Monroe et al., 1997). *C. orbiculare* over-winters by surviving on the debris of infected plants. Watermelon anthracnose is more severe on fields that had cucurbits as previous crops (Sheldon, 1904). Overall, *C. orbiculare* spreads by rain, irrigation, seeds, fruits, and overwintering, and survives between seasons on infected plant debris, volunteer plants, in and on seeds from infected fruits (Keinath, 2017).

Currently, watermelon anthracnose has four races; 1, 2, 2b and 3. Races are identified based on host reaction and vegetative group compatibility (Goode, 1958; Wasilwa et al., 1996; Wasilwa et al., 1993). Most isolates before 1954 are defined as race 1. Isolates found in 1954 and 1955 were defined as race 2 and were highly pathogenic on all cucurbit cultivars of that time. Some isolates were defined as race 3. Watermelon plants resistant to race 1 are also resistant to race 3, the difference between these races is pathogenicity on squash cultivars (Jenkins & Winstead, 1964; Winstead et al., 1959). A race two was identified by further characterizing vegetative compatibility and virulence (Wasilwa et al., 1996). Race 2 is not well characterized yet and has been found on watermelon, bottle gourd and melon (Keinath, 2017).

Management practices for anthracnose include clean seed material, deep plowing of crop residue, crop rotation with non-cucurbit crops, no usage of machinery among fields with wet foliar, fungicides and resistant plant cultivars (Keinath, 2017). For reducing fruit damage, avoid mechanical injury, discard infected fruits during harvest, surface disinfection and refrigerate fruits after harvest (Keinath, 2017). Fungicide application should be started with the occurrence of the symptoms and sprayed every 5 to 10 days later. In rainy weather, fungicide application can be challenging, and the spray interval should be reduced. The active ingredients against anthracnose are trifloxystrobin, azoxystrobin, pyraclostrobin, fluoxastrobin, pyraclostrobin, boscalid, fluxapyroxad; group 3: difenoconazole, chlorothalonil, and mancozeb (FRAC, 2018; Lina Quesada-Ocampo, 2018). These ingredients belong to FRAC group 11 (Qol- Quinone outside Inhibitors), group 7 (SDHI- Succinate dehydrogenase inhibitors), group 3 (DMI- Demethylation inhibitors) and M05, M03 (multi-site contact activity). Few example products of sold fungicides are ‘Kocide 3000’, ‘Pristine,’ ‘Cabrio,’ ‘Quadris Top,’ ‘Bravo WeatherStik,’ ‘TopGaurd EQ’ (Egel & Marchino, 2018; Everts & Korir, 2017; FRAC, 2018).

Anthracnose was identified as a major disease in the early 20th century, and many efforts were focused on developing resistant cultivars. In 1937, Layton started breeding for anthracnose resistance. Layton identified sources of anthracnose resistance from Africa and used them as parents to develop commercial cultivars. The first widely accepted anthracnose resistant watermelon cultivars were ‘Congo’ (1949), ‘Fairfax’ (1953), and ‘Charleston Gray’ (1955), released by Andrus (Winstead et al., 1959a). Charleston Gray, Congo, and Fairfax are resistant to races 1 and 3 but susceptible to race 2 (Goode, 1958). Resistance to race 2 was first found in a citron W695, which was also resistant to race 1 and 3 (Winstead et al., 1959a). PI326515 was the first cultigen reported to have resistance to race 2 (Suvanprakorn & Norton, 1980). More resistant sources to race 2 including PI189225, PI271775, and PI271778, PI512385 were identified later (Boyhan et al., 1994; Sowell et al., 1980). Resistance to anthracnose race 2 was also identified in *Citrullus colocynthis*, designated as R309 (Love & Rhodes, 1988).

Every year a few watermelon cultivars with anthracnose resistance are introduced in the market. Examples of few anthracnose resistant watermelon cultivars include ‘Valentino,’ ‘Sweet Treasure,’ ‘Melody,’ ‘Captivation,’ ‘Cooperstown,’ ‘Majestic,’ ‘Maistros F1’, ‘Accomplice.’ These commercial cultivars claim to have intermediate to high level of resistance to anthracnose. Nearly all the commercial cultivars claim resistance to anthracnose race 1, and some cultivars don’t specify the race. Hybrid watermelon cultivars are resistant to races 1 and 2B and susceptible to race 2 (Keinath, 2017).

Resistance to race 1 segregate as a single gene, and race 1 and 3 resistant is controlled by the same gene, *Ar-1* (Winstead et al., 1959a). Like race 1, inheritance of race 2 also segregates as a single gene (Suvanprakorn & Norton, 1980). Two studies found that resistance in *Citrullus colocynthis*, R309 did not follow the single gene inheritance, and was suggested to be multigenic (Love & Rhodes, 1988). These studies suggested that a single dominant gene confers major resistant, but there are other genes also playing a part in the resistance. R309 has been the only source of multigenic resistance, no more such multigenic resistance sources have been reported.

The last watermelon anthracnose resistance study was done in 1994 (Boyhan et al., 1994). Since then, no new resistant sources are reported for watermelon anthracnose. The currently known resistant sources were identified at least 25 years back. The possible explanation for this gap in watermelon anthracnose research could be 1) the durability of the current resistant sources and chemical controls, 2) priority for other watermelon diseases like bacterial fruit blotch. Researchers agree on anthracnose as an essential priority (Kousik et al., 2016).

Further, the former studies on watermelon anthracnose resistance have screened a small set of cultigens. The objective of this study is to find new and better sources of resistant to watermelon anthracnose. In this study, we screened the USDA watermelon germplasm of 1408 cultigens for anthracnose races 1 and 2. Resistance for race 1 was screened in growth chambers, greenhouse, and field, while race 2 was screened in the greenhouse only. A subset of resistance lines identified in the first screening was retested under higher replications. The identified resistance lines are essential for breeding programs and further pathological studies.

MATERIAL AND METHODS

C. orbiculare Isolates

Race 1 isolate of *C. orbiculare* was collected in North Carolina in 1998. Dr. Wehner, Cucurbit breeding laboratory at NCSU maintained the race 1 isolate. The race 1 isolate was reconfirmed using resistant and susceptible checks (Figure 2.1). Dr. Anthony Keinath at Clemson University, South Carolina provided the race 2 isolate. Race 2 isolate was isolated in 2013 in Charleston, SC.

All the isolates were grown on green bean agar (GBA) media (Wasilwa et al., 1993). For GBA preparation, in 1 L of distilled water add 18 g of agar and two jars (142 g) of green bean baby food (Gerber®). New plates were inoculated from older plates every three weeks for maintaining the isolate.

Spores were extracted from 3-week old Petri plates. 10-15 ml distilled (DI) water was added to each Petri plate, and a sterile metal spreader was used to rub the surface. The water was filtered through 4 layers of cheesecloth in a sterile conical flask. The spore concentration was estimated using a hemocytometer. The spore mixture was then diluted to 10^5 sp/ml concentration, and one drop of Tween20 was added to every 500ml of spore inoculum.

Inoculation

A 10^5 sp/ml of spore concentration was used to inoculate all the experiments. The concentration of spores for inoculation was determined using a method test. The inoculum was spread on 3-weeks old watermelon plants. For field experiment plants were inoculated twice at 4-week and 5-week stage. The inoculated plants were kept in a high humidity environment with 80-100 % RH humidity for 48 hours (Figure 2.2). After 48 hours, plants were kept at normal conditions as per the environment (GH/Growth chamber).

Rating

A rating scale of 0 - 100% was used, with an interval of 5%. A rating of 0 being resistant and 100 as susceptible (Figure 2.3). The rating scheme considered all the aerial parts of the seedling true leaves, meristem, hypocotyl and cotyledon. All parts were given different importance, true leaves (50% total: yellowing- 5%, complete necrotic leaf- 40%, petiole-10%), meristem (25% total: necrosis spots - 10%, mostly necrotic- 20%, dead-25%), hypocotyl (20% total: 1-2 brown patches-5%, many brown patches-15%, completely brown- 20%), cotyledons (5% total: little to complete necrosis: 5%). This rating scale was used for both the races during chamber and greenhouse experiments. For field experiment, plants were rated similarly from 0-100%, but based only on foliar symptoms.

The rating days were determined using a method test for each race. For race1 screening in greenhouse and growth chambers, plants were rated three times on 8^{th}, 11^{th} and 14^{th}-day post inoculation (dpi). For race 1 field screening, plants were monitored after inoculation for symptoms.

Mild anthracnose symptoms were observed on field plants around 8-10 dpi, and data was collected thrice on 14th, 21st and 28th dpi.

For race 2, plants were also rated three times, but on 3rd, 5th and 7th dpi. The isolate for race 2 was more virulent and infected rapidly as compared to race one isolate.

Environments

The USDA watermelon germplasm was screened in three environments, greenhouse, field and growth chamber. Greenhouse screening was carried out in Fox greenhouses, NCSU, and chamber screening was done in chambers at Phytotron, NCSU. Both the locations were at North Carolina State University. Field screenings were conducted in summer of 2017 at Cunningham Research Station Kinston, NC.

For anthracnose race 1 greenhouse screening, plants were grown on greenhouse benches for 3 weeks and moved to the humidity chamber setup. Watermelon seeds were planted in the 4P soil mix. Greenhouse temperature ranged from 75^{O} F to 95^{O} F (24^{O} C to 35^{O} C). The inoculated plants were kept in a high humidity environment with 70-85 % RH humidity for 48 hours post inoculation. Plants were watered daily throughout the experiment.

For race 2 screening, plants were grown on greenhouse benches like race 1 screening but inoculated in a disease chamber at Kilgore Hall, North Carolina State University. Chamber temperature was maintained at 80^{O} F (~26^{O} C) throughout the experiment. The inoculated plants were kept in a high humidity environment with 85-98 % RH humidity for 48 hours post inoculation. Plants were watered every third day throughout the experiment. Race 2 inoculated plants were autoclaved before discarding.

For race 1 growth chamber screening, plants were grown on carts in phytotron greenhouses at 80^{O} F (27^{O} C) and water daily. Watermelon seeds were plants in a soil mix with 3 parts soil, 1-

part sand, 2-part gravel, and 1-part peat. 3-week old seedlings were moved inside the chamber. Chamber temperature was set at 75^{O} F/71^{O} F (24^{O} C/21^{O} C) for day/night. Day length was kept at 14 hours, using fluorescent tube lights. The inoculated plants were kept in a high humidity environment with 80-90 % RH humidity for 48 hours post inoculation. Plants were watered every other day.

For race 1 field screening, plants were grown on raised beds covered with black plastic. Cultigens were directly seeded in single plant hills with space of 4 ft, on raised beds covered with black plastic. The field consisted of 60 rows of 200 ft with row spacing of 10 ft. Plants were spiral trained to maintain the single hill plots. The plants were screening in field environment at flowering stage. No fungicides were applied to the watermelon plants during the whole experiment.

Plant Materials

A total of 1408 watermelon cultigens were collected based on 2016 germplasm availability from the Plant Genetic Resources Unit in Griffin, Georgia. Cultigens and commercial cultivars with documented anthracnose resistance were used as controls. For race 1 greenhouse and growth chamber, the resistant control was ‘Charleston Gray,’ and for race 2 resistant control was PI189225. ‘New Hampshire Midget’ was the susceptible control for both races. For race 1 field screening eight controls were used, ‘Allsweet’, ‘AU-Producer’, ‘Charleston Gray’, ‘New Hampshire Midget’, ‘Sweet Dawn’, ‘Sweet treasure’, ‘Topgun’, ‘Valentino’. Multiple cultigens were identified from the literature and determined as control during the method test. In the retests along with the cultigens, four commercial cultivars were included: ‘Sweet Dawn,’ ‘Sweet Treasure,’ ‘Valentino’ and ‘Top Gun.’

Experimental Design

Disease screenings were performed in the year 2016, 2017 and 2018, in greenhouse, field and growth chambers. Anthracnose race 1 had four, two and two replications in greenhouse, field and growth chambers, respectively, while anthracnose race 2 had two replications in the greenhouse.

For race 1 greenhouse replications, randomized incomplete block design was used. For a total of 1408 cultigens, each replication had of 3 plants per cultigen. Cultigens were grown in 24-cell trays, with each tray having 23 cultigens and 1 control. All 3 plants of each cultigen were grown in the same tray cell and were treated as sub-sample. Overall each tray consisted of a total of 72 plants from 23 cultigens and 1 control. 62 such trays made one replication. A complete replication (62 trays) was infected at the same time and followed by next replication in the next week. Total four replications were inoculated throughout four weeks with a 1-week interval. For race 2 the experimental design was the same as race 1, but each replication was divided into two parts, and each half replication was infected one week apart. Two replications (4 half replications) of race 2 were inoculated throughout four weeks with a 1-week interval.

For growth chamber replications, randomized incomplete block design was used. Like the greenhouse screening, all 1408 cultigens were screened in the chamber with 2 replications, with each replication having 3 plants per cultigen. Cultigens were grown in Styrofoam coffee cups, and 36 such cups were kept on each cart. Each cart consisted of 34 cultigen and two controls. All three plants of each cultigen were grown in the same cup and treated as sub-sample. Overall each cart consisted of a total of 108 plants from 34 cultigens and 1 control. One replication consisted of into seven runs, due to chamber size. One run consisted of six carts that were inoculated at the same time. A total of 42 carts completed one replication. The time interval between each run was two weeks.

For race 1 field screening, randomized complete block design was used. All 1408 cultigens were screened with 2 replications, with each replication having single plant hill per cultigen. The controls had 10 replications. Each field row was 200 ft and included 50 plots/row. A total of 29 rows completed one replication.

Data Analysis

Statistical analysis and data visualization were performed using R studio (Version 1.0.143 – © 2009-2016 RStudio, Inc.). Mixed model analysis of disease severity was performed using ASReml-R package (Ver. 3.0) and ASReml standalone software (Version 4.1). Cultigens with at least three observation were included for analysis. There was a total of four datasets 'Anthracnose race1-Greenhouse', 'Anthracnose race1-Chamber', 'Anthracnose race1-Field' and 'Anthracnose race2-Greenhouse'. Separate models were used for all three data sets. Cultigens were treated as a fixed effect, and all other factors (Replication, Run, Tray, Cart, and Plot) were treated as random effects. The final models were determined by adding random effects sequentially and comparing incremental complex models using the REML likelihood ratio tests from the asremlPlus 2.0-12 package. The best models for each dataset were determined in using ASReml-R using 3rd rating for all the datasets. The best models were then used to run a repeated measure model in ASReml standalone using all three ratings.

The best model for 'Anthracnose race1-Greenhouse' designated 'Cultigen' as the only fixed effect and the random effects were 'Replication', 'Tray' nested in 'Replication' and 'Plot'. Notation for this model in ASReml-R is,

‘Rating3 ~ 1 + Cultigen, random =~ Replication + Replication/Tray + Plot’

For repeated measure model the notation in ASReml standalone is,

```
‘Rating1 Rating2 Rating3 ~ Trait Trait.Cultigen,
        !r Trait.Replication Trait.Replication/Tray Trait.Plot
        residual id(units).us(Trait)
        predict Cult !Average Trait’
```

Similarly, the best model for ‘Anthracnose race1-Chamber’ designated ‘Cultigen’ as the only fixed effect and the random effects were ‘Replication’, ‘Run’, ‘Cart’ and ‘Plot’. Notation for this model in ASReml-R is,

‘Rating3 ~ 1 + Cultigen, random =~ Replication + Run + Run/Cart/Plot’

For repeated measure model the notation in ASReml standalone is,

```
‘Rating1 Rating2 Rating3 ~ Trait Trait.Cultigen,
        !r Trait.Replication Trait.Run Trait.Run/Cart/Plot
        residual id(units).us(Trait)
        predict Cultigen !Average Trait’
```

Similarly, the best model for ‘Anthracnose race1-Field’ designated ‘Cultigen’ as the only fixed effect and the random effects were ‘Replication’, ‘Row’ and ‘Column’. Notation for this model in ASReml-R is,

‘Rating3 ~ 1 + Cultigen, random =~ Replication + Row + Column’

For repeated measure model the notation in ASReml standalone is,

```
‘Rating1 Rating2 Rating3 ~ Trait Trait.Cultigen,
        !r Trait.Replication Trait.Row Trait.Column
        residual id(units).us(Trait)
        predict Cultigen !Average Trait’
```

Similarly, the best model for ‘Anthracnose race2-Greenhouse’ designated ‘Cultigen’ as the only fixed effect and the random effects were ‘Replication’, ‘Run’, ‘Tray’ and ‘Plot’. Notation for this model in ASReml-R is,

‘Rating3 ~ 1 + Cultigen, random =~ Replication + Replication/Run + Run/Tray + Plot’

For repeated measure model the notation in ASReml standalone is,

‘Rating1 Rating2 Rating3 ~ Trait Trait.Cultigen,
!r Trait.Replication Trait.Replication/Run Trait.Run/Tray Trait.Plot
residual id(units).us(Trait)
predict Cultigen !Average Trait’

The predicted means, standard error for each cultigen and average standard error of the differences (SEDs) were calculated using the ‘predict” function in ASReml standalone. Predicted means were used as the measure for resistance against anthracnose.

Retest

The most resistant and susceptible cultigens were selected for a retest. For Anthracnose race 1 selection was based only on greenhouse and growth chamber screenings, and was as follows, 1) 20 most resistant cultigens from both greenhouse and chamber data, 2) cultigens that were in top 100 most resistant in both environment, 3) cultigens that were in the top 100 in one environment and susceptible in other, 4) 18 susceptible cultigens from both the environments. The sample size was 91 for the race 1 retest. Retests for race 1 results were performed in both greenhouse and chamber with the same cultigen set. As anthracnose race 1 field data consisted of 2 plants per cultigen, selection were not made for retest from this data. For Anthracnose race 2, the selection was as follows, 1) 30 most resistant, 2) 20 most susceptible cultigens. Six replications with two plants per replication were carried out. The sample size was 60 for race 2 retest. Ten controls were also included in the retests for both races 1 and 2; ‘Allsweet’, ‘Charleston Gray’, ‘New Hampshire Midget’, PI189225, PI271775, PI271779, ‘Sweet Dawn’, ‘Sweet Treasure’, ‘Top Gun’, ‘Valentino’. Greenhouse retest was performed for both race 1 and race 2 results, and chamber retest was performed for race 1 data.

A randomized incomplete block design was used for all the retests. For greenhouse retest, each replication consisted of 2 plants per cultigen. Cultigens were grown in 24-cell trays, and each tray consisted of 24 cultigens. For each cultigen, both the plants were grown in the same tray cell and treated as sub-sample. Overall each tray consisted of a total of 48 plants. For race 1 retest, all six replications were grown in 23 trays and were inoculated at the same time. For race 2 the experimental design was the same as race 1 greenhouse retest, with all six replications grown in 15 trays that were inoculated at the same time. Plants were grown in Fox greenhouses and inoculated in disease chamber at Kilgore Hall, NCSU. Greenhouse retest experiment's data was collected similarly to the first screening studies respectively for both race 1 and race 2. For race 1 chamber retest each replication had 2 plants per cultigen grown in 24-cell trays. The experimental design was like race 1 greenhouse retest but divided in runs. Each run had three replications grown in 12 trays and inoculated three weeks apart. Plants were grown and inoculated at phytotron.

All the inoculation and post-inoculation parameters were like first screen studies, respectively for each retest.

Retest Data Analysis

Data from Retest was analyzed similarly to the first screen data. A univariate model was selected in ASReml-R, and ASReml standalone was used for the repeated measures model. For all three retest studies: 'Anthracnose race 1 - Greenhouse retest'; 'Anthracnose race 1 - Chamber retest'; 'Anthracnose race 2 - Greenhouse retest', cultigen with at least three observations were included for analysis. Models were selected and analyzed similarly to first screen data analysis in R and ASReml.

In the 'Anthracnose race1-Greenhouse', 'Cultigen' was the only fixed effect and the random effects were 'Replication', 'Tray' and 'Plot'. Notation for this model in ASReml-R is,

'Rating3 ~ 1 + Cultigen, random =~ Replication + Tray + Tray/Plot'

The repeated measure model the notation in ASReml standalone is,

'Rating1 Rating2 Rating3 ~ Trait Trait.Cultigen
!r Trait.Replication Trait.Tray Trait.Tray/Plot
residual id(units).us(Trait)
predict Cultigen !Average Trait'

In the 'Anthracnose race1-Chamber Retest', 'Cultigen' was the only fixed effect and the random effects were 'Replication', 'Run', 'Cart' and 'Plot'. Notation for this model in ASReml-R is,

'Rating3 ~ 1 + Cultigen, random =~ Replication + Run + Run/Cart + Plot'

The repeated measure model the notation in ASReml standalone is,

'Rating1 Rating2 Rating3 ~ Trait Trait.Cultigen
!r Trait.Replication Trait.Run Trait.Run/Cart Trait.Plot
residual id(units).us(Trait)
predict Cultigen !Average Trait'

Similarly, in the 'Anthracnose race 2 - Greenhouse retest', 'Cultigen' was the only fixed effect and the random effects were 'Replication', 'Tray' and 'Plot'. Notation for this model in ASReml-R is,

'Rating3 ~ 1 + Cultigen, random =~ Replication + Tray + Plot'

The repeated measure model the notation in ASReml standalone is,

'Rating1 Rating2 Rating3 ~ Trait Trait.Cultigen
!r Trait.Replication Trait.Tray Trait.Plot
residual id(units).us(Trait)
predict Cultigen !Average Trait'

Predicted means, standard errors and SEDs were also calculated for all three datasets like in the first screen data analysis.

RESULTS

The watermelon germplasm collection of 1408 cultigens was screened for anthracnose resistance with race 1 and 2. The germplasm was screened against race 1 in three different environments: Greenhouse, Chambers, and Field. Anthracnose race 2 screening was performed in a greenhouse environment only. Data sets from each environment differed in number of replications, number of plants per replication, and total cultigens analyzed (Table 2.1). Anthracnose race 1 field screening only consisted of two replications of single plant per replication. For the field data, there are only 2 data points per cultigen.

From the 1408 cultigens screened in greenhouse and growth chambers, accessions with three or more number of plants were included in data analysis. From race 1 field screening, only cultigens with data from two plants were included in the analysis. Data analysis of race 1 consisted of 1308 cultigens in greenhouse, 1343 in chambers and 1254 in field. While, race 2 data analysis had 1196 cultigens. The total number of plants germinated for each cultigen varied significantly, leading to a large amount of missing data (Diagram 1). The plant to plant variation within cultigen was similar for cultigens and cultivar (Table 2.2).

Anthracnose Race 1 Greenhouse

In the analysis of race 1 greenhouse data, the log likelihood (LogL) was -118.85 for the model. The estimated means for disease ranged from 4.88 to 65.3 with the standard error (SE) from 3.3 to 6.25 with an average standard error of difference (SED) of 5.13. The resistant check 'Charleston Gray' had an estimated mean value of 15.34 and SE of 2.25, while the susceptible checks 'New Hampshire Midget' and PI189225 had estimated means (SE) of 24.2 (2.26) and 21.2 (2.34), respectively. The five most resistant cultigens against anthracnose race1 in the greenhouse are PI635712, PI512350, PI392291, PI255139, PI525088. The correlation between screening and retest results of the selected lines was 0.72.

Anthracnose Race 1 Chamber

The estimated means from this data were adjusted to a non-zero scale by using PROC standard in SAS. The Population mean was adjusted from 11 to 36. The LogL was -1150.28 for the model. The estimated means for disease ranged from 4.87 to 68.58 with the standard error (SE) from 3.85 to 5.18 with an average standard error of difference (SED) of 5.73. The resistant check 'Charleston Gray' had an estimated mean value of 32.19 and SE of 2.02, while the susceptible checks 'New Hampshire Midget' and PI189225 had estimated means and SE of 39.19 (1.98) and 37.61 (2.08), respectively. The five most resistant cultigens against anthracnose race1 in chambers are PI596677, PI482371, PI564536, PI500309, PI482276. The correlation between screening and retest results of the selected lines was 0.79.

Anthracnose Race 1 Field

In the analysis of race 1 field data, the log likelihood (LogL) was -2801.46 for the model. The estimated means for disease ranged from 10.19 to 93.34 with the standard error (SE) from 2.42 to 10.6 with an average standard error of difference (SED) of 10.56. The ratings for the checks were 'Allsweet' (19.22 + 2.43), 'AU-Producer' (15.99 + 2.43), 'Charleston Gray' (19.06 + 2.42), 'New Hampshire Midget' (28.1 + 2.48), 'Sweet Dawn' (19.03 + 2.43), 'Sweet Treasure' (18.96 + 2.62), 'Topgun' (31.38 + 2.49), 'Valentino' (23.41 + 2.42). The five most resistant cultigens against anthracnose race1 in the field are PI635659, PI269679, PI512376, Grif 15898, PI629106.

Although between greenhouse and chamber data for anthracnose race 1, the correlation was only 0.21, some cultigens were resistant in both the environment (Table 2.3). PI635712 was highly resistant to anthracnose race 1 in both the environments. These cultigens were included in the retest and the correlation among the environments, first screening and retests are reported (Table 2.4).

Anthracnose Race 2 Greenhouse

In the analysis of race 2 data, the log likelihood (LogL) was -3726.21 for the model. The estimated means for disease ranged from 6.33 to 62.97 with the standard error (SE) from 4.06 to 6.04 with an average standard error of difference (SED) of 5.27. Only 44 cultigens were more resistant than the resistant check PI189225 that had a mean value of 19.28 and SE of 4.06. The susceptible checks 'New Hampshire Midget' and 'Charleston Gray' had estimated means and SE of 38.34 (4.46) and 32.68 (4.49), respectively. The five most resistant cultigens against anthracnose race2 are PI500303, PI482293, PI482333, PI244018, PI494817. The resistant cultigens and their means in the first screening and the retest are reported (Table 2.5). The correlation between screening and retest results of the selected lines was 0.94.

DISCUSSION

This study screened the *Citrullus* spp. accessions for the resistance against anthracnose races 1 and 2. For anthracnose race 1 we identified five highly resistant lines PI635712, PI482251, PI482323, PI560013, and PI164636. These cultigens showed high resistance in both the greenhouse and chamber screenings. PI635712, PI593359 and PI500334 were found to show resistance to anthracnose race 1 in all environments. For the PI635712 a total of 25 plants were screened in both the environments including first screening and retest. The disease incident on the 14^{th}-day post inoculation (3^{rd} rating) ranged from 0 to 20 %, with only one plant of rating 20%. The average disease incident on 14 dpi was 8.02 %. Although only two plants were screened in the field environment, PI635712 had predicted mean of 15.86. Whereas for the susceptible line PI500340 a total of 31 plants were screened with 14 dpi disease incident ranging from 10 to 100 % with three plants less than 20%. The average disease incident on 14 dpi was 63.45 %. The previous studies for anthracnose race 1 screened few wild accessions and commercial cultivars of that time (Goode 1958; Layton 1937; Wasilwa et al. 1993; Winstead et al. 1959). No numerical ratings were provided by screening studies of Wasilwa et al. (1993) and Winstead et al. (1959). Hence it's difficult to compare the level of resistance with some of the earlier studies. 'Charleston Gray' showed moderate to high level of resistance to race 1 (Goode, 1958; Wasilwa et al., 1993; Winstead, Goode, & Barham, 1959b). Our screening rated 'Charleston Gray' with mean ratings of 15.33 (Greenhouse), 32.2 (Chamber), 8.67 (Greenhouse retest) and 5.44 (Chamber retest), similarly to resistance in earlier studies. It is a challenge to compare the results of the wild accessions from earlier studies to this study due to multiple renaming of the wild accessions. In retests, the latest commercial watermelon cultivars: 'Top Gun,' 'Sweet Treasure,' 'Sweet Dawn' and 'Valentino' were screened. In race 1 retests all the commercial cultivars showed resistance, but less than the identified resistance cultigens.

Similarly, for anthracnose race 2 the five most resistant lines identified were PI500303, PI482293, PI482333, PI244018, and PI494817. For the PI500303 a total of 17 plants were screened in both the first screening and the retest. The disease incident on the 7-dpi ranged from 5 to 35 %, with only one plant of rating 35%. The average disease incident on seven dpi was 15.29 %. 44 cultigens were more resistant than the resistant check PI189225. On 7 dpi, the susceptible PI174101 had disease incident ranging from 55 to 100 % for the 15 plants screened., with an average disease incident of 73.67 %. Previously many studies screened smaller sets of watermelon germplasm for race 2 resistant (Boyhan et al. 1994; Goode 1958; Sowell 1980; Winstead et al. 1959). Winstead et al. (1959) and Goode (1958) reported no resistance to race 2. Sowell et al. (1980) identified PI189225, PI271775, PI299379, PI271778 to have resistance to anthracnose race 2. A test of 76 cultigens identified only one cultigen to resistant to race 2, PI512385 (Boyhan et al., 1994). In our test PI189225, PI271775, PI512385, and PI271779 were also found to be resistant. All the latest commercial cultivars tested were susceptible to race 2, 'Sweet Treasure' was not included in the race 2 retest analysis due to low germination.

The anthracnose symptoms started with yellowing of the leaf, followed by the occurrence of dark black irregular lesions. The lesions expanded eventually killing the plant tissue. The first symptoms occurred on the leaves and cotyledons, while symptoms on the hypocotyl and meristem appeared a few days later. The symptoms on the meristematic tissue were like the leaf spots. The hypocotyl infections were a random occurrence of light brown spots that later expanded and turned dark brown. The texture on hypocotyl symptoms became watery and softer but never turned to dark black lesions like leaves. On both the resistant and susceptible plants the symptoms occurred at the same time. But the lesions stopped expanding on resistant plants and kept expanding on susceptible ones. The difference between a non-inoculated and inoculated greenhouse replication were apparent within one week of inoculation (Figure 2.2).

For both the races, for any of the cultigen there was no complete absence of symptoms, even the most resistant lines had some symptoms. It should be noted that in these tests the identified resistant lines were highly tolerant rather than entirely resistant. Besides the differential resistant reaction of anthracnose race 1 and 2, for these two isolates, we observed race 2 isolate being more virulent and aggressive than race 1 isolate. The initial symptoms for race 2 isolate appear on 3 dpi, were as for race 1 it took 8 dpi. Most of the plants were dead by 14 dpi during race 2 screening, like an earlier study by Winstead et al. (1959). Plants could not overgrow the race 2 infection with new growth, whereas plants were able to grow faster than the race 1 infection. Overall race 2 is more virulent and devastating than race 1. Irrespective of the race the anthracnose infection would be problematic in the field as it would affect both fruit yield and quality.

Humidity and temperature had a significant effect on the disease inoculation and infection. We observed anthracnose infected slowly with higher temperatures. Irrespective of the temperature, humidity was necessary for anthracnose inoculation and infection. Humidity was critical in the first 24-48 hrs after inoculation for the disease to be established. No infection was observed in experiments with zero humidity. In an experiment were humidity was maintained for over five days, all the cultivars were completely infected and died within 12-14 days. Humidity is an essential factor for infection, during continuous rain anthracnose could severely infect resistance cultigens/cultivars in the field. The resistant cultigens identified here should be tested further in field environment under high humidity.

For the anthracnose race 1 screening, we observed cultigens showing different amount of resistance in greenhouse and chambers. Cultigens that showed the most resistance in one environment were not that resistant in the other environment. An example is PI564536 which is highly resistant in the chamber, but moderately resistant in the greenhouse. Further, some cultigens showed a different reaction in both environments. PI270546, PI500343, and PI535948 were highly resistant in the greenhouse but highly susceptible in the chamber. Such variation in disease has been reported earlier (Boyhan et al., 1994; Sowell et al., 1980). Cultigens performed differently in two greenhouse tests (Sowell et al., 1980), e.g., PI299379 was susceptible in 1977 with a mean rating of 5.0 and resistant in 1978 with a mean rating of 2.0. Another example is PI512385 whose rating was significantly different in the first screening and retest, 4.5 and 2.2, respectively (Boyhan et al., 1994). Overall this suggests some effect of environment on cultigens response to anthracnose. Resistant sources must perform consistently in different environments. The cultigens identified as resistant to anthracnose race 1 in this study were resistant in both greenhouse and chamber (Table 2.3).

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FIGURES

Figure 2.1: Race 1 confirmation using Charleston Gray (CG), New Hampshire Midget (NHM) and PI189225. Infection of plants on 14-days post inoculation. CG plants are alive, while NHM and PI189225 plants are dead.

Figure 2.2: Greenhouse inoculation for anthracnose race 1. A) Humidity chamber in greenhouse B) Inoculated replication (right) and non-inoculated replication (Left).

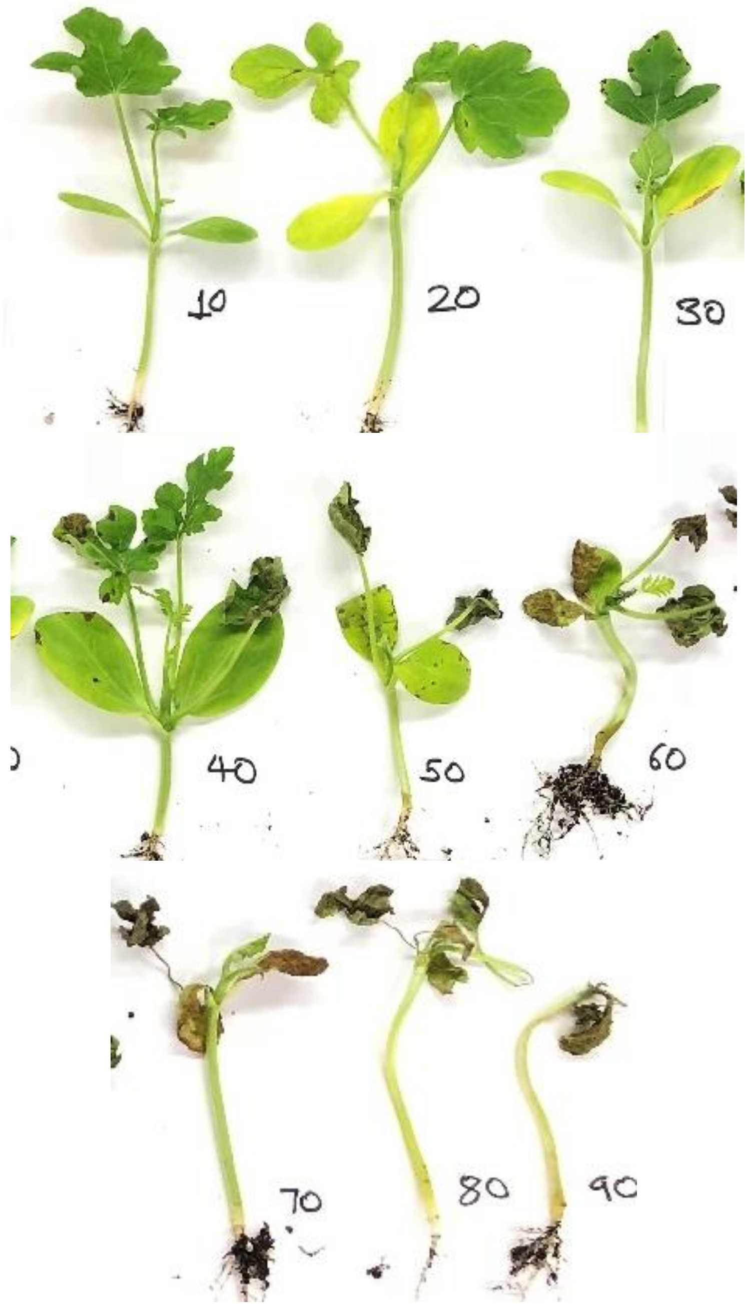

Figure 2.3: The Rating scale for watermelon anthracnose, from 0 - 100%. The figure only shows intervals of 10%.

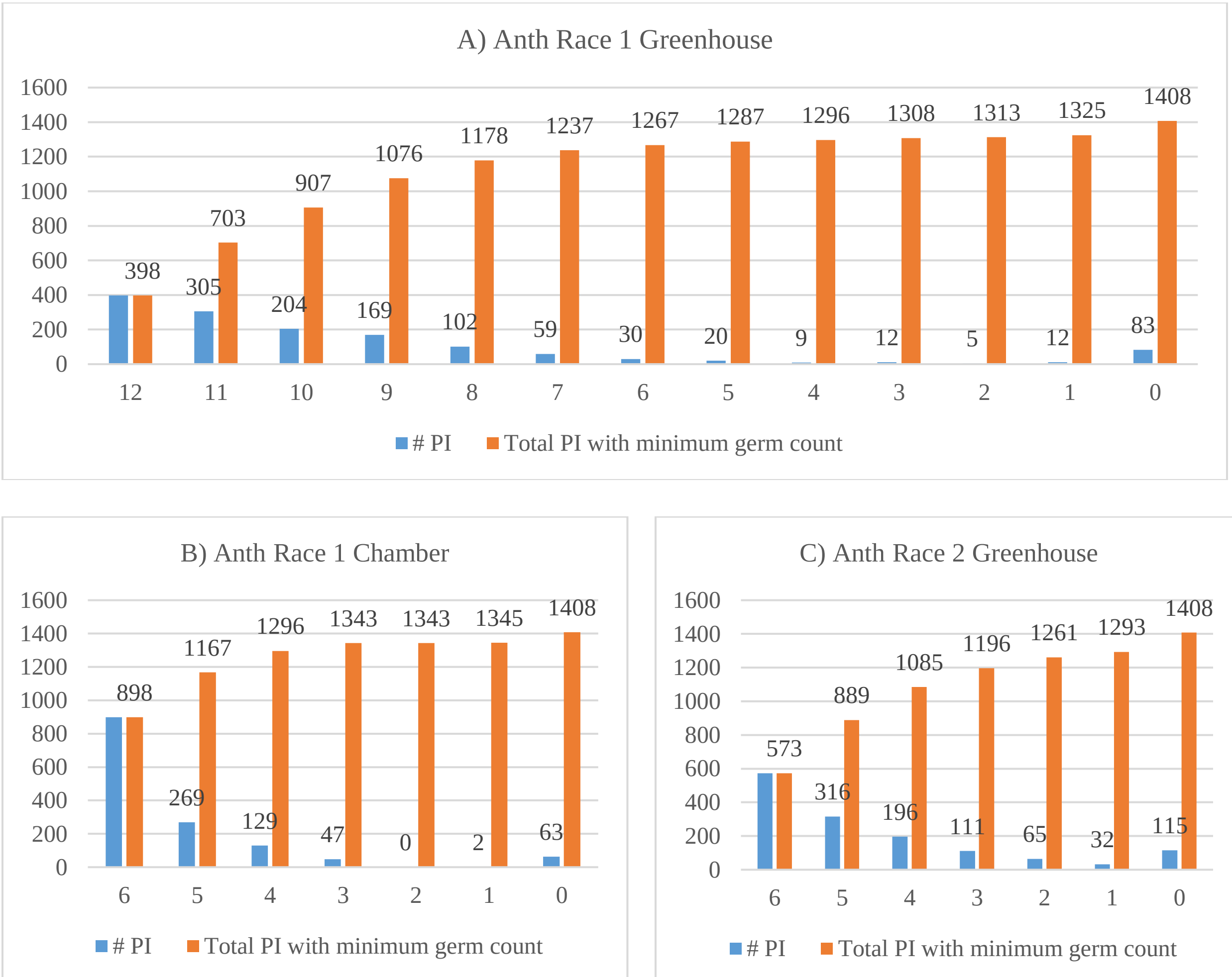

Figure 2.4: Germination count for screening studies. Graphs a cumulative count with the minimum seeds germinated and cultigens with germination count A) Cultigen germination count in anthracnose race1 experiment in greenhouse. B) Cultigen germination count in anthracnose race1 experiment in growth chamber. C) Cultigen germination count in anthracnose race 2 experiment in greenhouse.

TABLES

Table 2.1: Number of Cultigens tested and analyzed for every dataset and plants per replication.

		First Screening				Retest			
Race	Environment	Cultigens		Replication	Plant/rep	Cultigens		Replication	Plant/rep
		Total	Analyzed			Total	Analyzed		
1	Greenhouse	1411	1308	4	3	91	91	6	2
1	Chamber	1411	1343	2	3	91	90	6	2
1	Field	1416	1261	2	1	-	-	-	-
2	Greenhouse	1411	1196	2	3	60	55	6	2

Table 2.2: Plant-to-plant variation for a resistant and a susceptible cultigen and a cultivar in each replication. P1, P2, P3 denote different plant within the replication.

2.2.A) Anthracnose race 1: Greenhouse and Chamber

Anthracnose race 1																		
Cultigen	Greenhouse												Chamber					
	Rep1			Rep2			Rep3			Rep4			Rep1			Rep2		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
PI635712	5	5	-	5	15	15	15	20	10	5	15	15	10	10	-	10	0	5
PI345546	65	-	-	45	45	55	30	50	40	55	55	60	20	35	-	45	40	-
CG**	10	15	15	20	15	5	15	15	10	25	15	20	15	5	5	10	15	10

**CG: Charleston Gray

2.2.B) Anthracnose race 2

Anthracnose race 2						
Cultigen	Greenhouse					
	Rep1			Rep2		
	P1	P2	P3	P1	P2	P3
PI244018	25	20	25	20	20	25
PI169269	100	95	100	45	90	50
NHM##	70	80	60	60	70	55

##NHM: New Hampshire Midget

Table 2.3: Predicted means for a subset of cultigens for consistent high resistance and susceptibility in greenhouse and growth chamber to anthracnose race 1.

Cultigen	Greenhouse						Chamber						Field		
	First Screen			Retest			First Screen			Retest			First Screen		
	Mean**	SE[$$]	Count[++]	Mean	SE	Count	Mean	SE	Count	Mean	SE	Count	Mean	SE	Count
PI635712	4.88	3.44	11	2.20	4.39	6	18.98	4.15	5	4.99	4.48	4	15.86	7.50	2
PI385964	7.54	3.94	8	14.26	4.39	6	28.93	3.89	6	5.36	3.71	6	31.73	7.50	2
PI186489	7.70	3.43	11	14.99	4.05	7	28.98	3.89	6	8.39	4.05	5	50.86	7.50	2
PI482251	8.79	3.34	12	14.67	5.27	4	18.99	3.89	6	10.49	3.45	7	26.84	7.50	2
PI482250	8.84	3.43	11	14.13	5.27	4	23.50	3.89	6	11.30	4.48	4	31.65	7.50	2
PI164636	8.86	4.13	7	12.35	4.08	7	26.57	4.15	5	4.11	4.05	5	33.37	7.50	2
PI560013	9.27	3.32	12	12.76	4.08	7	26.06	3.89	6	11.67	4.05	5	32.46	7.50	2
PI512362	9.70	3.56	10	13.35	6.09	3	27.97	4.15	5	13.89	4.48	4	26.07	7.50	2
PI388021	9.71	3.72	9	25.48	4.39	6	27.23	3.89	6	8.87	3.71	6	31.84	7.50	2
PI482323	9.73	3.31	12	16.75	4.39	6	21.82	3.89	6	13.56	3.46	7	36.69	7.50	2
PI561122	10.04	3.43	11	24.32	5.34	4	22.66	3.89	6	12.71	5.11	3	-	-	
PI560004	10.13	3.58	10	13.77	6.09	3	18.01	3.89	6	7.80	3.08	9	36.64	7.50	2
PI482280	10.36	3.32	12	19.97	4.08	7	25.99	3.89	6	9.98	4.05	5	28.13	7.50	2
PI635620	10.63	4.16	7	20.82	4.34	6	27.38	4.15	5	6.73	5.11	3	20.90	7.50	2
PI635722	10.75	3.76	9	13.17	4.39	6	28.04	4.54	4	12.66	4.48	4	21.43	7.50	2
PI482297	10.85	4.13	7	19.71	4.02	7	27.15	4.54	4	7.83	3.69	6	25.74	7.50	2
PI593359	10.91	3.31	12	14.02	4.08	7	21.82	3.89	6	10.43	3.71	6	19.11	7.50	2
PI500334	10.95	3.31	12	21.70	5.34	4	28.26	4.15	5	6.70	4.05	5	18.51	7.50	2
PI675116	11.05	3.43	11	34.09	5.34	4	26.08	3.89	6	-	-		28.92	7.50	2
PI482371	22.03	3.56	12	14.89	3.58	9	15.44	3.89	6	9.53	2.82	6	22.58	7.50	2
PI482361	24.55	3.32	10	51.05	4.77	5	53.36	3.89	6	32.71	5.11	3	16.86	7.50	2
PI169242	29.68	3.90	8	53.78	4.82	5	52.22	4.51	4	33.58	4.48	4	35.88	7.50	2
PI345546	30.60	3.58	10	76.25	6.20	3	49.79	4.51	4	34.21	3.46	7	34.26	7.50	2
PI288522	30.75	4.82	5	58.71	3.58	9	49.29	4.15	5	31.57	4.45	4	19.97	7.50	2
PI593373	32.14	3.75	9	39.75	5.42	4	48.98	3.89	6	29.96	4.00	5	25.20	7.50	2

Table 2.3 (continued)

PI635598	45.70	3.72	9	38.56	4.43	6	61.53	3.89	5	38.01	4.05	5	43.11	7.50	2
PI500340	56.26	3.56	10	47.87	4.05	7	58.46	3.89	6	26.32	3.71	8	27.41	7.50	2
Charleston Gray	15.34	2.26	240	8.66	4.39	6	31.52	2.02	127	5.44	3.09	9	19.06	2.43	20
PI189225	21.20	2.34	123	53.14	4.08	7	36.96	2.09	82	22.73	3.72	6	28.45	7.50	2
NH Midget	24.22	2.27	221	57.71	4.39	6	38.55	1.98	165	29.03	3.08	9	28.09	2.48	19
Allsweet	-	-	-	8.93	5.42	4	-	-	-	11.39	3.46	7	19.22	2.43	29
Top Gun	-	-	-	11.86	4.08	7	-	-	-	7.29	5.16	3	31.39	2.49	19
Sweet Treasure	-	-	-	13.14	3.84	8	-	-	-	10.29	4.05	5	18.96	2.62	17
Sweet Dawn	-	-	-	16.01	4.82	5	-	-	-	12.58	3.46	7	19.03	2.43	20
Valentino	-	-	-	27.23	4.08	7	-	-	-	9.38	3.26	8	23.41	2.43	20
PI271779	-	-	-	43.99	4.39	6	-	-	-	17.20	4.48	4	-	-	
PI271775	-	-	-	46.42	5.34	4	-	-	-	32.45	4.48	4	30.80	7.50	2

**Mean: Predicted means; $$SE: standard error; ++Count: total plants tested

Table 2.4: Correlation of cultigens performing consistently against race 1 (PI from Table 2.3).

	Chamber FS**	**Greenhouse RT$$**	**Chamber RT**	**Field FS**
Greenhouse FS	0.88	0.72	0.82	0.08
Chamber FS		0.79	0.89	0.12
Greenhouse RT			0.88	0.14
				0.17

**FS: First Screening; $$RT: Retest

Table 2.5: Predicted means for a subset of cultigens for high resistance and susceptibility to anthracnose race 2.

Cultigen	First Screening			Retest		
	Mean**	SE$^{\$\$}$	Count^{++}	Mean	SE	Count
PI500303	6.33	4.89	6	6.87	1.68	11
PI482293	8.78	4.89	6	6.72	1.62	12
PI482333	9.16	5.31	4	6.55	2.03	7
PI244018	9.30	4.89	6			
PI494817	10.33	5.06	5	12.53	1.62	12
PI482316	11.37	5.03	4	7.45	1.83	9
PI500308	12.08	5.04	5	11.81	1.77	10
PI500331	12.26	5.05	5			
PI500335	12.32	4.87	6	7.18	1.62	12
PI255137	12.79	4.88	6	13.31	1.62	12
PI674448	13.02	4.88	6			
PI482259	13.55	5.12	5	6.62	2.26	6
PI482292	13.67	4.88	6	11.90	1.62	12
PI482261	13.77	4.88	6	7.18	1.62	12
PI482315	14.19	5.24	4			
PI470249	14.43	5.23	4	13.26	1.75	10
PI482319	14.69	4.88	6	5.74	1.62	12
PI482308	15.08	5.99	3	8.13	1.62	12
PI635730	15.23	5.61	3	13.33	1.75	10
PI482355	15.45	4.88	6	6.32	1.62	12
PI482340	15.54	5.05	5	13.26	1.62	12
PI635715	15.62	5.98	3	19.58	1.75	10
PI612473	15.75	4.89	6	13.49	1.62	12
PI485583	16.48	4.88	6	6.67	1.75	10
PI596676	16.56	5.97	3	11.29	1.68	11
PI482324	16.82	5.30	4	13.68	2.19	6
PI482371	16.92	5.03	5	15.29	1.83	9
PI596670	17.07	5.96	3	9.47	1.62	12
PI270564	17.34	4.88	6	11.06	1.62	12
PI482314	17.56	5.61	3	16.55	1.62	12
PI593381	46.19	5.02	5	33.32	1.62	12
PI525083	46.21	5.04	5	31.73	1.75	10
PI169269	46.89	4.88	6	36.95	1.62	12
PI379227	47.76	4.88	6	35.65	1.62	12
PI500346	48.09	5.03	5	37.33	1.62	12
PI177330	48.14	5.61	3	35.14	2.62	4
PI430615	48.71	5.32	4	29.69	1.85	9
PI288232	48.96	5.23	4	30.91	2.22	6

Table 2.5 (continued)

PI169276	49.42	5.04	5	36.31	1.68	11
PI508443	49.78	5.63	3	30.77	1.68	11
PI635609	50.47	4.88	6	34.05	1.75	10
PI179886	51.76	5.31	4	35.93	1.62	12
PI278055	52.12	5.31	4	34.20	2.19	6
PI211915	52.58	5.03	5	29.62	1.69	11
PI381715	52.83	5.05	5	36.19	1.75	10
PI254430	54.17	5.30	4	29.51	2.19	6
PI172803	54.53	5.04	5	31.75	1.83	9
PI169246	55.94	5.98	3	31.61	1.68	11
PI177329	56.76	5.24	4	34.75	1.75	10
PI174101	62.98	5.32	4	33.56	1.69	11
PI189225	19.28	4.06	123	8.63	1.62	12
CharlestonGray	32.69	4.49	71	33.62	1.62	12
NHM	38.34	4.46	109	33.69	1.62	12
PI271775	-	-	-	11.54	2.22	6
PI271779	-	-	-	19.08	1.62	12
Allsweet	-	-	-	28.99	1.85	9
Valentino	-	-	-	31.43	1.83	9
Sweet Dawn	-	-	-	32.56	1.68	11
TopGun	-	-	-	34.90	1.62	12

**Mean: Predicted means; $^{\$\$}$SE: standard error; $^{++}$Count: total plants tested

Chapter 3

INHERITANCE AND HERITABILITY OF ANTHRACNOSE RESISTANCE IN WATERMELON

INTRODUCTION

Watermelon (*Citrullus lanatus* [Thunb.] Matsum. & Nakai) is an economically important crop, with 117 million tonnes production in 2016 (FOA, UN, 2016). Watermelon production was 17 million tonnes in 1961 (FOA, UN, 2016), and increased by 100 million megatons in 60 years. In the USA, watermelon is a $500 million crop (USDA National Agricultural Statistics Service, 2017). Most of the states grow watermelon, with Florida, Georgia, California, and Texas being the primary producers (Wehner, 2008). The introduction of seedless cultivars has increased the per capita consumption of watermelon by 37% since 1980 (Wehner, 2008). Disease is a significant limiting factor for agricultural production of watermelon. The important diseases of watermelon are *Fusarium* wilt, anthracnose, gummy stem blight, powdery mildew, *Phytophthora*, bacterial fruit blotch and more than 10 virus diseases. Although *Fusarium* wilt and *Phytophthora* are considered the most critical diseases of watermelon, infections of foliar diseases like anthracnose, gummy stem blight, and powdery mildew occur every year and cause significant investment in crop protection. In a recent survey, the top 8 of 10 research priorities for watermelon research were disease controls (Kousik et al., 2016).

Anthracnose is caused by *Colletotrichum orbiculare* [(Berk. & Mont.) Arx] (formely *Colletotrichum lagenarium*) infects the cucurbit crops including cucumber, melon, watermelon, squash, gourd, pumpkin, and *Luffa* spp. (Wasilwa et al., 1993). Anthracnose has been a major problem in watermelon worldwide since the 19^{th} century, but probably before then. Passerini in

Italy first observed anthracnose on calabash/bottle gourd in 1867 (Layton, 1937). In 1875, Passerini reported anthracnose on watermelon and cantaloupe, which is the first known scientific report of anthracnose on watermelon. In the USA, Dr. Eckfeldt (Philadelphia) and Prof. A. B. Seymour (Wisconsin) noted anthracnose on gourds and watermelons, respectively in 1885. In 1889, Galloway reported melon anthracnose in New Jersey, Virginia and North Carolina. Substantial losses of cantaloupes, cucumbers, and watermelons due to anthracnose epidemics started during 1904 in Nebraska, Indiana, New Jersey, West Virginia, North Carolina, South Carolina, Wisconsin, and Ohio. Anthracnose became a significant plant disease during the late 19th century. By early 20th century, many USA states started focusing on anthracnose as an important watermelon pathogen (Gardner, 1918).

C. orbiculare is a hemibiotrophic fungus. *C. orbiculare* infect all the above-ground parts of watermelon including leaves, stem, flowers, and fruits. *C. orbiculare* causes disease at both preharvest and postharvest period, besides infecting watermelon at all growing stages from seedling to mature plants. All the above-ground parts of plants are susceptible to anthracnose. Severe infections during preharvest, i.e., growing season lead to a decrease in yield and unmarketable produce. Watermelon anthracnose produces blackish brown lesions which at later stage fall out giving a 'shot-hole' appearance. Petiole and stem show sunken and dark color spindled shape lesions, which penetrate deeply and finally grids the stem. Infected young fruits show aborted growth or are abnormal. Lesions on young fruit are small, black depressed spots. On mature fruits, lesions start as yellow translucent centered elevated pimples, which later turn flat-topped, circular, water-soaked elevations. Lesions on mature fruit further sunk and show pink spore masses on a black or cream-colored background. The black lesions are the result of black stroma left behind after washing of spores.

C. orbiculare spreads widely in wet weather conditions like rain, morning due and overhead irrigation. Conidia are mainly dispersed by rain splashing, but also by wind, instruments, and workers (Keinath, 2017). A wetness period of 16hrs or more shows maximum disease development (Thompson & Jenkins, 1985). In fields, 2-3 hours of wetness period is enough for anthracnose to cause infection. Further, temperatures from 18^{o} to 27^{o} C (65^{o} to 80^{o} F) are idle for establishment and growth of *C. orbiculare* on watermelon (Monroe et al., 1997). *C. orbiculare* over-winters by surviving on the debris of infected plants. Watermelon anthracnose is more severe on fields that had cucurbits as previous crops (Sheldon, 1904). Overall, *C. orbiculare* spreads by rain, irrigation, seeds, fruits, and overwintering, and survives between seasons on infected plant debris, volunteer plants, in and on seeds from infected fruits (Keinath, 2017).

Currently, watermelon anthracnose has four races; 1, 2, 2b and 3. Races are identified based on host reaction and vegetative group compatibility (Goode, 1958; Wasilwa et al., 1996; Wasilwa et al., 1993). Most isolates before 1954 were defined as race 1. Isolates found in 1954 and 1955 were defined as race 2 and were highly pathogenic on all cucurbit varieties of that time. Some isolates were defined as race 3. Watermelon plants resistant to race 1 are also resistant to race 3, the difference between these races is pathogenicity on squash varieties (Jenkins & Winstead, 1964; Winstead et al., 1959). A race 2B was identified by further characterizing vegetative compatibility and virulence (Wasilwa et al., 1996). Race 2B is not well characterized yet and has been found on watermelon, bottle gourd and muskmelon (Keinath, 2017).

Management practices for anthracnose include clean seed material, deep plowing of crop residue, crop rotation with non-cucurbit crops, no usage of machinery among fields with wet foliar, fungicides and resistant plant cultivars (Keinath, 2017). For reducing fruit damage, avoid mechanical injury, discard infected fruits during harvest, surface disinfection and refrigerate fruits after harvest (Keinath, 2017). Fungicide application should be started with the occurrence of the symptoms and sprayed every 5 to 10 days later. In rainy weather, fungicide application can be challenging, and the spray interval should be reduced. The active ingredients against anthracnose are trifloxystrobin, azoxystrobin, pyraclostrobin, fluoxastrobin, pyraclostrobin, boscalid, fluxapyroxad; group 3: difenoconazole, chlorothalonil, and mancozeb (FRAC, 2018; Lina Quesada-Ocampo, 2018). These ingredients belong to FRAC group 11 (Qol- Quinone outside Inhibitors), group 7 (SDHI- Succinate dehydrogenase inhibitors), group 3 (DMI- Demethylation inhibitors) and M05, M03 (multi-site contact activity). Few example products of sold fungicides are 'Kocide 3000', 'Pristine,' 'Cabrio,' 'Quadris Top,' 'Bravo WeatherStik,' 'TopGaurd EQ' (Egel & Marchino, 2018; Everts & Korir, 2017; FRAC, 2018).

Anthracnose was identified as an important watermelon disease in the early 20th century, and many efforts were focused on developing resistant cultivars. In 1937, Layton started breeding for anthracnose resistance. Layton identified sources of anthracnose resistance from Africa and used them as parents to develop commercial varieties. The first widely accepted anthracnose resistant watermelon varieties were 'Congo' (1949), 'Fairfax' (1953), and 'Charleston Gray' (1955), released by Andrus (Winstead et al., 1959a). Charleston Gray, Congo, and Fairfax are resistant to races 1 and 3 but susceptible to race 2 (Goode, 1958). Resistance to race 2 was first found in a citron W695, which was also resistant to race 1 and 3 (Winstead et al., 1959a). PI 326515 was the first PI reported to have resistance only to race 2 (Suvanprakorn & Norton, 1980). More resistant sources to race 2 including PI 189225, 271775, and 271778, 512385 were identified (Boyhan et al., 1994; Sowell et al., 1980). Resistance to anthracnose race 2 was also identified in *Citrullus colocynthis*, designated as R309 (Love & Rhodes, 1988).

Every year a few watermelon cultivars with anthracnose resistance are introduced in the market. Examples of few anthracnose resistant watermelon cultivars include ‘Valentino,’ ‘Sweet Treasure,’ ‘Melody,’ ‘Captivation,’ ‘Cooperstown,’ ‘Majestic,’ ‘Maistros F1’, ‘Accomplice.’ These commercial cultivars claim to have intermediate to high level of resistance to anthracnose. Nearly all the commercial cultivars claim resistance to anthracnose race 1, and some cultivars do not specify the race. Hybrid watermelon cultivars are resistant to races 1 and 2B and susceptible to race 2 (Keinath, 2017).

Inheritance studies of watermelon anthracnose resistance were done by Layton (1937), Winstead et al. (1959) and Suvanprakorn & Norton (1980). These studies used the biparental cross populations of six generations: Parent1, Parent2, F1, F2, F1 backcross Parent1 and F1 backcross Parent2. Resistance to race 1 segregate as a single gene, and race 1 and 3 resistant is controlled by the same gene, *Ar-1* (Winstead et al., 1959a). Like race 1 inheritance of race 2 also segregates as a single gene (Suvanprakorn & Norton, 1980). Two studies found that resistance in *Citrullus colocynthis*, R309 did not follow the single gene inheritance, and was suggested to be multigenic (Love & Rhodes, 1988). These studies suggested that a single dominant gene confers major resistant, but there are other genes also playing a part in the resistance. R309 has been the only source of multigenic resistance, no more such multigenic resistance sources are reported yet. No heritability estimates have been reported earlier for watermelon anthracnose resistance.

In this study, we studied the inheritance of watermelon anthracnose for race 1 and race 2 isolates using biparental cross populations. We estimated heritability from biparental crosses and 1408 cultigen data.

MATERIAL AND METHODS

C. orbiculare Isolates

Race 1 isolate of *C. orbiculare* was collected in North Carolina 1998 (check) from the field (which station). Dr. Wehner, Cucurbit breeding laboratory at NCSU maintained the race 1 isolate.. Dr. Anthony Keinath at Clemson University, South Carolina provided the race 2 isolate. Race 2 isolate was isolated in 2013 in Charleston, SC.

All the isolates were grown on green bean agar (GBA) media (Wasilwa et al., 1993). For GBA preparation, in 1 L of distilled water add 18 g of agar and two jars (142 g) of green bean baby food (Gerber®). New plates were inoculated from the older plates every three weeks for maintaining the isolate.

Spores were extracted from 3-week old Petri plates. 10-15 ml distilled (DI) water was added to each Petri plate, and a sterile metal spreader was used to rub the surface. The water was filtered through 4 layers of cheesecloth in a sterile conical flask. The spore concentration was estimated using a hemocytometer. The spore mixture was then diluted to 10^5 sp/ml concentration, and one drop of Tween20 was added to every 500ml of spore inoculum.

Inoculation

A 10^5 sp/ml of spore concentration was used to inoculate all the experiments. The concentration of spores for inoculation was determined using a method test. The inoculum was spread on 3-weeks old watermelon plants. The inoculated plants were kept in a high humidity environment with 80-100 % RH humidity for 48 hours. After 48 hours, plants were kept at 70-80 F (22-26^o C) under fluorescent lights (14 hr daylight).

Plant Materials/Populations

Two families were developed from the biparental crosses between Charleston Gray × New Hampshire Midget and PI 189225 × New Hampshire Midget were used in this experiment. Charleston Gray (CG) is resistant to anthracnose race 1 (Winstead et al., 1959a), PI 189225 is resistant to anthracnose race 2 (Boyhan et al., 1994), and New Hampshire Midget is susceptible to all anthracnose races. For each family, we developed six generations in the greenhouses at North Carolina State University in Raleigh, North Carolina: Parent 1 (P1), Parent 2 (P2), F1, F2, F1 backcross to Parent 1 (BC1P1) and F1 backcross to Parent 2 (BC1P2).

Experimental Design

The six generations of each biparental cross were grown in 24-cell trays, and each tray consisted of 24 plants. The six generations for both the crosses were planted in the following order: P1, P2, F1, BC1P1, BC1P2, F2. The number of plants tested for each generation varied based on the generation tested (Table 3.1). Each experiment consisted of 17 trays. Race 1 and 2 experiments were carried out separately to avoid any cross-contamination.

Plants were grown on greenhouse benches for 3 weeks. Watermelon seeds were planted in the 4P soil mix. Greenhouse temperature ranged from 75^{O} F to 95^{O} F (24^{O} C to 35^{O} C). 3 weeks old plants were moved to the disease chamber at Kilgore Hall, North Carolina State University for inoculation. Disease chamber temperature was maintained at 70-80^{O} F (~22-26^{O} C) throughout the experiment. Inoculated plants were kept in a high humidity environment with 70-85 % RH humidity for 48 hours. After inoculation, plants were watered as needed.

Data Collection

For data collection, the same scale as used in the first screening study was used to rate the disease incidence. For the race1 study of ‘Charleston Gray’ x ‘New Hampshire Midget,’ ratings were collected on the 14-day post inoculation (DPI). For the race2 experiment of PI189225 x 'New Hampshire Midget,' ratings were collected on 7 DPI.

Data Analysis

This experiment was designed to test the qualitative inheritance of resistance to watermelon anthracnose. The segregation analysis and goodness-of-fit tests were performed in R. Earlier studies suggest a single gene inheritance, we verified the distribution of BC1P1, BC1P2 and F2 data for each cross and plotted the disease ratings against their frequencies. All χ^2 tests were performed at the 95% confidence level.

Variances

Variances components, phenotypic (σ^2_P), genotypic (σ^2_G), environmental (σ^2_E), and additive (σ^2_A) were estimated from generation variances of the biparental cross populations as follows (Warner, 1952; Wright, 1968).

$$\sigma_P^2 = \sigma_{F2}^2$$

$$\sigma_E^2 = \frac{[\sigma_{P1}^2 + \sigma_{P2}^2 + (2\sigma_{F1}^2)]}{4}$$

$$\sigma_G^2 = \sigma_P^2 - \sigma_E^2$$

$$\sigma_A^2 = [2\sigma_{F2}^2] - [\sigma_{BC1P1}^2 + \sigma_{BC1P2}^2]$$

Heritability

Narrow-sense (h^2) and broad-sense (H^2) heritabilities were calculated using the variance components (Wright, 1968; Fehr, 1991).

$$h^2 = \frac{\sigma_A^2}{\sigma_P^2}$$

$$H^2 = \frac{\sigma_G^2}{\sigma_G^2 + \sigma_P^2}$$

Broad-sense heritability (H^2) for the germplasm was also estimated using variance components based on the anthracnose first screening datasets from the earlier chapter. H^2 was calculated separately for the three datasets: Anthracnose race1-Greenhouse, Anthracnose race1-Chambers, and Anthracnose race2-Greenhouse.

In ASReml standalone software (Version 4.1), variance components were estimated from models in which all components were treated as random effects. The final models were determined by adding random effects sequentially and comparing incremental complex models using the REML likelihood ratio tests from the asremlPlus 2.0-12 package. The best models for each dataset were determined in using ASReml-R using third rating for all the datasets. The best models were then used in ASReml standalone to estimate the H^2 with standard error.

The model used for 'Anthracnose race1-Greenhouse' is,

'Rating3 ~ 1,

random =~ Cultigen + Replication + Replication (Tray) + Plot'

The model used for 'Anthracnose race1-Chambers' is,

'Rating3 ~ 1,

random =~ Cultigen + Replication + Run + Run (Cart) + Run (Cart (Plot))'

The model used for ‘Anthracnose race2-Greenhouse’ is,

Rating3 ~ 1,

random =~ Cultigen + Replication + Run (Tray) + Plot’

Heritability Equations

The data from the first screening study was highly unbalanced, and to account for the unbalance data we used harmonic means (HM) to approximate replications per cultigen, plants per plot, and run per cultigen. H^2 for each dataset was calculated using the following equations,

‘Anthracnose race1-Greenhouse.’

$$H_G^2 = \frac{\sigma^2_{Cultigen}}{\sigma^2_{Cultigen} + \frac{\sigma^2_{Plot}}{HM_{Rep\ per\ Cultigen}} + \frac{\sigma^2_{error}}{HM_{Plant\ per\ Plot}}}$$

‘Anthracnose race1-Chambers.’

$$H_G^2 = \frac{\sigma^2_{Cultigen}}{\sigma^2_{Cultigen} + \frac{\sigma^2_{Run(Cart(Plot))}}{HM_{Run\ per\ Cult}} + \frac{\sigma^2_{error}}{HM_{Plant\ per\ Plot}}}$$

‘Anthracnose race2-Greenhouse.’

$$H_G^2 = \frac{\sigma^2_{Cultigen}}{\sigma^2_{Cultigen} + \frac{\sigma^2_{Plot}}{HM_{Rep\ per\ Cultigen}} + \frac{\sigma^2_{error}}{HM_{Plant\ per\ Plot}}}$$

RESULTS AND DISCUSSION

Anthracnose caused by *C. orbiculare* is a significant watermelon disease, especially in the southeastern states of the USA. Although, there are methods to control and manage anthracnose in watermelon fields like fungicides. However, during the growing season rains are frequent in the southeastern states, that make chemical controls less effective. In such condition, these methods could add significant cost for growers. Resistant cultivars are a more efficient method to control watermelon anthracnose. For the development of cultivars, it is necessary to understand the genetics of the underlying resistance.

This study screened six generations of the two bi-parental cross populations. To determine a plant as a resistant or susceptible needs a cutoff. The assignment of this cutoff is straightforward when two phenotypically distinct parents are crossed to make the segregating population. In this case, the parents for both the crosses are resistant and susceptible to anthracnose races 1 and 2 (Figure 3.1). The mean and standard deviation (SD) was utilized to define the cutoff. The value of mean plus two times SD of the resistant parent should capture the distribution of resistant plants in the F2, BC1P1 and BC1P2 generations. For the race 1 resistant parent 'Charleston Gray', the mean and SD were 16.94 and 10.59, respectively (Table 3.1). The resistant cutoff value for the cross between 'Charleston Gray' x 'New Hampshire Midget' was 38.12 (rounded to 40). Plants with the rating of less than or equal to 40 were considered resistant in the 'Charleston Gray' x 'New Hampshire Midget' cross, while all other ratings were considered as susceptible. Similarly, for the race 2 resistant parent PI189225, the mean and SD were 27.5 and 9.59, respectively (Table 3.1). The resistant cutoff value for the cross between PI189225 x 'New Hampshire Midget' was 46.68 (rounded to 45).

‘New Hampshire Midget’ is equally susceptible to race 1 and 2 (Table 3.1). Although ‘Charleston Gray’ and PI189225 are both resistant, respectively to races 1 and 2, the damage caused by race 2 is more as compared to race 1. The mean rating for ‘Charleston Gray’ is 16.94, whereas for PI189225 is 27.5. Race 2 more virulent to race 1, which was observed in the germplasm screening in chapter 2. Further, non-additive variance plays a more significant role in race 2 resistant as compared to race 1.

The segregation ratios of the resistant, and susceptible plants to the anthracnose races in the F1, F2, BC1P1, and BC1P2 are similar to earlier studies (Layton, 1937; Suvanprakorn & Norton, 1980; Winstead et al., 1959a). All the F1 plants were resistant in both the populations (Table 3.2). The χ^2 test of F2 generations verifies a segregation ratio of 3:1 for resistant:suceptible (Table 3.2). The segregation ratio of F2 generations suggested that the anthracnose resistance for both race 1 and race 2 is controlled by a single gene, with resistance as dominant. The plants in the backcross generation BC1P1 (F1 x Resistant parent) were all resistant in both populations (Table 3.2). While the plants of the backcross generation BC1P2 (F1 x Suceptible parent) segregated as 1:1 for resistant:suceptible (Table 3.2). The segregation ratios of the backcross generations support the single gene inheritance observed in F2 generation.

The data are presented by populations (Table 3.1). The variance of ‘New Hampshire midget’ was similar for both races. The variance of F1 generation was low because F1 is a heterozygous but homogenous population. The variation in the parental generation is all environmental, while the variation in F2 generations is the combination of environmental and genetic (Total phenotypic variance). The environmental variance for both populations was smaller than genetic variance indicating qualitative inheritance, supporting the segregating ratio outcome.

The broad sense and narrow sense heritability estimates were based on the variances of the six generations (Table 3.3). This study is the first report of heritability of anthracnose resistance in watermelon. The broad-sense(H^2) and narrow-sense(h^2) heritability from the biparental cross population for race 1 resistance were 0.885 and 0.639, respectively. Similarly, for race 2 resistance H^2 and h^2 were 0.802 and 0.545. As expected, for both the races h^2 was smaller than H^2. Anthracnose resistance in watermelon is highly heritable for both races.

The heritability was estimated from the germplasm screening studies in chapter 2. The cultigens mean was treated as family mean for the analysis. To account for the unbalanced data, harmonic means (HM) to approximate replication per cultigen, run per cultigen, and plant per plot were calculated for each dataset (Table 3.4) (Holland et al., 2003).

For the three datasets 'Anthracnose race1- Greenhouse', 'Anthracnose race1- Chambers', 'Anthracnose race2- Greenhouse', the cultigen variance, $\sigma^2_{Cultigen}$ was 49.76, 19.8602, and 65.5459, respectively (Table 3.5). $\sigma^2_{Cultigen}$, was the total genetic variance including the additive, dominance and epistatic variance. This was because there were no crosses made and the population structure was unaccounted. We only estimated broad sense heritability from the germplasm studies. The heritability for race 1 in greenhouse and chambers were 0.3405 and 0.146, respectively. The heritability for race 2 resistance was 0.3743. Same race 1 isolate was used in both environments, but the heritability was lower in chambers. This suggest that greenhouse is a better environment for selection.

This study provides heritability estimates from two types of populations, 1) a designed biparental cross population, and 2) the germplasm with unaccounted population structure. We cannot compare the heritability from these two population. Stating the obvious here, but the best strategy to integrate the anthracnose resistance into the elite cultivars would be first developing an inbreed cultigen of the wild accession, and then use backcrossing.

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FIGURES

Figure 3.1: Symptoms of resistant and susceptible parents. 'Charleston Gray'(Left) is resistant with few symptoms, 'New Hampshire Midget' (right) thoroughly infected.

TABLES

Table 3.1: Mean, standard deviation and variance of six generations of the biparental cross population.

Population		P1	P2	F1	F2	BC1P1	BC1P2
Charleston Gray x NH Midget	Mean	16.94	74.17	12.5	29.91	21.5	42.25
	Standard deviation	10.59	11.53	4.42	23.83	7.94	27.86
	Variance	112	133	19.6	617	63	777
PI189225 x NH Midget	Mean	27.5	76.18	29.17	43.42	24.75	47.63
	Standard deviation	9.59	11.66	7.02	20.3	10.77	21.96
	Variance	91.9	136	49.3	412	116	482

Table 3.2: Segregation of anthracnose resistance in sex generations of the biparental cross populations.

Population	Pedigree	Count	Resistance (≤40%)	Susceptible (≥45%)	Expected ratio	Chi-sq	P-value
Charleston Gray x NH Midget	P1	18	18	0			
	P2	18	0	18			
	F1	24	24	0			
	F2	228	173	55	3:1	0.094	0.7597
	BC1P1	60	60	0			
	BC1P2	60	32	28	1:1	0.267	0.6056
			Resistance (≤45%)	Susceptible (≥50%)			
PI189225 x NH Midget	P1	18	18	0			
	P2	18	0	18			
	F1	24	24	0			
	F2	228	174	54	3:1	0.211	0.6464
	BC1P1	60	59	1			
	BC1P2	55	29	26	1:1	0.163	0.6858

Table 3.3: Variance components and heritability estimates for anthracnose resistance.

Population	σ_P^2	σ_E^2	σ_G^2	σ_A^2	h^2	H^2
Charleston Gray x NH Midget	617	71.1	546	394	0.639	0.885
PI189225 x NH Midget	412	81.6	330	225	0.545	0.802
Anthracnose race1-Greenhouse	145.565		49.7618			0.3405
Anthracnose race1- Chambers	136.051		19.8602			0.146
Anthracnose race2-Greenhouse	175.08		65.5459			0.3743

Table 3.4: Harmonic means of replication per cultigen, run per cultigen and plant per plot from the germplasm data.

Population	Replication per Cultigen	Run per Cultigen	Plant per plot
Anthracnose race1- Greenhouse	3.84	-	2.63
Anthracnose race1- Chambers	-	1.98	2.6
Anthracnose race2- Greenhouse	1.95	-	2.41

Table 3.5: Variance component estimates of the germplasm datasets.

Population	$\sigma^2_{Cultigen}$	σ^2_{Plot}	$\sigma^2_{Run(Cart(Plot))}$	σ^2_{error}
Anthracnose race1- Greenhouse	49.7618	86.1653	-	192.947
Anthracnose race1- Chambers	19.8602	-	115.211	151.282
Anthracnose race2- Greenhouse	65.5459	113.528	-	123.668

APPENDICES

Appendix A
Predicted means for anthracnose disease screening of the watermelon cultigens

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
Grif12336	14.4957	32.833	20.7436	25.1718	WJK-PRC-75	*Citrullus lanatus*	China, Yunnan
Grif14199	19.3985	41.8189	23.5438	43.0766	USM 137	*Citrullus lanatus*	India, Rajasthan
Grif15895	16.3486	38.7817	21.5141	36.6266	Sugar Baby	*Citrullus lanatus*	Canada
Grif15898	8.8788	40.764	11.6604	30.5818	472	*Citrullus lanatus*	United States, Iowa
Grif16135	NA	NA	24.978	NA	86308	*Citrullus amarus*	
Grif17032	28.9233	52.0698	NA	NA	AL 163	*Citrullus amarus*	United States, Arizona
Grif1730	NA	34.3869	23.1817	NA	Grif 1730	*Citrullus lanatus*	China, Jiangsu
Grif5595	20.2221	37.7156	35.0375	27.7522	USM 141	*Citrullus lanatus*	India
Grif5596	16.9069	31.2464	31.8039	34.613	USM 3	*Citrullus lanatus*	India
Grif5598	20.7386	35.0484	23.3722	39.1878	USM 140	*Citrullus lanatus*	India
Grif5600	19.795	32.7109	38.238	42.581	USM 220	*Citrullus lanatus*	India
PI105445	15.5189	36.5386	23.4088	43.9703		*Citrullus lanatus*	Turkey, Amasya
PI113326	24.6816	35.1679	28.511	26.8192	289	*Citrullus lanatus*	China
PI161373	16.4276	38.0837	28.1954	29.3532	BAH SHIM MA KOWHA	*Citrullus lanatus*	Korea, South, Kyonggi
PI162667	16.9967	24.9496	25.726	35.0272	MENDOCINA	*Citrullus lanatus*	Argentina, Buenos Aires
PI163202	17.9826	29.2902	32.3137	34.5723	HINDUANA	*Citrullus lanatus*	India, Punjab
PI163203	18.1608	28.3617	NA	37.6753	TARBUZA	*Citrullus lanatus*	India, Punjab

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI163204	19.2792	45.044	25.8524	35.0372	TARBUZA	*Citrullus lanatus*	India, Punjab
PI163205	21.3812	40.1972	34.2317	38.3156	TARBUZA	*Citrullus lanatus*	India, Punjab
PI163572	12.6082	33.9746	54.2051	36.0787	1018	*Citrullus lanatus*	Guatemala, Jutiapa
PI163574	14.4752	44.9965	24.174	42.8389	1020	*Citrullus lanatus*	Guatemala, Jutiapa
PI164146	18.3809	30.2178	25.8812	40.6292	TARBUZA	*Citrullus lanatus*	India
PI164247	17.1935	34.7021	16.6835	40.2993		*Citrullus lanatus*	Liberia
PI164248	23.2538	41.562	38.2975	33.2475	Egusi	*Citrullus mucosospermus*	Liberia
PI164474	21.4828	39.4411	NA	37.1667	TARBUZA	*Citrullus lanatus*	India, Rajasthan
PI164539	20.3289	36.6146	27.4993	33.8147	TINDA	*Citrullus lanatus*	India, Rajasthan
PI164543	22.2535	32.8286	32.3855	38.1952	Tarbuza	*Citrullus lanatus*	India, Rajasthan
PI164550	29.1121	31.6888	35.2568	33.8913	TARBUZA	*Citrullus lanatus*	India, Madhya Pradesh
PI164570	30.9334	39.2478	35.8638	39.2576	PUSHANI	*Citrullus lanatus*	India, Tamil Nadu
PI164633	12.9701	31.9003	NA	31.5475	PUSHANI	*Citrullus lanatus*	India, Karnataka
PI164634	12.3371	28.5138	17.4368	27.4624	PUSHANI	*Citrullus lanatus*	India, Karnataka
PI164636	8.8599	26.5664	33.3751	NA	PUSHANI	*Citrullus lanatus*	India, Karnataka
PI164639	18.4849	38.2619	29.1696	38.1074	9063	*Citrullus lanatus*	India, Karnataka
PI164655	15.3876	39.8042	30.8214	37.3369	9080	*Citrullus lanatus*	India, Karnataka

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI164685	18.4926	34.2006	21.6405	38.8611	9110	*Citrullus lanatus*	India, Tamil Nadu
PI164687	14.0774	36.7607	27.7412	NA	9112	*Citrullus lanatus*	India, Karnataka
PI164708	25.6458	45.3164	29.0372	34.7486	9135	*Citrullus lanatus*	India, Karnataka
PI164709	NA	35.5209	21.1245	NA	9136	*Citrullus lanatus*	India, Karnataka
PI164737	21.9441	40.225	36.8145	35.0419	ANDRAWAN KAPSHAL	*Citrullus lanatus*	India, Karnataka
PI164748	15.039	35.086	23.1685	43.1038	Tarbuza	*Citrullus lanatus*	India, Karnataka
PI164804	12.1218	38.9537	NA	30.7844	TARBUZA	*Citrullus lanatus*	India, Maharashtra
PI164977	17.5138	34.6059	32.4039	33.6589	BURSA	*Citrullus lanatus*	Turkey, Istanbul
PI164992	22.7116	29.5278	24.1315	35.3323	KARPUZ	*Citrullus lanatus*	Turkey, Ankara
PI164998	18.5451	34.3975	30.9048	44.2334	KARPUZ	*Citrullus lanatus*	Turkey, Ankara
PI165002	22.2208	40.0753	30.9729	41.8293	KARPUZ	*Citrullus lanatus*	Turkey, Ankara
PI165024	23.5888	32.434	32.6632	38.9699	KARAKARPUZ	*Citrullus lanatus*	Turkey, Ankara
PI165448	11.0295	31.0399	25.7926	29.2503	1079	*Citrullus lanatus*	Mexico, Oaxaca
PI165451	16.5992	31.253	34.7516	34.8786	1082	*Citrullus lanatus*	Mexico, Oaxaca
PI165523	21.27	45.8891	69.2441	27.0711	TARBUZA	*Citrullus lanatus*	India
PI166993	25.419	37.7932	47.6157	35.7226	191	*Citrullus lanatus*	Turkey, Hatay
PI167026	16.1279	35.9817	27.6312	33.4212	223	*Citrullus lanatus*	Turkey, Hatay

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI167045	20.5425	31.3706	31.5022	35.3827	Karpuz	*Citrullus lanatus*	Turkey, Hatay
PI167059	21.4164	36.2338	29.1328	34.0916	Karpuz	*Citrullus lanatus*	Turkey, Hatay
PI167124	13.4206	32.3472	30.1093	30.9587	Ala Topak Karpuz	*Citrullus lanatus*	Turkey, Adana
PI167125	23.7299	29.3319	25.1691	34.8785	Beyaz Uzan Karpuz	*Citrullus lanatus*	Turkey, Adana
PI167126	20.1548	36.7999	NA	43.0549	Beyaz Topak Karpuz	*Citrullus lanatus*	Turkey, Adana
PI167222	17.6875	32.0392	24.2689	39.8676	Karpuz	*Citrullus lanatus*	Turkey, Icel
PI169232	22.5964	37.325	21.6624	41.0986	1376	*Citrullus lanatus*	Turkey, Izmir
PI169233	21.9471	34.515	27.8303	19.9841	Karpuz Siyah	*Citrullus lanatus*	Turkey, Manisa
PI169234	22.5117	34.8437	27.4252	37.5799	1454	*Citrullus lanatus*	Turkey, Manisa
PI169235	28.4952	36.2495	35.743	33.2366	Yenidunya	*Citrullus lanatus*	Turkey, Manisa
PI169236	17.341	49.9494	27.7565	40.3151	Karpuz	*Citrullus lanatus*	Turkey, Manisa
PI169237	19.1512	36.6752	36.4259	41.8309	1465	*Citrullus lanatus*	Turkey, Izmir
PI169238	30.761	47.5927	23.3719	40.2831	1466	*Citrullus lanatus*	Turkey, Manisa
PI169239	27.4348	43.5392	28.1348	35.6525	Karpuz Siyah	*Citrullus lanatus*	Turkey, Manisa
PI169240	24.2884	41.9218	NA	31.3076	Kaymakam	*Citrullus lanatus*	Turkey, Antalya
PI169241	26.6772	35.2013	30.6943	28.8413	1541	*Citrullus lanatus*	Turkey, Antalya
PI169242	29.6804	53.3622	35.8786	31.1109	Kaymakam	*Citrullus lanatus*	Turkey, Antalya

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI169243	NA	43.5484	28.4344	NA	1652	*Citrullus lanatus*	Turkey, Antalya
PI169244	NA	36.5435	NA	NA	Karpuz	*Citrullus lanatus*	Turkey, Antalya
PI169245	23.2749	35.7917	NA	37.4157	1721	*Citrullus lanatus*	Turkey, Burdur
PI169246	24.4156	43.6065	32.5638	55.9417	1809	*Citrullus lanatus*	Turkey, Mugla
PI169247	20.2012	36.4873	21.8418	34.3224	1812	*Citrullus lanatus*	Turkey, Mugla
PI169248	23.8772	37.9353	29.168	37.5971	1819	*Citrullus lanatus*	Turkey, Mugla
PI169249	NA	41.4843	25.0196	NA	1908	*Citrullus lanatus*	Turkey, Mugla
PI169250	14.159	48.192	36.6429	31.5474	1925	*Citrullus lanatus*	Turkey, Mugla
PI169251	NA	38.0801	22.4318	NA	Muz	*Citrullus lanatus*	Turkey, Mugla
PI169252	18.0708	36.8443	25.8585	33.0592	1954	*Citrullus lanatus*	Turkey, Aydin
PI169253	22.12	32.3323	31.6664	38.0433	1963	*Citrullus lanatus*	Turkey, Aydin
PI169254	18.1023	33.4849	34.8773	28.9128	1992	*Citrullus lanatus*	Turkey, Izmir
PI169255	NA	37.9361	30.934	NA	2009	*Citrullus lanatus*	Turkey, Manisa
PI169256	19.6489	35.0955	23.3548	33.3817	2029	*Citrullus lanatus*	Turkey, Manisa
PI169257	19.0485	32.0464	32.4351	39.4948	2085	*Citrullus lanatus*	Turkey, Manisa
PI169258	19.8297	35.2348	19.2994	32.6202	2112	*Citrullus lanatus*	Turkey, Manisa
PI169259	21.6189	46.4189	71.3541	NA	Dilimli	*Citrullus lanatus*	Turkey, Manisa

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI169260	NA	39.1216	24.4882	NA	2133	*Citrullus lanatus*	Turkey, Manisa
PI169261	23.2678	45.4362	30.0989	41.9481	Siyah Kadin Budu	*Citrullus lanatus*	Turkey, Manisa
PI169262	26.6563	42.2681	39.1265	38.1899	2182	*Citrullus lanatus*	Turkey, Manisa
PI169263	21.0998	34.5536	66.2122	NA	2232	*Citrullus lanatus*	Turkey, Izmir
PI169264	30.4962	33.4915	22.3694	NA	Yenidunya	*Citrullus lanatus*	Turkey, Istanbul
PI169265	16.5625	33.6127	30.2095	33.9139	Manyaz	*Citrullus lanatus*	Turkey, Istanbul
PI169267	19.6002	32.906	34.727	34.7474	2504	*Citrullus lanatus*	Turkey, Edirne
PI169268	NA	37.7261	14.8691	NA	2515	*Citrullus lanatus*	Turkey, Edirne
PI169269	17.3978	44.8131	26.8076	46.8949	2543	*Citrullus lanatus*	Turkey, Kirklareli
PI169270	NA	39.9217	28.4312	NA	2590	*Citrullus lanatus*	Turkey, Kirklareli
PI169271	17.3729	39.7575	30.7492	NA	2592	*Citrullus lanatus*	Turkey, Kirklareli
PI169272	NA	30.3157	NA	NA	2684	*Citrullus lanatus*	Turkey, Edirne
PI169273	24.4234	40.9313	NA	32.1036	2785	*Citrullus lanatus*	Turkey, Kirklareli
PI169274	23.3682	39.8296	32.4633	36.2545	Yenidunya	*Citrullus lanatus*	Turkey, Kirklareli
PI169275	21.7193	33.9173	27.6606	42.7362	2876	*Citrullus lanatus*	Turkey, Canakkale
PI169276	29.6407	40.4958	68.1923	49.423	2877	*Citrullus lanatus*	Turkey, Canakkale
PI169277	27.1096	36.7594	26.4562	29.4868	2945	*Citrullus lanatus*	Turkey, Canakkale

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI169278	19.6809	29.1769	NA	27.8089	3096	*Citrullus lanatus*	Turkey, Canakkale
PI169279	34.2616	40.0817	23.3152	39.555	3111	*Citrullus lanatus*	Turkey, Canakkale
PI169280	28.4289	39.4716	29.9983	31.553	3123	*Citrullus lanatus*	Turkey, Balikesir
PI169281	22.9795	36.468	22.6316	39.2161	3133	*Citrullus lanatus*	Turkey
PI169282	19.3316	36.7815	24.2786	35.8606	3149	*Citrullus lanatus*	Turkey, Balikesir
PI169283	28.6892	39.5364	29.043	NA	3179	*Citrullus lanatus*	Turkey, Balikesir
PI169284	13.615	43.7506	23.3708	35.0724	3188	*Citrullus lanatus*	Turkey, Balikesir
PI169285	12.1998	30.7658	25.0483	32.8964	Yenidunya	*Citrullus lanatus*	Turkey, Balikesir
PI169286	29.9439	46.8042	31.6427	32.6154	3329	*Citrullus lanatus*	Turkey, Balikesir
PI169287	20.346	30.5431	24.1046	NA	Kurba Alaca	*Citrullus lanatus*	Turkey, Bursa
PI169288	NA	32.515	NA	NA	Yenidunya	*Citrullus lanatus*	Turkey, Bursa
PI169289	24.5394	39.3331	28.3118	38.3569	Yenidunya	*Citrullus lanatus*	Turkey, Bursa
PI169290	24.1355	34.5219	31.0821	38.8821	Kurbagi Alacasi	*Citrullus lanatus*	Turkey, Bursa
PI169291	29.5795	34.1781	25.7699	32.6899	Yenidunya	*Citrullus lanatus*	Turkey, Bursa
PI169293	18.7788	32.2477	19.8333	22.9036	Cinilikiz	*Citrullus lanatus*	Turkey, Bursa
PI169294	11.6777	31.0511	NA	33.1939	Cinilikiz	*Citrullus lanatus*	Turkey, Bursa
PI169295	20.8666	30.6258	30.2912	31.8118	Yenidunya	*Citrullus lanatus*	Turkey, Bursa

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI169296	35.7366	30.9178	19.4499	29.965	3703	*Citrullus lanatus*	Turkey, Kocaeli
PI169297	31.5871	35.2469	19.0432	29.9108	3729	*Citrullus lanatus*	Turkey, Kocaeli
PI169299	NA	NA	29.1497	NA	3809	*Citrullus lanatus*	Turkey, Hatay
PI169300	27.1669	37.0106	27.6611	40.0955	Karasik	*Citrullus lanatus*	Turkey, Hatay
PI171392	15.4148	NA	19.693	NA	Tsamma	*Citrullus lanatus*	South Africa, Transvaal
PI171579	25.7809	37.3529	20.1172	38.0577	6612	*Citrullus lanatus*	Turkey, Zonguldak
PI171580	25.8676	50.9129	NA	38.3894	6718	*Citrullus lanatus*	Turkey, Samsun
PI171581	25.2947	28.358	37.187	39.3232	6835	*Citrullus lanatus*	Turkey, Tokat
PI171582	22.992	37.3995	39.8649	42.5597	6845	*Citrullus lanatus*	Turkey, Amasya
PI171583	21.3177	36.1568	31.4536	40.1617	6866	*Citrullus lanatus*	Turkey, Tokat
PI171584	17.3068	32.3005	30.2919	35.5535	6901	*Citrullus lanatus*	Turkey, Tokat
PI171585	19.9597	49.4407	21.8662	38.4922	6928	*Citrullus lanatus*	Turkey, Tokat
PI171586	25.5929	38.9507	26.5508	38.9115	7232	*Citrullus lanatus*	Turkey, Erzurum
PI171587	27.5366	44.0901	29.1096	NA	7380	*Citrullus lanatus*	Turkey, Artvin
PI172787	25.2306	40.052	38.2676	38.7482	7403	*Citrullus lanatus*	Turkey, Trabzon
PI172788	21.4557	36.8629	30.0667	38.2505	7436	*Citrullus lanatus*	Turkey, Trabzon
PI172789	32.8955	35.4726	34.8584	33.7575	Dize	*Citrullus lanatus*	Turkey, Kars

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI172790	16.813	33.4648	36.49	34.7389	7542	*Citrullus lanatus*	Turkey, Kars
PI172791	23.0629	35.5607	80.0218	34.0289	7580	*Citrullus lanatus*	Turkey, Kars
PI172792	40.0442	36.5321	27.3694	30.0262	7592	*Citrullus lanatus*	Turkey, Kars
PI172793	26.25	35.418	17.6645	43.0907	Cit	*Citrullus lanatus*	Turkey, Van
PI172794	19.2619	34.2962	NA	30.6673	7791	*Citrullus lanatus*	Turkey, Van
PI172795	18.5973	36.0852	26.7306	35.1792	8040	*Citrullus lanatus*	Turkey, Diyarbakir
PI172796	35.4976	46.1278	28.3141	37.285	8109	*Citrullus lanatus*	Turkey, Mardin
PI172797	23.7164	56.7172	24.8435	34.1866	8120	*Citrullus lanatus*	Turkey, Mardin
PI172798	20.6865	29.8382	30.7416	25.003	8170	*Citrullus lanatus*	Turkey, Mardin
PI172800	24.4627	42.643	28.0662	36.3809	8251	*Citrullus lanatus*	Turkey, Urfa
PI172801	31.6594	29.9418	30.6706	42.2513	Kural	*Citrullus lanatus*	Turkey, Urfa
PI172802	30.3744	37.5771	33.3093	41.4688	8361	*Citrullus lanatus*	Turkey, Urfa
PI172803	24.6738	36.0131	23.4357	54.5264	8499	*Citrullus lanatus*	Turkey, Maras
PI172805	NA	42.4196	19.1702	NA	8561	*Citrullus lanatus*	Turkey, Malatya
PI173669	17.7094	33.0105	19.9985	40.2988	7993	*Citrullus lanatus*	Turkey, Bitlis
PI173670	19.8008	32.5979	29.9649	28.7485	8196	*Citrullus lanatus*	Turkey, Urfa
PI173888	26.5907	50.7157	28.6777	34.1914	Tarbuza	*Citrullus lanatus*	India, Uttar Pradesh

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI174098	NA	42.8076	25.9258	NA	7737	*Citrullus lanatus*	Turkey, Corum
PI174099	27.2714	36.235	29.3449	38.68	8018	*Citrullus lanatus*	Turkey, Elazig
PI174100	18.5803	36.4397	28.4013	33.3573	8040	*Citrullus lanatus*	Turkey, Diyarbakir
PI174101	21.5248	32.2887	29.9785	62.9772	Mercan	*Citrullus lanatus*	Turkey, Mardin
PI174103	NA	36.0674	24.0431	NA	Capli	*Citrullus lanatus*	Turkey, Mardin
PI174104	28.0907	30.9046	47.4469	34.4326	8301	*Citrullus lanatus*	Turkey, Urfa
PI174105	14.3068	37.2087	23.2911	32.0146	8405	*Citrullus lanatus*	Turkey, Gaziantep
PI174106	15.2684	35.0959	30.0388	41.6242	Kilis	*Citrullus lanatus*	Turkey, Gaziantep
PI174107	20.9964	32.034	34.2651	34.984	Alaca	*Citrullus lanatus*	Turkey, Malatya
PI174108	32.0708	42.4062	59.279	41.82	8673	*Citrullus lanatus*	Turkey, Malatya
PI174109	19.9953	33.097	26.0225	32.7722	8774	*Citrullus lanatus*	Turkey, Elazig
PI175102	24.9316	33.3712	30.9179	40.6384	Tarbuza	*Citrullus lanatus*	India, Uttar Pradesh
PI175650	18.9094	35.7105	24.8259	31.3033	Kurbagi Alacasi	*Citrullus lanatus*	Turkey, Balikesir
PI175651	23.2058	44.7052	28.3843	35.07	5463	*Citrullus lanatus*	Turkey, Balikesir
PI175652	25.1377	32.5454	29.2021	42.7949	5524	*Citrullus lanatus*	Turkey, Kastamonu
PI175653	22.6499	34.215	23.3404	31.9258	5718	*Citrullus lanatus*	Turkey, Diyarbakir
PI175654	16.6463	43.0179	32.5725	31.6059	5742	*Citrullus lanatus*	Turkey, Canakkale

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI175655	21.0336	27.7837	25.6543	34.5246	5964	*Citrullus lanatus*	Turkey, Canakkale
PI175656	19.2187	36.7822	39.4139	36.5949	6026	*Citrullus lanatus*	Turkey, Urfa
PI175657	20.5077	38.0367	22.6128	36.0636	6067	*Citrullus lanatus*	Turkey, Urfa
PI175658	29.8807	38.7627	27.4929	35.5044	9047	*Citrullus lanatus*	Turkey, Yozgat
PI175659	21.4174	33.6412	32.5089	43.9649	9074	*Citrullus lanatus*	Turkey, Kirsehir
PI175660	37.0097	44.4134	34.9265	39.2385	Yenidunya	*Citrullus lanatus*	Turkey, Kirsehir
PI175661	27.9295	38.1269	31.5389	NA	9096	*Citrullus lanatus*	Turkey, Kirsehir
PI175662	18.6545	29.5475	30.012	36.8977	9133	*Citrullus lanatus*	Turkey, Kayseri
PI175663	25.3948	33.6029	34.159	34.1802	9167	*Citrullus lanatus*	Turkey, Kayseri
PI175664	23.1396	43.4172	30.8925	28.7117	9178	*Citrullus lanatus*	Turkey, Kayseri
PI175665	19.7957	40.9081	18.9384	42.6909	9177	*Citrullus lanatus*	Turkey, Kayseri
PI176485	23.5119	36.0724	38.2565	37.7436	Beydan	*Citrullus lanatus*	Turkey, Tunceli
PI176486	14.8197	33.3866	45.6184	37.0148	8815	*Citrullus lanatus*	Turkey, Tunceli
PI176487	21.8321	33.5161	22.4185	36.8117	8840	*Citrullus lanatus*	Turkey, Tunceli
PI176488	18.3197	46.7767	22.4639	32.3059	8881	*Citrullus lanatus*	Turkey, Erzincan
PI176489	37.5398	44.1424	25.7037	40.5866	8958	*Citrullus lanatus*	Turkey, Sivas
PI176490	17.7598	37.8067	31.7519	33.1975	8960	*Citrullus lanatus*	Turkey, Sivas

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI176491	26.2043	48.895	NA	42.5989	8977	*Citrullus lanatus*	Turkey, Sivas
PI176492	28.7037	36.5391	40.5934	23.6714	9229	*Citrullus lanatus*	Turkey, Nigde
PI176493	29.2518	35.3463	26.7054	41.9278	9236	*Citrullus lanatus*	Turkey, Nigde
PI176494	40.6124	39.5155	62.9027	NA	9371	*Citrullus lanatus*	Turkey, Konya
PI176495	13.6626	30.7054	30.7066	37.2156	Yeniduna	*Citrullus lanatus*	Turkey, Konya
PI176496	26.1803	NA	28.1736	35.3317	9421	*Citrullus lanatus*	Turkey
PI176497	20.0311	39.7569	35.668	37.3149	9475	*Citrullus lanatus*	Turkey, Kutahya
PI176498	25.8994	34.1937	32.5878	36.9408	9568	*Citrullus lanatus*	Turkey, Eskisehir
PI176499	21.2089	35.1157	27.6304	39.5685	9572	*Citrullus lanatus*	Turkey, Eskisehir
PI176905	32.794	37.8049	29.3089	41.4762	2504	*Citrullus lanatus*	Turkey, Edirne
PI176906	14.4064	32.0165	23.4821	41.6271	5599	*Citrullus lanatus*	Turkey, Urfa
PI176907	19.0363	32.1767	39.9189	NA	5671	*Citrullus lanatus*	Turkey, Samsun
PI176908	24.3728	33.3361	20.149	30.9994	Kara Dumanli	*Citrullus lanatus*	Turkey, Edirne
PI176909	15.9714	36.5943	21.5089	39.7361	6137	*Citrullus lanatus*	Turkey, Edirne
PI176910	19.5681	33.6366	26.8169	41.5926	6150	*Citrullus lanatus*	Turkey, Canakkale
PI176912	29.0131	NA	26.5582	NA	9279	*Citrullus lanatus*	Turkey, Konya
PI176913	15.862	42.807	28.5299	31.0418	Kirkagac	*Citrullus lanatus*	Turkey, Konya

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI176914	31.4906	36.7341	25.0526	41.7651	9318	*Citrullus lanatus*	Turkey, Konya
PI176915	27.2963	36.4138	25.8443	30.9643	Konya Buz	*Citrullus lanatus*	Turkey, Konya
PI176916	22.8936	36.9415	23.3324	NA	Kirkagac	*Citrullus lanatus*	Turkey, Konya
PI176917	17.9661	30.5766	28.2633	34.8562	Kadin Budu	*Citrullus lanatus*	Turkey, Manisa
PI176918	22.8479	37.6171	34.261	33.611		*Citrullus lanatus*	Turkey, Manisa
PI176919	14.5747	48.8572	NA	30.622		*Citrullus lanatus*	Turkey, Manisa
PI176921	19.1022	34.7582	29.0785	NA	Kirkagac	*Citrullus lanatus*	Turkey, Manisa
PI176922	25.3438	44.9505	31.5631	35.4273		*Citrullus lanatus*	Turkey, Manisa
PI176923	15.7764	34.9247	NA	32.8652		*Citrullus lanatus*	Turkey
PI177318	17.3419	32.4257	64.9072	38.6956	4380	*Citrullus lanatus*	Turkey, Ankara
PI177319	12.3939	43.7911	NA	45.8581	4381	*Citrullus lanatus*	Turkey, Ankara
PI177320	24.3604	37.603	22.6976	26.283	4382	*Citrullus lanatus*	Turkey, Ankara
PI177322	27.8038	39.1184	NA	42.6613	4389	*Citrullus lanatus*	Turkey, Istanbul
PI177325	19.7087	37.7615	30.801	30.5365	6354	*Citrullus lanatus*	Turkey, Hakkari
PI177326	17.351	35.2568	NA	34.0137	Cegisdegi	*Citrullus lanatus*	Turkey, Hakkari
PI177327	25.0097	45.6806	28.3342	37.8456	6275	*Citrullus lanatus*	Turkey, Hakkari
PI177328	12.6286	45.9638	31.5365	40.4338	6277	*Citrullus lanatus*	Turkey, Hakkari

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI177329	25.7772	32.2752	22.3942	56.7562	6294	*Citrullus lanatus*	Turkey, Hakkari
PI177330	19.7595	30.591	23.2534	48.1438	9762	*Citrullus lanatus*	Syria
PI178870	21.4049	36.7751	29.9555	30.3165	5021	*Citrullus lanatus*	Turkey, Zonguldak
PI178871	13.1236	32.4401	16.8104	35.9856	Gecit	*Citrullus lanatus*	Turkey, Erzincan
PI178872	21.1096	32.478	26.0598	34.0465	Yenindunya	*Citrullus lanatus*	Turkey, Kutahya
PI178873	19.337	39.4204	NA	38.9396	9663	*Citrullus lanatus*	Turkey, Cankiri
PI178874	15.5147	34.5967	35.0372	32.4741	9690	*Citrullus lanatus*	Turkey, Cankiri
PI178876	9.9088	30.7411	26.6785	36.0922	Bostan	*Citrullus lanatus*	Turkey, Bursa
PI178877	17.5829	32.8283	35.5485	25.0933	10224	*Citrullus lanatus*	Turkey, Diyarbakir
PI179232	33.4145	33.8428	26.6661	33.5182	Cekirdegi	*Citrullus lanatus*	Turkey, Tekirdag
PI179233	26.7971	39.7941	NA	30.1944	Bostan Cekirdegi	*Citrullus lanatus*	Turkey, Bursa
PI179234	23.4816	NA	29.1891	45.2351	Yenidunya Cekirdegi	*Citrullus lanatus*	Turkey, Bursa
PI179235	20.6323	31.1649	24.2935	44.2974	Taygan	*Citrullus lanatus*	Turkey, Samsun
PI179236	12.8774	33.3785	25.7857	NA	5824	*Citrullus lanatus*	Turkey, Tekirdag
PI179237	11.3271	34.1502	32.4263	37.0243	5932	*Citrullus lanatus*	Turkey, Balikesir
PI179238	20.2146	39.5355	NA	NA	6035	*Citrullus lanatus*	Turkey, Canakkale
PI179239	24.528	NA	NA	31.3075	6106	*Citrullus lanatus*	Turkey, Tokat

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI179240	22.7883	38.4725	30.2319	27.7323	6127	*Citrullus lanatus*	Turkey, Edirne
PI179241	20.9164	47.8155	32.4722	37.2576	9874	*Citrullus lanatus*	Iraq
PI179242	17.7363	21.0205	29.2144	44.0294	9876	*Citrullus lanatus*	Iraq
PI179243	20.0832	39.2753	30.1361	NA	Cekirdegi	*Citrullus lanatus*	Turkey, Bursa
PI179661	15.7699	29.7179	28.4094	41.0636	Matira	*Citrullus lanatus*	India, Rajasthan
PI179662	NA	40.4602	25.0204	NA	Kolangra	*Citrullus lanatus*	India, Maharashtra
PI179876	12.7912	30.3688	33.2421	34.4058	Matira	*Citrullus lanatus*	India, Rajasthan
PI179877	15.6637	32.9735	NA	31.5587	Matira	*Citrullus lanatus*	India, Rajasthan
PI179878	24.2769	33.6382	35.8749	39.3665	Matira	*Citrullus lanatus*	India, Rajasthan
PI179880	13.2257	37.4239	35.7642	40.4432	Matira	*Citrullus lanatus*	India, Rajasthan
PI179881	20.4424	47.5902	32.6386	32.7351	Kalinga	*Citrullus amarus*	India, Gujarat
PI179882	17.1696	35.4073	25.0251	45.8004	Tarbuch	*Citrullus lanatus*	India, Gujarat
PI179883	21.5433	30.444	29.9085	38.3939	Tarbuch	*Citrullus lanatus*	India, Gujarat
PI179884	15.9082	30.9486	20.126	31.6955	Tarbuch	*Citrullus lanatus*	India, Gujarat
PI179885	14.8364	35.9236	38.3265	34.2083	Tarbuch	*Citrullus lanatus*	India, Gujarat
PI179886	15.8957	33.1999	37.268	51.7624	Tarbuch	*Citrullus lanatus*	India, Gujarat
PI180276	32.8577	46.1028	35.7669	37.6805	Matira	*Citrullus lanatus*	India, Rajasthan

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI180277	21.0922	37.015	34.1006	33.4817	Tarbuz	*Citrullus lanatus*	India, Gujarat
PI180278	14.5572	29.8762	NA	39.331	Kalinga	*Citrullus lanatus*	India, Gujarat
PI180426	25.0185	46.9743	NA	33.8743	Kolangra	*Citrullus lanatus*	India, Madhya Pradesh
PI180427	16.9746	33.1931	21.6541	34.6305	Tarbuza	*Citrullus lanatus*	India, Gujarat
PI181741	14.4613	43.5298	33.405	37.4553	Mohammad M. Jarrah	*Citrullus lanatus*	Lebanon
PI181742	17.5215	39.0429	30.1911	38.0964	Ahmad Sheikh	*Citrullus lanatus*	Lebanon
PI181743	24.4457	34.0474	29.9711	36.9778	Pasteque	*Citrullus lanatus*	Lebanon
PI181744	16.902	32.9188	38.4047	27.0804	9989	*Citrullus lanatus*	Lebanon
PI181868	27.8712	38.3619	39.1913	40.5148	Aleppo 13	*Citrullus lanatus*	Syria
PI181935	17.7367	36.1267	26.9376	38.8843	Homs No. 1	*Citrullus lanatus*	Syria
PI181936	23.8176	45.4859	28.3317	36.819	Homs No. 2	*Citrullus lanatus*	Syria
PI181937	27.7563	33.7302	37.5497	NA	Homs No. 3	*Citrullus lanatus*	Syria
PI181938	34.553	33.9126	26.8011	NA	Homs No. 4	*Citrullus lanatus*	Syria
PI182175	23.4089	33.2063	25.9098	39.3787	Zebes	*Citrullus lanatus*	Turkey, Mardin
PI182177	31.1615	41.2998	NA	39.8165	Tekke	*Citrullus lanatus*	Turkey, Kirklareli
PI182178	34.0418	43.1554	27.5907	31.8188	Tekkesehler	*Citrullus lanatus*	Turkey, Tekirdag
PI182179	NA	30.6564	25.9617	NA	10474	*Citrullus lanatus*	Turkey, Mardin

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI182180	16.2939	35.3514	23.3048	35.1936	10523	*Citrullus lanatus*	Turkey, Maras
PI182181	15.4145	26.7454	20.7908	42.6076	10580	*Citrullus lanatus*	Turkey, Balikesir
PI182183	23.5504	33.8669	27.5734	35.4169	10654	*Citrullus lanatus*	Turkey, Maras
PI182932	20.2582	33.6916	71.842	NA	Tarbuza	*Citrullus lanatus*	India, Maharashtra
PI182933	16.1082	44.2555	NA	29.6416	Tarbuch	*Citrullus lanatus*	India, Maharashtra
PI182934	27.5539	33.7129	48.1707	33.5119	Tarbuch	*Citrullus lanatus*	India, Maharashtra
PI182935	25.7153	39.1469	57.3524	36.693	Tarbuza	*Citrullus lanatus*	India, Madhya Pradesh
PI183022	21.6865	NA	NA	NA	Tarbuch	*Citrullus lanatus*	India, Maharashtra
PI183023	NA	NA	59.357	NA	Tarbuch	*Citrullus lanatus*	India, Maharashtra
PI183123	NA	29.0505	28.3052	NA	Tarbuch	*Citrullus lanatus*	India, Gujarat
PI183124	27.1822	34.4422	17.5579	NA	Tarbuch	*Citrullus lanatus*	India, Gujarat
PI183125	16.352	NA	29.1404	NA	Tarbuch	*Citrullus lanatus*	India, Maharashtra
PI183126	19.2437	36.9928	30.8541	35.6007	Tarbuch	*Citrullus lanatus*	India, Maharashtra
PI183218	24.031	35.6746	NA	43.6559	No. 2	*Citrullus lanatus*	Egypt, Giza
PI183299	12.6029	30.5441	26.7108	35.1166	Tarbuza	*Citrullus lanatus*	India, Madhya Pradesh
PI183300	12.9697	38.2056	30.8091	NA	Rakri Kumri	*Citrullus lanatus*	India, Madhya Pradesh
PI183398	12.6543	45.0326	NA	37.064	Tarbuch	*Citrullus lanatus*	India, Gujarat

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI183399	21.7105	38.7357	34.8565	31.555	Lakri Kumda	*Citrullus lanatus*	India, Madhya Pradesh
PI183673	26.219	35.3031	44.1079	30.3799	No. 10739	*Citrullus lanatus*	Turkey, Trabzon
PI184800	24.2189	39.4245	NA	33.8464	Egusi	*Citrullus mucosospermus*	Nigeria
PI185030	NA	33.241	36.5116	NA	No. 10911	*Citrullus lanatus*	Turkey, Erzincan
PI185636	12.0645	44.377	34.8149	32.0423		*Citrullus lanatus*	Ghana
PI186489	7.7018	28.9777	50.8599	29.0398	Egusi	*Citrullus mucosospermus*	Nigeria
PI186490	11.9418	37.0282	16.4286	27.7805	Egusi	*Citrullus mucosospermus*	Nigeria
PI186974	13.1241	27.7881	32.4659	32.3612		*Citrullus lanatus*	Ghana
PI186975	14.5212	47.1672	31.6529	36.5407	Egusi	*Citrullus mucosospermus*	Ghana
PI189225	13.987	48.6137	28.4454	19.2785	No. 1	*Citrullus amarus*	Zaire
PI189225	21.2019	48.6137	28.4454	19.2785	No. 1	*Citrullus amarus*	Zaire
PI189317	10.284	29.255	35.7385	31.8885	No. 69	*Citrullus lanatus*	Nigeria
PI189318	15.2429	41.0295	43.7701	NA	Egusi	*Citrullus mucosospermus*	Nigeria
PI190050	15.21	35.4978	23.9122	38.0085		*Citrullus lanatus*	Serbia
PI192937	15.0279	27.251	34.9328	25.8162	Greenskin Red	*Citrullus lanatus*	China, Shanghai
PI192938	15.8529	34.4082	35.6163	23.5156	Medium	*Citrullus lanatus*	China, Shanghai
PI193490	17.4659	39.333	25.1161	24.0218	Anguria a Seme Nero	*Citrullus lanatus*	Ethiopia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI193963	17.6299	35.876	39.0059	34.652	8669	*Citrullus lanatus*	Ethiopia
PI193964	26.5034	40.2426	36.634	38.3827	8670	*Citrullus lanatus*	Ethiopia
PI193965	16.8921	48.3415	20.9245	21.5336	8671	*Citrullus lanatus*	Ethiopia
PI195562	13.3263	31.146	34.1465	27.286	9616	*Citrullus lanatus*	Ethiopia
PI195771	13.0625	30.3608	18.4917	34.9687	2805	*Citrullus lanatus*	Guatemala, Izabal
PI195928	25.14	37.8141	20.982	NA	9617	*Citrullus lanatus*	Ethiopia
PI197416	NA	33.4982	35.728	NA	10223	*Citrullus lanatus*	Ethiopia
PI200732	15.8433	29.497	28.466	34.2966	3419	*Citrullus lanatus*	El Salvador
PI200733	9.6271	32.1534	23.3562	30.4155	3544	*Citrullus lanatus*	Guatemala, Alta Verapaz
PI203551	31.2267	36.4484	29.9615	NA		*Citrullus lanatus*	United States, New Mexico
PI207471	27.7463	49.4281	NA	NA	No. 12611	*Citrullus lanatus*	Afghanistan, Kabul
PI207472	17.2207	41.713	24.021	32.9121	No. 12655	*Citrullus lanatus*	Afghanistan, Kabul
PI207473	36.5689	45.5195	22.9617	36.7186	No. 12685	*Citrullus lanatus*	Afghanistan, Kabul
PI208740	17.8193	24.8009	19.4543	28.2745	No. 309	*Citrullus lanatus*	Cuba
PI211849	17.5189	29.8485	23.2469	36.6751	No. 1	*Citrullus lanatus*	Iran, Tehran
PI211851	22.5286	40.3654	NA	18.5052	No. 3	*Citrullus lanatus*	Iran, Tehran
PI211852	14.5373	35.9628	33.4879	30.651	No. 4	*Citrullus lanatus*	Iran, Tehran

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI211915	10.8105	29.5062	12.596	52.5807	No. 5	*Citrullus lanatus*	Iran, Tehran
PI211917	38.7015	34.5104	35.7521	NA	No. 7	*Citrullus lanatus*	Iran, Tehran
PI212094	24.3823	45.4145	40.8162	32.7241	13073	*Citrullus lanatus*	Afghanistan, Ghazni
PI212208	NA	49.5755	NA	NA	No. 1	*Citrullus lanatus*	Greece
PI212209	16.4789	32.961	33.3594	NA	No. 2	*Citrullus lanatus*	Greece
PI212287	22.1733	35.9706	25.0995	32.6399	No. 12923	*Citrullus lanatus*	Afghanistan, Herat
PI212288	19.8552	37.8407	60.7324	34.058	No. 12930	*Citrullus lanatus*	Afghanistan, Herat
PI212289	20.8681	38.6457	29.124	36.5591	No. 12948	*Citrullus lanatus*	Afghanistan, Herat
PI212596	17.0361	36.5293	26.2031	32.4191	No. 13102	*Citrullus lanatus*	Afghanistan
PI212983	17.4453	38.5589	25.7739	34.3879	No. 13423	*Citrullus lanatus*	India, Madhya Pradesh
PI214044	15.1754	33.5061	27.3585	30.6041	No. 13461	*Citrullus lanatus*	India, Karnataka
PI214316	28.9434	27.8078	30.8439	35.5224	No. 13681	*Citrullus lanatus*	India, Punjab
PI216029	14.1859	46.7699	44.2499	27.6424	13767	*Citrullus lanatus*	India, Delhi
PI217939	26.3566	31.63	NA	30.8982	14126	*Citrullus lanatus*	Pakistan
PI219691	28.4734	34.3553	32.6654	38.2155	14150	*Citrullus lanatus*	Pakistan
PI219906	16.3446	33.3721	24.2398	35.6681	Hindwanah	*Citrullus lanatus*	Afghanistan
PI219907	20.3583	38.4425	21.6279	40.5366	Tarboz	*Citrullus lanatus*	Afghanistan

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI220779	24.5181	49.5893	27.4958	37.1493	Terboz	*Citrullus lanatus*	Afghanistan
PI221430	15.9199	27.2637	31.5088	42.7663	Sharif Abad	*Citrullus lanatus*	Iran
PI222137	14.5355	43.1691	NA	39.9927	Pasteque	*Citrullus lanatus*	Algeria, Oran
PI222184	9.9819	31.7504	26.471	32.6567	755	*Citrullus lanatus*	Afghanistan, Kandahar
PI222711	16.8675	34.6772	36.0599	38.1292	Hendevaneh	*Citrullus lanatus*	Iran, West Azerbaijan
PI222712	28.3184	37.1475	34.3768	29.6558	Hendevaneh	*Citrullus lanatus*	Iran, West Azerbaijan
PI222713	13.9524	39.4768	25.7797	41.6315	Hendevaneh	*Citrullus lanatus*	Iran, Bakhtaran
PI222714	29.0662	31.9754	17.5558	35.8555	Hendevaneh	*Citrullus lanatus*	Iran, Bakhtaran
PI222715	16.1228	35.3273	32.5951	37.3517	Hendevaneh	*Citrullus lanatus*	Iran, Tehran
PI222775	22.7292	34.29	34.0013	30.8174	Kharbozeh	*Citrullus lanatus*	Iran
PI222776	15.8318	33.5484	28.3589	32.5939	Kharbozeh	*Citrullus lanatus*	Iran
PI223764	34.4314	33.7386	29.3533	43.4177	1148	*Citrullus lanatus*	Afghanistan, Badakhshan
PI223765	NA	NA	38.2245	NA	1190	*Citrullus lanatus*	Afghanistan, Badakhshan
PI225557	27.4032	34.6712	23.3056	22.4728	110	*Citrullus lanatus*	Zimbabwe
PI226445	18.8201	40.6624	32.2452	NA	Malali Improved	*Citrullus lanatus*	Israel, Tel Aviv
PI226459	25.0431	30.6683	NA	43.0825	Hendavanch Sharifabad	*Citrullus lanatus*	Iran
PI226506	24.9919	34.2078	NA	35.6984	Hindavana	*Citrullus lanatus*	Iran, Khuzestan

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI226634	25.43	35.5363	27.5068	41.7241	14786	*Citrullus lanatus*	Iran, Kerman
PI227202	11.4793	32.6223	23.4518	23.6438	Shin-yamato No.2	*Citrullus lanatus*	Japan, Shizuoka
PI227203	14.6646	32.2595	18.608	NA	Asahi-yamato	*Citrullus lanatus*	Japan, Shizuoka
PI227204	17.4612	28.8361	15.9754	38.0912	Otume	*Citrullus lanatus*	Japan, Aichi
PI227205	20.6975	40.9686	29.9058	NA	Shin-yamato	*Citrullus lanatus*	Japan, Aichi
PI227206	18.7657	37.9417	NA	42.5029	Asahi-yamato	*Citrullus lanatus*	Japan, Aichi
PI228237	16.9865	38.3677	26.7487	43.4101	Malali	*Citrullus lanatus*	Israel
PI228238	22.5785	33.4254	25.0933	31.7952	Malali	*Citrullus lanatus*	Israel
PI228342	25.6859	40.5355	35.693	36.412	15398	*Citrullus lanatus*	Iran, West Azerbaijan
PI229604	17.8496	36.9132	NA	30.9538	15757	*Citrullus lanatus*	Iran, Mazandaran
PI229605	29.1528	46.7252	25.8505	39.0312	15796	*Citrullus lanatus*	Iran, Mazandaran
PI229686	23.6926	33.0838	32.492	40.1321	15760	*Citrullus lanatus*	Iran, Mazandaran
PI229748	20.6092	32.1069	14.5533	37.7111	Anduvani	*Citrullus lanatus*	Iran, Mazandaran
PI229749	46.0198	38.0932	NA	NA	Anduvani	*Citrullus lanatus*	Iran, Mazandaran
PI234287	18.4688	32.8767	33.2153	34.5383		*Citrullus lanatus*	Portugal, Lisboa
PI234603	NA	30.8474	34.9735	NA		*Citrullus lanatus*	New Zealand, Auckland Islands
PI234605	17.7213	34.8639	65.0349	35.3574	Ong Hock Bee King of Melon	*Citrullus lanatus*	Singapore

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI240532	19.4729	27.4476	29.1354	30.4852		*Citrullus lanatus*	Iran, Hamadan
PI242906	26.1075	32.7699	37.5115	33.8006		*Citrullus lanatus*	Afghanistan, Kabul
PI244018	21.0581	31.1063	33.2714	9.3001	No. 2	*Citrullus amarus*	South Africa, Transvaal
PI244019	NA	34.9841	27.5081	NA	Delagoa	*Citrullus amarus*	South Africa, Transvaal
PI246029	13.827	39.5869	34.9026	NA	Sandia	*Citrullus lanatus*	Chile, Bio-Bio
PI246559	16.3605	34.9211	NA	34.9605	21003	*Citrullus lanatus*	Senegal
PI247398	8.9432	30.26	36.5467	34.2872	Astakon	*Citrullus mucosospermus*	Greece
PI247399	10.7643	31.6171	29.1636	37.3945	Manolados	*Citrullus lanatus*	Greece, Peloponnese
PI248178	NA	48.2333	34.2385	NA	Mangara	*Citrullus mucosospermus*	Zaire
PI248774	30.4769	NA	30.5073	NA	Summa	*Citrullus amarus*	Namibia
PI249009	10.8394	34.3149	27.5866	22.6037	Egusi	*Citrullus mucosospermus*	Nigeria, Kaduna
PI249010	8.9434	37.5008	40.8469	23.8507	57-478	*Citrullus lanatus*	Nigeria, Kaduna
PI249559	16.22	39.5245	15.866	20.9371	Teang-mo	*Citrullus lanatus*	Thailand
PI250146	20.5508	38.9181	49.212	36.2422	Tarbooz	*Citrullus lanatus*	Pakistan, Punjab
PI251515	31.9846	43.5857	23.3412	28.9096	Tukhm-Handayand	*Citrullus lanatus*	Iran, Esfahan
PI251796	8.3202	31.1165	24.9891	34.4709	17524	*Citrullus lanatus*	Serbia
PI253174	14.5633	30.8171	25.8857	33.3913	17492	*Citrullus lanatus*	Serbia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI254429	16.9632	35.9552	24.9065	32.6119	No. 2	*Citrullus lanatus*	Lebanon
PI254430	23.9512	42.5329	26.9157	54.1734	No. 3	*Citrullus lanatus*	Lebanon
PI254431	18.368	32.7419	27.4447	31.5917		*Citrullus lanatus*	Lebanon
PI254622	12.7425	42.9923	19.2991	33.2627	Bol El Homar	*Citrullus lanatus*	Sudan, Khartoum
PI254623	11.4865	34.1445	32.4145	34.7975	Nahudi	*Citrullus lanatus*	Sudan, Khartoum
PI254624	16.1076	36.8921	29.7003	42.1681	Red	*Citrullus lanatus*	Sudan, Khartoum
PI254716	11.0842	35.1347	29.0644	23.432	Melik	*Citrullus lanatus*	Sudan, Khartoum
PI254735	14.1557	28.6791	31.489	39.8458	Egusi	*Citrullus mucosospermus*	Senegal
PI254736	16.7892	31.9348	28.605	35.8179	Egusi	*Citrullus mucosospermus*	Senegal
PI254737	29.6106	32.6034	39.8967	41.2872	Egusi	*Citrullus mucosospermus*	Senegal
PI254738	27.8823	43.8838	NA	22.8294	B 5	*Citrullus lanatus*	Senegal
PI254739	16.6417	27.5429	33.8744	25.2753	B 6	*Citrullus lanatus*	Senegal
PI254740	17.1542	27.3856	20.0169	35.9673	Egusi	*Citrullus mucosospermus*	Senegal
PI254741	11.5929	31.7902	20.2845	33.2873	Egusi	*Citrullus mucosospermus*	Senegal
PI254742	9.9682	30.5876	24.1814	24.0099	Egusi	*Citrullus mucosospermus*	Senegal
PI254743	13.8574	17.5817	26.7161	28.3314	Egusi	*Citrullus mucosospermus*	Senegal
PI254744	14.5778	31.0974	24.986	27.7536	A 746	*Citrullus amarus*	Senegal

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI255137	22.23	31.4343	25.8321	12.7912	Large Tsamma	*Citrullus amarus*	South Africa, Transvaal
PI255139	6.3469	29.5613	24.9692	31.6605		*Citrullus lanatus*	South Africa
PI255662	14.7418	23.1142	30.0139	30.4648	K-1800	*Citrullus lanatus*	Afghanistan, Herat
PI260733	22.1369	39.2872	15.849	30.9484		*Citrullus lanatus*	Sudan, Khartoum
PI266015	9.5217	30.5248	12.6545	42.1101	59.1006 (4) (X)	*Citrullus lanatus*	Venezuela, Aragua
PI266025	19.7446	39.9989	17.6896	37.2757	59.1006 (20) (X)	*Citrullus lanatus*	Venezuela, Aragua
PI266027	28.2179	35.7701	25.0185	NA	59.1007 (1) (X)	*Citrullus lanatus*	Venezuela, Aragua
PI266028	19.7567	36.1819	20.0387	NA	59.1007 (2) (X)	*Citrullus lanatus*	Venezuela, Aragua
PI269464	15.8538	38.1175	19.415	31.5745	Tarbriza	*Citrullus lanatus*	Pakistan, North-West Frontier
PI269466	21.2641	37.7768	34.9975	33.8369	931	*Citrullus lanatus*	Pakistan, Northern Areas
PI269676	11.0639	30.0739	28.2453	40.931	Excell	*Citrullus lanatus*	Belize
PI269678	10.4199	38.8826	15.039	27.5711	Rattlesnake	*Citrullus lanatus*	Belize
PI269679	NA	37.5619	10.8288	NA	Rattlesnake	*Citrullus lanatus*	Belize
PI269680	11.6187	37.7565	25.1369	26.938	Sweetheart	*Citrullus lanatus*	Belize
PI270140	15.6766	50.1061	35.8428	NA	V13	*Citrullus lanatus*	India, Delhi
PI270144	NA	35.2131	25.7473	NA	Angelokastron	*Citrullus lanatus*	Greece
PI270145	NA	36.148	NA	NA	Manolados	*Citrullus lanatus*	Greece

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI270306	22.876	45.4325	30.0135	31.7752	No. 1	*Citrullus lanatus*	Philippines
PI270307	14.7325	34.1007	NA	33.4713	Filipino Red	*Citrullus lanatus*	Philippines
PI270309	19.5931	42.9883	32.5284	29.9986	No. 4	*Citrullus lanatus*	Philippines
PI270525	15.0837	40.3588	26.5123	35.2089	Malali	*Citrullus lanatus*	Israel
PI270545	16.873	47.4039	33.2276	42.0647		*Citrullus lanatus*	Sudan, Khartoum
PI270546	10.4137	49.5103	28.3253	NA	No. 1	*Citrullus lanatus*	Ghana, Capital District
PI270547	NA	39.839	29.8855	NA	No. 2	*Citrullus lanatus*	Ghana
PI270548	18.1637	36.6914	19.9328	NA	No. 3	*Citrullus lanatus*	Ghana
PI270549	14.1709	34.1272	NA	34.7152	No. 4	*Citrullus lanatus*	Ghana
PI270551	15.8439	30.7801	21.6411	29.8697	No. 6	*Citrullus lanatus*	Ghana
PI270562	NA	NA	24.382	NA	18633	*Citrullus amarus*	South Africa
PI270563	28.4549	30.8052	24.989	19.4662	Tsamma	*Citrullus amarus*	South Africa
PI270564	25.3482	32.6911	23.296	17.3392	18656	*Citrullus amarus*	South Africa
PI271446	NA	NA	22.5611	NA	NA	*NA*	NA
PI271747	32.131	40.0887	68.1045	40.0917	No. 1	*Citrullus lanatus*	Afghanistan, Helmand
PI271751	12.7796	44.655	28.2116	29.4087	No. 2	*Citrullus lanatus*	Ghana, Upper
PI271752	16.6522	30.5838	18.3218	21.6432	No. 3	*Citrullus lanatus*	Ghana, Central

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI271767	NA	NA	35.8413	NA	Tsamnia	*Citrullus amarus*	South Africa, Transvaal
PI271769	33.5563	20.9506	24.3368	29.183	Karkaer	*Citrullus amarus*	South Africa, Transvaal
PI271770	NA	NA	25.5367	NA	P.H.R.S. No. 16	*Citrullus amarus*	South Africa, Transvaal
PI271771	20.1277	48.8496	16.5899	36.9732	P.H.R.S. No. 17	*Citrullus amarus*	South Africa, Transvaal
PI271773	37.9022	31.2473	37.2959	23.9673	P.H.R.S. No. 19	*Citrullus amarus*	South Africa, Transvaal
PI271774	27.0826	51.2218	29.9719	29.1186	No. 4	*Citrullus lanatus*	South Africa, Transvaal
PI271775	14.7698	NA	30.7966	NA	Kaffir	*Citrullus amarus*	South Africa, Transvaal
PI271776	14.3965	33.341	32.8512	26.4591	No. W4-3	*Citrullus lanatus*	South Africa, Transvaal
PI271777	11.5108	37.9282	28.9663	31.8584	No. W4-4	*Citrullus lanatus*	South Africa, Transvaal
PI271778	21.4081	39.0208	24.8398	22.3301	No. 13	*Citrullus lanatus*	South Africa, Transvaal
PI271981	15.9915	31.484	38.2617	35.2622	No. 1	*Citrullus lanatus*	Somalia
PI271982	12.5545	30.8472	27.2836	31.7391	No. 2	*Citrullus lanatus*	Somalia
PI271983	14.1275	34.5526	29.1622	33.9094	No. 3	*Citrullus lanatus*	Somalia
PI271984	14.2117	34.4244	20.8378	39.4974	Campo Arviazioni No.1	*Citrullus lanatus*	Somalia
PI271985	16.9694	52.1177	23.3894	33.2391	Campo Arviazioni No.2	*Citrullus lanatus*	Somalia
PI273480	25.858	NA	NA	NA	No. 2	*Citrullus lanatus*	Ethiopia
PI273481	NA	38.2186	NA	NA	No. 3	*Citrullus lanatus*	Ethiopia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI274035	NA	NA	30.8837	NA	956	*Citrullus lanatus*	South Africa, Cape Province
PI274561	23.6001	36.815	NA	42.7754		*Citrullus lanatus*	Portugal
PI274785	18.0671	34.0069	27.4044	26.7071		*Citrullus lanatus*	India, Delhi
PI274794	22.6978	34.8343	28.3836	34.8068	Turmuz	*Citrullus lanatus*	Pakistan
PI274795	18.0587	39.143	32.6734	29.7205	Turmuz	*Citrullus lanatus*	Pakistan
PI275628	30.6211	38.2644	33.3292	36.6151	702	*Citrullus lanatus*	Pakistan, Northern Areas
PI275631	NA	43.2061	NA	NA	1348-A	*Citrullus lanatus*	India, Rajasthan
PI275632	16.758	34.2897	27.6967	41.6833	1350-A	*Citrullus lanatus*	India, Rajasthan
PI276444	21.9654	33.0125	22.3911	39.1733	Baladi	*Citrullus lanatus*	Jordan
PI276445	20.8983	34.3116	NA	34.3922	Jadouhi	*Citrullus lanatus*	Jordan
PI276657	22.731	39.2715	28.4771	27.8478	Bykovshij 23	*Citrullus lanatus*	Russian Federation
PI276658	23.9028	28.852	26.7658	NA	No. 3749	*Citrullus lanatus*	Russian Federation
PI276659	21.0588	34.6031	26.7268	34.3973	No. 3868	*Citrullus lanatus*	Russian Federation
PI277279	10.6118	30.9538	31.4888	39.0317	Tarmuj	*Citrullus lanatus*	India
PI277970	17.3904	36.3116	60.8924	38.9888	No. 1	*Citrullus lanatus*	Turkey, Adiyaman
PI277971	17.8107	27.696	29.1406	37.5962	No. 2	*Citrullus lanatus*	Turkey, Adiyaman
PI277972	24.7413	37.7291	28.3238	30.421	No. 3	*Citrullus lanatus*	Turkey, Adiyaman

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI277973	21.9016	37.621	28.2878	27.4656	No. 4	*Citrullus lanatus*	Turkey, Adiyaman
PI277974	20.1075	41.9251	33.241	35.0282	No. 5	*Citrullus lanatus*	Turkey, Adiyaman
PI277975	22.5122	34.5022	33.3154	32.2576	No. 6	*Citrullus lanatus*	Turkey, Adiyaman
PI277976	22.4986	31.0728	21.7383	29.8614	No. 7	*Citrullus lanatus*	Turkey, Adiyaman
PI277977	15.2816	34.6599	28.9554	NA	No. 8	*Citrullus lanatus*	Turkey, Afyon
PI277978	21.4648	34.0636	NA	35.0202	No. 9	*Citrullus lanatus*	Turkey, Afyon
PI277979	30.6468	32.222	35.7402	36.4673	No. 10	*Citrullus lanatus*	Turkey, Afyon
PI277980	18.5401	33.83	33.2566	41.5656	No. 11	*Citrullus lanatus*	Turkey, Amasya
PI277981	20.4098	33.4373	23.3295	35.6626	No. 12	*Citrullus lanatus*	Turkey, Ankara
PI277982	12.2957	34.1786	27.545	28.8515	No. 13	*Citrullus lanatus*	Turkey, Antalya
PI277984	22.9931	39.1644	26.5396	35.8084	No. 15	*Citrullus lanatus*	Turkey, Antalya
PI277985	27.387	40.0624	28.3565	34.4113	No. 16	*Citrullus lanatus*	Turkey, Artvin
PI277986	28.7565	21.5625	27.6923	28.7266	No. 17	*Citrullus lanatus*	Turkey, Aydin
PI277987	18.8427	32.61	23.1807	34.9656	No. 18	*Citrullus lanatus*	Turkey, Aydin
PI277988	27.2878	33.9307	NA	42.364	No. 19	*Citrullus lanatus*	Turkey, Aydin
PI277989	25.8005	41.6781	NA	37.9767	No. 20	*Citrullus lanatus*	Turkey, Aydin
PI277990	19.6098	40.9529	27.4208	34.9894	No. 21	*Citrullus lanatus*	Turkey, Aydin

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI277992	17.2482	30.1938	30.8975	35.1866	No. 23	*Citrullus lanatus*	Turkey, Balikesir
PI277993	25.8792	36.4517	NA	34.9298	No. 24	*Citrullus lanatus*	Turkey, Bilecik
PI277994	19.7228	38.4624	22.4333	31.0456	No. 25	*Citrullus lanatus*	Turkey, Bilecik
PI277995	24.2041	31.5645	35.0352	34.8764	No. 26	*Citrullus lanatus*	Turkey, Bilecik
PI277996	26.1443	47.5782	30.8453	31.2181	No. 27	*Citrullus lanatus*	Turkey, Bitlis
PI277997	25.9524	45.2821	31.0792	31.7716	No. 28	*Citrullus lanatus*	Turkey, Bingol
PI277998	18.1306	40.0718	29.1617	36.9456	No. 29	*Citrullus lanatus*	Turkey, Bolu
PI277999	15.7974	33.4009	39.1279	30.5446	No. 30	*Citrullus lanatus*	Turkey, Bolu
PI278000	17.1631	36.18	30.4342	30.9899	No. 31	*Citrullus lanatus*	Turkey, Burdur
PI278001	13.6105	41.8117	29.2376	NA	No. 32	*Citrullus lanatus*	Turkey, Bursa
PI278002	22.0927	49.0107	NA	31.6597	No. 33	*Citrullus lanatus*	Turkey, Bursa
PI278003	15.1367	35.8453	29.25	35.5521	No. 34	*Citrullus lanatus*	Turkey, Bursa
PI278004	28.5279	35.8165	26.3391	45.2406	No. 35	*Citrullus lanatus*	Turkey, Bursa
PI278005	28.1323	37.0324	30.9531	31.2767	No. 36	*Citrullus lanatus*	Turkey, Canakkale
PI278006	26.8589	37.1695	32.7029	34.3077	No. 37	*Citrullus lanatus*	Turkey, Gaziantep
PI278007	30.1293	33.0967	NA	37.6628	No. 38	*Citrullus lanatus*	Turkey, Gaziantep
PI278008	27.3364	29.7084	21.7269	38.1634	No. 39	*Citrullus lanatus*	Turkey, Gaziantep

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI278009	17.1045	36.9453	29.078	34.4709	No. 40	*Citrullus lanatus*	Turkey, Gaziantep
PI278010	19.9627	28.0502	34.2021	32.2363	No. 41	*Citrullus lanatus*	Turkey, Gaziantep
PI278011	23.1403	37.3596	NA	29.9954	No. 42	*Citrullus lanatus*	Turkey, Gaziantep
PI278012	19.0543	42.6572	31.6239	32.2734	No. 43	*Citrullus lanatus*	Turkey, Gaziantep
PI278013	18.9805	39.4335	30.3034	38.1712	No. 44	*Citrullus lanatus*	Turkey, Hatay
PI278014	30.2842	32.6074	NA	41.3977	No. 45	*Citrullus lanatus*	Turkey, Hatay
PI278016	14.9644	37.3982	27.3743	35.278	No. 47	*Citrullus lanatus*	Turkey, Izmir
PI278017	21.6026	35.0276	NA	31.8936	No. 48	*Citrullus lanatus*	Turkey, Izmir
PI278018	21.164	53.8413	30.9634	35.7938	No. 49	*Citrullus lanatus*	Turkey, Izmir
PI278019	17.9286	44.567	26.9505	39.5981	No. 50	*Citrullus lanatus*	Turkey, Izmir
PI278020	20.721	41.5642	NA	29.7422	No. 51	*Citrullus lanatus*	Turkey, Izmir
PI278021	23.6057	31.8118	27.2005	44.0032	No. 52	*Citrullus lanatus*	Turkey, Kars
PI278022	NA	34.3465	36.4026	NA	No. 53	*Citrullus lanatus*	Turkey, Kars
PI278023	16.5528	35.532	30.8061	40.6681	No. 54	*Citrullus lanatus*	Turkey, Kars
PI278024	24.3179	39.1086	28.3276	37.6819	No. 55	*Citrullus lanatus*	Turkey, Kayseri
PI278025	18.6662	32.092	26.1336	27.2203	No. 56	*Citrullus lanatus*	Turkey, Kirklareli
PI278026	25.5715	37.0808	NA	36.17	No. 57	*Citrullus lanatus*	Turkey, Kirklareli

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI278027	28.2265	38.0355	22.7485	45.6552	No. 58	*Citrullus lanatus*	Turkey, Kirklareli
PI278028	18.584	35.446	22.8404	25.3115	No. 59	*Citrullus lanatus*	Turkey, Kirklareli
PI278029	29.4116	33.982	32.5107	28.0743	No. 60	*Citrullus lanatus*	Turkey, Kirklareli
PI278030	22.9029	33.002	22.6675	NA	No. 61	*Citrullus lanatus*	Turkey, Kirsehir
PI278031	29.773	34.9146	NA	37.7292	No. 62	*Citrullus lanatus*	Turkey, Kirsehir
PI278034	27.4295	35.1309	32.3882	30.3884	No. 65	*Citrullus lanatus*	Turkey, Maras
PI278036	25.9545	29.3832	35.9038	33.4049	No. 68	*Citrullus lanatus*	Turkey, Mardin
PI278037	28.0185	29.432	22.5998	NA	No. 69	*Citrullus lanatus*	Turkey, Mardin
PI278040	7.232	33.5649	27.5764	35.2531	No. 72	*Citrullus lanatus*	Turkey, Mugla
PI278041	18.6231	35.5015	28.3482	38.4778	No. 73	*Citrullus lanatus*	Turkey, Mugla
PI278042	39.7296	33.6708	32.6008	36.8629	No. 74	*Citrullus lanatus*	Turkey, Mugla
PI278043	20.357	31.6822	29.8583	28.3492	No. 75	*Citrullus lanatus*	Turkey, Mugla
PI278044	19.2944	33.3043	27.4656	35.9563	No. 76	*Citrullus lanatus*	Turkey, Mugla
PI278045	26.6869	34.5728	38.3613	17.6853	No. 77	*Citrullus lanatus*	Turkey, Mus
PI278046	15.3723	30.0612	NA	37.0339	No. 78	*Citrullus lanatus*	Turkey, Nigde
PI278047	33.821	32.9642	27.4268	34.2124	No. 79	*Citrullus lanatus*	Turkey, Sakarya
PI278049	18.1043	36.6387	NA	35.4419	No. 81	*Citrullus lanatus*	Turkey, Sinop

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI278050	20.0921	30.7204	30.1576	37.3583	No. 82	*Citrullus lanatus*	Turkey, Sivas
PI278051	26.2289	36.3589	24.892	25.0271	No. 83	*Citrullus lanatus*	Turkey, Sivas
PI278052	30.561	34.3943	39.7378	28.2155	No. 84	*Citrullus lanatus*	Turkey, Sivas
PI278053	18.2311	31.1216	28.1012	34.3205	No. 85	*Citrullus lanatus*	Turkey, Tunceli
PI278054	18.2875	34.1648	22.7678	33.5161	No. 86	*Citrullus lanatus*	Turkey, Tunceli
PI278055	11.8191	32.5908	17.5152	52.1185	No. 87	*Citrullus lanatus*	Turkey, Tunceli
PI278057	14.2519	31.0655	34.0951	35.7888	No. 89	*Citrullus lanatus*	Turkey, Urfa
PI278058	NA	31.4868	19.976	NA	No. 90	*Citrullus lanatus*	Turkey, Usak
PI278060	22.926	34.7379	NA	39.8864	No. 92	*Citrullus lanatus*	Turkey, Yozgat
PI278061	24.5338	34.0082	29.3262	45.024	No. 93	*Citrullus lanatus*	Turkey, Yozgat
PI278062	33.9481	47.4446	26.5151	28.0391	No. 95	*Citrullus lanatus*	Turkey, Zonguldak
PI279456	13.2164	34.2144	NA	42.0869	Strain II	*Citrullus lanatus*	Japan
PI279458	16.1907	32.1624	31.8936	38.425	Strain II	*Citrullus lanatus*	Japan
PI279459	15.8462	34.3652	24.3017	36.6733	Strain II	*Citrullus lanatus*	Japan
PI279460	20.6058	37.3575	24.1197	33.9598	Strain I	*Citrullus lanatus*	Japan
PI279461	15.8394	32.6784	38.4712	34.022	Strain II	*Citrullus lanatus*	Japan
PI279462	11.2529	35.0386	22.3674	29.3197	Strain III	*Citrullus lanatus*	Japan

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI288232	22.1681	30.9511	25.7914	48.9646	Freska	*Citrullus lanatus*	Egypt
PI288317	17.5202	34.5385	26.9244	35.1727	353	*Citrullus lanatus*	India, Rajasthan
PI288522	30.7474	49.7896	19.9671	37.3561	281	*Citrullus lanatus*	India, Gujarat
PI290855	17.1009	41.2586	24.2979	28.0967	WILLS SUGAR MELON	*Citrullus lanatus*	United States
PI293765	10.1333	33.5454	21.6368	36.2082	1336	*Citrullus lanatus*	Soviet Union, Former
PI293766	15.0927	29.64	24.8863	26.9038	1340	*Citrullus lanatus*	Soviet Union, Former
PI295842	16.0582	24.0093	NA	25.9857	DL/64/83	*Citrullus amarus*	South Africa
PI295843	9.8979	31.6632	19.2971	24.0187	DL/64/78	*Citrullus amarus*	South Africa
PI295845	15.9432	34.0698	49.2025	25.7692	DL/64/85	*Citrullus lanatus*	South Africa
PI295850	NA	NA	28.3355	NA	DL/61/82	*Citrullus amarus*	South Africa
PI296334	23.5892	43.1367	30.8301	33.3674	Makatan	*Citrullus amarus*	South Africa, Limpopo
PI296335	40.4989	30.6633	26.6754	NA	DL/64/187	*Citrullus amarus*	South Africa, KwaZulu-Natal
PI296337	NA	NA	27.5223	NA	Tsamma	*Citrullus amarus*	South Africa, Cape Province
PI296339	27.3891	27.1048	33.1995	26.278	Tsamma	*Citrullus amarus*	South Africa, Cape Province
PI296341	37.8602	NA	23.2777	NA	Tsamma	*Citrullus amarus*	South Africa, Cape Province
PI296342	15.9137	NA	25.9852	NA	Tsamma	*Citrullus amarus*	South Africa, Cape Province
PI296343	NA	NA	28.4674	NA	Tsamma	*Citrullus amarus*	South Africa, Cape Province

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI299378	24.2131	27.8913	33.2576	26.7517	DL/64/489	*Citrullus amarus*	South Africa, Cape Province
PI299379	30.9677	34.4793	19.2752	23.8409	DL/64/490	*Citrullus amarus*	South Africa, Cape Province
PI299563	20.1268	41.5399	34.1772	20.2375	Amakeba	*Citrullus lanatus*	South Africa
PI306364	NA	38.5233	23.4501	NA	Foobao	*Citrullus lanatus*	Gabon
PI306365	20.401	NA	27.2892	NA	Fookwang	*Citrullus lanatus*	Gabon
PI306366	13.6285	36.9356	25.9603	20.7689	Tiho	*Citrullus lanatus*	Gabon
PI306782	11.3055	34.222	53.4286	37.5773	Egusi	*Citrullus mucosospermus*	Nigeria
PI307608	18.1932	31.4252	22.6167	39.627		*Citrullus lanatus*	Nigeria
PI307609	6.853	36.367	14.3421	38.5675		*Citrullus lanatus*	Nigeria
PI307748	22.3366	36.1462	27.2981	37.0104	CA 2561	*Citrullus lanatus*	Philippines
PI307749	15.0575	29.0185	27.4417	29.1933	530	*Citrullus lanatus*	Philippines
PI307750	17.4172	36.2087	24.1682	40.4851	528	*Citrullus lanatus*	Philippines, Luzon
PI314148	34.3081	29.4632	32.1341	37.8331	Moziac	*Citrullus lanatus*	Uzbekistan, Samarqand
PI314178	19.7434	31.5163	24.9998	33.3985	55	*Citrullus lanatus*	Uzbekistan, Farghona
PI314655	19.0402	32.1011	25.7149	44.3684	369	*Citrullus lanatus*	Uzbekistan
PI319235	10.8228	33.1632	34.1291	33.3627	No. 1	*Citrullus lanatus*	Japan
PI319236	14.5215	28.7588	19.9321	31.4354	No. 2	*Citrullus lanatus*	Japan

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI319237	NA	30.4202	18.3965	NA	No. 3	*Citrullus lanatus*	Japan
PI320988	18.4795	37.5074	29.9805	NA	SWEET SENSATION	*Citrullus lanatus*	Sierra Leone
PI325248	19.1538	39.0935	35.9921	33.4682	S-121	*Citrullus lanatus*	Soviet Union, Former
PI326516	16.779	46.497	30.0861	34.106	Egusi	*Citrullus mucosospermus*	Ghana
PI331106	12.5336	34.5518	24.8207	28.9805	29	*Citrullus lanatus*	Uruguay, Tacuarembo
PI344066	21.0071	42.8353	30.1273	38.2056	22673	*Citrullus lanatus*	Turkey, Gaziantep
PI344298	13.4267	35.9169	42.5115	44.5211	Kagen Budu	*Citrullus lanatus*	Turkey, Izmir
PI344300	26.0169	50.2079	29.1613	35.4267	91	*Citrullus lanatus*	Turkey, Mus
PI344301	21.3653	43.5823	NA	41.2143	182	*Citrullus lanatus*	Turkey, Antalya
PI344395	24.3403	38.7219	41.5906	34.2502	Ganaghan	*Citrullus lanatus*	Iran
PI345544	20.3284	31.0778	19.9065	23.027	Melitopol Skij 60	*Citrullus lanatus*	Ukraine
PI345545	15.7698	35.1607	33.3196	30.3379	Ogonek	*Citrullus lanatus*	Ukraine
PI345546	30.5982	52.2153	34.2596	21.3215	Roza Jugo vostoka	*Citrullus lanatus*	Soviet Union, Former
PI346787	21.2999	32.9454	25.9635	40.1821		*Citrullus lanatus*	Serbia
PI357656	20.6254	35.256	NA	38.7601	Crn brzak	*Citrullus lanatus*	Macedonia
PI357657	17.4296	25.1741	28.5123	32.1184	Saren brzak	*Citrullus lanatus*	Macedonia
PI357659	20.6848	48.027	28.483	32.1796	Bela zimska	*Citrullus lanatus*	Macedonia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI357662	19.4964	35.3649	34.0309	29.76	18	*Citrullus lanatus*	Macedonia
PI357663	NA	44.7006	23.5238	NA	21	*Citrullus lanatus*	Macedonia
PI357664	17.119	34.6507	19.1719	30.9183	23	*Citrullus lanatus*	Macedonia
PI357665	25.8243	28.6155	31.606	44.5678	25	*Citrullus lanatus*	Macedonia
PI357671	22.5475	39.4049	65.7394	35.6456	33	*Citrullus lanatus*	Macedonia
PI357673	17.9198	32.6978	32.5663	29.5914	51	*Citrullus lanatus*	Macedonia
PI357674	19.55	30.6125	31.0255	29.0484	71	*Citrullus lanatus*	Macedonia
PI357675	33.3042	37.2965	28.1987	32.1305	89	*Citrullus lanatus*	Macedonia
PI357678	18.2396	32.0296	29.0217	30.5722	92	*Citrullus lanatus*	Macedonia
PI357679	21.8906	45.3479	35.0371	25.3152	96	*Citrullus lanatus*	Macedonia
PI357680	27.056	29.4622	41.5866	NA	97	*Citrullus lanatus*	Macedonia
PI357682	26.8127	50.9017	34.1929	29.34		*Citrullus lanatus*	Macedonia
PI357684	21.0828	33.2318	21.5511	34.5471	122	*Citrullus lanatus*	Macedonia
PI357685	21.3123	31.7185	35.8327	43.2367	123	*Citrullus lanatus*	Macedonia
PI357686	27.936	43.8846	29.113	NA	131	*Citrullus lanatus*	Macedonia
PI357687	18.2237	39.2169	NA	37.0721	138	*Citrullus lanatus*	Macedonia
PI357689	19.1374	34.4733	29.5868	35.5169	145	*Citrullus lanatus*	Macedonia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI357691	23.5502	45.1847	26.7159	39.0782	170	*Citrullus lanatus*	Macedonia
PI357692	18.0623	40.1448	30.6993	32.3439	171	*Citrullus lanatus*	Macedonia
PI357694	21.6801	31.3332	27.439	31.1949	174	*Citrullus lanatus*	Macedonia
PI357695	24.369	30.1695	18.2765	37.2777	177	*Citrullus lanatus*	Macedonia
PI357696	19.0826	31.0556	39.2079	30.2466	218	*Citrullus lanatus*	Macedonia
PI357697	24.1521	37.2999	NA	36.5015	219	*Citrullus lanatus*	Macedonia
PI357698	20.7233	35.9914	23.1376	38.9058	220	*Citrullus lanatus*	Macedonia
PI357699	14.3419	34.4887	28.2666	37.9114	221	*Citrullus lanatus*	Macedonia
PI357700	23.1297	39.3148	58.4349	26.4997	228	*Citrullus lanatus*	Macedonia
PI357701	26.1593	36.9922	33.2152	43.2567	229	*Citrullus lanatus*	Macedonia
PI357702	22.9757	32.2224	23.4262	36.3731	237	*Citrullus lanatus*	Macedonia
PI357703	31.7697	36.5056	28.8033	35.3837	238	*Citrullus lanatus*	Macedonia
PI357704	26.5554	30.2448	34.0036	32.5416	239	*Citrullus lanatus*	Macedonia
PI357705	21.9338	31.6522	25.8698	NA	266	*Citrullus lanatus*	Macedonia
PI357708	17.1708	37.9436	29.3247	40.1024	269	*Citrullus lanatus*	Macedonia
PI357710	25.0907	41.7949	33.1918	NA	278	*Citrullus lanatus*	Macedonia
PI357711	23.9954	40.5692	35.0418	39.3167	283	*Citrullus lanatus*	Macedonia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI357716	26.5546	38.5072	NA	35.9698	322	*Citrullus lanatus*	Macedonia
PI357717	27.0398	34.4987	28.421	39.5198	323	*Citrullus lanatus*	Macedonia
PI357718	20.8389	40.195	31.8228	33.6068	324	*Citrullus lanatus*	Macedonia
PI357719	18.5905	39.3331	24.9839	44.0196	325	*Citrullus lanatus*	Macedonia
PI357720	15.7381	34.6775	30.7312	33.5996	420	*Citrullus lanatus*	Macedonia
PI357721	14.5679	42.8583	33.9564	32.3252	421	*Citrullus lanatus*	Macedonia
PI357722	13.3825	47.0058	31.6897	NA	441	*Citrullus lanatus*	Macedonia
PI357723	18.9646	39.7243	19.1119	41.6682	457	*Citrullus lanatus*	Macedonia
PI357724	22.5977	38.8996	21.7444	30.5306	458	*Citrullus lanatus*	Macedonia
PI357725	23.9151	35.7938	59.092	33.7584	459	*Citrullus lanatus*	Macedonia
PI357726	26.2613	38.0172	28.4393	32.0892	468	*Citrullus lanatus*	Macedonia
PI357729	18.0384	32.6024	21.6205	33.3095	499	*Citrullus lanatus*	Macedonia
PI357730	22.5189	38.9512	21.591	34.0727	523	*Citrullus lanatus*	Macedonia
PI357731	24.3512	38.5517	30.7904	NA	530	*Citrullus lanatus*	Macedonia
PI357732	28.2343	37.5694	NA	39.6911	531	*Citrullus lanatus*	Macedonia
PI357733	21.8925	37.3826	28.5802	36.6319	678	*Citrullus lanatus*	Macedonia
PI357734	27.1518	36.9295	24.2277	38.9705	710	*Citrullus lanatus*	Macedonia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI357735	17.4773	32.1546	29.1964	36.4966	763	*Citrullus lanatus*	Macedonia
PI357736	24.9362	33.6201	22.5471	35.0954	851	*Citrullus lanatus*	Macedonia
PI357739	19.9882	39.7476	29.1131	34.4943	878	*Citrullus lanatus*	Macedonia
PI357740	19.9783	36.3021	33.8493	37.8614	968	*Citrullus lanatus*	Macedonia
PI357742	24.8799	38.7168	34.9156	NA	999	*Citrullus lanatus*	Macedonia
PI357744	24.6062	36.9779	25.6995	NA	1022	*Citrullus lanatus*	Macedonia
PI357745	27.3854	38.7137	22.8555	17.5711	1026	*Citrullus lanatus*	Macedonia
PI357746	23.8148	37.1795	23.3303	39.783	1031	*Citrullus lanatus*	Former Serbia and Montenegro
PI357747	20.5828	32.8047	30.8327	35.3958	1036	*Citrullus lanatus*	Macedonia
PI357750	25.0278	33.4926	33.3235	34.3526	1049	*Citrullus lanatus*	Macedonia
PI357751	16.7141	36.4232	26.0778	39.9426	1114	*Citrullus lanatus*	Macedonia
PI357752	22.9597	33.73	64.9041	31.1954	115	*Citrullus lanatus*	Macedonia
PI357753	25.6435	35.8207	21.878	33.4524	1122	*Citrullus lanatus*	Macedonia
PI357754	13.9312	33.1406	33.4807	32.0132	1140	*Citrullus lanatus*	Macedonia
PI364460	14.5141	19.2892	31.5584	29.9075	1634	*Citrullus lanatus*	South Africa, Limpopo
PI368493	23.2189	41.8477	18.8353	31.8882	1184	*Citrullus lanatus*	Macedonia
PI368494	18.6871	33.9059	28.4133	34.3622	1221	*Citrullus lanatus*	Macedonia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI368496	29.0512	40.0789	37.9712	37.5652	1223	*Citrullus lanatus*	Macedonia
PI368497	24.9717	36.8665	15.9824	43.3492	1224	*Citrullus lanatus*	Macedonia
PI368498	27.5738	41.8164	19.9563	33.3387	1225	*Citrullus lanatus*	Macedonia
PI368499	29.9033	35.5704	27.5829	35.0645	1226	*Citrullus lanatus*	Macedonia
PI368501	24.4665	33.6561	32.284	NA	1252	*Citrullus lanatus*	Macedonia
PI368504	14.7803	46.3084	29.9614	35.3551	1289	*Citrullus lanatus*	Macedonia
PI368505	26.8787	33.454	15.0412	39.5361	1306	*Citrullus lanatus*	Macedonia
PI368506	20.4504	31.8043	30.793	31.1405	1310	*Citrullus lanatus*	Macedonia
PI368507	22.9515	40.1305	38.3559	33.2431	1311	*Citrullus lanatus*	Macedonia
PI368508	NA	31.5651	33.4957	NA	1321	*Citrullus lanatus*	Macedonia
PI368509	27.2457	46.1756	29.9546	33.1508	1398	*Citrullus lanatus*	Macedonia
PI368512	12.9379	31.2405	27.3479	34.0541	1457	*Citrullus lanatus*	Former Serbia and Montenegro
PI368513	14.9807	34.3335	30.6798	30.7831	1458	*Citrullus lanatus*	Former Serbia and Montenegro
PI368514	19.921	36.1935	28.2523	30.915	1474	*Citrullus lanatus*	Macedonia
PI368515	21.7153	35.2058	14.019	NA	1481	*Citrullus lanatus*	Macedonia
PI368516	12.6906	37.1813	23.2859	22.6368	1482	*Citrullus lanatus*	Macedonia
PI368518	19.3152	33.1891	33.4401	41.8816	1509	*Citrullus lanatus*	Macedonia

Cultigen	**Race 1 Greenhouse**	**Race 1 Chambers**	**Race 1 Field**	**Race 2 Greenhouse**	**Plant.Name**	**Taxonomy**	**Origin**
PI368519	22.6847	32.1825	33.3577	34.5089	1510	*Citrullus lanatus*	Macedonia
PI368520	22.3568	44.5214	29.1813	32.4096	1511	*Citrullus lanatus*	Macedonia
PI368521	25.6196	40.1232	34.2034	37.7299	1512	*Citrullus lanatus*	Macedonia
PI368522	20.9313	33.2903	23.3109	31.145	1531	*Citrullus lanatus*	Macedonia
PI368524	20.1044	38.799	29.7838	40.5641	1539	*Citrullus lanatus*	Montenegro
PI368525	37.7952	42.8181	23.5402	28.2607	1540	*Citrullus lanatus*	Montenegro
PI368526	39.7455	45.8228	40.8554	35.7828	1541	*Citrullus lanatus*	Montenegro
PI368527	13.8599	31.7925	25.1786	34.3751	1542	*Citrullus lanatus*	Montenegro
PI368528	14.2106	32.9595	27.4998	33.1217	1550	*Citrullus lanatus*	Macedonia
PI368529	21.3163	40.2607	20.9057	37.9836	1593	*Citrullus lanatus*	Macedonia
PI369220	17.994	33.8236	23.407	NA	1693	*Citrullus lanatus*	Soviet Union, Former
PI370015	19.0457	31.5136	20.8678	40.8033	Ci. 70-01	*Citrullus lanatus*	India
PI370422	25.0579	47.2882	29.8544	37.484	1845	*Citrullus lanatus*	Serbia
PI370423	21.8253	36.1881	29.1381	31.0186	1861	*Citrullus lanatus*	Macedonia
PI370424	21.4926	35.24	24.2171	35.2699	1866	*Citrullus lanatus*	Macedonia
PI370425	29.8335	36.0206	24.2577	35.0402	1882	*Citrullus lanatus*	Macedonia
PI370427	16.6716	39.7897	32.5862	40.6173	1996	*Citrullus lanatus*	Macedonia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI370429	17.7325	31.3145	24.5963	34.703	2001	*Citrullus lanatus*	Macedonia
PI370431	23.4766	33.6094	NA	38.1757	2046	*Citrullus lanatus*	Macedonia
PI370433	18.8707	37.9177	26.961	38.6541	2096	*Citrullus lanatus*	Serbia
PI378611	17.4857	48.1312	20.9536	29.5662	Nyanga No. 1	*Citrullus lanatus*	Zaire
PI378613	17.7013	47.4177	26.4443	32.8006	Nyanga No.3	*Citrullus lanatus*	Zaire
PI378614	16.756	39.8549	NA	22.7363	Nyanga No.4	*Citrullus lanatus*	Zaire
PI378615	13.3525	40.2805	22.5281	23.2357	Nyanga No.5	*Citrullus lanatus*	Zaire
PI378617	18.3033	41.0292	27.3196	29.7954	Nyanga No. 7	*Citrullus lanatus*	Zaire
PI379222	17.152	32.7402	29.8809	37.3671	2194	*Citrullus lanatus*	Serbia
PI379223	22.4996	36.4918	34.1712	42.5501	Banatska	*Citrullus lanatus*	Serbia
PI379224	11.2657	38.2749	26.7426	33.1288	2241	*Citrullus lanatus*	Macedonia
PI379225	20.4382	36.3695	30.7874	40.9563	Bela	*Citrullus lanatus*	Macedonia
PI379226	17.3735	40.9209	NA	30.3787	Mala	*Citrullus lanatus*	Macedonia
PI379227	19.2442	40.2291	26.6513	47.7606	Bakarka	*Citrullus lanatus*	Macedonia
PI379228	24.1971	35.9533	28.3178	35.8511	Zolta	*Citrullus lanatus*	Macedonia
PI379229	15.9045	40.8913	21.459	33.0164	Sarena	*Citrullus lanatus*	Macedonia
PI379230	15.2949	38.6875	23.4866	35.6782	Temno Zelena	*Citrullus lanatus*	Macedonia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI379231	25.8295	34.1259	35.1546	35.3992	Mrezasto zelena	*Citrullus lanatus*	Macedonia
PI379232	21.6519	30.389	35.7751	35.4395	Sarena	*Citrullus lanatus*	Macedonia
PI379233	19.2496	34.448	19.5815	41.7097	Sarena	*Citrullus lanatus*	Macedonia
PI379234	13.6296	34.6926	32.4129	36.1124	Zimna	*Citrullus lanatus*	Macedonia
PI379235	24.203	45.402	24.748	35.5988	2357	*Citrullus lanatus*	Macedonia
PI379236	21.7245	39.8704	30.1377	31.1257	2358	*Citrullus lanatus*	Macedonia
PI379237	16.3715	44.3647	30.7237	39.299	Okrugla	*Citrullus lanatus*	Macedonia
PI379238	20.5353	36.4823	25.8759	32.3436	Zelkarka	*Citrullus lanatus*	Macedonia
PI379239	20.0252	46.0158	27.6583	33.1337	Zimorka	*Citrullus lanatus*	Macedonia
PI379240	26.032	28.4132	NA	37.6567	Lokalna	*Citrullus lanatus*	Macedonia
PI379241	18.7733	30.4549	20.2372	39.1163	Bakarka	*Citrullus lanatus*	Macedonia
PI379242	23.2833	38.5213	28.1359	36.2049	Zimnica	*Citrullus lanatus*	Macedonia
PI379243	41.9281	32.8591	40.5868	20.8325	Slatkarka	*Citrullus amarus*	Macedonia
PI379245	28.5531	41.7845	19.5972	35.4583	ZIMNA	*Citrullus lanatus*	Macedonia
PI379246	15.6556	29.3295	34.0209	30.8909	Letna	*Citrullus lanatus*	Macedonia
PI379247	14.8738	29.6658	23.3059	33.4746	Koresta	*Citrullus lanatus*	Macedonia
PI379248	21.2596	30.181	38.7213	33.4541	Okrugla	*Citrullus lanatus*	Macedonia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI379249	18.0756	34.2542	36.5389	38.1674	Zimna	*Citrullus lanatus*	Macedonia
PI379250	16.2178	40.9233	28.1664	27.0574	Zimna	*Citrullus lanatus*	Macedonia
PI379251	12.6476	32.952	37.6012	27.5426	Slatkarka	*Citrullus lanatus*	Macedonia
PI379254	25.2047	38.2815	26.6123	45.1397	Zimska	*Citrullus lanatus*	Macedonia
PI379255	26.5491	37.475	NA	39.6417	Letna	*Citrullus lanatus*	Macedonia
PI379256	16.5508	38.8546	18.381	34.4269	Zimna	*Citrullus lanatus*	Macedonia
PI379257	17.7553	50.4611	28.3567	33.5183	Sarena	*Citrullus lanatus*	Former Serbia and Montenegro
PI381694	11.5283	33.5094	33.2295	30.197	Wm-1	*Citrullus lanatus*	India
PI381695	10.1501	36.591	29.5805	31.3269	Wm-2	*Citrullus lanatus*	India
PI381696	17.4855	43.7696	32.3992	38.49	Wm-3	*Citrullus lanatus*	India
PI381697	19.395	34.5382	30.7139	NA	Wm-4	*Citrullus lanatus*	India
PI381698	18.5268	37.0144	30.0392	44.5786	Wm-5	*Citrullus lanatus*	India
PI381699	NA	35.6816	32.1903	NA	Wm-6	*Citrullus lanatus*	India
PI381701	16.4263	34.0351	NA	38.6904	Wm-8	*Citrullus lanatus*	India
PI381704	17.5089	34.3954	44.0109	40.5848	Wm-11	*Citrullus lanatus*	India
PI381705	24.5719	28.6428	33.4985	37.7114	Wm-12	*Citrullus lanatus*	India
PI381706	25.0949	49.0942	36.4534	37.8381	Wm-14	*Citrullus lanatus*	India

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI381707	20.2168	40.9219	22.7231	30.5855	Wm-15	*Citrullus lanatus*	India
PI381708	13.4222	33.1655	29.9154	36.6694	Wm-18	*Citrullus lanatus*	India
PI381709	14.9301	29.8959	39.1638	36.3235	Wm-19	*Citrullus lanatus*	India
PI381711	16.6695	43.7898	25.8544	37.368	Wm-21	*Citrullus lanatus*	India
PI381712	10.6953	31.9823	31.8135	34.3622	Wm-22	*Citrullus lanatus*	India
PI381714	19.1475	31.3966	19.5712	39.671	Wm-24	*Citrullus lanatus*	India
PI381715	18.263	47.2107	26.0747	52.8269	Wm-25	*Citrullus lanatus*	India
PI381716	11.1784	30.1085	18.3084	36.793	Wm-26	*Citrullus lanatus*	India
PI381717	14.3835	30.0207	22.6518	38.4308	Wm-27	*Citrullus lanatus*	India
PI381720	NA	NA	32.0033	NA	Wm-30	*Citrullus lanatus*	India
PI381721	16.4371	37.0272	30.6941	42.498	Wm-31	*Citrullus lanatus*	India
PI381722	22.0954	36.9327	29.8851	30.1035	Wm-32	*Citrullus lanatus*	India
PI381723	15.7234	46.7271	NA	33.3895	Wm-35	*Citrullus lanatus*	India
PI381725	18.3301	28.2215	30.8409	33.6513	Wm-37	*Citrullus lanatus*	India
PI381728	15.8982	31.8361	NA	36.5343	Wm-40	*Citrullus lanatus*	India
PI381733	21.246	41.4999	27.348	39.4886	Wm-47	*Citrullus lanatus*	India
PI381734	13.4031	34.0162	23.5404	32.5844	Wm-48	*Citrullus lanatus*	India

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI381736	25.1109	33.3299	25.7037	33.3312	Wm-50	*Citrullus lanatus*	India
PI381737	20.6134	41.2042	NA	35.6122	Wm-51	*Citrullus lanatus*	India
PI381739	21.2009	35.9233	33.3601	39.8775	Wm-53	*Citrullus lanatus*	India
PI381741	18.899	43.0869	31.6007	29.5385	Wm-56	*Citrullus lanatus*	India
PI385964	7.5427	28.9335	31.7345	32.5496	Congo	*Citrullus lanatus*	Kenya
PI388021	9.7107	27.2303	31.8374	29.4847	Arka Jyoti	*Citrullus lanatus*	India, Karnataka
PI392291	5.9726	39.3748	25.8094	24.325	FAO 35.599	*Citrullus lanatus*	Kenya, Coast
PI418762	22.1874	48.4809	32.522	37.3007	32	*Citrullus lanatus*	Afghanistan
PI420320	17.1094	39.0207	15.2092	24.2386	32	*Citrullus lanatus*	Italy
PI430615	20.1442	32.9735	22.4432	48.7134	Tsao hua	*Citrullus lanatus*	China
PI431579	11.5899	28.8384	23.2944	45.9111	Pusa Rasal	*Citrullus lanatus*	India
PI435085	26.5065	38.4347	27.511	37.6546		*Citrullus lanatus*	China, Xinjiang
PI435282	16.7927	39.6257	34.179	NA		*Citrullus lanatus*	Iraq
PI435990	21.0343	34.377	18.3152	39.5818	Chou Cheh Red	*Citrullus lanatus*	China, Shaanxi
PI435991	14.1475	31.8105	25.904	29.5928	Tso Hua	*Citrullus lanatus*	China, Shaanxi
PI438671	15.2993	37.1816	22.4274	34.7921	W-C 2135	*Citrullus lanatus*	Mexico, Yucatan
PI438673	14.0694	31.1053	20.8804	32.708	W-C 2161	*Citrullus lanatus*	Mexico, Yucatan

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI438675	13.3264	36.9987	NA	26.7511	W-C 2382	*Citrullus lanatus*	Mexico, Chiapas
PI438676	15.308	33.4047	NA	32.2877	Charleston Gray	*Citrullus lanatus*	Mexico, Yucatan
PI441722	13.1943	32.5847	17.5727	30.3229	553	*Citrullus lanatus*	Brazil, Federal District
PI457916	12.0379	33.3645	30.3242	31.8855	Egusi	*Citrullus mucosospermus*	Liberia
PI458738	16.5932	31.7552	25.7426	29.6101	TWW-110	*Citrullus lanatus*	Paraguay, Chaco
PI458739	14.541	31.7904	NA	27.0167	TWW-111	*Citrullus lanatus*	Paraguay, Chaco
PI459074	21.4005	30.1598	29.3011	35.7537		*Citrullus lanatus*	Botswana
PI459075	12.5704	43.3071	31.8592	24.8021		*Citrullus lanatus*	Botswana
PI464872	16.7101	38.2514	NA	33.6211		*Citrullus lanatus*	China
PI470246	21.6955	37.1579	23.4658	31.4734	DB 11	*Citrullus lanatus*	Indonesia, Kalimantan
PI470247	14.9113	32.1236	20.7837	32.1337	DB 12	*Citrullus lanatus*	Indonesia
PI470248	20.4951	33.9154	25.8683	31.0775	DB 14	*Citrullus lanatus*	Indonesia, Kalimantan
PI470249	16.2042	26.1095	23.1124	14.4285	DB 22	*Citrullus lanatus*	Indonesia, Kalimantan
PI475746	20.2589	30.9513	23.3764	NA	TWW-116	*Citrullus lanatus*	Paraguay, Misiones
PI476324	12.7157	34.3038	33.2815	34.5647	Cel'nolistnyj 215	*Citrullus lanatus*	Soviet Union, Former
PI476325	20.5941	32.0165	34.3824	27.6095	Cernocemianuyj	*Citrullus lanatus*	Ukraine
PI476326	16.1377	37.4508	22.3558	37.7304	VIR 4573	*Citrullus lanatus*	Soviet Union, Former

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI476329	16.0581	33.3242	17.6856	39.1479	Astrahanskij	*Citrullus lanatus*	Soviet Union, Former
PI476330	22.6029	35.8924	15.1218	36.7558	VIR 4668	*Citrullus lanatus*	Soviet Union, Former
PI479704	16.691	37.3359	NA	17.6419	Blue Frost	*Citrullus lanatus*	United States
PI481871	8.7551	NA	17.5086	32.9489	191	*Citrullus lanatus*	Sudan, Darfur
PI482247	14.0857	44.03	27.2256	24.565	TGR 41	*Citrullus lanatus*	Zimbabwe
PI482248	13.8827	46.1345	21.5182	34.2249	TGR 56	*Citrullus lanatus*	Zimbabwe
PI482249	12.7913	18.9963	28.4214	35.1243	TGR 57	*Citrullus lanatus*	Zimbabwe
PI482250	8.8402	23.5027	31.6506	43.9307	TGR 58	*Citrullus lanatus*	Zimbabwe
PI482251	8.7931	18.9882	26.8386	25.8907	TGR 59	*Citrullus lanatus*	Zimbabwe
PI482252	23.3878	31.8977	28.3685	18.186	TGR 98	*Citrullus amarus*	Zimbabwe
PI482253	18.0922	36.577	28.3749	34.0887	TGR 102	*Citrullus lanatus*	Zimbabwe
PI482254	14.7222	36.8275	26.6408	40.3972	TGR 112	*Citrullus lanatus*	Zimbabwe
PI482255	8.7864	35.3059	29.2286	30.123	TGR 130	*Citrullus lanatus*	Zimbabwe
PI482256	10.3292	31.2038	27.4942	34.4874	TGR 143	*Citrullus lanatus*	Zimbabwe
PI482257	30.0945	44.768	18.575	21.0327	TGR 173	*Citrullus amarus*	Zimbabwe
PI482259	19.1334	17.5889	33.0982	13.5504	TGR 183	*Citrullus amarus*	Zimbabwe
PI482260	NA	40.8763	14.1895	NA	TGR 203	*Citrullus lanatus*	Zimbabwe

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI482261	24.5536	29.4502	34.0621	13.7674	TGR 204	*Citrullus amarus*	Zimbabwe
PI482262	11.7053	29.0661	29.0125	19.2397	TGR 219	*Citrullus lanatus*	Zimbabwe
PI482263	27.2839	35.7109	32.2751	35.6296	TGR 246	*Citrullus lanatus*	Zimbabwe
PI482264	15.3086	44.9714	33.3984	27.9771	TGR 256	*Citrullus lanatus*	Zimbabwe
PI482265	19.5477	32.2717	29.2314	17.7362	TGR 273	*Citrullus amarus*	Zimbabwe
PI482267	13.8482	39.4683	21.7223	31.6539	TGR 275	*Citrullus lanatus*	Zimbabwe
PI482268	17.8806	38.8098	NA	30.9926	TGR 299	*Citrullus lanatus*	Zimbabwe
PI482269	23.4605	42.1702	23.5311	28.0282	TGR 308	*Citrullus lanatus*	Zimbabwe
PI482272	20.1341	32.6118	21.8101	32.5252	TGR 326	*Citrullus lanatus*	Zimbabwe
PI482273	22.298	NA	21.7828	NA	TGR 345	*Citrullus amarus*	Zimbabwe
PI482275	14.3308	36.723	26.6042	33.4179	TGR 347	*Citrullus lanatus*	Zimbabwe
PI482276	33.9423	17.4372	17.6127	35.2814	TGR 348	*Citrullus amarus*	Zimbabwe
PI482277	15.023	31.7284	NA	NA	TGR 349	*Citrullus amarus*	Zimbabwe
PI482278	16.8312	39.8852	31.1131	20.759	TGR 360	*Citrullus lanatus*	Zimbabwe
PI482280	10.363	25.986	28.1285	28.5539	TGR 483	*Citrullus lanatus*	Zimbabwe
PI482281	30.7226	21.1344	27.55	26.4676	TGR 560	*Citrullus lanatus*	Zimbabwe
PI482282	23.6192	27.6231	26.8651	NA	TGR 620	*Citrullus amarus*	Zimbabwe

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI482283	24.1924	30.2264	30.9828	37.4785	TGR 649	*Citrullus amarus*	Zimbabwe
PI482284	21.1461	27.5429	NA	NA	TGR 660	*Citrullus lanatus*	Zimbabwe
PI482287	10.1016	31.4278	25.1259	22.3953	TGR 678	*Citrullus lanatus*	Zimbabwe
PI482288	24.3985	37.0272	28.1946	26.5402	TGR 679	*Citrullus lanatus*	Zimbabwe
PI482292	15.1039	35.6042	32.4019	13.67	TGR 695B	*Citrullus lanatus*	Zimbabwe
PI482293	15.2489	33.1137	29.2391	8.7844	TGR 711	*Citrullus amarus*	Zimbabwe
PI482294	16.7922	39.3323	25.0511	27.4416	TGR 712A	*Citrullus lanatus*	Zimbabwe
PI482295	10.6793	32.0415	16.8124	40.069	TGR 712B	*Citrullus lanatus*	Zimbabwe
PI482296	20.1467	27.8199	28.6582	30.6366	TGR 712C	*Citrullus lanatus*	Zimbabwe
PI482297	10.8524	27.1491	25.7434	32.6164	TGR 725	*Citrullus lanatus*	Zimbabwe
PI482298	30.2006	35.7046	33.308	21.1263	TGR 726	*Citrullus amarus*	Zimbabwe
PI482304	14.7144	31.1421	20.1638	32.997	TGR 745	*Citrullus lanatus*	Zimbabwe
PI482305	20.1375	36.9337	31.5264	39.8873	TGR 752	*Citrullus lanatus*	Zimbabwe
PI482306	18.9528	29.4949	23.4173	25.3942	TGR 770	*Citrullus lanatus*	Zimbabwe
PI482308	34.9129	35.0215	33.1385	15.0815	TGR 775	*Citrullus amarus*	Zimbabwe
PI482309	22.177	31.4133	32.6092	30.3828	TGR 777	*Citrullus amarus*	Zimbabwe
PI482310	8.0348	31.8741	NA	21.7439	TGR 842	*Citrullus lanatus*	Zimbabwe

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI482311	24.6233	31.3988	22.387	27.8271	TGR 848	*Citrullus amarus*	Zimbabwe
PI482314	13.4154	37.0876	21.6172	17.5613	TGR 870	*Citrullus lanatus*	Zimbabwe
PI482315	44.1047	28.7884	22.3183	14.1874	TGR 875	*Citrullus amarus*	Zimbabwe
PI482316	20.5496	30.4559	23.4826	11.3679	TGR 891	*Citrullus amarus*	Zimbabwe
PI482317	14.2991	42.3231	20.9536	28.6037	TGR 892	*Citrullus lanatus*	Zimbabwe
PI482318	18.1662	28.4181	32.4956	23.6404	TGR 904	*Citrullus lanatus*	Zimbabwe
PI482319	26.3688	28.2754	NA	14.6895	TGR 905	*Citrullus amarus*	Zimbabwe
PI482320	17.5754	44.1503	35.0354	26.1699	TGR 916	*Citrullus lanatus*	Zimbabwe
PI482321	20.8331	30.6884	26.5303	25.0024	TGR 919	*Citrullus amarus*	Zimbabwe
PI482322	19.3416	33.2232	30.0916	18.1443	TGR 924	*Citrullus amarus*	Zimbabwe
PI482323	9.7261	21.8214	36.6921	23.9457	TGR 925	*Citrullus lanatus*	Zimbabwe
PI482324	34.9225	31.1426	30.8285	16.8201	TGR 1041	*Citrullus amarus*	Zimbabwe
PI482325	15.321	35.9295	21.9635	28.7949	TGR 1063	*Citrullus lanatus*	Zimbabwe
PI482326	37.0231	30.8934	33.3244	21.4081	TGR 1069	*Citrullus amarus*	Zimbabwe
PI482328	27.7586	34.5816	26.7768	26.1034	TGR 1109	*Citrullus lanatus*	Zimbabwe
PI482329	14.5277	31.0633	21.085	26.4253	TGR 1134	*Citrullus lanatus*	Zimbabwe
PI482330	16.8747	47.9253	24.8776	30.6882	TGR 1144	*Citrullus lanatus*	Zimbabwe

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI482333	29.754	37.5819	32.3414	9.1627	TGR 1154	*Citrullus amarus*	Zimbabwe
PI482334	31.1558	41.1991	30.7421	26.7261	TGR 1168	*Citrullus amarus*	Zimbabwe
PI482335	31.3395	32.2582	26.6528	20.2205	TGR 1170	*Citrullus amarus*	Zimbabwe
PI482336	19.0044	33.6869	26.9474	30.0796	TGR 1185	*Citrullus amarus*	Zimbabwe
PI482337	12.8861	38.8846	25.0124	20.3694	TGR 1187	*Citrullus lanatus*	Zimbabwe
PI482339	15.2024	34.0561	NA	31.4009	TGR 1238	*Citrullus lanatus*	Zimbabwe
PI482340	10.2664	33.5862	32.5698	15.5359	TGR 1328	*Citrullus lanatus*	Zimbabwe
PI482342	16.2598	44.1184	20.7603	19.5462	TGR 1431	*Citrullus amarus*	Zimbabwe
PI482343	21.5911	32.9237	29.9666	22.6516	TGR 1454	*Citrullus lanatus*	Zimbabwe
PI482344	20.6443	35.3681	32.4747	25.4879	TGR 1457	*Citrullus lanatus*	Zimbabwe
PI482345	16.6463	22.7138	36.8291	30.0295	TGR 1465	*Citrullus lanatus*	Zimbabwe
PI482346	13.1051	40.112	33.0623	27.0342	TGR 1512	*Citrullus lanatus*	Zimbabwe
PI482347	8.0135	33.575	22.4447	31.889	TGR 1530	*Citrullus lanatus*	Zimbabwe
PI482348	19.0002	38.7913	32.0785	27.6326	TGR 1547	*Citrullus lanatus*	Zimbabwe
PI482349	23.0646	36.764	NA	23.4885	TGR 1564	*Citrullus lanatus*	Zimbabwe
PI482350	16.9748	23.4559	26.7335	25.0662	TGR 1571	*Citrullus lanatus*	Zimbabwe
PI482351	20.5398	38.5186	24.2581	26.472	TGR 1624	*Citrullus lanatus*	Zimbabwe

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI482352	16.6669	32.9652	43.2293	31.9921	TGR 1630	*Citrullus lanatus*	Zimbabwe
PI482353	26.6652	44.4315	39.0738	25.505	TGR 1633	*Citrullus lanatus*	Zimbabwe
PI482354	22.0939	32.145	25.5273	38.6354	TGR 1652	*Citrullus lanatus*	Zimbabwe
PI482355	21.2255	34.2469	39.8773	15.4498	TGR 1667	*Citrullus amarus*	Zimbabwe
PI482357	14.121	32.0478	32.7988	31.8288	TGR 1677	*Citrullus lanatus*	Zimbabwe
PI482359	25.7648	27.794	20.2836	22.0215	TGR 1754	*Citrullus lanatus*	Zimbabwe
PI482360	15.2473	37.1716	32.349	27.533	TGR 1762	*Citrullus lanatus*	Zimbabwe
PI482361	37.5401	58.4615	16.8569	33.4936	TGR 1763	*Citrullus amarus*	Zimbabwe
PI482362	18.7081	50.4376	24.1343	26.2612	TGR 1772	*Citrullus lanatus*	Zimbabwe
PI482363	12.7828	44.9406	29.9552	33.3418	TGR 1782	*Citrullus lanatus*	Zimbabwe
PI482364	22.2885	25.3128	24.9957	31.2347	TGR 1798	*Citrullus lanatus*	Zimbabwe
PI482365	14.2001	31.586	30.9619	28.1393	TGR 1802	*Citrullus lanatus*	Zimbabwe
PI482366	24.5944	37.2902	40.7919	31.0988	TGR 1828	*Citrullus lanatus*	Zimbabwe
PI482367	14.9894	30.9802	31.6241	22.1905	TGR 1858	*Citrullus lanatus*	Zimbabwe
PI482370	16.8795	35.7248	26.5691	35.565	TGR 1899	*Citrullus lanatus*	Zimbabwe
PI482371	9.5242	15.4384	22.5826	16.9181	TGR 1927	*Citrullus lanatus*	Zimbabwe
PI482372	18.8814	24.6183	33.5779	33.5189	TGR 1938	*Citrullus lanatus*	Zimbabwe

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI482373	16.8701	38.4842	22.8179	34.8776	TGR 1947	*Citrullus lanatus*	Zimbabwe
PI482374	17.5103	38.5888	26.9274	38.139	TGR 1959	*Citrullus lanatus*	Zimbabwe
PI482375	22.0306	30.9109	16.1806	26.3891	TGR 1968	*Citrullus lanatus*	Zimbabwe
PI482376	9.2294	34.1102	20.8885	30.7278	TGR 1984	*Citrullus lanatus*	Zimbabwe
PI482377	15.6095	35.1621	32.3848	22.0508	TGR 2005	*Citrullus lanatus*	Zimbabwe
PI482378	15.8545	43.0676	26.0003	23.885	TGR 2006	*Citrullus lanatus*	Zimbabwe
PI482380	13.5395	32.5269	26.6506	29.4921	TGR 2035	*Citrullus lanatus*	Zimbabwe
PI482381	11.89	37.8486	24.1845	19.3243	TGR 2084	*Citrullus lanatus*	Zimbabwe
PI485580	NA	NA	26.7988	NA	M-307B-1	*Citrullus amarus*	Botswana
PI485581	26.2436	30.7185	24.2985	22.7609	M-307B-2	*Citrullus amarus*	Botswana
PI485583	23.3122	31.1722	33.0574	16.4784	M-307B-4	*Citrullus amarus*	Botswana
PI487458	25.3027	30.7462	45.7134	36.0161	Patilla	*Citrullus lanatus*	Venezuela, Amazonas
PI487459	9.8133	35.062	29.4071	23.059	2909	*Citrullus lanatus*	Venezuela, Amazonas
PI487476	NA	38.6441	37.5528	NA	Malali	*Citrullus lanatus*	Israel
PI490376	23.5013	33.0676	21.7333	30.3484	Linkinda	*Citrullus lanatus*	Mali
PI490377	17.1854	42.2689	28.2105	40.87	Dennemaoundi	*Citrullus mucosospermus*	Mali
PI490379	22.549	31.5058	29.1063	32.0618	Egusi	*Citrullus mucosospermus*	Mali

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI490380	21.396	43.1023	25.8526	27.6612	Egusi	*Citrullus mucosospermus*	Mali
PI490381	23.8519	NA	12.4581	36.9125	Egusi	*Citrullus mucosospermus*	Mali
PI490384	NA	34.7648	24.3201	NA	Egusi	*Citrullus mucosospermus*	Mali
PI490386	14.3434	41.2982	35.38	31.1599	Egusi	*Citrullus mucosospermus*	Mali
PI491265	11.6876	29.796	25.1684	27.8513	TGR 2103	*Citrullus lanatus*	Zimbabwe
PI494527	16.2045	42.6492	29.1873	34.8626	Egusi	*Citrullus mucosospermus*	Nigeria, Ogun
PI494528	10.8625	31.6087	37.4933	31.5663	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI494529	65.3031	39.9994	37.4369	27.903	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI494531	20.834	31.7661	26.4653	30.866	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI494815	24.583	37.432	29.8786	35.2061	Inamunwa	*Citrullus lanatus*	Zambia
PI494816	22.8943	36.5735	30.7667	22.9127	ZFA 3271	*Citrullus lanatus*	Zambia
PI494817	24.2031	36.9764	26.7356	10.3305	ZFA 3288	*Citrullus amarus*	Zambia
PI494819	NA	42.6539	70.8237	NA	ZFA 3333	*Citrullus lanatus*	Zambia
PI494820	15.8169	34.8338	23.4005	30.0906	ZFA 3335	*Citrullus lanatus*	Zambia
PI494821	17.8052	41.8439	28.3467	29.5105	ZFA 3381	*Citrullus lanatus*	Zambia
PI500301	15.3671	32.0628	30.7913	29.7065	ZM-1031	*Citrullus lanatus*	Zambia
PI500302	7.5775	36.9621	22.5378	21.4043	ZM-1039	*Citrullus lanatus*	Zambia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI500303	19.8606	31.0869	30.534	6.3335	ZM-1143	*Citrullus amarus*	Zambia
PI500304	10.3631	34.1457	26.5304	26.1225	ZM-1177	*Citrullus lanatus*	Zambia
PI500305	17.7943	45.8503	18.3939	27.0374	ZM-1193	*Citrullus lanatus*	Zambia
PI500306	14.996	42.5865	27.3473	25.5138	ZM-1195	*Citrullus lanatus*	Zambia
PI500308	36.9322	45.1829	21.7663	12.0823	ZM-1296	*Citrullus amarus*	Zambia
PI500309	15.1663	17.0625	22.4117	26.8982	ZM-1297	*Citrullus lanatus*	Zambia
PI500310	11.5431	30.8908	24.2302	28.3193	ZM-1299	*Citrullus lanatus*	Zambia
PI500311	13.9888	33.9056	28.2343	31.5146	ZM-1303	*Citrullus lanatus*	Zambia
PI500312	26.0815	30.2588	31.5895	NA	ZM-1323	*Citrullus lanatus*	Zambia
PI500314	8.8085	39.6855	22.503	29.3893	ZM-1331	*Citrullus lanatus*	Zambia
PI500315	9.6452	29.214	27.4766	36.1508	ZM-1361	*Citrullus lanatus*	Zambia
PI500317	7.0197	41.8407	21.01	25.4612	ZM-1406	*Citrullus lanatus*	Zambia
PI500318	NA	37.0716	26.6666	NA	ZM-1445	*Citrullus lanatus*	Zambia
PI500319	19.357	47.5979	39.1596	19.8581	ZM-1446	*Citrullus lanatus*	Zambia
PI500321	NA	44.9369	25.7594	NA	ZM-1459	*Citrullus lanatus*	Zambia
PI500323	9.1545	43.3838	23.1873	18.1143	ZM-1496	*Citrullus lanatus*	Zambia
PI500328	23.6676	22.7947	21.7815	30.2542	ZM-1722	*Citrullus lanatus*	Zambia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI500331	15.5704	30.9842	25.7867	12.2625	ZM-1925	*Citrullus amarus*	Zambia
PI500332	20.2416	32.7032	26.7674	35.6606	ZM-1958	*Citrullus amarus*	Zambia
PI500333	17.8975	36.6702	33.3602	35.8139	ZM-2055	*Citrullus lanatus*	Zambia
PI500334	10.9522	28.2633	18.5114	19.1057	ZM-2062	*Citrullus amarus*	Zambia
PI500335	15.3252	32.3747	25.4918	12.3162	ZM-2109	*Citrullus amarus*	Zambia
PI500336	15.7695	41.4028	26.7556	32.9875	ZM-2110	*Citrullus lanatus*	Zambia
PI500337	22.1621	37.9917	25.9015	21.9691	ZM-2132	*Citrullus lanatus*	Zambia
PI500338	23.025	45.3808	22.6303	24.3395	ZM-2143	*Citrullus lanatus*	Zambia
PI500340	56.2557	61.5296	27.4113	20.9815	ZM-2176	*Citrullus lanatus*	Zambia
PI500342	22.9301	39.7975	23.2762	35.3435	ZM-2295	*Citrullus lanatus*	Zambia
PI500343	10.7084	54.9844	23.1809	28.8089	ZM-2331	*Citrullus lanatus*	Zambia
PI500344	16.6324	22.7326	27.5054	32.6408	ZM-2332	*Citrullus lanatus*	Zambia
PI500345	11.7666	31.2089	20.0242	26.0575	ZM-2381	*Citrullus lanatus*	Zambia
PI500346	29.9178	34.0437	36.609	48.0944	ZM-2393	*Citrullus lanatus*	Zambia
PI500347	15.1406	36.8609	29.9129	21.5723	ZM-2428	*Citrullus lanatus*	Zambia
PI500348	NA	34.1699	21.7497	NA	ZM-2526	*Citrullus lanatus*	Zambia
PI500349	9.8214	35.8614	25.0496	33.3561	ZM-2595	*Citrullus lanatus*	Zambia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI500350	19.2072	23.5796	37.3638	30.7391	ZM-2605	*Citrullus lanatus*	Zambia
PI500352	18.1031	36.6547	32.679	23.7142	ZM-2730	*Citrullus lanatus*	Zambia
PI500353	10.5632	33.4227	24.8638	30.3553	ZM-2769	*Citrullus lanatus*	Zambia
PI500354	27.5968	28.0786	31.705	32.1821	ZM-2793	*Citrullus amarus*	Zambia
PI502316	23.225	43.8835	NA	32.228	AR-259	*Citrullus lanatus*	Uzbekistan, Samarqand
PI504519	NA	NA	27.5421	NA	CFS-101	*Citrullus lanatus*	Australia
PI505585	24.4664	45.4153	30.6674	30.0134	ZM/A 5011	*Citrullus lanatus*	Zambia
PI505586	NA	31.7314	34.865	NA	ZM/A 5206	*Citrullus lanatus*	Zambia
PI505587	9.5938	35.251	26.6687	37.941	ZM/A 5313	*Citrullus lanatus*	Zambia
PI505588	14.8205	42.1268	15.8738	29.6579	ZM/A 5320	*Citrullus lanatus*	Zambia
PI505589	16.3713	34.4791	48.0494	32.3189	ZM/A 5322	*Citrullus lanatus*	Zambia
PI505590	7.3868	29.8956	29.1917	28.1293	ZM/A 5329	*Citrullus lanatus*	Zambia
PI505591	11.0347	34.6976	25.8607	23.2731	ZM/A 5372	*Citrullus lanatus*	Zambia
PI505592	15.0081	33.9965	26.6058	29.6755	ZM/A 5380	*Citrullus lanatus*	Zambia
PI505593	9.4875	31.0207	23.224	28.1882	ZM/A 5386	*Citrullus lanatus*	Zambia
PI505594	15.6268	28.6428	29.9407	32.4274	ZM/A 5395	*Citrullus lanatus*	Zambia
PI505595	13.8153	31.286	18.3534	28.2636	ZM/A 5399	*Citrullus lanatus*	Zambia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI505604	29.9033	30.5766	NA	NA	ZM/A 5335	*Citrullus amarus*	Zambia
PI506439	21.6469	32.5823	33.4486	28.6316		*Citrullus lanatus*	Moldova
PI507859	17.4272	45.7508	25.0561	35.3736	2700782	*Citrullus lanatus*	Hungary
PI507860	18.3726	49.1523	19.8327	31.6686	2700783	*Citrullus lanatus*	Hungary, Szabolcs-Szatmar
PI507862	23.6986	39.8431	30.8376	32.1386	2700785	*Citrullus lanatus*	Hungary
PI507863	18.3958	39.2593	26.9315	35.6088	2700786	*Citrullus lanatus*	Hungary, Szabolcs-Szatmar
PI507864	23.1924	39.9225	28.2959	NA	2700787	*Citrullus lanatus*	Hungary, Szabolcs-Szatmar
PI507865	31.053	48.6494	24.9072	34.8727	2700788	*Citrullus lanatus*	Hungary, Szabolcs-Szatmar
PI507867	NA	46.1166	24.887	NA	2701027	*Citrullus lanatus*	Hungary
PI507869	15.106	37.6655	27.242	35.5393	2701030	*Citrullus lanatus*	Hungary, Szabolcs-Szatmar
PI508443	15.3106	48.5876	14.3126	49.7781	Olympia	*Citrullus lanatus*	Korea, South
PI508445	NA	44.9593	27.3001	NA	Summer king	*Citrullus lanatus*	Korea, South
PI508446	16.9476	30.8096	30.8386	26.3742	Summer queen	*Citrullus lanatus*	Korea, South
PI512331	16.1072	34.8667	31.8305	30.885	DDW 368	*Citrullus lanatus*	China, Beijing
PI512332	20.1053	37.463	29.9918	36.2197	DDW 369	*Citrullus lanatus*	China, Beijing
PI512341	13.2183	31.7742	23.5438	34.1172	A-CI-3	*Citrullus lanatus*	Spain, Zaragoza
PI512342	13.4039	36.0369	19.1773	27.8444	A-CI-4	*Citrullus lanatus*	Spain, Zaragoza

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI512343	11.2822	30.9928	NA	38.1188	A-CI-5	*Citrullus lanatus*	Spain, Zaragoza
PI512345	14.2891	34.8968	25.851	32.3531	C-CI-1	*Citrullus lanatus*	Spain, Tarragona
PI512346	10.5838	39.027	20.9285	40.5487	C-CI-2	*Citrullus lanatus*	Spain, Tarragona
PI512347	18.3309	42.9567	24.2508	26.4858	C-CI-3	*Citrullus lanatus*	Spain, Tarragona
PI512348	16.3617	36.9282	32.4924	35.9041	C-CI-4	*Citrullus lanatus*	Spain, Tarragona
PI512349	19.0778	37.9425	33.2508	41.4823	C-CI-5	*Citrullus lanatus*	Spain, Tarragona
PI512350	16.2833	35.362	NA	NA	CM-CI-1	*Citrullus lanatus*	Spain, Toledo
PI512351	21.4058	38.1608	35.1697	36.8898	CM-CI-2	*Citrullus lanatus*	Spain, Toledo
PI512352	11.7254	32.2358	25.0515	36.0391	CM-CI-3	*Citrullus lanatus*	Spain, Toledo
PI512353	11.6773	28.5007	24.9179	41.3249	CM-CI-4	*Citrullus lanatus*	Spain, Toledo
PI512354	22.6579	32.3733	30.8619	32.6896	CM-CI-5	*Citrullus lanatus*	Spain, Toledo
PI512356	18.439	41.8177	35.7464	40.3519	CM-CI-7	*Citrullus lanatus*	Spain, Toledo
PI512358	20.6944	46.4979	34.2121	26.3187	E-CI-1	*Citrullus lanatus*	Spain, Caceres
PI512360	5.5118	40.6167	30.1034	34.3731	E-CI-3	*Citrullus lanatus*	Spain, Caceres
PI512362	9.7008	27.9739	26.0659	39.2237	E-CI-5	*Citrullus lanatus*	Spain, Caceres
PI512363	15.9538	37.0009	28.3809	39.0063	E-CI-6	*Citrullus lanatus*	Spain, Caceres
PI512364	20.9436	NA	60.8751	NA	E-CI-7	*Citrullus lanatus*	Spain, Caceres

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI512365	17.6754	37.5955	26.6512	37.2882	E-CI-8	*Citrullus lanatus*	Spain, Caceres
PI512369	14.9032	NA	27.5221	41.7904	V-CI-3	*Citrullus lanatus*	Spain, Valencia
PI512370	NA	36.2781	26.574	NA	V-CI-4	*Citrullus lanatus*	Spain, Alicante
PI512371	17.7939	34.927	24.1661	40.6595	V-CI-5	*Citrullus lanatus*	Spain, Alicante
PI512373	16.5682	38.7826	24.7134	36.521	V-CI-7	*Citrullus lanatus*	Spain, Alicante
PI512374	21.7343	38.4809	28.2823	38.767	V-CI-8	*Citrullus lanatus*	Spain, Alicante
PI512375	14.6575	33.3238	22.2127	22.7877	V-CI-9	*Citrullus lanatus*	Spain, Alicante
PI512376	14.9564	39.4678	11.0826	25.0055	V-CI-10	*Citrullus lanatus*	Spain, Alicante
PI512377	19.3062	33.1815	26.9415	33.7398	V-CI-11	*Citrullus lanatus*	Spain, Alicante
PI512378	10.962	35.7133	33.4568	33.1516	V-CI-12	*Citrullus lanatus*	Spain, Valencia
PI512382	20.9627	31.4463	NA	32.9667	V-CI-16	*Citrullus lanatus*	Spain, Castellon de Plana
PI512383	12.0567	34.9654	NA	20.3986	V-CI-17	*Citrullus lanatus*	Spain, Valencia
PI512384	12.3717	34.7075	25.9903	29.2627	V-CI-18	*Citrullus lanatus*	Spain, Valencia
PI512386	22.0262	37.8352	26.7435	43.3504	V-CI-20	*Citrullus lanatus*	Spain, Valencia
PI512388	26.8907	49.5654	24.9646	31.169	V-CI-22	*Citrullus lanatus*	Spain, Valencia
PI512389	11.6397	32.6992	NA	32.0412	V-CI-23	*Citrullus lanatus*	Spain, Valencia
PI512390	18.1422	35.7167	32.5178	43.4401	V-CI-24	*Citrullus lanatus*	Spain, Valencia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI512392	22.01	33.0556	20.7406	34.2209	V-CI-26	*Citrullus lanatus*	Spain, Castellon de Plana
PI512393	9.9137	40.4894	43.3064	NA	V-CI-27	*Citrullus lanatus*	Spain, Castellon de Plana
PI512394	14.7406	40.4553	22.4604	28.3763	V-CI-28	*Citrullus lanatus*	Spain, Castellon de Plana
PI512395	NA	35.9983	23.3894	NA	V-CI-29	*Citrullus lanatus*	Spain, Valencia
PI512396	18.7391	35.4036	29.214	32.7564	V-CI-30	*Citrullus lanatus*	Spain, Valencia
PI512397	20.6822	31.3444	22.5021	27.8011	AN-CI-1	*Citrullus lanatus*	Spain, Cordoba
PI512398	19.3536	34.6215	28.3879	32.5366	AN-CI-2	*Citrullus lanatus*	Spain, Granada
PI512400	13.5203	36.2657	23.3596	31.3581	AN-CI-4	*Citrullus lanatus*	Spain, Malaga
PI512401	23.5677	39.9339	20.0456	NA	AN-CI-5	*Citrullus lanatus*	Spain, Cadiz
PI512402	18.7634	40.7896	23.3542	39.0191	AN-CI-6	*Citrullus lanatus*	Spain, Cadiz
PI512403	18.3321	25.9802	15.5681	41.9686	AN-CI-7	*Citrullus lanatus*	Spain, Cadiz
PI512404	16.8009	42.0144	26.6538	35.3615	AN-CI-8	*Citrullus lanatus*	Spain, Cadiz
PI512407	12.5713	41.2506	21.8213	29.3456	AN-CI-11	*Citrullus lanatus*	Spain, Cadiz
PI512828	7.8078	36.6111	28.1596	30.2562	V-CU-42	*Citrullus lanatus*	Spain, Valencia
PI512833	27.984	38.4376	24.0908	28.6323	V-CU-49	*Citrullus lanatus*	Spain, Castellon de Plana
PI512854	29.8589	29.5068	31.2008	28.3256	V-CU-77	*Citrullus amarus*	Spain, Valencia
PI518606	14.7743	35.8847	21.8116	26.0344	Astrakhanskij	*Citrullus lanatus*	Russian Federation

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI518607	28.4415	38.9385	31.7137	24.2314	BOGAEVSKIJ MUR	*Citrullus lanatus*	Soviet Union, Former
PI518610	21.0596	34.2214	41.4087	36.1934	MOZAICHNYJ	*Citrullus lanatus*	Soviet Union, Former
PI518611	17.0391	40.8729	27.5026	29.0205	TAVRIJSKIJ	*Citrullus lanatus*	Soviet Union, Former
PI518612	23.5404	34.3179	14.8459	36.9119	VAHKSHSKIJ TEMNOK	*Citrullus lanatus*	Soviet Union, Former
PI525081	NA	NA	23.5786	NA	27	*Citrullus amarus*	Egypt, Qena
PI525083	23.4858	44.271	23.2385	46.2129	102	*Citrullus amarus*	Egypt
PI525084	27.0251	60.8221	NA	39.1267	3	*Citrullus lanatus*	Egypt, Qena
PI525086	10.4943	36.3467	59.1395	34.8827	48	*Citrullus lanatus*	Egypt, Sawhaj
PI525087	14.1576	46.7262	53.2405	34.4826	49	*Citrullus lanatus*	Egypt, Qena
PI525088	6.6154	32.9686	39.0505	35.3053	58	*Citrullus lanatus*	Egypt, Sawhaj
PI525089	17.4591	37.3855	20.1056	32.3742	67	*Citrullus lanatus*	Egypt, Sawhaj
PI525090	22.7242	27.2	14.9859	NA	69	*Citrullus lanatus*	Egypt, Asyut
PI525091	7.329	30.2808	20.7287	35.216	71	*Citrullus lanatus*	Egypt, Asyut
PI525093	13.1767	27.6861	30.0236	43.1962	108	*Citrullus lanatus*	Egypt, New Valley
PI525094	27.9076	31.8336	33.2271	38.0695	199	*Citrullus lanatus*	Egypt, Sinai
PI525095	22.4133	40.4387	22.7316	38.1695	202	*Citrullus lanatus*	Egypt, Sinai
PI525096	15.0613	43.4602	NA	28.0336	203	*Citrullus lanatus*	Egypt

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI525097	16.4482	31.28	19.2139	32.4354	206	*Citrullus lanatus*	Egypt, Sinai
PI525098	18.2658	33.9485	23.4395	NA	Giza 1	*Citrullus lanatus*	Egypt, Giza
PI525099	20.4503	30.7809	NA	29.6459	328	*Citrullus lanatus*	Egypt, Matruh
PI525100	21.8026	43.5359	24.117	33.1524	403	*Citrullus lanatus*	Egypt, Cairo
PI526231	19.7358	35.8513	29.4054	30.3934	AMM 023	*Citrullus lanatus*	Zimbabwe
PI526232	13.1388	29.0802	25.6469	24.5184	AMM 418	*Citrullus lanatus*	Zimbabwe
PI526233	18.2221	29.4793	26.6841	33.9547	AMM 419	*Citrullus lanatus*	Zimbabwe
PI526236	16.6179	36.4257	29.0549	25.1873	AMM 1267	*Citrullus lanatus*	Zimbabwe
PI526237	15.726	33.6715	30.7256	31.6495	AMM 1268	*Citrullus lanatus*	Zimbabwe
PI526238	9.3649	33.5695	23.2961	29.43	AMM 1269	*Citrullus lanatus*	Zimbabwe
PI526239	16.4093	39.638	24.2299	27.334	AMM 1326	*Citrullus lanatus*	Zimbabwe
PI532659	51.2891	35.2938	26.5946	20.7621	152	*Citrullus amarus*	South Africa
PI532664	NA	NA	33.354	NA	145	*Citrullus amarus*	Swaziland
PI532666	17.9876	28.6109	29.1233	NA	147	*Citrullus amarus*	Swaziland
PI532668	39.2755	28.9327	28.2953	NA	150	*Citrullus amarus*	Swaziland
PI532670	NA	NA	23.5325	NA	151	*Citrullus amarus*	Botswana
PI532722	12.7467	38.0917	26.6384	29.3658	Egusi	*Citrullus mucosospermus*	Zaire, Bas-Zaire

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI532723	19.6575	37.1764	25.0204	31.9494	Egusi	*Citrullus mucosospermus*	Zaire, Bas-Zaire
PI532730	21.9169	32.137	30.7606	29.4839	Egusi	*Citrullus mucosospermus*	Zaire, Bandundu
PI532732	15.1948	38.2275	32.5487	37.1429	Egusi	*Citrullus mucosospermus*	Zaire, Bandundu
PI532733	13.481	40.7204	40.7178	33.1776	Egusi	*Citrullus mucosospermus*	Zaire, Bandundu
PI532810	10.1759	30.931	27.2661	30.6301	AI ZAO SHENG	*Citrullus lanatus*	China
PI532811	12.6305	30.3436	28.2864	31.6869	HUA PI ZI GUA	*Citrullus lanatus*	China
PI532813	15.0503	39.8006	19.1265	34.4867	LAN ZHOU HEI PI	*Citrullus lanatus*	China
PI532814	15.2894	39.4637	19.4172	32.9139	LAN ZHOU HUA PI	*Citrullus lanatus*	China
PI532816	20.4484	36.8691	NA	38.2646	WU WEI HEI PI	*Citrullus lanatus*	China
PI532817	17.6601	44.5782	25.8759	39.4515	ZHUANG LANG 1	*Citrullus lanatus*	China
PI532818	28.187	35.8342	23.4198	34.6599	ZHUANG LANG 2	*Citrullus lanatus*	China
PI534530	17.1626	36.7191	20.8157	35.0337	OA 35	*Citrullus lanatus*	Syria
PI534531	18.8902	30.5717	16.6932	37.9993	OA 201	*Citrullus lanatus*	Syria
PI534532	NA	33.0867	25.1045	NA	OA 234	*Citrullus lanatus*	Syria
PI534533	29.665	31.042	33.0226	34.6649	OA 294	*Citrullus lanatus*	Syria
PI534534	13.8205	34.5192	21.1191	37.7089	OA 298	*Citrullus lanatus*	Syria
PI534535	14.2299	31.7623	22.6041	29.653	OA 327	*Citrullus lanatus*	Syria

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI534583	21.6544	34.1272	44.295	38.5959	OM 10332	*Citrullus lanatus*	Syria
PI534584	17.1068	43.6224	19.7683	38.3547	OM 10341	*Citrullus lanatus*	Syria
PI534585	20.9655	32.6704	24.1988	32.2541	OM 10362	*Citrullus lanatus*	Syria
PI534586	20.2412	30.4405	29.0743	NA	OM 10371	*Citrullus lanatus*	Syria
PI534587	13.6343	31.1206	28.2115	29.3591	OM 10383	*Citrullus lanatus*	Syria
PI534588	14.2488	32.4775	23.2995	26.4077	OM 10385	*Citrullus lanatus*	Syria
PI534589	23.2879	32.1093	25.8819	35.0702	OM 10391	*Citrullus lanatus*	Syria
PI534590	19.6616	36.8661	27.5278	26.6584	OM 10409	*Citrullus lanatus*	Syria
PI534591	23.9782	35.0259	39.7757	33.5729	OD 10422	*Citrullus lanatus*	Syria
PI534592	29.1119	25.6653	35.0389	NA	OD 10508	*Citrullus lanatus*	Syria
PI534593	23.2886	41.3747	28.1919	NA	OD 10509	*Citrullus lanatus*	Syria
PI534594	16.678	47.4907	20.8101	NA	OD 10513	*Citrullus lanatus*	Syria
PI534595	22.0292	33.9931	28.5796	38.9416	OD 10517	*Citrullus lanatus*	Syria
PI534596	16.7969	30.8029	23.0798	35.7887	OD 10518	*Citrullus lanatus*	Syria
PI534597	35.0724	46.7855	25.1289	41.4498	OD 10524	*Citrullus lanatus*	Syria
PI534598	25.5913	36.4775	18.3643	35.1448	OD 10527	*Citrullus lanatus*	Syria
PI535947	24.4511	32.0278	22.4828	29.7161	Faah-leh (Arabic language)	*Citrullus lanatus*	Cameroon

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI535948	9.8156	45.5589	18.3148	29.5438	C038	*Citrullus lanatus*	Cameroon
PI536446	20.0961	27.0092	27.2577	21.3866	KLM-1410	*Citrullus lanatus*	Maldives
PI536448	17.3028	49.9732	16.4712	23.1463	KLM-1431	*Citrullus lanatus*	Maldives
PI536449	19.7087	32.8901	19.2778	28.8743	KLM-1438	*Citrullus lanatus*	Maldives
PI536450	17.0541	31.834	28.3819	35.8531	KLM-1459	*Citrullus lanatus*	Maldives
PI536451	NA	30.4372	77.2459	NA	KLM-1468	*Citrullus lanatus*	Maldives
PI536452	18.485	39.4839	62.1905	32.7134	KLM-1504	*Citrullus lanatus*	Maldives
PI536454	17.2204	NA	93.3458	28.8389	KLM-1583	*Citrullus lanatus*	Maldives
PI536457	18.4912	34.2091	NA	32.7343	KLM-1632	*Citrullus lanatus*	Maldives
PI536458	22.8435	40.3337	47.4244	39.5669	KLM-1638	*Citrullus lanatus*	Maldives
PI536459	22.0433	48.9338	NA	28.0347	KLM-1643	*Citrullus lanatus*	Maldives
PI536460	19.2361	34.0082	69.9824	43.6944	KLM-1645	*Citrullus lanatus*	Maldives
PI536462	25.896	34.9447	75.1763	36.7462	KLM-1866	*Citrullus lanatus*	Maldives
PI536463	21.4705	37.1487	49.4387	34.4536	KLM-1909	*Citrullus lanatus*	Maldives
PI536464	37.0616	41.3925	70.7824	36.4315	KLM-2011	*Citrullus lanatus*	Maldives
PI537265	17.3009	30.416	38.2365	36.0213	WKP-88-45	*Citrullus lanatus*	Pakistan, Punjab
PI537266	19.2385	32.0208	30.181	43.6795	WKP-88-46	*Citrullus lanatus*	Pakistan, Punjab

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI537267	24.9299	31.9339	33.1734	36.5768	WKP-88-47	*Citrullus lanatus*	Pakistan, Punjab
PI537268	14.5634	34.883	29.1746	35.9195	WKP-88-48	*Citrullus lanatus*	Pakistan, Punjab
PI537269	19.6602	36.0023	29.9904	37.9493	WKP-88-49	*Citrullus lanatus*	Pakistan, Punjab
PI537270	14.276	33.255	25.1907	32.4589	WKP-88-50	*Citrullus lanatus*	Pakistan, Punjab
PI537271	16.8305	32.9675	31.512	40.6092	WKP-88-51	*Citrullus lanatus*	Pakistan, Punjab
PI537273	13.3645	44.8231	25.0354	28.233	WKP-88-53	*Citrullus lanatus*	Pakistan, Punjab
PI537274	21.2145	32.7483	22.4718	41.2949	WKP-88-54	*Citrullus lanatus*	Pakistan, Punjab
PI537275	21.1022	46.7454	28.4372	32.625	WKP-88-55	*Citrullus lanatus*	Pakistan, Punjab
PI537276	22.9388	35.4524	NA	30.2827	WKP-88-56	*Citrullus lanatus*	Pakistan, Punjab
PI537461	24.8661	33.8193	28.1329	31.6586	Sandia melade	*Citrullus lanatus*	Spain
PI537465	15.1849	32.2907	31.603	34.0295	Sandia melada	*Citrullus lanatus*	Spain, La Palmas
PI537467	15.6687	36.1801	15.9701	24.6519	Sandia de la Peuiunila	*Citrullus lanatus*	Spain, La Palmas
PI537468	18.8806	46.3972	76.3464	41.3903	Sindria	*Citrullus lanatus*	Spain, Gerona
PI537470	17.274	43.8703	31.5805	35.7789	Sandia	*Citrullus lanatus*	Spain, Albacete
PI537471	9.4567	39.8876	33.4658	25.4293	Sandia cartagenera	*Citrullus lanatus*	Spain, Murcia
PI537472	12.4968	41.7764	34.8964	36.1237	Sandia verde	*Citrullus lanatus*	Spain, Alicante
PI538012	21.9405	37.7231	26.7145	36.2792	CUTTER 55	*Citrullus lanatus*	United States

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI538888	16.9189	35.1297	26.1202	29.9147	AJC581	*Citrullus lanatus*	Russian Federation
PI542114	20.5684	38.934	38.3093	18.8111	JT 58	*Citrullus amarus*	Botswana
PI542115	40.8821	31.6602	34.0137	NA	524	*Citrullus lanatus*	Botswana
PI542617	18.3403	40.1872	35.822	33.576	1088	*Citrullus lanatus*	Algeria
PI543210	14.3453	30.702	44.192	33.3165	Muchas shandia (Chamane)	*Citrullus lanatus*	Bolivia, Beni
PI543212	19.6543	37.7397	24.9135	28.5873	Sandia	*Citrullus lanatus*	Bolivia, Beni
PI547106	NA	29.7864	24.2284	NA	TASTIGOLD	*Citrullus lanatus*	United States
PI549160	NA	NA	24.3444	NA	TCD 007	*Citrullus lanatus*	Chad
PI549162	14.5128	36.2467	14.9664	29.5046	BTERE	*Citrullus lanatus*	Chad
PI549163	NA	68.6817	19.9818	NA	TCD 064	*Citrullus lanatus*	Chad
PI556994	20.4447	36.5665	23.3504	NA	AU-SWEET SCARLET	*Citrullus lanatus*	United States, Alabama
PI556995	12.3298	33.1633	23.3772	35.4861	AU-GOLDEN PRODUCER	*Citrullus lanatus*	United States, Alabama
PI560000	20.2208	36.061	NA	30.1591	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560001	15.5263	35.933	18.2872	26.5167	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560002	20.7264	33.2218	30.7264	28.3391	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560003	8.1255	36.1128	36.5029	40.5005	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560004	10.1341	18.0091	36.6364	33.2586	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI560005	19.1762	31.4605	NA	33.935	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560007	9.6195	39.0648	32.4657	28.8498	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560008	16.9039	30.3632	65.5945	25.1576	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560009	18.6961	34.563	32.6192	28.6449	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560010	15.0777	30.6704	27.4267	39.4853	Egusi	*Citrullus mucosospermus*	Nigeria, Ogun
PI560011	7.5978	30.9817	64.7463	30.0002	Egusi	*Citrullus mucosospermus*	Nigeria, Ogun
PI560012	20.3296	33.4968	44.8477	33.7335	Egusi	*Citrullus mucosospermus*	Nigeria, Ogun
PI560013	9.2714	26.0566	32.4566	36.9609	Egusi	*Citrullus mucosospermus*	Nigeria, Ogun
PI560014	15.049	32.4046	23.3432	23.1092	Egusi	*Citrullus mucosospermus*	Nigeria, Ogun
PI560015	7.7208	35.1193	40.6846	32.5132	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560016	9.0793	34.9626	NA	43.5262	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560020	25.4039	37.8594	34.0916	28.585	Egusi	*Citrullus mucosospermus*	Nigeria, Oyo
PI560901	13.3849	25.373	15.7166	30.9902	JING XING NO. 1	*Citrullus lanatus*	China
PI561041	20.5003	31.8381	28.4887	21.2455	JULIETT	*Citrullus lanatus*	United States
PI561122	10.0415	22.6592	NA	29.001		*Citrullus lanatus*	China, Hebei
PI564535	11.5273	27.6104	17.3761	24.4465	JIMMY	*Citrullus lanatus*	United States
PI564536	12.2462	15.6675	12.5957	40.093	LISA	*Citrullus lanatus*	United States

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI593341	10.3167	31.1155	20.767	27.8546	Bin Gua	*Citrullus lanatus*	China, Shanghai
PI593344	24.8147	36.0805	31.5949	NA	ZWRM 10	*Citrullus lanatus*	China, Shanghai
PI593345	22.2073	43.5774	28.159	22.6393	ZWRM 11	*Citrullus lanatus*	China, Shanghai
PI593347	21.0422	29.8845	19.9519	NA	Yixuang	*Citrullus lanatus*	China, Henan
PI593348	17.1067	36.4222	24.7523	26.5616	Zhongyu No. 1	*Citrullus lanatus*	China, Henan
PI593349	22.6948	30.6241	28.5109	32.1999	Shan Bei	*Citrullus lanatus*	China, Henan
PI593350	20.9394	32.3886	29.6034	30.0278	Malingua	*Citrullus lanatus*	China, Henan
PI593351	17.5238	32.7421	20.1469	17.8105	Hetaowen	*Citrullus lanatus*	China, Henan
PI593352	24.4529	38.868	19.8297	34.5857	Xiao Hua Li Hu	*Citrullus lanatus*	China, Henan
PI593355	19.7461	24.7187	26.6637	31.7321	ZWRM 46	*Citrullus lanatus*	China, Shaanxi
PI593356	22.1257	36.0451	19.2935	NA	Lanzhou Edible Seed	*Citrullus lanatus*	China, Shaanxi
PI593357	17.883	33.0431	18.286	25.7665	High quality commercial	*Citrullus lanatus*	China, Shaanxi
PI593358	15.8758	35.7001	20.8911	29.7096	Yellow Rind Watermelon	*Citrullus lanatus*	China, Shaanxi
PI593359	10.9112	21.815	19.1066	36.1244	ZWRM 50	*Citrullus lanatus*	China, Shaanxi
PI593360	14.2679	40.6433	17.5401	39.6627	ZWRM 51	*Citrullus lanatus*	China, Shaanxi
PI593361	13.3939	36.1008	19.2952	30.0276	Zhongyau No. 6	*Citrullus lanatus*	China, Xinjiang
PI593363	22.1954	26.8732	26.6962	32.9982	Sulian No. 1	*Citrullus lanatus*	China, Xinjiang

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI593364	13.6892	41.3714	31.8594	31.5144	Three Dan No. 4	*Citrullus lanatus*	China, Xinjiang
PI593365	18.3975	NA	NA	NA	Xinchenhong	*Citrullus lanatus*	China, Xinjiang
PI593366	22.3291	47.4273	36.5087	42.0812	Kalatawuzi	*Citrullus lanatus*	China, Xinjiang
PI593368	11.4622	42.333	26.731	39.3979	Yixuan	*Citrullus lanatus*	China, Xinjiang
PI593369	30.9235	40.1585	26.8587	38.845	Jizaogua (Chicken Feed)	*Citrullus lanatus*	China, Xinjiang
PI593371	21.7605	39.0807	24.16	39.4346	Raketawuzi	*Citrullus lanatus*	China, Xinjiang
PI593373	32.1404	49.2876	25.196	42.9269	Mapimazi	*Citrullus lanatus*	China, Xinjiang
PI593375	17.2628	32.5173	26.6087	24.8871	Dahongzianchong	*Citrullus lanatus*	China, Xinjiang
PI593376	21.579	43.8448	28.0152	31.6609	Fuyang	*Citrullus lanatus*	China, Xinjiang
PI593377	12.7701	34.6291	14.4437	23.0406	Meiliquinfeng	*Citrullus lanatus*	China, Xinjiang
PI593378	23.713	23.6469	22.48	24.7897	Hetaowen	*Citrullus lanatus*	China, Xinjiang
PI593379	29.0102	40.4742	35.9338	31.1849	Xianxiaogua	*Citrullus lanatus*	China, Xinjiang
PI593380	15.1812	36.9439	21.4751	34.7358	Jinlu	*Citrullus lanatus*	China, Xinjiang
PI593381	22.1112	32.955	51.6744	46.1916	Xiaozihulu	*Citrullus lanatus*	China, Xinjiang
PI593383	16.8765	45.616	24.1805	30.7627	Zaohua	*Citrullus lanatus*	China, Xinjiang
PI593384	18.76	40.3058	26.0328	36.9369	Dhogyu No. 1	*Citrullus lanatus*	China, Xinjiang
PI593385	NA	39.8077	24.0294	NA	Zhengza No. 5	*Citrullus lanatus*	China, Xinjiang

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI593386	19.4099	35.7916	28.2903	34.3349	Jinhuabao F1	*Citrullus lanatus*	China, Xinjiang
PI593388	17.6184	35.3544	25.8146	31.786	Hongyou No. 9	*Citrullus lanatus*	China, Xinjiang
PI593389	11.3041	35.0163	23.3031	38.0298	Hongyou No. 11	*Citrullus lanatus*	China, Xinjiang
PI593390	14.252	38.5482	17.5587	36.5142	Xiaoqinpi	*Citrullus lanatus*	China, Xinjiang
PI595200	27.2479	40.3645	35.8894	32.3446	WM-1	*Citrullus lanatus*	United States, Georgia
PI595201	10.7205	34.8519	28.4994	26.9109	WM-2	*Citrullus lanatus*	United States, Georgia
PI595202	24.66	38.7913	29.176	30.7361	WM-3	*Citrullus lanatus*	United States, Georgia
PI595365	NA	33.2305	30.1944	26.0018	NA	*NA*	NA
PI596653	16.5486	29.001	34.3121	28.8356	20	*Citrullus amarus*	South Africa
PI596656	18.4827	42.6648	39.8595	36.4605	23	*Citrullus amarus*	South Africa
PI596659	25.897	35.2099	34.9482	25.159	26	*Citrullus amarus*	South Africa
PI596662	36.176	44.6764	NA	33.113	37	*Citrullus amarus*	South Africa, Transvaal
PI596665	36.2599	34.7804	28.2901	NA	44	*Citrullus amarus*	South Africa, Transvaal
PI596666	18.7126	36.5681	27.521	20.8994	45	*Citrullus amarus*	South Africa, Transvaal
PI596668	31.1916	35.1265	25.8879	19.3989	48	*Citrullus amarus*	South Africa, Transvaal
PI596669	16.821	29.3689	24.2336	27.3514	49	*Citrullus amarus*	South Africa, Cape Province
PI596670	12.6726	27.5212	24.3366	17.0718	51	*Citrullus amarus*	South Africa, Cape Province

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI596671	16.1446	NA	40.0952	24.1185	53	*Citrullus amarus*	South Africa
PI596675	27.9588	50.917	29.2006	25.4474	60	*Citrullus amarus*	South Africa
PI596676	20.5733	34.5037	35.0584	16.5586	61	*Citrullus amarus*	South Africa
PI596677	17.105	4.8779	26.676	NA	62	*Citrullus amarus*	South Africa
PI596696	26.2532	31.4119	17.5846	25.8502	112	*Citrullus amarus*	South Africa, Transvaal
PI600790	23.2684	40.9644	20.7392	37.195	PEROLA	*Citrullus lanatus*	United States, Michigan
PI600896	20.6787	43.2978	12.4119	34.7853	SUN GOLD	*Citrullus lanatus*	United States
PI600950	7.2381	30.2053	17.5282	NA	CRIMSON DIAMOND	*Citrullus lanatus*	United States
PI600951	18.0593	21.3634	23.2768	22.1388	CHUBBY GRAY	*Citrullus lanatus*	United States
PI600962	17.3475	33.9101	25.0876	37.0521	BIG CRIMSON	*Citrullus lanatus*	United States
PI601101	14.6743	30.4446	29.814	41.5977	LONG CRIMSON	*Citrullus lanatus*	United States
PI601182	13.4579	36.0461	24.8042	32.9597	CHARLESTON ELITE	*Citrullus lanatus*	United States
PI601221	22.0426	41.4143	29.0085	27.0857	CHARLEE	*Citrullus lanatus*	United States, Florida
PI601228	14.4079	38.7335	32.4672	30.2066	YELLOW CRIMSON	*Citrullus lanatus*	United States
PI601289	15.3245	28.0367	25.0838	29.9998	SUNSUGAR	*Citrullus lanatus*	United States
PI601662	16.3001	34.3268	25.9287	19.7939	JUBILEE II	*Citrullus lanatus*	United States, Florida
PI606135	15.2459	32.7535	30.7794	18.6914	K-4992	*Citrullus amarus*	Russian Federation

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI608047	15.7106	37.7967	27.5477	34.3575	Illiniwek Red Seeded Watermelon	*Citrullus lanatus*	United States, Illinois
PI612457	18.7904	36.3167	20.1272	23.6175	Shindewha 2ho	*Citrullus lanatus*	Korea, South, Pusan
PI612458	17.1996	39.5278	19.8992	37.7877	Ukdewha	*Citrullus lanatus*	Korea, South, Pusan
PI612460	14.3639	31.1727	29.9492	25.3621	Shindungtewha	*Citrullus lanatus*	Korea, South, Pusan
PI612461	10.427	33.7919	14.8338	24.5598	Chunseo	*Citrullus lanatus*	Korea, South, Pusan
PI612462	21.3102	42.3865	18.5925	29.7718	Kiwon	*Citrullus lanatus*	Korea, South, Pusan
PI612464	23.0221	37.6242	22.4816	22.8184	Dewhangsoobak	*Citrullus lanatus*	Korea, South, Pusan
PI612467	14.0206	42.7562	20.228	20.3524	Shindewha 3	*Citrullus lanatus*	Korea, South, Pusan
PI612468	13.3556	32.9273	24.1395	28.965	Handuel	*Citrullus lanatus*	Korea, South, Pusan
PI612469	12.9891	29.8487	NA	30.2427	Shinyang	*Citrullus lanatus*	Korea, South, Pusan
PI612470	16.8905	33.8783	21.8383	19.6153	Kumsang	*Citrullus lanatus*	Korea, South, Pusan
PI612471	13.2191	39.1455	16.682	33.8297	Lucky	*Citrullus lanatus*	Korea, South, Pusan
PI612472	11.1015	35.6585	21.5147	26.904	Bingguare	*Citrullus lanatus*	Korea, South, Pusan
PI612473	15.7549	28.8206	NA	15.7515	Chilbo	*Citrullus lanatus*	Korea, South, Pusan
PI612475	11.1058	42.3043	17.5145	25.3135	Shinbookuk	*Citrullus lanatus*	Korea, South, Pusan
PI629101	10.974	32.5977	18.4333	33.9398	Grif 1732	*Citrullus lanatus*	China, Jiangsu
PI629102	13.3919	36.5022	30.0484	31.6657	COBB GEM	*Citrullus lanatus*	United States, Idaho

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI629103	14.2169	36.9574	19.3249	35.538	CL-99-07	*Citrullus lanatus*	India, Rajasthan
PI629104	20.238	38.374	33.2126	32.597	S027	*Citrullus lanatus*	Syria
PI629105	18.2749	45.4565	26.5683	33.6909	Cream of Saskatchewan	*Citrullus lanatus*	United States, North Carolina
PI629106	22.4689	35.9003	11.9715	26.4011	Florida Favorite	*Citrullus lanatus*	United States, North Carolina
PI629108	17.8793	34.1378	21.7607	28.1076	GOLDEN HONEY	*Citrullus lanatus*	United States, California
PI629109	12.9819	41.6522	24.062	36.6686	IMPROVED PEACOCK	*Citrullus lanatus*	United States, Colorado
PI629110	12.1958	31.6556	22.5851	28.809	RHODE ISLAND RED	*Citrullus lanatus*	United States, Colorado
PI632754	16.1414	34.5417	20.7131	27.4731	B92-106	*Citrullus lanatus*	Bulgaria
PI634691	15.2146	39.2933	25.836	38.9951	203	*Citrullus lanatus*	
PI635590	12.9015	39.3198	14.2439	NA	EARLY CANADA	*Citrullus lanatus*	United States, California
PI635592	16.5838	34.4609	38.1931	NA	EARLY ARIZONA	*Citrullus lanatus*	United States, California
PI635594	24.6483	30.2308	29.2059	40.0475	FAIRFAX WILT RESISTANT	*Citrullus lanatus*	United States, California
PI635597	NA	40.4522	20.8541	NA	GOLDEN HONEY CREAM	*Citrullus lanatus*	United States, California
PI635598	45.6974	48.9761	43.1091	NA	GOLDEN MIDGET	*Citrullus lanatus*	United States, California
PI635600	15.1935	36.4622	20.0178	26.9105	HALBERT HONEY	*Citrullus lanatus*	United States, California
PI635601	17.0226	31.7846	29.0202	33.1171	HAWKESBURY	*Citrullus lanatus*	United States, California
PI635603	14.2785	29.0584	25.0472	27.6734	ICE CREAM	*Citrullus lanatus*	United States, Missouri

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI635606	24.08	28.9807	30.0096	34.7444	KING AND QUEEN WINTER	*Citrullus lanatus*	United States, California
PI635609	13.8507	34.1346	27.816	50.4699	KLONDIKE BLACK SEEDED	*Citrullus lanatus*	United States, California
PI635610	27.2299	42.6855	25.9592	NA	KLONDIKE BROWN SEEDED	*Citrullus lanatus*	United States, California
PI635611	18.8388	36.7114	34.1642	NA	KLONDIKE MORSES BROWN SEEDED	*Citrullus lanatus*	United States, California
PI635612	12.9555	40.278	25.1115	NA	KLONDIKE R 7	*Citrullus lanatus*	United States, Minnesota
PI635613	15.1386	32.2678	20.2434	28.8006	KLONDIKE RS 57	*Citrullus lanatus*	United States, Colorado
PI635614	17.2208	34.0216	NA	35.3344	KLONDIKE STRIPED BLUE RIBBON	*Citrullus lanatus*	United States, Colorado
PI635616	15.3707	34.1933	25.2367	30.3886	MARKET MIDGET	*Citrullus lanatus*	United States, New York
PI635618	22.6839	30.0187	24.2037	28.8247	NORTHERN SWEET	*Citrullus lanatus*	United States, California
PI635619	21.1241	40.2774	24.0389	38.6548	PEACOCK IMPROVED SHIPPER	*Citrullus lanatus*	United States, California
PI635620	10.6343	27.375	20.8962	30.9664	SHIPPER	*Citrullus lanatus*	United States, Mississippi
PI635621	14.2878	39.4314	33.4839	29.6492	STONE MOUNTAIN	*Citrullus lanatus*	United States, California
PI635626	26.5602	44.5189	23.4489	39.5626	WHITE HOPE	*Citrullus lanatus*	United States, California
PI635630	13.6397	35.3525	15.0555	21.1618	MERRIMACK SWEETHEART	*Citrullus lanatus*	United States, New Hampshire
PI635631	13.6957	35.0069	28.5194	27.7254	SUPER REDHART STONE MOUNTAIN	*Citrullus lanatus*	United States, Georgia
PI635635	20.819	44.4527	14.893	NA	DUNBARTON	*Citrullus lanatus*	United States, South Carolina
PI635637	12.9227	29.142	22.5317	30.6017	ICE BOX RED FLESH	*Citrullus lanatus*	United States, Illinois

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI635639	NA	34.5046	NA	NA	MILES	*Citrullus lanatus*	United States, Michigan
PI635640	21.6785	34.8743	23.1597	NA	LEESBURG	*Citrullus lanatus*	United States, Florida
PI635642	15.1878	38.9447	21.7633	19.4593	CHARLESTON GRAY 133	*Citrullus lanatus*	United States, Indiana
PI635644	20.5856	38.5476	30.0834	29.7848	PRINCETON	*Citrullus lanatus*	United States, Indiana
PI635647	25.6622	39.0919	34.9436	26.4187	CALHOUN SWEET	*Citrullus lanatus*	United States, Louisiana
PI635653	21.2622	37.2198	23.4665	NA	BLACKLEE	*Citrullus lanatus*	United States, California
PI635659	13.4479	NA	10.1876	NA	EARLY JUMBO	*Citrullus lanatus*	United States, Minnesota
PI635660	23.4808	45.2263	26.7484	NA	KLONDIKE WR-3 WILT RESISTANT	*Citrullus lanatus*	United States, California
PI635661	15.2626	41.7352	NA	34.8198	KLONDIKE BLACK SEED 3	*Citrullus lanatus*	United States, California
PI635662	20.255	30.9457	23.611	35.8311	PEACOCK STRIPED	*Citrullus lanatus*	United States, California
PI635663	18.9597	34.3664	43.4833	36.5197	PEACOCK WR-50	*Citrullus lanatus*	United States, California
PI635664	21.882	35.3677	26.725	30.0372	KLONDIKE WR65 GREEN RIND	*Citrullus lanatus*	United States, California
PI635665	13.8516	35.2134	NA	33.956	GRAYBELLE	*Citrullus lanatus*	United States, South Carolina
PI635666	15.7569	30.5382	29.9956	NA	DARK GREEN KLONDIKE	*Citrullus lanatus*	United States, Michigan
PI635668	23.9676	43.2237	22.638	34.166	ARIKARA	*Citrullus lanatus*	United States, Wyoming
PI635670	23.4273	33.7567	28.342	31.891	RED-SEEDED CITRON	*Citrullus lanatus*	United States, Wyoming
PI635672	25.0579	47.5736	40.9594	NA	CALABRIA	*Citrullus lanatus*	United States, Wyoming

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI635682	19.6907	29.4737	26.0141	32.8348	ROS A BUCCIA NORA	*Citrullus lanatus*	Argentina
PI635683	21.1229	35.3958	29.2259	44.3146	SWEET SIBERIAN	*Citrullus lanatus*	United States, Wyoming
PI635686	22.2515	35.2304	23.3699	35.0575	WILLS SUGAR	*Citrullus lanatus*	United States, Wyoming
PI635688	16.4637	35.1501	17.6447	39.3738	CRIMSON SWEET	*Citrullus lanatus*	United States, Kansas
PI635695	14.6404	31.747	15.2418	29.0962	WHITE SEEDED WATSON	*Citrullus lanatus*	United States, Texas
PI635696	10.3755	31.3457	14.2954	26.4222	CHARLESTON TETRA NO 1	*Citrullus lanatus*	United States, South Carolina
PI635698	9.0091	NA	24.9029	33.2271	CHARLESTON TETRA NO 3	*Citrullus lanatus*	United States, South Carolina
PI635699	14.4205	34.3954	NA	36.9655	CHARLESTON DIPLOID 59-1	*Citrullus lanatus*	United States, South Carolina
PI635700	12.0454	28.2146	18.3153	36.2908	CHARLESTON DIPLOID 59-6	*Citrullus lanatus*	United States, South Carolina
PI635702	15.7252	32.0741	16.9616	NA	BLACK SEEDED ICE CREAM	*Citrullus lanatus*	United States, Oregon
PI635703	11.6546	44.1393	31.5384	40.539	KLONDIKE STRIPED 11	*Citrullus lanatus*	United States, Missouri
PI635704	30.3541	34.458	29.9112	45.7559	KLONDIKE 3	*Citrullus lanatus*	United States, Missouri
PI635709	20.0113	34.7822	30.9469	22.649	HAWKESBURY WILT RESISTANT	*Citrullus lanatus*	Australia, Queensland
PI635712	4.8823	18.9802	15.8632	33.5439	VERONA	*Citrullus lanatus*	United States, Mississippi
PI635713	23.2091	34.9399	25.8417	33.2269	CALHOUN GRAY	*Citrullus lanatus*	United States, Louisiana
PI635714	17.6502	39.2421	20.7786	36.2468	SUNNY BOY	*Citrullus lanatus*	United States, California
PI635715	15.7241	34.9979	NA	15.6162	KLONDIKE 53 WILT RESISTANT	*Citrullus lanatus*	United States, Michigan

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI635721	11.9067	29.4503	25.7439	33.5101	DELICIOUS BIG SUGAR	*Citrullus lanatus*	United States, Maryland
PI635722	10.7515	28.0397	21.4278	28.5867	SPALDING WATERMELON	*Citrullus lanatus*	United States, Georgia
PI635726	12.9639	31.903	34.2589	34.1872	SUNSHADE	*Citrullus lanatus*	United States
PI635728	11.707	36.2269	16.5679	NA	SUGAR BUSH	*Citrullus lanatus*	United States
PI635730	12.4736	38.8131	18.6318	15.2347	SUGARLEE	*Citrullus lanatus*	United States, Florida
PI635732	11.4878	38.7289	15.1635	36.0792	SUPER SWEET	*Citrullus lanatus*	United States, Colorado
PI635755	16.7915	35.8604	25.0968	31.5706	FORDHOOK	*Citrullus lanatus*	United States, Maryland
PI635763	13.9477	31.6671	22.5636	28.6021	RED SEEDED ASAHI	*Citrullus lanatus*	United States, Maryland
PI635769	25.2069	30.6048	NA	26.9385	TEXAS WHEELER	*Citrullus lanatus*	United States, Maryland
PI635772	8.9156	35.2936	19.9206	38.1929	YELLOW FLESH NO NAMES EASTERN	*Citrullus lanatus*	United States, Maryland
PI658554	18.4563	32.3309	30.0219	33.7855	MKDW-002	*Citrullus lanatus*	Turkmenistan
PI658680	12.0241	27.9557	24.7488	25.4591	Grif 1728	*Citrullus lanatus*	China, Jiangsu
PI660975	24.6066	34.4172	28.0023	26.639	Turkmen Black Seed	*Citrullus lanatus*	Turkmenistan
PI660976	14.4977	30.5232	34.3193	34.8653	Broshka	*Citrullus lanatus*	Turkmenistan
PI662034	23.9174	30.7999	22.3887	32.0694	Chilim	*Citrullus lanatus*	Turkmenistan
PI665007	15.621	34.0357	12.6343	34.4324	SUGAR BABY	*Citrullus lanatus*	United States, Colorado
PI673137	NA	35.2609	20.9248	33.9847	Bitter Hawkesbury	*Citrullus lanatus*	United States, Georgia

Cultigen	Race 1 Greenhouse	Race 1 Chambers	Race 1 Field	Race 2 Greenhouse	Plant.Name	Taxonomy	Origin
PI674448	37.4902	31.4853	33.4872	13.0243	43-522	*Citrullus amarus*	Russian Federation
PI674463	22.6058	22.5734	NA	30.7256	Moon and Stars (Van Doren)	*Citrullus lanatus*	United States, Iowa
PI674464	13.7786	40.7936	NA	29.0831	GSMO 2-30	*Citrullus lanatus*	Georgia
PI674465	22.5363	30.1733	30.1225	27.9637	Davis-Benny Citron	*Citrullus lanatus*	United States, Texas
PI674466	10.6586	30.1306	28.3365	31.958	PI 525088-PMR	*Citrullus lanatus*	United States, Oklahoma
PI675114	16.978	37.7919	18.0218	25.1003	Moon and Stars (Cherokee)	*Citrullus lanatus*	United States, Iowa
PI675115	18.857	38.9873	NA	31.0097	Silver Emblem	*Citrullus lanatus*	Turkmenistan
PI675116	11.0506	26.0788	28.9215	37.2873	Gara Chigit	*Citrullus lanatus*	Turkmenistan
PI675117	15.312	37.2954	28.5231	30.3443	Turkmen Ir Bisher Ala Garpyz	*Citrullus lanatus*	Turkmenistan

Appendix B
ASReml Codes and Outputs for mixed model analysis

ASReml Code Anthracnose Race 1 Greenhouse

```
##################################################
# Anthracnoce Race 1 Grennhouse data Multivariate analysis
# Takshay Patel
# NC State University - 2018
##################################################

!ARGS $  !RENAME 2 !OUTFOLDER
C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth1GH\GHASREML_outp
ut

Title: Anthracnose Race 1 Greenhouse Data


 Plt  !A
 Cult  !A
 Plant  *
 Rep  *
 Rating1
 Rating2
 Rating3
 Block  *
 Tray  *


!FOLDER C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth1GH
GH_Data.csv  !SKIP 1  !DOPART $A   !CONTINUE  !MVINCLUDE  !BRIEF -1


### ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ###
# Multivariate model  - Cult = fixed effect
### ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ###
!PART 3
!MAXIT 1000 !WORKSPACE 8000 !AISING #CON()

Rating1 Rating2 Rating3 ~ Trait Trait.Cult,
        !r Trait.Rep Trait.Rep/Tray Trait.Plt
        residual id(units).us(Trait)
predict Cult !Average Trait
```

ASReml Output ASR file Anthracnose Race 1 Greenhouse

```
ASReml 4.1 [28 Dec 2014] Title: GVBV OP data single site analysis
  Build mn [13 Jan 2017]   64 bit  Windows x64
 31 May 2018 14:23:59.828   8000 Mbyte  z\Desktop\Takshay\out/gh_data3
 Licensed to: North Carolina State University    30-nov-2018
 ***************************************************************
 * Contact support@asreml.co.uk for licensing and support       *
 ********************************************************* ARG *
 Folder: C:\Users\mshaliz\Desktop\Takshay
 Plt  !A
 Cult  !A
 QUALIFIERS: !SKIP 1              !CONTINUE  !MVINCLUDE
 QUALIFIERS: !MAXIT 1000 !WORKSPACE 8000 !AISING
 QUALIFIER: !DOPART 3 is active
 Reading C:\Users\mshaliz\Desktop\Takshay\gh_data.csv  FREE FORMAT skipping     1 lines

 Multivariate analysis of Rating1       Rating2       Rating3
 Summary of 13886 records retained of 17637 read
 Notice: 3751 records dropped because all traits are missing.

  Model term          Size #miss #zero   MinNon0    Mean      MaxNon0  StndDevn
   1 Plt             5635     0     0      1  2324.6855       5054
   2 Cult            1411     0     0      1   626.2314       1327
   3 Plant              3     0     0      1     1.8895          3
   4 Rep                4     0     0      1     2.4979          4
   5 Rating1       Variate     0  2841  3.000      9.482      100.0      9.822
   6 Rating2       Variate     3   488  5.000      17.91      100.0      13.44
   7 Rating3       Variate    13    66  5.000      30.87      100.0      20.14
   8 Block             84     0     0      1    42.1743         84
   9 Tray             244     0     0      1   122.5305        244
  10 Trait                   3
  11 Trait.Cult            4233 10 Trait     :   3   2 Cult          : 1411
  12 Trait.Rep               12 10 Trait     :   3   4 Rep           :    4
  13 Rep.Tray               976  4 Rep       :   4   9 Tray          :  244
  14 Trait.Rep.Tray        2928 10 Trait     :   3  13 Rep.Tray      :  976
  15 Trait.Plt            16905 10 Trait   :     3   1 Plt           :  5635

 Notice: Too many fixed terms for !DENSE block.
        Trait.Cult is moved to SPARSE block
         Use !DENSE 4238 to include Trait.Cult in Wald F table
 us(Trait) in id(units).us(Trait) has size 3, parameters:  11  16
  id(units).us(Trait)             [ 10: 16] initialized.
 Forming    24081 equations:   3 dense.
 Initial updates will be shrunk by factor    0.300
 Notice: ReStartValues taken from C:\Users\mshaliz\Desktop\Takshay\out/gh_data3.rsv
```

```
Notice: LogL values are reported relative to a base of -110000.00
Notice: 255 singularities detected in design matrix.
  1 LogL=-118.848     S2=  1.0000      37661 df
  2 LogL=-118.848     S2=  1.0000      37661 df
  3 LogL=-118.848     S2=  1.0000      37661 df

         - - - Results from analysis of Rating1 Rating2 Rating3 - - -
Akaike Information Criterion   220255.70 (assuming 9 parameters).
Bayesian Information Criterion 220332.52

Model_Term                             Sigma         Sigma   Sigma/SE   % C
Trait.Rep              IDV_V   12   21.1213       21.1213       2.09   0 P
Trait.Rep.Tray         IDV_V 2928   13.2967       13.2967      13.92   0 P
Trait.Plt              IDV_V 16905   8.72562       8.72562      18.40   0 P
id(units).us(Trait)          41658 effects
Trait                  US_V  1  1   63.6182       63.6182      70.32   0 P
Trait                  US_C  2  1   57.6907       57.6907      56.49   0 P
Trait                  US_V  2  2   126.813       126.813      73.81   0 P
Trait                  US_C  3  1   48.0516       48.0516      37.66   0 P
Trait                  US_C  3  2   113.776       113.776      57.90   0 P
Trait                  US_V  3  3   247.276       247.276      75.18   0 P
Covariance/Variance/Correlation Matrix US Residual
  63.62      0.6423      0.3831
  57.69       126.8      0.6425
  48.05       113.8       247.3

                               Wald F statistics
   Source of Variation          NumDF            F-inc

                  Solution       Standard Error    T-value     T-prev
 12 Trait.Rep                        12 effects fitted
 14 Trait.Rep.Tray                 2928 effects fitted (     2196 are zero)
 11 Trait.Cult                     3981 effects fitted (+     252 singular)
 15 Trait.Plt                     16905 effects fitted (     1806 are zero)
       230  possible outliers: see .res file
Finished: 31 May 2018 14:24:12.864   LogL Converged
```

ASReml Code Anthracnose Race 1 Chambers

```
##################################################
# Anthracnoce Race 1 Chambers data Multivariate analysis
# Takshay Patel
# NC State University - 2018
##################################################


!ARGS 3 !RENAME 2 !OUTFOLDER
C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth1Phy\out
Title: phy.


 Plot  !A     2820
 Cult  !A    1415
 Plant  *
 Rep  *       # 1
 Rating1        # 5
 Rating2        # 5
 Rating3       # 10
 Run  *       # 7
 Cart  *       # 3

!FOLDER C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth1Phy
Anth1Phy.csv  !SKIP 1 !CONTINUE !DENSE !DOPART 3

### ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ###
# Multivariate model  - Cult = fixed effect
### ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ###
!PART 3
!MAXIT 1000 !WORKSPACE 8000 !AISING #CON()

Rating1 Rating2 Rating3 ~ Trait Trait.Cult,
          !r Trait.Rep Trait.Run Trait.Run/Cart/Plot
          residual id(units).us(Trait)
predict Cult !Average Trait
```

ASReml Output ASR Anthracnose Race 1 Chamber

```
ASReml 4.1 [28 Dec 2014] Title: phy.
  Build mv [29 Nov 2017]   64 bit  Windows x64
 25 Jun 2018 13:44:12.677   8000 Mbyte  lysis\ASReml\Anth1Phy\out/phy3
 Licensed to: North Carolina State University    30-nov-2018
 ***************************************************************
 * Contact support@asreml.co.uk for licensing and support        *
 ********************************************************* ARG *
 Folder: C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth1Phy
 Plot  !A     2820
 Cult  !A    1415
 QUALIFIERS: !SKIP 1 !CONTINUE !DENSE
 QUALIFIERS: !MAXIT 1000 !WORKSPACE 8000 !AISING
 QUALIFIER: !DOPART 3 is active
 Reading
C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth1Phy\Anth1Phy.csv
FREE FORMAT skipping     1 lines

 Multivariate analysis of Rating1       Rating2       Rating3
 Summary of 7834 records retained of 8538 read
 Notice: 704 records dropped because all traits are missing.

  Model term          Size #miss #zero   MinNon0    Mean      MaxNon0  StndDevn
  Warning: Fewer levels found in Plot  than specified
   1 Plot             2820     0     0      1  1418.7575       2690
  Warning: Fewer levels found in Cult  than specified
   2 Cult             1415     0     0      1   709.6911       1347
   3 Plant               3     0     0      1     1.9288          3
   4 Rep                 2     0     0      1     1.5019          2
   5 Rating1        Variate    2  5397  5.000      2.380      60.00      4.609
   6 Rating2        Variate   13  1782  5.000      10.57      100.0      14.34
   7 Rating3        Variate   13   445  5.000      22.13      100.0      22.86
   8 Run                15     0     0      1     8.1134         15
   9 Cart                6     0     0      1     3.4322          6
  10 Trait                   3
  11 Trait.Cult             4245 10 Trait     :   3   2 Cult          : 1415
  12 Trait.Rep                 6 10 Trait     :   3   4 Rep           :    2
  13 Trait.Run                45 10 Trait     :   3   8 Run           :   15
  14 Run.Cart                 90  8 Run       :  15   9 Cart          :    6
  15 Trait.Run.Cart          270 10 Trait     :   3  14 Run.Cart      :   90
  16 Cart.Plot             16920  9 Cart      :   6   1 Plot          : 2820
  17 Run.Cart.Plot        253800  8 Run       :  15  16 Cart.Plot     : 16920
  18 Trait.Run.Cart.Plot  761400 10 Trait     :   3  17 Run.Cart.Plot :253800

 Notice: Too many fixed terms for !DENSE block.
```

```
        Trait.Cult is moved to SPARSE block
         Use !DENSE 4250 to include Trait.Cult in Wald F table
 us(Trait) in id(units).us(Trait) has size 3, parameters:  13  18
  id(units).us(Trait)            [ 12: 18] initialized.
 Forming   765969 equations:   3 dense.
 Initial updates will be shrunk by factor    0.300
 Notice: ReStartValues taken from
C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth1Phy\out/phy3.rsv
 Notice: LogL values are reported relative to a base of -50000.000
 Notice: 207 singularities detected in design matrix.
   1 LogL=-1150.28     S2=  1.0000      19433 df
   2 LogL=-1150.28     S2=  1.0000      19433 df
   3 LogL=-1150.28     S2=  1.0000      19433 df

         - - - Results from analysis of Rating1 Rating2 Rating3 - - -
 Akaike Information Criterion   102320.55 (assuming 10 parameters).
 Bayesian Information Criterion 102399.30

 Model_Term                          Sigma        Sigma   Sigma/SE   % C
 Trait.Rep              IDV_V    6   8.79006      8.79006       0.50   0 P
 Trait.Run              IDV_V   45   89.5230      89.5230       4.23   0 P
 Trait.Run.Cart         IDV_V  270   14.8378      14.8378       8.20   0 P
 Trait.Run.Cart.Plot   IDV_V 761400   3.50213      3.50213      13.18   0 P
 id(units).us(Trait)          23502 effects
 Trait                 US_V  1  1   11.9294      11.9294     51.09   0 P
 Trait                 US_C  2  1   15.9721      15.9721     33.22   0 P
 Trait                 US_V  2  2   86.1059      86.1059     54.29   0 P
 Trait                 US_C  3  1   16.2320      16.2320     22.68   0 P
 Trait                 US_C  3  2   93.6410      93.6410     44.39   0 P
 Trait                 US_V  3  3   215.948      215.948     55.47   0 P
 Covariance/Variance/Correlation Matrix US Residual
   11.93     0.4984     0.3198
   15.97      86.11     0.6867
   16.23      93.64      215.9

                              Wald F statistics
    Source of Variation          NumDF            F-inc

                   Solution      Standard Error    T-value     T-prev
  12 Trait.Rep                        6 effects fitted
  13 Trait.Run                       45 effects fitted
  15 Trait.Run.Cart                   270 effects fitted (      21 are zero)
  11 Trait.Cult                    4041 effects fitted (+     204 singular)
  18 Trait.Run.Cart.Plot            761400 effects fitted (  752952 are zero)
        282  possible outliers: see .res file
 Finished: 25 Jun 2018 13:44:47.028   LogL Converged
```

ASReml Code Anthracnose Race 2 Greenhouse

```
################################################
# Anthracnoce Race 2 Grennhouse data Multivariate analysis
# Takshay Patel
# NC State University - 2018
################################################

!ARGS 2  !RENAME 2 !OUTFOLDER
C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth2GH\GHAnthR2_output

Title: Anthracnose Race 2 Greenhouse Data


 Cult  !A
 Plot  !A
 Plant  *
 Rating1
 Rating2
 Rating3
 Tray  *
 Run  *
 Rep  *

!FOLDER C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth2GH
AnthR2GH.csv  !SKIP 1  !DOPART 2   !CONTINUE  !MVINCLUDE !BRIEF -1


### ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ###
# Multivariate model  - Cult = fixed effect
### ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ###
!PART 3
!MAXIT 1000 !WORKSPACE 8000 !AISING #CON()

Rating1 Rating2 Rating3 ~ Trait Trait.Cult,
        !r Trait.Rep Trait.Rep/Run Trait.Run/Tray Trait.Plot
        residual id(units).us(Trait)
predict Cult !Average Trait
```

ASReml Output ASR Anthracnose Race 2 Greenhouse

```
ASReml 4.1 [28 Dec 2014] Title: Anthracnose R2 Greenhouse Data
  Build mv [29 Nov 2017]   64 bit  Windows x64
 06 Aug 2018 08:47:30.589   8000 Mbyte  GHAnthR2_output/GHAnthR2_Data3
 Licensed to: North Carolina State University    30-nov-2018
 ***************************************************************
 * Contact support@asreml.co.uk for licensing and support       *
 ********************************************************* ARG *
 Folder: C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth2GH
 Cult  !A
 Plot  !A
 QUALIFIERS: !SKIP 1              !CONTINUE  !MVINCLUDE
 QUALIFIERS: !MAXIT 1000 !WORKSPACE 8000 !AISING
 QUALIFIER: !DOPART 3 is active
 Reading
C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth2GH\AnthR2GH.csv
FREE FORMAT skipping     1 lines

 Multivariate analysis of Rating1       Rating2       Rating3
 Summary of 6438 records retained of 7554 read
 Notice: 1116 records dropped because all traits are missing.

  Model term          Size #miss #zero   MinNon0    Mean      MaxNon0  StndDevn
   1 Cult             1199     0     0      1   583.2162       1199
   2 Plot             2397     0     0      1  1164.6841       2397
   3 Plant               3     0     0      1     1.8869          3
   4 Rating1       Variate     0  4700  5.000      1.959      100.0      4.688
   5 Rating2       Variate     0    99  5.000      29.50      100.0      17.25
   6 Rating3       Variate     0     6  5.000      65.61      100.0      24.07
   7 Tray              124     0     0      1    63.5803        124
   8 Run                 2     0     0      1     1.5023          2
   9 Rep                 2     0     0      1     1.5230          2
  10 Trait                 3
  11 Trait.Cult          3597 10 Trait     :  3   1 Cult          : 1199
  12 Trait.Rep              6 10 Trait     :  3   9 Rep           :    2
  13 Rep.Run                4  9 Rep       :  2   8 Run           :    2
  14 Trait.Rep.Run         12 10 Trait     :  3  13 Rep.Run       :    4
  15 Trait.Run              6 10 Trait     :  3   8 Run           :    2
  16 Run.Tray             248  8 Run       :  2   7 Tray          :  124
  17 Trait.Run.Tray       744 10 Trait     :  3  16 Run.Tray      :  248
  18 Trait.Plot          7191 10 Trait     :  3   2 Plot          : 2397
```

```
 Notice: Too many fixed terms for !DENSE block.
        Trait.Cult is moved to SPARSE block
         Use !DENSE 3602 to include Trait.Cult in Wald F table
 us(Trait) in id(units).us(Trait) has size 3, parameters:  14  19
  id(units).us(Trait)              [ 13: 19] initialized.
 Forming    11559 equations:   3 dense.
 Initial updates will be shrunk by factor    0.300
 Notice: ReStartValues taken from
C:\Users\taksh\Desktop\ProjectAnt\Project\DataAnalysis\ASReml\Anth2GH\GHAnthR2_output
/GHAnthR2_Data3.rsv
 Notice: LogL values are reported relative to a base of -40000.000
 Notice: 3 singularities detected in design matrix.
   1 LogL=-3726.21     S2=  1.0000      15717 df    :   1 components restrained
   2 LogL=-3726.21     S2=  1.0000      15717 df    :   1 components restrained
   3 LogL=-3726.21     S2=  1.0000      15717 df

         - - - Results from analysis of Rating1 Rating2 Rating3 - - -
 Akaike Information Criterion    87474.42 (assuming 11 parameters).
 Bayesian Information Criterion  87558.71

 Model_Term                             Sigma        Sigma   Sigma/SE   % C
 Trait.Rep              IDV_V    6  0.404772E-09  0.404772E-09   0.00    0 B
 Trait.Run              IDV_V    6   27.7694       27.7694       0.44   0 P
 Trait.Rep.Run          IDV_V   12   85.6267       85.6267       1.69   0 P
 Trait.Run.Tray         IDV_V  744   57.3248       57.3248      11.90   0 P
 Trait.Plot           IDV_V 7191   22.6573       22.6573      18.73   0 P
 id(units).us(Trait)          19314 effects
 Trait                  US_V  1  1   11.6874      11.6874      45.21   0 P
 Trait                  US_C  2  1   5.27288      5.27288       9.74   0 P
 Trait                  US_V  2  2   95.4517      95.4517      45.24   0 P
 Trait                  US_C  3  1   2.24324      2.24324       3.28   0 P
 Trait                  US_C  3  2   54.6147      54.6147      27.04   0 P
 Trait                  US_V  3  3   153.722      153.722      46.11   0 P
 Warning: Code B - fixed at a boundary (!GP)       F - fixed by user
              ? - liable to change from P to B    P - positive definite
              C - Constrained by user (!VCC)      U - unbounded
              S - Singular Information matrix
 S means there is no information in the data for this parameter.
 Very small components with Comp/SE ratios of zero sometimes indicate poor
          scaling.  Consider rescaling the design matrix in such cases.
 Covariance/Variance/Correlation Matrix US Residual
   11.69      0.1579      0.5292E-01
   5.273       95.45      0.4509
   2.243       54.61       153.7
```

Wald F statistics

Source of Variation NumDF F-inc

Solution Standard Error T-value T-prev

12 Trait.Rep 6 effects fitted (6 are zero)
15 Trait.Run 6 effects fitted
14 Trait.Rep.Run 12 effects fitted
17 Trait.Run.Tray 744 effects fitted (372 are zero)
11 Trait.Cult 3597 effects fitted
18 Trait.Plot 7191 effects fitted (342 are zero)
174 possible outliers: see .res file
Finished: 06 Aug 2018 08:47:50.069 LogL Converged

Appendix C
R code for inheritance and variance component estimates from biparental crosses

```
---
title: "Anth Inheritance Heritability"
author: "Takshay"
date: "October 14, 2018"
output: html_document
---

setwd("C:/Users/taksh/Desktop/ProjectAnt/Project/Anthracnose/AnthInheritance")

Anth1cross<-read.csv("Anth1CrossCSV.csv", sep = ',')
Anth1cross <- Anth1cross[!is.na(Anth1cross$Rating),]
str(Anth1cross)
Anth2cross<-read.csv("Anth2CrossCSV.csv",sep = ',')
Anth2cross <- Anth2cross[!is.na(Anth2cross$Rating),]

#Race 1 Heritability
# Generation values
P1<-subset(Anth1cross, Cult== 'CG' , Rating)
P2<-subset(Anth1cross, Cult== 'NHM' , Rating)
F1<-subset(Anth1cross, Cult== 'F1' , Rating)
F2<-subset(Anth1cross, Cult== 'F2' , Rating)
BC1P1<-subset(Anth1cross, Cult== 'BC1P1' , Rating)
BC1P2<-subset(Anth1cross, Cult== 'BC1P2' , Rating)
#Variance for each geneation
VarP1<-var(subset(Anth1cross, Cult== 'CG' , Rating))
VarP2<-var(subset(Anth1cross, Cult== 'NHM' , Rating))
VarF1<-var(subset(Anth1cross, Cult== 'F1' , Rating))
VarF2<-var(subset(Anth1cross, Cult== 'F2' , Rating))
VarBC1P1<-var(subset(Anth1cross, Cult== 'BC1P1' , Rating))
VarBC1P2<-var(subset(Anth1cross, Cult== 'BC1P2' , Rating))

#Assigning variances

P<-VarF2 ##Phenotypic Variance
E<-(VarP1 + VarP2 + (2*VarF1))/4 ##Environmental Variance
G<- P - E ##Environmental Variance
A<- ((2*VarF2) - (VarBC1P1 + VarBC1P2)) ## Additive Variance

#Heritability
Anth1h<-A/P ##narrow sense heritability
Anth1H<- G/P ## Broad Sense heritability
print(Anth1h)
print(Anth1H)


#Race 1 Inheritance
```

```
#Inheritance
F1rating<-table(F1)
print(F1rating)

F2rating<-table(F2)
print(F2rating)

BC1P1rating<-table(BC1P1)
print(BC1P1rating)

BC1P2rating<-table(BC1P2)
print(BC1P2rating)

## Chisqaure test
F1values<- c(23, 1)
F1test2<-prop.test(x=c(23,1), n = c())
F1test<-chisq.test(F1values, p = c(1, 0))
F1test

F2values<- c(173, 55)
F2test2<-prop.test(x =c(173,55), n = c(210,70))
F2test2
F2test<-chisq.test(F2values, p = c(3/4, 1/4))
F2test

BC1P1values<- c(59, 1)
BC1P1test<-chisq.test(BC1P1values, p = c(1, 0))
BC1P1test

BC1P2values<- c(32, 28)
BC1P2test<-chisq.test(BC1P2values, p = c(1/2, 1/2))
BC1P2test
BC1P2test2<-prop.test(x =c(32,28), n = c(35,35))
BC1P2test2


#Race 2 Heritability
# Generation values
P1<-subset(Anth2cross, Cult== 'PI189225' , Rating)
P2<-subset(Anth2cross, Cult== 'NHM' , Rating)
F1<-subset(Anth2cross, Cult== 'F1' , Rating)
F2<-subset(Anth2cross, Cult== 'F2' , Rating)
BC1P1<-subset(Anth2cross, Cult== 'BC1P1' , Rating)
BC1P2<-subset(Anth2cross, Cult== 'BC1P2' , Rating)
#Variance for each geneation
VarP1<-var(subset(Anth2cross, Cult== 'PI189225' , Rating))
```

```
VarP2<-var(subset(Anth2cross, Cult== 'NHM' , Rating))
VarF1<-var(subset(Anth2cross, Cult== 'F1' , Rating))
VarF2<-var(subset(Anth2cross, Cult== 'F2' , Rating))
VarBC1P1<-var(subset(Anth2cross, Cult== 'BC1P1' , Rating))
VarBC1P2<-var(subset(Anth2cross, Cult== 'BC1P2' , Rating))

#Assigning variances

P<-VarF2 ##Phenotypic Variance
E<-(VarP1 + VarP2 + (2*VarF1))/4 ##Environmental Variance
G<- P - E ##Environmental Variance
A<- ((2*VarF2) - (VarBC1P1 + VarBC1P2)) ## Additive Variance

#Heritability
Anth2h<-A/P ##narrow sense heritability
Anth2H<- G/P ## Broad Sense heritability
print(Anth2h)
print(Anth2H)

#Race 2 Inheritance
#Inheritance
F1rating<-table(F1)
print(F1rating)

F2rating<-table(F2)
print(F2rating)

BC1P1rating<-table(BC1P1)
print(BC1P1rating)

BC1P2rating<-table(BC1P2)
print(BC1P2rating)

## Chisqaure test
F1values<- c(18, 0)
F1test2<-prop.test(x=c(18,0), n = c())
F1test<-chisq.test(F1values, p = c(1, 0))
F1test

F2values<- c(173, 55)
F2test2<-prop.test(x =c(174,54), n = c(210,70))
F2test2
F2test<-chisq.test(F2values, p = c(3/4, 1/4))
F2test

BC1P1values<- c(59, 1)
```

```
BC1P1test<-chisq.test(BC1P1values, p = c(1, 0))
BC1P1test

BC1P2values<- c(29, 26)
BC1P2test<-chisq.test(BC1P2values, p = c(1/2, 1/2))
BC1P2test
BC1P2test2<-prop.test(x =c(18,37), n = c(35,35))
BC1P2test2
```