2
Watermelon Breeding

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Introduction *37*
Origin and General Botany *38*
  Climatic Requirements *38*
  Taxonomy and Origin *38*
  Uses *38*
  Species Descriptions and Cross Compatibility *39*
  General Botany *39*
Floral Biology and Controlled Pollination *41*
  Flowers *41*
  Pollination *41*
  Fruit Setting *41*
  Controlled Pollination *42*
Major Breeding Achievements of the Past *42*
  Fusarium Wilt Resistance *42*
  Anthracnose Resistance *43*
  Resistance to Gummy Stem Blight *44*
  Durability *44*
  Flavor *44*
  Seeds *45*
  Seedless Triploid Hybrids *45*
  Fruit Size *46*
  Fruit Shape *47*
  Rind Color *47*
  Plant Habit *47*
  Leaf Shape *49*
  Sex Expression *50*
  Flesh Color *50*
Current Goals of Watermelon Breeding Programs *50*
  Yield and Quality *50*
  Earliness *51*
  Exploiting the Dwarf Habit *51*
  Disease Resistance *52*
  Development of F_1 Hybrid Cultivars *52*
Selection Techniques for Specific Characters *54*
  Dwarfs *54*
  Fusarium Wilt Resistance *54*
  Anthracnose Resistance *55*
  Gummy Stem Blight Resistance *55*
  Fruit Shape *55*
  Earliness *55*
  Tough Rind *55*
  Leaf Type *56*
  Seeds *56*
  Miscellaneous *56*
Design of the Complete Breeding Program *56*
  Sequence of Development *56*
  Examples of Some Complete Programs *57*
  A Typical Year's Work *61*
Trials of Advanced Lines *63*
  Evaluation of Commercial Potential *63*
  Evaluation of Garden Value *63*
References *64*

INTRODUCTION

In the 1964–1978 period the acreage of watermelons in the United States varied from a high of 286,320 in 1965 to a low of 210,700 in 1975. The trend toward reduced acreage is noticeable during this period. Yield per acre has tended to improve (from a low of 95 cwt per acre in 1969 to 116 cwt per acre in 1978), but total annual production has tended to decline from a high of 29,602,000 cwt in 1965 and to a low of 23,034,000 cwt in 1974. Thus, there appears to be an overall downward trend in production.

The principal acreages of watermelons are in Texas, with approximately 25,000 acres

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in spring production and another 25,000 acres in summer production; Florida, with 50,000 acres, all in spring production; and Georgia, with approximately 10,000 acres in spring production and 20,000 acres in summer production. It is noteworthy that Florida's production per acre is the highest, with approximately 9,000,000 cwt from 50,000 acres (*1*).

Commercial production continues to be dominated by the cv. Charleston Gray, which was introduced in 1954. Several other cultivars have been introduced since that time, notably Crimson Sweet and Jubilee (both in 1963), and these have achieved considerable popularity as high-quality melons. The consumption of watermelons in the United States has fallen from 18.2 lb per capita in the 10-year period 1946–1955 to approximately 13.5 lb in the 1967–1976 period. This represents a 25% decrease in per capita consumption, obviously a matter of concern to producers (*8*). The answer to this problem seems to lie in the development of superior quality cultivars that also enable growers to produce more efficiently. Thus, watermelons could be more competitively priced in relation to other dessert fruits. New cultivars that would permit production closer to the markets could help reverse the downward per capita trend by reducing the transportation costs from distant production areas of the rather bulky product. Smaller-fruited new cultivars could be priced lower, also helping to overcome buyer resistance to the high price per melon demanded for larger fruit.

ORIGIN AND GENERAL BOTANY

Climatic Requirements

The watermelon is tender to frost and most cultivars require a relatively long growing season (*21*). Plant growth and fruit development are favored by high temperatures and abundant sunlight. Atmospheric humidity appears to be a factor principally as it may affect the occurrence and severity of fruit and foliage diseases.

Taxonomy and Origin

Until recently the watermelon was classified as *Citrullus vulgaris* Schrad., but in 1963 Thieret called attention to the correct name, *Citrullus lanatus* (Thunb.) Mansf. (*54*). In 1857 David Livingstone, the famous missionary–explorer, found both bitter and sweet melons growing wild together in Africa and noted that the natives used them as a source of water in the dry season. It has thus been generally concluded that Africa is the center of origin of the genus (*6*).

Culture of the watermelon goes back to prehistoric times, as revealed by pictures made in ancient Egypt. Names for the watermelon appear in the old literature of the Arabic, Berber, Sanskrit, Spanish, and Sardinian languages. Apparently early cultivation of the crop occurred in the Mediterranean area and as far east as India. Now the watermelon is also important in the warmer parts of the Soviet Union as well as in other parts of Asia Minor, the Near East, China, and Japan. It is believed to have been brought to the United States by the earliest European colonists and is recorded as being grown in Massachusetts as early as 1629.

Uses

Although the watermelon is used as a fresh dessert fruit in America, it has some other uses elsewhere in the world. In the Soviet Union, it is reported that watermelon has been used in making a beer, and sometimes the juice is boiled down to make a heavy sweet syrup. In

the Mediterranean area, watermelon may be a staple food for both human and livestock consumption. In Asia, the seeds are roasted, with or without salting, and eaten.

Species Descriptions and Cross Compatibility

Cogniaux and Harms [1924, cited by Shimotsuma (*50*)] recognized four *Citrullus* species, viz. *C. vulgaris* Schrad. [now called *C. lanatus* (Thunb.) Mansf.], *Citrullus colocynthis* (L.) Schrad., *Citrullus ecirrhosus* Cogn., and *Citrullus naudinianus* (Sond.) Hook., all originating in Africa (*50*). Descriptions of these species, as explored by Shimotsuma (*50*), are as follows:

C. vulgaris is an annual watermelon originating in Southern (perhaps Central) Africa. It is widely distributed in Egypt and in southern, western, and central Asia. It has large, broad green leaves, which are orbicular to triangular–ovate in shape and deeply three to five lobed or sometimes simple. Medium-sized flowers are monoecious and have short pedicels. Fruits are of medium to large size, with thick rind and solid flesh with high water content. Flesh color may be red, yellow, or white. Seeds are ovate to oblong, are strongly compressed, and have white or brown seed coats.

C. colocynthis is a perennial, indigenous to northern Africa. It differs from *C. vulgaris* chiefly in the size of plant organs. Leaves are small with narrow lobes, and are hairy and grayish in color. Flowers are monoecious and small. Bloom is profuse in autumn, when fresh vegetative growth also occurs. Seeds are small and brown. Fruits are small, not exceeding 3 in. in diameter, with rind and spongy flesh that is always bitter.

C. naudinianus and *C. ecirrhosus* are both perennials indigenous to the desert areas of South-West Africa. The vegetative characters of *C. naudinianus* differ from those of the other species. Leaves are deeply palmatifid and covered with dense, fine hairs. Tendrils are simple, straight, elongated, or slightly curved at the apex. Flowering is dioecious, and flowers are not formed until the second year of growth. Fruits are ellipsoid in shape, of medium to large size, with thin rind and soft juicy flesh. Seeds are white and would not germinate under natural conditions. *C. ecirrhosus* closely resembles *C. colocynthis* in vegetative characteristics, but its leaves are more divided, are covered with dense fine hairs, and have strongly recurved margins. Tendrils are lacking. Fruits are subglobose with white flesh and bitter like *C. colocynthis*. No flowers are produced until the second year of growth.

A fifth species, *Citrullus fistulosus*, was investigated and was found more closely to resemble *Cucumis* species. It was suggested that it be reclassified, since it would not hybridize with the above four *Citrullus* species and has a different chromosome number. All four *Citrullus* species could be crossed with each other successfully, and F_1 seeds from almost all crosses germinated well. F_1 seedlings grew normally and set fruit with good seeds.

It was concluded by Shimotsuma that a bitter-fruited form of *C. vulgaris* is the ancestor of the cultivated watermelon. The four species *lanatus, colocynthus, naudinianus,* and *ecirrhosus* all have 22 chromosomes ($2n$) according to results of Shimotsuma's cytological studies (*50*) (see Table 2.1).

General Botany

The watermelon plant resembles plants of *Cucumis*, but the stems are angular in cross section and the leaves, which are cordate at the base, are pinnately divided into three or

TABLE 2.1. List of *Citrullus* Species Investigated and Their Major Characteristics[a]

Species	Origin	Periodicity	Chromosome number (2*n*)
C. vulgaris Schrad. (cultivated watermelon)	Japan	Annual	22
C. vulgaris Schrad. (bitter wild race)	Cape Province (South Africa)	Annual	22
C. vulgaris Schrad. (non-bitter wild race)	Cape Province (South Africa)	Annual	22
C. colocynthis (L.) Schrad.	Rabat (Morocco)	Perennial	22,
C. ecirrhosus Cogn.	South-West Africa	Perennial	22
C. naudinianus (Sond.) Hook.	South-West Africa	Perennial	22
C. fistulosus Stocks	India	Annual	24

[a]Adapted from Shimotsuma (*50*).

four pairs of lobes. A non-lobed (entire) leaved mutant was found and may be used as a genetic marker whenever it is unique (*31*).

Roots

The root system is very extensive but shallow, consisting of a tap root and many lateral roots growing within the top 2 ft of soil. Early destruction of the tap root (as in transplanting) may be advantageous in getting superior yields (*13*).

Growth Habit

The plant typically is a trailing (vine) annual, but recently dwarf forms, which may be described as "bush," have been located and are being used to develop cultivars suitable for growth in a limited space. Dwarfs may have a total diameter of as little as 2 ft, whereas the more rampant vine cultivars may be 30 ft or more in diameter. Dwarfing is primarily related to shortened internodes (*32*).

In the typical vine, there is a delay in the development of lateral branches, with a dominant single "runner" reaching several feet in length before branching is initiated, and maintaining dominance for some time thereafter. In some of the new dwarf types, multiple branching occurs simultaneously from the crown of the plant when it is quite young, which provides more potential bearing areas for concentrated fruit set (*34*).

Pollination

While watermelon is classed as a naturally cross-pollinated crop, there is a large amount of self-pollination and sibbing that occurs normally. This was demonstrated by interplanting two parental lines, one of which carried a marker gene, and then examining the progeny from the marker parent (*31*).

Fruit

The range of fruit size in existing cultivars is great, from the 3-lb melons typical of the New Hampshire Midget cultivar to the large-fruited Cobb Gem and Tom Watson cultivars, which may occasionally produce melons in excess of 100 lb. Most present-day cultivars produce melons of approximately 25 lb, but the future market trend appears to be toward smaller-fruited cultivars.

Fruit shape varies, ranging from long, cylindrical fruits to spherical fruits, with the

melons of most cultivars intermediate in shape. Rind colors vary from white to various shades of green, with some cultivars having striped rind and some mottled rind. Rind ranges from brittle to tough and flexible, from very thin to excessively thick, and from very soft to very hard.

Flesh color may be white, yellow, orange, pink, or red; flesh texture varies from fine grained and "melting" to firm, coarse, and fibrous. Seeds range in size from very small (size of tomato seed) to large (size of pumpkin seed). Seeds usually range in color from white to black, but red, green, brown, and mottled colors also occur.

The greater part of the fruit is the edible flesh, which is mostly derived from the placentae, whereas the cantaloupe and squash are largely pericarp. The pericarp of the watermelon is its hard outer "rind."

FLORAL BIOLOGY AND CONTROLLED POLLINATION

Flowers

The flowers of watermelon are smaller and less showy than those of most other species of cultivated Cucurbitaceae (*46*). They are located in leaf axils, most commonly singly. Most cultivars are monoecious (producing pistillate and staminate flowers separately), but a few older cultivars are andromonoecious (producing perfect flowers and staminate flowers). The pistillate or hermaphroditic flowers normally occur in every seventh-leaf axil, the intervening axils being occupied by staminate flowers. The corolla is greenish yellow, united in a tube, deeply five lobed. Three stamens are inserted at the base of the corolla.

Pollination

Watermelons are generally pollinated by honey bees (*41*). In andromonoecious cultivars the hermaphroditic flowers must be visited by insects to effect pollination; therefore, the hermaphroditic flowers of watermelon do not confer the advantage of self-pollination one might expect, and andromonoecy has no advantage over monoecy in maintaining pure lines. The method of pollination naturally favors considerable cross-pollination, and consequently considerable genetic variability within a cultivar is maintained.

Flowers open shortly after sunrise and normally remain open only one day. The pistillate flower, and the staminate flower in the axil just below it, open on the same day. Usually the anthers have dehisced when the corolla expands, and the pollen is visually evident in sticky masses adhering to the anther. The stigma is receptive throughout the day, but it has been established that fruit-setting frequency following artificial self-pollination is much higher when pollination occurs between 6 and 9 A.M. than when it occurs later in the day. High atmospheric humidity favors fruit setting. The ovary, which is inferior, is readily apparent, and its relative size is an important factor in fruit setting. Small, poorly developed ovaries rarely set, whereas pollination of flowers that have large ovaries results in a high percentage of success. The largest ovaries are usually found on flowers near the tips of the most vigorous branches of a plant.

Fruit Setting

Unlike some other members of the cucurbit family, the watermelon does not have flowering peaks or fruiting cycles (*41*). However, there is an inhibitory influence produced by

fruit already set that reduces further fruit setting. Thus, if the controlled pollination desired on a plant has not been obtained, it is necessary to continue to remove all of the open-pollinated fruit until success in setting the controlled pollination is attained.

Controlled Pollination

Controlled pollinations are made by bending back the petals of the staminate flower until they break, leaving the stamens protruding prominently. Holding this staminate flower by the pedicel, the anthers, with their masses of sticky pollen, are lightly brushed against the stigmatic surface of the pistillate flower.

Prior to pollination, the unopened buds should be protected from insect visitation. This may be done with small screen cages placed over the selected flowers (*56*) or by preventing the buds from opening with paper clips (*41*) or Scotch Tape. After pollination, the protection must be replaced and continued for at least one day. A helpful procedure for locating flowers to be used in controlled pollinations is the placement of plastic flags at each flower to be used. Different colors can be used to designate the location of developing fruits, flowers to provide pollen, and pistillate buds not yet opened. Tags should be attached to the pedicel of the pistillate flower identifying the pollen parent and indicating the date of pollination.

MAJOR BREEDING ACHIEVEMENTS OF THE PAST

Fusarium Wilt Resistance

A major objective of watermelon breeding has been to develop cultivars with disease resistance, particularly resistance to fusarium wilt, *Fusarium oxysporum* f. sp. *niveum* (E. F. Smith) Snyder and Hansen. One can understand this emphasis when considering that the alternative to effective resistance is a crop rotation that would permit watermelon production on the same land only once every 8–10 years. The organism responsible for fusarium wilt is a soil-inhabiting fungus that increases rapidly when watermelons occupy the land. It invades the roots of the plant and enters the vascular system where it plugs the xylem vessels, resulting in the wilting of the plant and eventual death. Plants suspected of being under attack can be checked by cutting through the stem of a branch showing wilting. If the interior shows a brown discoloration, it verifies that it is caused by the *Fusarium* organism.

The acute need for a resistant cultivar was recognized by W. A. Orton, an early scientist in the USDA, who initiated one of the first organized plant breeding programs with disease resistance as a goal (*35*). In 1911 he introduced the cv. Conqueror, which was the first vegetable cultivar developed by hybridization for resistance to a plant disease (*36*). The source of resistance was the inedible stock "citron." While Conqueror was acceptable, it lacked quality and consequently failed to achieve popularity. In addition, its resistance to fusarium wilt was not consistently high, a complaint that has plagued most so-called wilt-resistant cultivars of watermelon up to today.

Efforts to develop a cultivar that would resist the ravages of fusarium wilt under all conditions prevalent in the various watermelon-growing areas have occupied the efforts of numerous plant breeders and/or plant pathologists for many years. Up to the present time this goal has not been fully achieved, but progress has been such that several recent cultivars, e.g., Calhoun Gray, Summit, Smokylee, and Dixielee, have resistance sufficient for most situations. It has been determined that inheritance of resistance may involve

several genes. Crall (*8*, p. 8), who has been involved in breeding for resistance to fusarium wilt for a number of years, states that "wilt resistance in watermelons is governed by multiple factors, mostly recessive, so that the development of resistant varieties has been a rather slow process. . . ."

Parris (*37*) has reviewed the inheritance of resistance to fusarium wilt and indicates that there may be recessive or dominant genes involved depending on the source of resistance being used by the breeder. No clear definition of the mode of inheritance of resistance has been published to date. Henderson *et al.* (*17*) established that there is at least one major dominant gene for resistance in the cv. Summit. All cultivars previously named have what Crall and Elmstrom (*9*) refer to as "high-type resistance." Summit was determined to inherit resistance as a dominant factor (*17*). Many of the early cultivars with lower levels of resistance obviously carried recessive genes for resistance since crosses with susceptible cultivars produced only susceptible F_1s (*37*). It may be concluded that resistance to wilt in watermelon is governed by multiple factors, most of them recessive. This has complicated the development of dependable cultivars possessing high-type resistance. The likelihood of cross-pollination between individuals heterozygous for wilt susceptibility in seed fields may account for the so-called running out of resistance experienced with some of the cultivars released as "resistant." Establishment of lines homozygous for the dominant gene for resistance, reported by Henderson *et al.* (*17*) in the cv. Summit, should give added impetus to the trend toward development of commercial F_1 hybrids with resistance. Other than the identification of the dominant resistance gene of Summit, no specific designation of individual resistance genes is available.

Barnes (*4*) ran screening tests of resistant cultivars using isolates of the *Fusarium* organism from various watermelon production areas of the United States. His results seem to indicate that these isolates vary in virulence, which could partially account for the differences in degree of resistance reported by different workers.

Anthracnose Resistance

Anthracnose, caused by the pathogen *Glomerella cingulata* var. *orbiculare* [formerly *Colletotrichum lagenarium* (Pass.) Ell. and Halst.] is a very destructive disease of watermelon. Anthracnose is found almost everywhere that watermelons are grown with the possible exception of some parts of California. It becomes particularly severe in periods of high humidity. It is caused by a fungus that is spread by airborne spores. It attacks both plant and fruit and may cause serious damage to the fruit during post-harvest handling. While field applications of fungicides can reduce the problem, resistance is clearly desirable.

Resistance to the disease was first located in some melons obtained from Africa. The Reverend Rush F. Wagner, Old Umtali Mission, Umtali, South Africa, sent seed of five cultivars of watermelon (not taxonomically classified) to D. V. Layton (*25*). Their seed and leaf characteristics were similar to those of commercial cultivars although two were described as inedible. All were susceptible to fusarium wilt, but were resistant to anthracnose. The three edible lines were crossed to U.S. cultivars and the F_1 was found to be resistant. It was determined that resistance was dominant over susceptibility, and segregation in the F_2 (and backcross F_1) suggested a single factor pair. The cvs. Congo, Fairfax, and Charleston Gray were the first introduced as anthracnose resistant; and Charleston Gray has been the dominant watermelon cultivar for over 20 years, with much of its popularity attributable to its disease resistance.

It has now been established that there are several different races of the pathogen causing anthracnose. The resistance derived from the original African watermelon introductions is not effective against some of these races. Fortunately, these new races are not as yet of widespread distribution, and this is permitting breeders and plant pathologists time in which to locate sources of resistance and to breed cultivars that can replace those susceptible to the new races.

Resistance to Gummy Stem Blight

A fungus *Didymella bryoniae* (formerly *Mycosphaerella citrullina*) causes a serious disease of watermelons, particularly in warm humid climates. It is called gummy stem blight and may attack fruit, seedling, cotyledons, leaves, and stems. If plants escape early damage, the organism may continue to grow slowly and cause severe injury later. A reddish-brown exudate appears on stems (near the crown) of infected plants, frequently as melons approach maturity, and wilting is followed by death of the plant. Resistance has been located in some plant introductions of the wild citron type, and breeders are working toward incorporating it into acceptable cultivars (*53*). The disease is controllable with fungicidal sprays; but, as is the case with anthracnose, resistance would provide additional protection and could reduce the costs of the spray program by reducing the frequency of application required for control.

Durability

Much of the early breeding emphasized durability of the melon to the rough handling in which it was often subjected. Melons were selected for thick, tough and flexible rinds and for firm flesh. Cultivars not capable of withstanding rough handling were failures, no matter how excellent in other respects. Now the emergence of a market for smaller melons opens the possibility for packaging and an associated lessening of emphasis on durability factors. Still, some attention should continue to be given in this area since extreme brittleness will not be acceptable. Such melons crack open in the field, sometimes even before maturity. Excessive supplies of moisture during development of the fruit seem to favor occurrence of this defect. Selecting for more flexible rind will reduce its prevalence. A technique for evaluation of flexibility has been proposed by Ivanoff (*20*). Andrus (*2*) demonstrated that flesh firmness is an important factor in durability. Firmness is apparently heritable, but its mode of inheritance has not been determined.

Rind may be extremely hard, as in the cv. Peacock, or very soft as in Calhoun Sweet. Most cultivars fall between these extremes, indicating that multiple factors are involved.

Flavor

The flavor of watermelon is not a clearly definable trait, but some evaluators recognize an off-flavor, which they call "caramel." To them, this flavor is objectionable, but others do not find it so. It seems to be associated with some of the "intense-red" breeding lines and appears to be heritable since it can be eliminated by selection.

Sugar content, as indicated by refractometer readings, is the most widely recognized criterion for flavor preference. The higher the reading, the greater the preference. Progress in breeding for soluble solids content has been good, with recently introduced cultivars running above 12%, whereas older cultivars generally are less than 9%.

Bitterness is an undesirable characteristic that is inherited from *C. colocynthis*. It is

dominant to non-bitter flavor and inheritance is controlled by one gene. It is mentioned because interspecific hybridization may be desirable in watermelon breeding if desired genes are present only in *C. colocynthis*.

Seeds

Seeds enter into an evaluation of watermelon quality. The quantity of seeds is heritable, and consumers obviously find large numbers of seeds objectionable. They may prefer relatively small numbers, but seedsmen do not like to handle cultivars with few seeds per fruit. The seed price of a cultivar producing few seeds is relatively high.

Seed size has been investigated and heritability reported (*24,39*). The author has found seed sizes below those reported, with some actually as small as tomato seed! Consumers apparently are not concerned with seed size, except that in some of the very small melons, 3–5 lb, a large number of large seeds results in a relatively low percentage of edible flesh, which is furthermore difficult to obtain.

Seed colors include white, tan, brown, black, red, green, and mottled black and brown. There is a rather strong prejudice against white seed color, which the consumer associates with melon immaturity. Black seed seems to intensify red flesh color and permits a very attractive color combination in the cut melon. Occasionally the breeder may have difficulty in attaining uniformity of seed characteristics when all other important characteristics are sufficiently uniform to justify naming and release.

Seedless Triploid Hybrids

No cases of naturally occurring parthenocarpy have been reported in watermelon. Much attention was attracted, therefore, to the research reported by Kihara (*23*) concerning a technique of creating triploid F_1 hybrids that produced seedless fruit. Production of seedless fruit by triploid plants in the grower's field is dependent upon the flowers of the triploids being pollinated with pollen from diploid plants. The diploid pollen stimulates parthenocarpy, but the ovules fail to develop because of the sterility accompanying the triploid condition (*27*).

To produce triploid seeds a tetraploid line must first be established. The use of colchicine to induce polyploidy is discussed by Eigsti (*12*). The cross of a diploid pollinator with a tetraploid female will yield triploid seed, but the reciprocal cross (tetraploid pollinator by diploid female) is unsuccessful. This fact partially accounts for the high price of triploid seed, which in 1982 was approximately 20 times that of open-pollinated cultivars. Tetraploid watermelons characteristically produce much smaller numbers of seeds than diploids. This also makes it expensive to maintain the tetraploid lines (Fig. 2.1).

An additional disadvantage to growers of seedless melons is the difficulty in germinating the triploid seed. The Japanese recommended removal of part of the seed coat to facilitate germination. They also recommended that seed be germinated at a temperature of 86°F, which would entail starting them in hotbeds or greenhouses and transplanting to the field in many areas. These additional cultural operations are obviously expensive and, coupled with the high cost of seed, apparently raised production costs so high that the prices that consumers would pay did not leave acceptable profits for the producer.

Thus, while seedless triploids are a notable plant breeding achievement, producing a triploid watermelon crop has not been considered economically feasible by most U.S. watermelon growers.

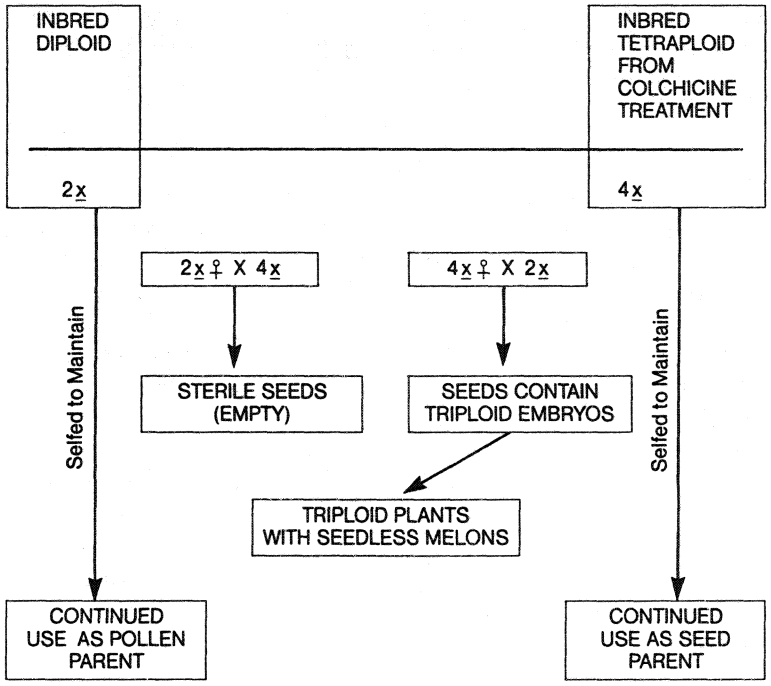

FIGURE 2.1. Procedure for producing seed of seedless triploid hybrid watermelons. The tetraploid line must be used as the female parent, because the reciprocal cross using the diploid as female results in empty seed. Seedless melons are the result of stimulative parthenocarpy (pollination with normal diploid pollen). Thus a diploid cultivar should be interplanted with the seedless hybrid.

Fruit Size

Older watermelon cultivars typically produced rather large fruit, and there was keen competition among growers to see who could produce the largest. Partially this related to the considerable market for "slicing watermelons" for restaurants and cafeterias. Also, as previously noted, melons were shipped in bulk and it was less time-consuming to harvest and load larger fruits.

The need for an early watermelon to mature in New Hampshire led Yeager (*61*) to import small-fruited cultivars from Japan and the Soviet Union that were early. From these he developed White Mountain and New Hampshire Midget, which required only 65 days to mature fruits weighing 2–4 lb. More recently the cultivar Petite Sweet (5–10 lb) was developed (*15*), and other small-fruited cultivars are under development, particularly at the Florida Agricultural Research Center at Leesburg and at the Kentucky Agricultural Experiment Station at Lexington.

Most of the present-day cultivars produce fruits in the range of 20–30 lb, but the trend seems to be toward fruits of 10–15 lb, and perhaps even smaller. The mode of inheritance of fruit size has been reported as polygenic (with 25 genes involved) by Poole and Grimball (*40*). A continuous array of sizes is obtained from the F_2 of large-fruited parents crossed with small-fruited parents.

Fruit Shape

Melon shape was determined to be qualitatively inherited, with one pair of alleles (round vs. elongated) involved (*40,42,59*). The F_1 was intermediate and the F_2 segregated in the ratio 1 round : 2 intermediate : 1 elongated. However, there appear to be modifier genes influencing shape. Some "elongate" cultivars are decidedly long–cylindrical in shape, others are tapered toward the ends. Some "round" cultivars produce melons almost perfectly spherical, whereas others are "blocky" in shape. Most elongated cultivars have a tendency to produce so-called gourd-neck fruit, which are classed as culls; whereas round-fruited cultivars tend to be quite susceptible to "hollow-heart", also a serious defect. The intermediate shape appears to be less subject to either of these defects, and this advantage is obtained in F_1 hybrids between long- and round-fruited parent lines.

Rind Color

A single gene determines the intensity of green color in the rind. Dark green is dominant to light green (called "gray") (*59*). Striped green is recessive to solid dark green but dominant to solid light green (*59*). Greenish white mottling of the rind is determined by a single recessive gene (*59*). Rind colors or color patterns are of little practical importance except that dark green melons seem to be more prone to sunburning, which results in collapse of rind tissues and may be a serious defect in regions of high light intensity. Barham (*3*) determined that a rind color change from green to orange is a good maturity indicator and is controlled by a single recessive gene pair. Unfortunately, the plant develops a chlorotic condition that accompanies the melon rind color change.

In addition to color there is a heritable characteristic known as "furrowing" or "grooving" of rind. It is recessive to smooth surface and apparently is of no practical importance.

Plant Habit

Taxonomists describe the plant of watermelon as a long, trailing vine. Considerable variation has been observed with regard to the vigor and extent of the vegetative growth of the various vine cultivars. Very limited vine growth occurs with cultivars such as New Hampshire Midget and Petite Sweet; but Charleston Gray, the presently dominant cultivar, produces vines that extend to a diameter of 20 ft or more, and there are cultivars with more rampant growth than this. No investigation of the genetics of vine size and vigor has been reported.

A mutant with much shortened internodes was discovered by the author (*32*). The resultant dwarf plant habit (Fig. 2.2) is recessive and is determined by a single gene (*dwl/dwl*). As with vines, there is heritable variability in the mature plant size, but this generally falls within the range of 1.5–6 ft for plant diameter. Such plants make feasible the culture of watermelons in home gardens where the area available is restricted. Another dwarfing gene (*dw2/dw2*), which also controls multiple branching from the crown of the plant (Fig. 2.3), was more recently discovered (*34*). When *dwl/dwl* was crossed with the dwarf *dw2/dw2*, the F_1 plants produced normal vines. The progeny segregated in the F_2 ratio of 9 vines : 3 short internode dwarfs : 3 multiple branched dwarfs : 1 "double-recessive dwarf," the latter being a totally new plant type (Fig. 2.4). A cultivar with the double-recessive genotype for dwarf is Kengarden, which is covered under the Plant

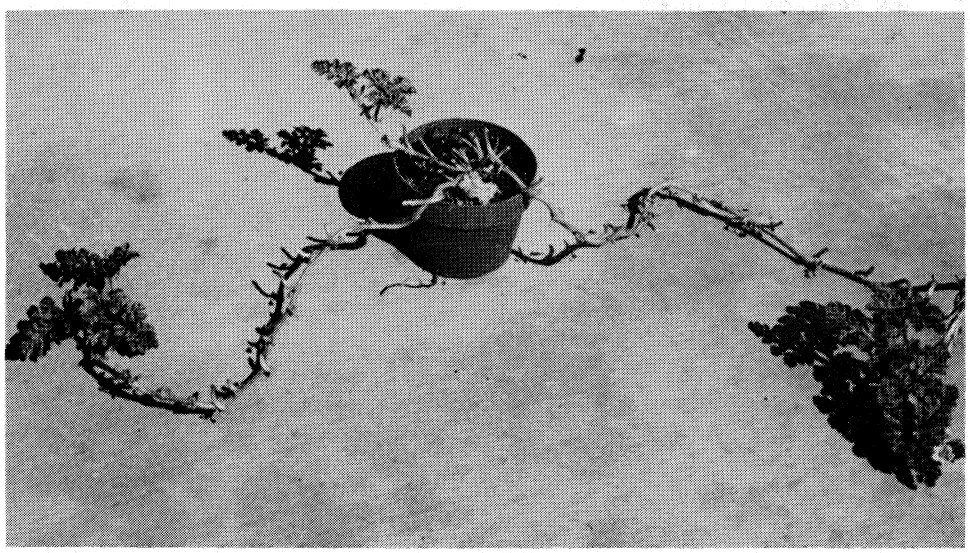

FIGURE 2.2. Branching typical of cv. Bush Desert King (*dw1/dw1*). Note short internodes and tendency for stems to be twisted (leaves removed). Stems are thickened and tend to be brittle.

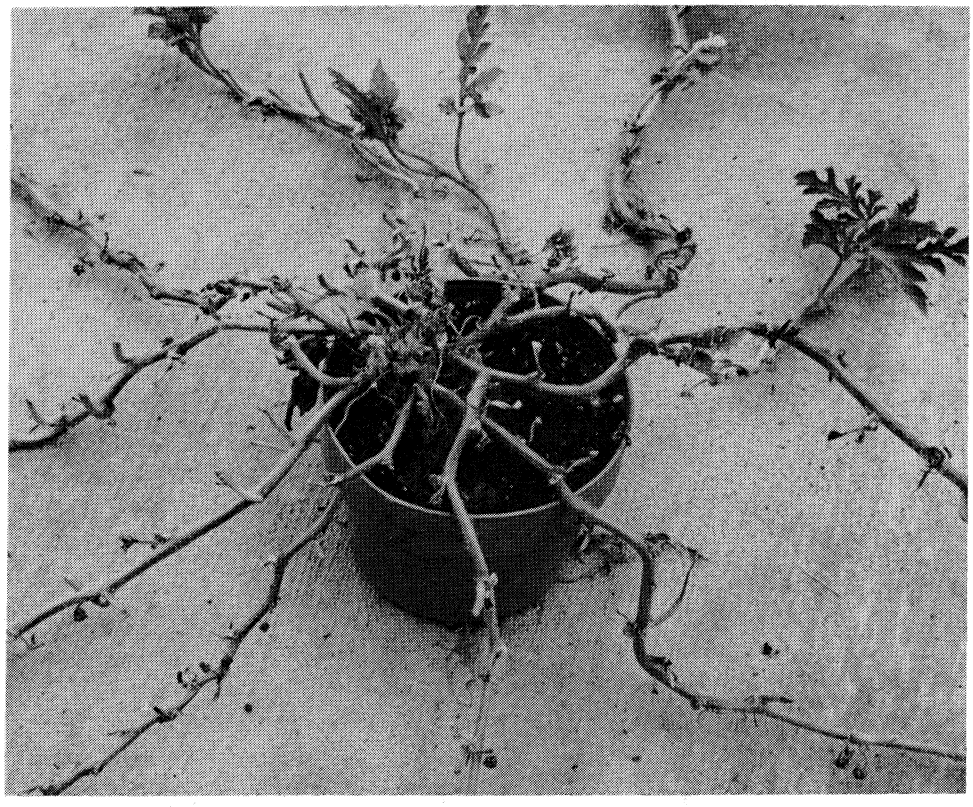

FIGURE 2.3. Branching typical of Japanese Dwarf (*dw2/dw2*). Note multiple branching from the crown of the plant, which is unique. Stems are normal except for short internodes (leaves removed).

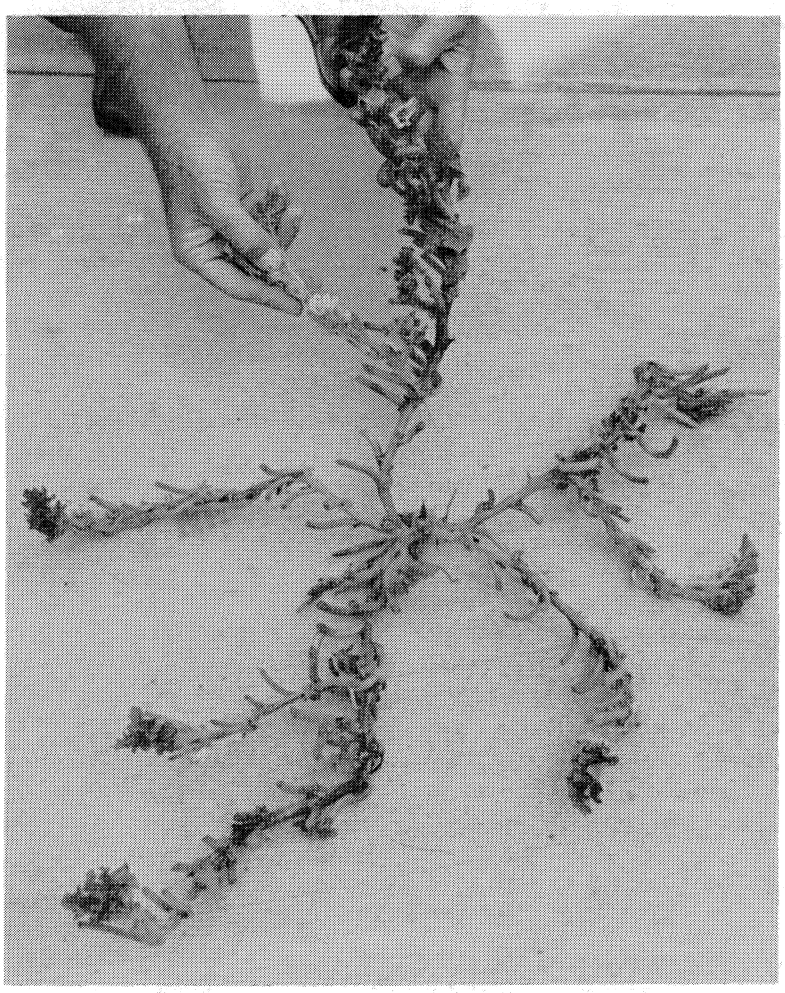

FIGURE 2.4. Very short internodes (leaves removed) typical of double-recessive dwarf (*dw1/dw1, dw2/dw2*). Crown branching derived from cv. Japanese Dwarf.

Variety Protection Act. In addition to suitability for garden culture, dwarf plant habits may have potential for adaptation to machine harvesting.

Leaf Shape

Typically, watermelon leaves are deeply indented and prominently lobed. A mutant without indentation and lobing on the leaves was discovered by the author (*30*). Lobed leaf shape is incompletely dominant to non-lobed. A single gene determines the non-lobed leaf character. It is an excellent seedling marker since the mutants are vigorous, fertile, and readily identified. When a line homozygous for this marker is used for a seed parent, it serves to identify F_1 hybrid progeny (normal leaf) and distinguishes them from progeny resulting from self-pollination (non-lobed type). The latter may be removed in the thinning of surplus seedlings, leaving only hybrids.

Sex Expression

A single pair of genes determines monoeciousness versus andromonoeciousness (*46*). Most cultivars are monoecious (*A*/–). Andromonoecious plants (*a*/*a*) have both staminate and perfect flowers. However, this does not appear to be advantageous since insect visitation of the perfect flowers is necessary to effect pollination.

Both monoecious and andromonoecious plants usually have a fixed ratio of six staminate flowers to one pistillate (or perfect) flower. The author has located lines that have a ratio of three to four staminate flowers to one pistillate flower, but the mode of inheritance has not yet been determined. The greater frequency of pistillate flowers when combined with multiple branching may enhance the concentration of fruit set near the crown of the plant, an important consideration in developing a plant suitable for mechanized harvesting.

Male sterility was present in an induced mutation discovered by Watts (*57*). Normal watermelon leaves are pubescent, but the mutant is glabrous. This distinctive pleiotropic marker associated with male sterility makes it easier to identify male-sterile plants in a segregating population. Male sterility is inherited as a single recessive gene (*gms*/*gms*).

Flesh Color

Yellow flesh is recessive (*y*/*y*) to red and is determined by a single gene. Another shade of yellow, called "canary," is dominant to pink flesh. The red flesh color of *C. lanatus* is recessive (*wf*/*wf*) to the white flesh color (*Wf*/–) of *C. colocynthis* (*51*). The intense-red flesh color now being incorporated in many of the recently introduced cultivars is derived from the old cv. Peacock. The mode of inheritance has not been reported.

CURRENT GOALS OF WATERMELON BREEDING PROGRAMS

Yield and Quality

High yield per acre, involving both numbers of melons and total weight, has been a major goal of past programs and is still one of the top priorities in breeding watermelons. While melon prices to the grower are most commonly quoted in terms of price per pound, retailers often prefer to sell on a price per melon basis; hence the need for the two kinds of yield data.

It appears that earlier preferences for large-sized melons are shifting toward the smaller-sized fruit and may eventually result in packaging of watermelons such as is practiced with cantaloupes and honeydew melons. This trend may also favor eventual mechanized harvest of the commercial crop.

With preference toward smaller melons, there is the need for thinner (but tougher) rind, firm flesh, and smaller seed size (to avoid being out of proportion with edible flesh).

Color of the melon flesh is being given more attention. Intense red seems to be preferred to paler red or pink. Surprisingly, a yellow-fleshed cultivar recently introduced has achieved considerable popularity, and so flexibility appears to exist in this goal.

Soluble solids, reflecting "sweetness" of the melon, continue to be given considerable emphasis in breeding, and recently introduced cultivars show marked improvement in this characteristic.

Flesh texture and firmness are factors of obvious concern in the evaluation of quality, but they have not been clearly defined. While observation indicates that these charac-

teristics are heritable, no information concerning mode of inheritance is available. Two types of texture are roughly described either as "melting" (or fine-grained) flesh or as "fibrous" (and/or coarse-grained) flesh. More recently there has appeared "firm flesh," a trait associated with shipping durability (*2*). Investigations into consumer preferences for different types of flesh is needed as well as inheritance studies.

Melon shape may determine the suitability of the fruit for packaging if this becomes the preferred method of shipping. Also, it is a factor influencing adaptability to machine harvesting.

Earliness

Time required to reach maturity is an important heritable characteristic. It is important to commercial growers because the price paid for the first melons harvested in an area is usually higher than that received later.

Early maturity for regions with a short growing season is the determining factor in whether watermelons will be planted. Generally the earliest maturing cultivars of the past have been small fruited. Obviously, there are physiological limitations on the amount of photosynthate that can be produced in a short growing period, which limits fruit size and number. Since recent trends favor smaller fruit, there may be no disadvantage to this.

The length of time required for fruit to mature following pollination has been reported in a number of different cultivar release publications. In early descriptive work, watermelons generally were reported to require approximately 30–35 days from setting to maturity. Data presented in later cultivar release publications indicate that fruit of early-maturing cultivars may require as little as 26 days to mature (Petite Sweet) and late-maturing ones as much as 45 days (Super Sweet) (*15*). Inheritance studies are needed so intelligent breeding can be undertaken. The number of days from seeding to maturity is given in many cultivar release publications and in most seed catalog descriptions of cultivars. Environmental conditions will play an important role in the expression of earliness, but genetically controlled plant characteristics also play an important role. A more thorough investigation of those characteristics contributing to early maturity needs to be undertaken in order that a more intelligent approach to breeding for this important characteristic can be taken.

Exploiting the Dwarf Habit

Cooperation between the plant breeder and the agricultural engineer usually precedes the development of machinery to harvest a crop mechanically. Excessively vegetative plants tend to clog up machinery and make engineering the equipment a difficult task. Until the discovery of dwarfing genes in watermelon, there was little hope that the typically rampant vine growth of the species would permit mechanized harvest. Now, mechanized harvest appears to be a difficult but feasible goal for watermelon breeders.

The economics of inflation have resulted in a home gardening boom. Since space is a limiting factor for the majority of gardeners, the extensive vine growth of watermelon eliminated it from the list of crops most gardeners plant. The dwarf forms, however, have been acceptable. Plant breeders need to combine dwarfness with early maturity, high quality, increased productivity, as well as other desirable characteristics to produce new cultivars suitable for home gardens and for mechanized harvest as well. Also, development of inbred lines for producing F_1 hybrid dwarfs should not be overlooked.

Disease Resistance

Incorporating the genes for "high-type" resistance to fusarium wilt into new cultivars is very important since there is no practical substitute for resistance to this soil-borne disease.

While anthracnose and gummy stem blight are controllable with fungicides, this is expensive and counter to the trend to avoid chemicals for control if possible. Since new races of the pathogens involved are likely to occur, it behooves the watermelon breeder constantly to seek alternative sources of resistance. These two diseases are problems principally in high-humidity areas, and resistance to them is not essential in cultivars developed for arid climates.

Development of F_1 Hybrid Cultivars

The popularity of F_1 hybrids of all vegetable crops has included watermelons in recent years. One of the most sensational F_1 hybrids among vegetables is the seedless triploid watermelon. Unfortunately, the technique of producing seedless triploids results in relatively high-priced seed, which when combined with difficult germination of the seed, has caused reluctance among commercial growers to produce seedless melons. Improvements in techniques that make triploid seed more economical and easier to germinate could result in a large-scale shift to this superior type of watermelon. Also, the development of dwarf seedless triploids could expand interest on the part of home gardeners.

It has been reported that inbreeding watermelons does not reduce vigor or productivity and tends to produce uniformity in many characteristics (*41*). Data to establish that there is yield superiority (and to what extent) in F_1 hybrid watermelons are lacking. This needs to be explored before setting a goal of establishing inbred lines with the intention of developing commercial hybrids.

Several techniques have been proposed for producing F_1 hybrid seed cheaply, including the use of the marked male-sterile mutant discovered by Watts (*57*) as a seed parent. Open-pollinated seed can be produced by using the genetic marker discovered by Mohr *et al.* (*31*).

From experiments concerning the cost of producing F_1 seed by hand pollination and by hand removal of male blossoms, it was determined that costs were not prohibitive by Singletary and Moore (*52*). This is not surprising considering that each fruit can produce a large number of seeds (approximately 225).

One obvious advantage that could relate to use of an F_1 hybrid would be that resistance to disease controlled by dominant genes in only one parent could be transmitted to the F_1 progeny without converting the other parent. Of course, this assumes that the two parents make a good F_1 in other respects. Also, the uniformity in size of fruit that is associated with F_1 hybrids would be advantageous to retailers who prefer to sell at a price per melon rather than per pound. F_1 hybrids provide the best way to take advantage of the intermediate fruit shape, where one parent is round fruited and the other long fruited. The intermediate fruit shape has less gourd necking and less hollow heart than the parental fruit shapes.

The characters of watermelon for which inheritance data have been obtained are listed in Table 2.2 along with suggested gene symbols. Insufficient genetic information exists for a mapping of the chromosomes, as has been possible with more intensely investigated crops such as the tomato. Such information as exists on linkage is presented in Table 2.3.

TABLE 2.2. Inherited Characters of Watermelon and Their Gene Symbols[a,b]

Preferred symbol	Synonym	Character description	Reference
Seed, color, shape			
w		*White* seed coat	*29*
t	(b^t)	*Tan* seed coat	*29*
r		*Red* seed coat	*39*
l		*Long* seed	*39,40*
s		*Short* seed	*40*
Fruit flesh color, flavor			
R	*Y*	*Red* flesh	*38*
y	(*r*)	*Yellow* flesh (recessive to red)	*38,42*
*Wf**	(*W*)	*White flesh* (dominant to red)	*51*
C		*Canary* yellow flesh (dominant to pink)	*38*
su*	(su^{Bi})	*Suppressor* of bitterness	*7*
Fruit rind color, texture			
g	(*D*)	Light *green* skin (recessive to dark green but dominant to light green skin)	*59*
g^s	(d^s)	*Striped green* skin (dominant to light green)	*38,59*
m		*Mottled* skin	*38,59*
p		*Pencilled* lines on skin	*38,59*
*go**	(*c*)	*Golden*	*3*
f		*Furrowed* fruit surface (recessive to smooth)	*38*
e	(*t*)	*Explosive* rind	*38,42*
Fruit shape			
O		Elongate fruit (incompletely dominant to spherical)	*40,59*
Dwarf habit			
dw-1		*Dwarf-1*	*26,32*
dw-2		*Dwarf-2*	*26,34*
Leaf shape, color, texture			
*nl**		*Non-lobed* leaves	*30*
*go**	(*c*)	*Golden*	*3*
*gms**	(ms_g)	*Glabrous male sterile*	*57,58*
Male sterility			
*gms**	ms_g	*Glabrous male sterile*	*57,58*
Sex inheritance			
a		*Andromonoecious* (recessive to monoecious)	*38,46*
Disease resistance			
*Ar**	(*B*) *Gc*	*Anthracnose* resistance	*16,25*
pm		*Powdery mildew* susceptibility	*45*

[a]Adapted from Robinson *et al.* (*44*).
[b]Asterisks indicate a proposed new symbol.

TABLE 2.3. Seven Cases of Probable Linkage in Watermelon[a]

	Genes	Crossover percentages or correlation coefficients indicated	Reference
1.	*M* and *G*	39.9 ± 4.3%	*59*
	M and g^s	33.8 ± 4.6%	*59*
2.	*M* and fruit weight	r = .38 in F_2; r = .65 in backcross to light-weight parent	*59*
3.	*A* and *O*	13.6 ± 2.9% in backcross; 20.7 ± 1.0% in F_3; 35.0 ± 3.5% in F_2	*40*
4.	*C* and *O*	26.5 ± 8.2% in F_2	
5.	*O* and fruit weight	r = −.31 total variance; r = −.86 Mendelian phenotypes	*40*
	Same	r = −.34 F_2 total variance; r = −.41 F_2 total variance.	*59*
6.	*A* and fruit weight	Linkage probable, but estimation impossible, difference between mean weight: A = 5.08 ± 0.24, a = 4.42 ± 0.22 kg	*40*
7.	*L* and *W*	15.8 ± 1.2% in backcross; 19.3 ± 1.1% in coupling F_2; 21.5 ± 7.2% in F_3; 24.7 ± 4.9% in repulsion F_2	*39*

[a]Crossover percentages are shown for qualitative characters; correlation coefficients are shown where one of the phenotypes is a quantitative character not convertible. [Adapted from Poole (*38*).]

SELECTION TECHNIQUES FOR SPECIFIC CHARACTERS

Dwarfs

Hypocotyl length of double-recessive dwarfs is approximately one-half that of vines. This permits elimination of the vine genotype in segregating populations of seedlings grown in peat pots for transplanting. In this way only dwarf plants are transplanted in the field.

The compact growth of dwarf seedlings is a characteristic of much value in production of transplants. Double-recessive dwarf seedlings remain in a condition suitable for setting out for several weeks, whereas vine types become overgrown and impossible to handle efficiently within a few days. By planting four seeds per peat pot (3 in. square) of lines expected to segregate, and clipping all long hypocotyl seedlings with scissors, nearly 100% of the pots will have a dwarf plant. The seedling populations described above are produced by selfing or crossing plants with the following genotypes: *dw1/dw1, Dw2/dw2* and *Dw1/dw1, dw2/dw2*.

Fusarium Wilt Resistance

Techniques for screening lines segregating for resistance vary considerably in the severity of the test. Some breeders use field testing on land with a history of severe wilt; others rely upon greenhouse screening of seedlings, sometimes in 3 in. square peat pots with survivors transplanted to the field. In any test, it is important to have a strain or race of the pathogen that is highly virulent. Failure to do this may result in later breakdown of resistance when the supposedly resistant line is exposed to a more virulent strain (*4*).

One greenhouse technique involves planting seeds in peat pots containing soil mixed with wheat grains on which mycelium of the wilt organism is growing. The inoculum is prepared by transferring mycelial fragments from a pure culture of a virulent strain of the organism to autoclaved flasks of whole wheat grains.

Most of the seedlings under this treatment die before reaching the transplanting stage, which saves time, effort, and space in the field. This technique (*33*) was used in selecting the resistant Texas W-5 Breeding Line described by Crall and Elstrom (*9*) as having "high-type" resistance and used by them in breeding the new wilt-resistant cvs. Smokylee, Dixielee, and Sugarlee.

Anthracnose Resistance

Resistance to anthracnose is dominant to susceptibility and is governed by a single pair of genes. The most prevalent races of the pathogen are designated as races 1 and 3, and these are the races to which most present cultivars are resistant. However, race 2 seems to be spreading and threatens to become a serious problem. So far, no cultivars are resistant to it, although resistance has been located in a plant introduction. Presumably the same inoculation and selection techniques will apply in developing cultivars resistant to race 2 that have been used successfully for resistance to races 1 and 3. These are described by Hall *et al.* (*16*).

Gummy Stem Blight Resistance

Resistance to gummy stem blight has been located in two plant introductions (*53*). One carries genes that promote a higher level of resistance than the other, but both are useful in developing cultivars with acceptable resistance. Greenhouse screening of seedlings, followed by transplanting of resistant segregates, is providing satisfactory progress. The screening technique is similar to that used in breeding for anthracnose resistance. The pathogen is grown on autoclaved frozen snap beans in 125 ml Erlenmeyer flasks for 7–10 days under fluorescent light at room temperature. Two cultures are blended in 500 ml of distilled water with a food blender for 2 min. Filtration of this inoculum through a Whatman No. 4 filter removes most of the snap bean substrate. It was found that this inoculum contained from 10^5 to 5×10^5 spores per milliliter. This was sprayed onto seedlings until run-off occurred. Plants were then incubated for 48 hr at 25° ± 2°C in a moisture-saturated atmosphere. This technique was developed by Sowell and Pointer (*53*), and followed in screening to locate the resistant plant introductions PI 189225 and PI 271778.

Fruit Shape

Selections for fruit shape can be made in the seedling stage; long, narrow cotyledons indicate elongated fruit shape, whereas round cotyledons indicate that round fruit will be produced (*59*).

Earliness

Selections for early maturity are more reliable when based on data that include the date of first fruit set *and* the number of days from fruit set to maturity. Data on soluble solids can assist in verifying that fruit is fully mature. A hand refractometer is useful for this purpose.

Tough Rind

A simple method of selecting for rind toughness is to cut a thin strip or ribbon of rind 1/16 to 1/8 in. thick and 3 in. long and bend it into a circle. If it makes a complete circle, it is

very tough; but if it breaks early in the attempt to make a circle, it is tender (''explosive''). The method is described in detail by Ivanoff (*20*).

Leaf Type

The non-lobed leaf type is readily selected in the young plant. Actually, the first two or three ''true leaves'' (''juvenile'' leaves) are often non-lobed in plants that are genotypically ''lobed leaf,'' but thereafter there is no question of identity of the homozygous non-lobed plant. With a little experience, the heterozygotes can be recognized by their intermediate lobing as described by Mohr *et al.* (*31*).

Seeds

Evaluation of seed characteristics must await the harvesting of fruit. During the extraction of seed from selected fruit an assessment may be made of the approximate numbers of seeds, using the subjective ratings very few, few, average or normal, above average, and excessive. These ratings will be related to size of the fruit. Thus, the *actual* number of seeds in a very small fruit (such as in New Hampshire Midget) may be no more than in a larger fruited cultivar, but because they are concentrated in a small space, they may be classified as excessive. Seed color and size must be uniform in a line ready for release because the seed trade demands this. The size of ''ideal'' seed has not been determined, but seedsman are reluctant to handle very small seed and/or cultivars with few seed per fruit. On the other hand, few seed per fruit may be preferred by watermelon consumers.

Poole and Grimball (*39*) studied inheritance of various characteristics of seed and reported in detail; most of the simply inherited traits of watermelon are presented in tabular form with their gene symbols and references in Table 2.2.

Miscellaneous

New and heritable biological variations can be discovered by careful observation while making selections in segregating populations. Photographs and objective measurements should be made, and the mode of inheritance studied and reported.

Plastic flags, such as used by civil engineers and foresters, are a cheap and effective means of marking selected plants for further observation and/or controlled pollinations.

DESIGN OF THE COMPLETE BREEDING PROGRAM

Sequence of Development

Breeding programs are usually designed to solve problems of the commercial grower, although in recent years some programs have placed emphasis on the needs of the home gardener. Actually breeders should consider both groups, as they may find segregants that are not suitable for their primary clientele, but represent notable advances for the other group.

Developing a Project

The first step in any breeding program is the development of a project proposal. In this the breeder states the principal objectives and the procedures to be followed in attaining them. A thorough review of the literature on the subject provides the background. Breeding projects are long term by reason of the amount of time required to attain homozygosity

following hybridizing. Projects are generally approved for a period of approximately 5 years, subject to renewal after revision. This revision affords an opportunity for the breeder to modify the project to take advantage of changes in clients' needs and to utilize new information and new germplasm.

Familiarity with Parental Material

Choice of parents is a critical matter that can make or break the program. The breeder must become intimately acquainted with existing cultivars, not only with respect to the characteristics primarily sought, but also to all other characteristics of importance. If undesirable characteristics are present in a parent, they may be very difficult to eliminate from the ensuing generations.

Critical evaluation of potential parent material should continue each year with examination of new cultivars and/or plant introductions that appear to be promising. Unusual characteristics may be found and, if sufficiently promising, may cause a major change in project objectives.

Pollination Techniques

A literature review will reveal descriptions of techniques used in other projects. It is advisable constantly to seek to improve techniques, since controlled pollinations comprise a considerable portion of the physical work in breeding watermelons. Local conditions may permit labor-saving modifications. For example, honey bees do not appear in our fields until several hours after daybreak, which permits pollinating unprotected flowers during that time (if the breeder starts early).

Examples of Some Complete Programs

The Florida Watermelon Breeding Program

This program has been quite productive, with the naming and recent introduction of the three cvs. Smokylee, Dixielee, and Sugarlee.

Smokylee combined the high-type resistance of Texas W-5 to fusarium wilt with the anthracnose resistance of Charleston Gray. In yield and quality it appears to be comparable to Charleston Gray, but should prove superior to it where fusarium wilt is a serious problem.

Dixielee's pedigree (Fig. 2.5) illustrates how the breeder brought together the following desirable characteristics: high-type wilt resistance, anthracnose resistance, firm flesh, and intense red flesh color. In 1961 three crosses were made: W-5 × Wilt Resistant Peacock 132 (source of intense red color, firm flesh, and tough rind), W-5 × Fairfax (source of anthracnose resistance), and W-5 × Summit (high-type wilt resistance). Note that all three involved W-5, which indicates the importance that the breeder attached to the high-type of resistance to fusarium wilt. Further indication of this is evident in the 1962 pollinations in which the three F_1 lines were backcrossed to W-5. In 1964 the line carrying genes from Wilt Resistant Peacock 132 was outcrossed to Graybelle, which introduced resistance to anthracnose into this line. The line carrying anthracnose resistance from Fairfax was merged with the line carrying high-type wilt resistance from Summit. Selections were made until the F_4, when the line was combined with the F_3 of the line from Wilt Resistant Peacock 132, which had been selected for the important characteristics contributed by that cultivar. The next seven generations involved selection and selfing until the line was sufficiently homozygous to be released. In total, 14 years were required

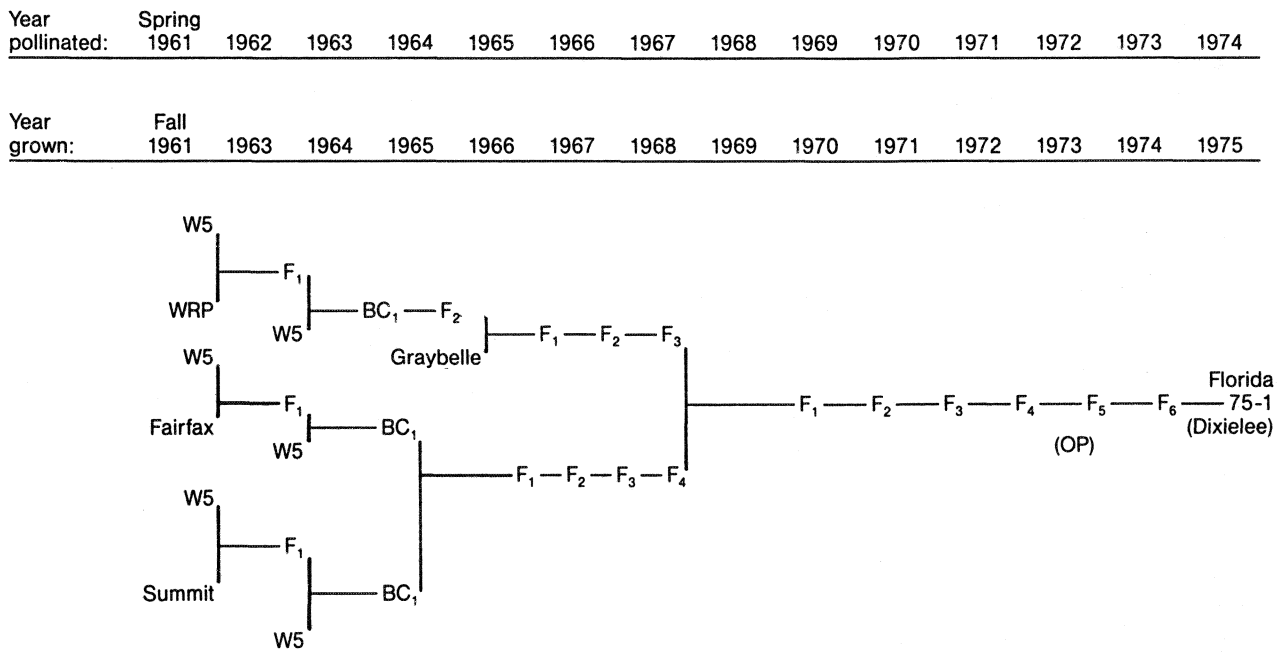

FIGURE 2.5. Pedigree of the cv. Dixielee developed at the Agricultural Research Center, Leesburg, Florida, illustrates the time span involved in combining disease resistance with superior quality factors. W-5, Texas W-5; WRP, Wilt Resistant Peacock 132; F_1–F_6, filial generation following a cross (from self-pollination except as noted); BC_1, first backcross generation; OP, open pollination.
After Crall and Elmstrom (*9*).

to attain the objectives, and some years of field testing in various trial locations still remained before naming and release.

Comparisons of the fruit characteristics of Dixielee with those of the dominant cv. Charleston Gray are given in Table 2.4. Notable superiority with respect to the percentage of soluble solids (flavor), flesh firmness (durability), and flesh color are indicated, and the rind firmness is equal to that of Charleston Gray although the rind is much thinner.

Results of consumer preference tests given in Table 2.5 indicate that the majority of consumers evaluating the two cultivars preferred Dixielee to Charleston Gray.

Tests such as presented in Tables 2.4 and 2.5 provide valuable information to other breeders who contemplate using the new cultivar as a parent in their programs. Unfortunately, evidence of yield superiority, as derived from replicated yield trials, has been until recently the principal concern of those concerned with authorizing the naming and release of new cultivars. Present trends, however, seem to be toward more complete evaluation of the breeding line, involving qualitative characteristics as well as quantitative.

The Florida program leading to the release of Dixielee has been presented as an example of a program that was well organized and carried through to the successful attainment of objectives. It is not meant to imply that Dixielee will necessarily attain the status of dominant cultivar because of its demonstrated merits. History reveals that many fine cultivars have failed to attain popularity with growers because of some defect that the breeders either considered to be of minor importance, or failed to recognize in their evaluations.

The pedigree of Dixielee clearly indicates the time span required in its development, but does not adequately portray the amount of work involved. In the early stages of development, extensive and time-consuming greenhouse screening for selections resistant to fusarium wilt and anthracnose were required.

It was also necessary to obtain numerous self-pollinations in the incorporation of the genes controlling flesh color and firmness because the segregants for these characteristics

TABLE 2.4. Comparison of Fruit Characteristics of Dixielee and Charleston Gray Watermelons, 1977[a]

Characteristics	Dixielee	Charleston Gray
Length (in.)	11.2	19.1
Diameter (in.)	10.8	9.6
Shape ratio	1:1	2:1
Rind firmness (lb)[b]		
Blossom end	17	17
Side	19	19
Flesh firmness (lb)[c]		
Heart	5.3	4.8
Outside seeds	6.3	5.6
Rind thickness (in.)	0.4	0.7
Soluble solids (%)	11.2	8.9
Flesh color	Dark red	Red

[a]Study conducted by A. K. Showalter, University of Florida, Gainesville, and reported by Crall and Elmstrom (*9*).

[b]Determined by pressure tester with 5/32-in. probe.

[c]Determined by pressure tester with 23/32-in. probe.

TABLE 2.5. Consumer Preferences for Dixielee and Charleston Gray Watermelons[a]

Factor evaluated	Test number	Number of tasters	Preference (%)		
			Dixielee	Charleston Gray	No choice
Sweetness	1	63	91	6	3
	2	287	78	16	6
	Mean		85	11	4
Flavor	1	63	76	11	13
	2	287	70	19	11
	Mean		73	15	12
Color	1	63	75	16	9
	2	287	78	10	12
	Mean		77	13	10
Texture	1	63	65	25	10
	2	287	67	20	13
	Mean		66	22	12
Off-flavor	1	63	0	0	—
	2	287	1	0	—
	3	332	4	0	—
	Mean		2	0	—
Overall	1	63	89	11	0
	2	287	77	18	5
	3	332	85	14	1
	Mean		84	14	2

[a]Studies conducted in 1977 by R. K. Showalter and Mary N. Harrison, University of Florida, Gainesville, and reported by Crall and Elmstrom (*9*).

could not be determined until the fruit was examined internally. Late-season pollinations (after fruit evaluations) are not dependable. When a number of selections have been made, as is usually the case, the breeder faces the problem of finding space to grow all of them and time to pollinate and evaluate them. Thus the task is not as simple as the pedigree might lead one to conclude.

The Kentucky Watermelon Breeding Program

In the development of Dixielee, emphasis was placed on improvement of disease resistance and quality. Other breeding programs in the United States have similar objectives. The Kentucky Program seeks to introduce new cultivars with dwarf plant habit (sometimes referred to as "bush"). Two different recessive genes for dwarfing are involved, with the double-recessive producing a third type of dwarf. Initiation of the program at Texas A&M University, College Station, followed the discovery of the first dwarf, apparently a mutant in a planting of the cv. Desert King. Following determination of the mode of inheritance, breeding lines of this type (*dw1/dw1*) of dwarf were established (*33*). The principal objective was to develop a commercially acceptable dwarf.

Undesirable characteristics of the Desert King bush mutant were yellow flesh, yellow rind, very late maturity, and disease susceptibility. Vine-type cultivars were selected as parents to overcome these disadvantages, and the desired genes were transmitted to

several bush breeding lines. At this point in the program the author moved to the University of Kentucky, Lexington, leaving the materials that had been developed behind, except for a small packet of seed of one advanced line designated W-45.

In 1962, a dwarf mutant was reported in the Japanese cv. Asahi Yamoto by M. Shimotsuma. Seed of it was obtained for comparison with W-45. Crossing this Japanese dwarf with W-45 was the beginning of the Kentucky program. In the F_2 the new double-recessive dwarf appeared. It was superior in plant characteristics to the single-gene dwarfs (Figs. 2.2–2.4).

The principal objective then became to develop dwarf cultivars that combined the most desirable characteristics of vine cultivars with this new plant growth habit. Several years were required to work out of the mode of inheritance and to obtain seed from self-pollinations of the double-recessive dwarf segregants. Exceptionally late maturity was a serious problem. Plants had to be started in the greenhouse and transplanted to the field to have sufficient growing time to mature seed. Unless earlier maturity could be combined with the double-recessive dwarf characteristic, the new cultivar was virtually worthless.

In 1968, an outcross to the vine cultivar New Hampshire Midget was made to introduce genes for earlier maturity. New Hampshire Midget had demonstrated outstanding earliness in our search for a parent to transmit this characteristic. In 1967, the F_1 of this cross was selfed, and in 1968, some F_2 segregants appeared that matured seed in the normal growing season.

By 1970, maturity of some double-dwarf segregants in the F_4 was satisfactory for Kentucky. Twenty-one different F_5 lines were established by selfing. These were evaluated in 1971, with emphasis placed on melon quality, since plant type and maturity were acceptably uniform. One of these 21 lines showed a satisfactory level of uniformity of melon quality factors except for seed color and size. In 1972 and 1973, continued selection and selfing established the desired uniformity in respect to all characteristics.

Traditionally the next step would have been extensive testing to evaluate commercial acceptability, as was done prior to the release of Dixielee. However, Kengarden, as the new cultivar was named, was designated as a home garden cultivar, with its principal merit the dwarf habit of plant growth. The latter characteristic being unique, Kengarden qualified for coverage under the Plant Variety Protection Act. Assignment of the right to propagate Kengarden was made by the University of Kentucky and royalties from sale of seed are received by the university.

The breeding program at Kentucky continues to emphasize development of dwarf types, and numerous improvements can be made in the double-recessive dwarf type. The single-gene dwarfs offer promise also. Progress with them can be more rapid, since one-quarter of the F_2 progeny from crosses with vine cultivars are of the desired plant growth habit, whereas only one-sixteenth of the progeny of double dwarfs crossed with vine habit segregate as the desired plant type.

A Typical Year's Work

Greenhouse Activities

One year can be saved by making a cross in the greenhouse or by selfing an F_1 to obtain seed for the F_2. This advantage relates to the abundant seed per fruit (average approximately 225 seeds per fruit). Peat–lite (peat plus vermiculite) mixtures are commercially available and work nicely if occasional "feedings" of a complete nutrient solution are applied. Large-sized (1 gal. or more) plastic nursery pots make satisfactory containers. If

vine-type plants are involved, cords for the vines to climb can be dropped from overhead wires. (Dwarf types do not require this, and some lines can be considered as potential "patio pot plant" cultivars.)

Screening for resistance to fusarium wilt can be undertaken either to evaluate the level of resistance in a breeding line by the percentage of seedling survival or, if done near planting season, to transplant survivors to the field where further selections can be made. In the former case, ordinary pots may be used and the screening may be conducted at any time. Soil-heating cable may be necessary to assure optimum soil temperature for the development of the *Fusarium* organism. In the second case seedlings should be started in 3-in. square peat pots, five to six seeds per pot (also with heat supplied by soil-heating cable). Usually the majority of seedlings will be killed if the lines are in an early generation, and the few resistant survivors can be transplanted to the field for selfing and/or sibbing.

Anthracnose resistance can be handled in the same fashion: either a test to confirm homozygosity of resistance, or a test followed by transplanting of resistant segregants. A humidity chamber, which is needed to maintain high humidity levels, can readily be constructed using plastic film. The inoculum is sprayed on the young seedlings, and this is followed by periodically spraying a fine mist of water into the chamber. When lesions appear on the leaves, the plants may be rated for resistance, and those free of lesions may be transplanted to the field if desired.

In lines segregating for dwarfness, seedlings may be started in 3-in. square peat pots (three to four seeds per pot), and the vine segregants can be eliminated by clipping all seedlings with long hypocotyls at the soil line. The dwarf seedlings that remain are ideal for transplants as they make slow-growing, compact plants that do not become entangled with each other in the seed flat. In fact, they make such ideal transplants that we recommend them to bedding-plant producers.

Field Activities

Seed to be planted is treated with a seed protectant such as Thiram. Seedlings are grown in peat pots for transplanting, and set out in beds covered with black plastic film (3 ft wide). Row spacings and in-row spacings are determined from notes on the size of plants from the previous generation of the breeding line. Holes are punched in the plastic and seedlings set with a trowel. They are watered-in to assure contact of roots with soil. The plastic provides almost complete weed control in the row, as well as a uniform moisture supply. Standard spray recommendations for control of insects and diseases are followed. Observations and note-taking start early and continue at regular intervals. Plants that are selected for meritorious characteristics are marked with colored plastic flags and are selfed when at the proper stage. Controlled pollinations are marked with distinctive flags and inspected periodically. When the pollination is unsuccessful, follow-up attempts are made.

As melons begin to mature, those which come from controlled pollinations are carefully marked with a felt marker pen (waterproof ink) and transferred to cold storage to await examination of melon characteristics. The remaining melons in the field, which resulted from open pollination, are cut to determine internal characteristics. Notes concerning the extent of variability of the line in this regard are useful.

Seed is extracted from fruits that have desirable melon characteristics, and notes describing these are taken. Seed from each melon is handled separately by placing it on a

square rack of ¼-in. mesh "hardware cloth." It is washed with water and the rack is placed in a well-ventilated room to dry. When dry it is packaged and stored in a metal cabinet at room temperature until needed for planting. Seed has been found to have good germination for at least 5–6 years, which is longer than necessary in a breeding program.

During the winter, notes are studied and priorities are established concerning which selections will be planted in the next growing season. Usually seed has been saved from more selections than the scope of an average breeding program will permit growing.

TRIALS OF ADVANCED LINES

Evaluation of Commercial Potential

Since a major goal of past breeding efforts with watermelon has been that of a high level of resistance to fusarium wilt, most of the testing of advanced lines has emphasized performance on land infested with the fusarium wilt organism.

The Southern Cooperative Watermelon Trials include trial locations in Alabama, Arizona, Arkansas, Florida, Kentucky, Louisiana, Missouri, North Carolina, Oklahoma, South Carolina, Texas, Virginia, and even the non-southern states of Indiana and Iowa. The trials are under the sponsorship of the Southern Region of the American Society for Horticultural Science. Entries first must be in an observational trial; and if the majority of the cooperators vote favorably, they advance to a replicated yield trial. Results of both observational and replicated trials are summarized and distributed to all cooperators annually. Data taken include the following: marketable yield in numbers of fruit per acre and in weight of melons per acre, average weight per melon, soluble solids (percentage) by location, maturity class, fusarium wilt resistance rating, and anthracnose resistance rating. Cooperators vote for the entry they rate as "best in trial" (both replicated and observational). The number of locations provides assurance of exposure of the entry to a wide range of environmental conditions. Entries that have done well in these trials have proved to be successful as commercial cultivars when introduced. These trials do not profess to evaluate cultivars being developed for home gardens, nor have they made provision to adjust plant spacing to permit dwarf plants to be competitive.

Evaluation of Garden Value

The All-America Trials[1] place emphasis on unique developments in breeding, whereas the Southern Cooperative Watermelon Trials have concentrated on improvements in yield and disease resistance. Trials of cultivars for garden use should emphasize superior qualitative characteristics, whereas trials of lines developed for commercial use must emphasize yield and disease resistance, and such factors as contribute to durability under existing shipping conditions.

Data such as were taken for the cultivar Dixielee (see Tables 2.4 and 2.5) are very helpful in evaluating the future performance of a new introduction. Cooperation with persons expert in evaluation of consumer preferences is required.

The Southern Cooperative Watermelon Trials depend upon the participation of breeders who eventually expect to submit their own prospective introductions for evaluation.

[1]All-America Selections, 628 Executive Drive, Willowbrook, IL 60521.

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