

## Genetic resources and watermelon breeding at Embrapa Semi-Arido

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### ABSTRACT

Watermelon genetic resources used to set the watermelon breeding program at the Embrapa's Semi-Arid Research Center are described as well as breeding objectives, program and methodologies. A germplasm flow chart shows the strategy used in the germplasm management of the Watermelon Germplasm Bank and in the breeding program. Selection for disease resistance and for plant and fruit characteristics of diploid and tetraploid lines are described and some relevant results are presented. Several diploid and triploid hybrid combinations, resistant to powdery mildew were evaluated. Some of these hybrid combinations presented good prospects as experimental hybrids to be tested in the field by farmers. New breeding tools to produce new generations of hybrids well adapted for the internal and external markets are discussed.

**KEY WORDS:** *Citrullus lanatus*, watermelon breeding, genetic resources.

### INTRODUCTION

Commercial watermelon (*Citrullus lanatus* (Thunb.) Matsum & Nakai) is cultivated in four major areas in Brazil, namely: in the Northeast (under irrigation); in the Savanna areas of the states of Goiás and Tocantins; in some counties in the state of São Paulo; and in Southern Brazil (mainly in the state of Rio Grande do Sul).

It is grown by medium and small farmers in an estimated area of 70,000 hectares, and it yields more than 1,000,000 tons of fruit, generating US\$ 150 million annually.

Watermelon was first introduced into Brazil more than 300 years ago by Africans from different parts of the continent during slave trading. Many watermelon seed samples were introduced into coastal areas from Rio de Janeiro to São Luís, in the state of Maranhão (Whitaker and Davis, 1962). From then on, watermelon spread inland and evolved among small farmers in traditional agriculture, under rainfed conditions and without any agrochemicals. Northeastern Brazil has been considered a secondary center for watermelon genetic diversity (Romão, 1995). In the fifties, seed samples from a few commercial American watermelon cultivars were introduced

in the county of Americana, in the state of São Paulo (Costa and Pinto, 1977). Some were spread in commercial field crops such as the Charleston Gray, and later replaced by the Crimson Sweet which is still under cultivation. Some Japanese varieties were also introduced in the state of São Paulo, mainly the Omarau Yamato. Despite having good fruit quality (color, fruit sweetness and rind resistance which allowed for long distance transportation of fruits), the commercial watermelon cultivars introduced presented a narrow genetic basis. Recently, new cultivars, mostly hybrids, are available, but they are not extensively cultivated.

Consumer preference in Brazil is for fruits greater than six kilograms, probably due to the availability of cultivars with large fruits in Brazil and to the poor quality of the smaller fruits. However, recently, small-fruit cultivars such as the Sugar Baby have become available in supermarket chains. Conversely, consumer preference in the USA is for fruits of smaller size and there is an increasing demand for seedless watermelons (more than 30% of the American market). An additional demand for watermelon fruits without or with few seeds comes from external markets, e.g., Argentina and Europe. However, the hybrids (seed and seedless) available in Brazil

have high seed costs and most of them are not adapted to the Brazilian conditions.

Considering the unavailability of adapted watermelon cultivars and the narrow genetic basis found in the commercial watermelon varieties, the Embrapa's Semi-Arid Research Center started a research project in 1990 to rescue the genetic variability of the traditional agriculture in Northeast Brazil and to use this genetic variability in a watermelon breeding program. The project also carries out an activity of training young students, in long and short term courses, involving several research studies in watermelon germplasm management and use.

## BREEDING PROGRAM

The Embrapa Semi-Arid watermelon breeding program has adopted a strategy which first collects the genetic variability for watermelon and then recovers the watermelon genetic variability in traditional agriculture. A Watermelon Germplasm Bank has been organized with more than 600 accessions (Queiroz, 1998), some of them resistant to powdery mildew, prolific and small-fruited, with low sugar content, white flesh, high number of seeds and late plants. Accessions from the USDA Watermelon Germplasm Bank were also introduced, specially those resistant to diseases such as gummy stem blight and the PRSV-w and WMV-2 viruses, as well as a tetraploid line, Charleston Tetra Number 3 (CT3).

During the germplasm studies, sources of resistance to powdery mildew, gummy stem blight and virus (Dias et al., 1996; Oliveira, 2000) as well as different fruit and plant characters such as plant yield, prolificacy, fruit size and shape, flesh color, sugar content and number of seeds per plant were identified (Assis et al., 1994; Ferreira, 1996). The second step was dedicated to the use of appropriated accessions in order to develop breeding lines, using a pre-breeding program.

The strategy adopted in the watermelon breeding program analyzed the management of the Watermelon Germplasm Bank in close

relationship with the breeding activities. This approach has the advantage of exposing all the described watermelon genetic variability to use in the breeding program (Figure 1).

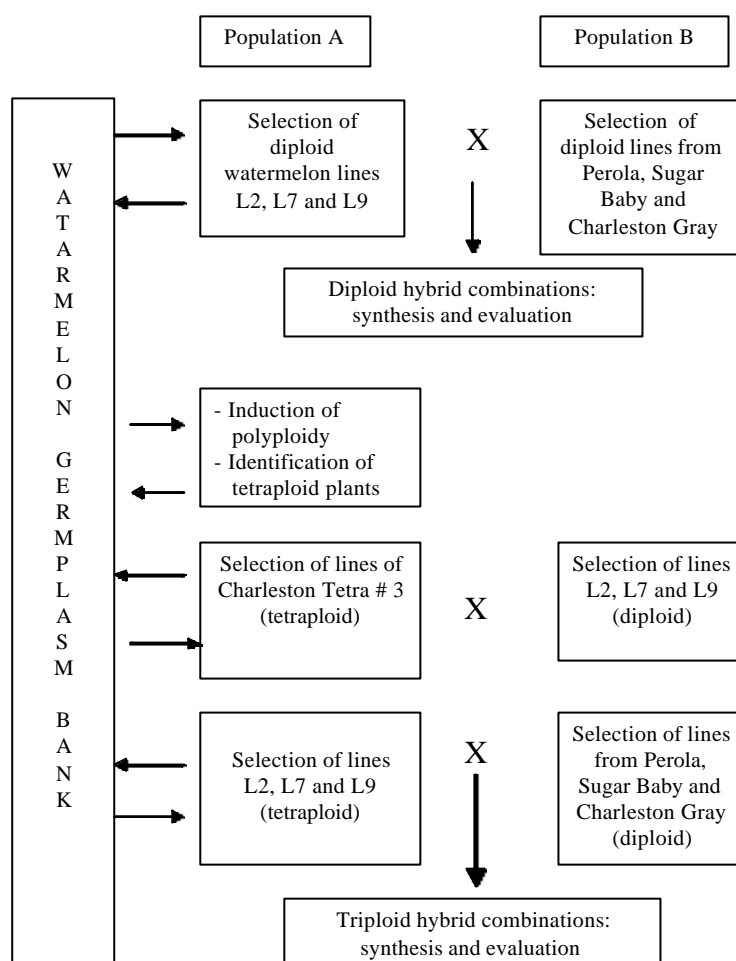
The watermelon germplasm management allowed identification of relevant plant characteristics that were incorporated in the breeding program. Thus, watermelon lines with different fruit and plant characteristics were selected in order to synthesize hybrids with a range of fruit and plant patterns to attend to the farmers' and consumers' preferences. Major breeding activities included the identification of sources of resistance to diseases; the genetic analysis of the gene action of the relevant characters, and the development of lines which were evaluated *per se* and in hybrid combinations, including diploid and tetraploid lines. This procedure allows for the continuous improvement of potential lines in order to synthesize different generation of hybrids in the future.

Stable experimental hybrids should be evaluated in the different watermelon growing areas around the country since genotype x environment interaction frequently affects their performance (Vencovsky and Barriga, 1992). However, an evaluation of available lines followed by a selection of the most adapted in order to select the appropriate hybrids for each area would be most successful.

Genotypes, plant density, fertilization, water use, and flowering management should be considered in the development of a cropping system for the watermelon market in the country and abroad, in order to produce fruits below five kilograms of good quality and of good fruit yield per hectare. The Embrapa Semi-Arid Research Center has developed more than 30 experimental diploid and tetraploid lines with different plant and fruit patterns for the development, in the near future, of diploid and triploid hybrids to be evaluated in different watermelon growing areas.

## RESEARCH OBJECTIVES

The major objectives of the Embrapa Semi-Arid



**Figure 1** - Germplasm flow chart and breeding strategies of the watermelon breeding program at the Embrapa Semi-Arid Research Center, Petrolina-PE, 2001.

genetic resources and watermelon breeding program are:

1. Increase watermelon genetic variability (rescue genetic variability from the traditional agriculture in areas not yet covered - states of Ceará, Paraíba, Alagoas, Sergipe and parts of Bahia);
2. Breeding for yield increase (yield per plant and number of fruits per plant);
3. Fruit quality (fruit size and shape; smaller fruits for local supermarket chains and for the external market; flesh color and firmness; sugar content and seedless fruits);
4. Disease resistance (foliar disease: powdery mildew (*Sphaerotheca fuliginea*); papaya ring spot virus - strain watermelon (PRSV-w); watermelon mosaic virus-2 (WMV-2); zucchini yellow mosaic virus (ZYMV); Vine disease:

gummy stem blight (*Didymella bryoniae*);

5. Agronomic traits (appropriate plant vigor in order to increase plant density; good seed germination, particularly in tetraploid and triploid genotypes; earliness, particularly in tetraploid lines; good fruit setting from early artificial pollination).

## BREEDING METHODOLOGIES

### I. Disease resistance

Sixteen accessions from the Watermelon Germplasm Bank and four commercial varieties, namely: Crimson Sweet, Pérola, Sunshade and Charleston Gray were tested in field experiments for three years, without replication, using 3-row plots, with the susceptible commercial "Charleston Gray" in the central row acting as both the control and the natural source of powdery mildew

(*Sphaerotheca fuliginea*) infection (Araújo et al., 1987). Seven accessions scored less than 1 and were resistant to powdery mildew. Nine accessions and the commercial varieties scored 3 and were susceptible to the disease. These findings are representative since the commercial varieties, particularly those from USA, the basis of the Brazilian watermelon varieties, are susceptible to the *Sphaerotheca fuliginea* found in the São Francisco valley (Araújo et al., 1987). The powdery mildew fungus was examined by Borges (1997) who found fibrosin bodies among the vacuoles in the conidia, indicating that the fungus species is *Sphaerotheca fuliginea* (Yarwood, 1978).

One of the accessions of small fruits (CPATSA 85-030), which is prolific and powdery mildew resistant, although of white flesh, was selected and crossed with Crimson Sweet, as a cultivar of wide adaptation to the watermelon-growing areas of Brazil and of good fruit quality. After four generations of selfing and two of backcrossing followed by three generations of selfing, some powdery mildew resistant lines were selected from which L2, L7 and L9 were used as experimental lines in the watermelon breeding program. L2 and L7 are high yielding, flower early, and produce large fruits with red flesh and good sugar content. They are similar to the Crimson Sweet fruit. L9 has a dark external color, smaller fruits, and a tendency to prolificacy and late flowering. The sugar content is lower than in the other two selected lines.

The cotyledonary leaves and the stem of young watermelon plants from sixty nine accessions of the Watermelon Germplasm Bank and one introduced from the USDA, the PI 189225, were inoculated with a conidial suspension of the *D. bryoniae* ( $3.18 \times 10^{-5}$  per milliliter) fungus. After inoculation, each plot was covered with a plastic bag to create a wet environment and a randomized block design with four replications was used, one replication as control (without inoculation). The accessions evaluated presented three different patterns of reaction. Fifteen were susceptible such as the Crimson Sweet (score 4 and 5) cultivar; thirty eight were intermediate (score from 3 to 4/5) and sixteen were resistant (score 2). The accessions evaluated are local populations from farmers' fields and they sometimes are seed mixtures from different fruits

or a single fruit (Queiroz, 1998). In general, the sources of resistance have fruits of white flesh and low sugar content and late plants which need a long process of backcrossing and selfing before improved watermelon resistant lines can be selected. However, Sowell and Pointer (1962) found resistance to gummy stem blight in the accessions PI 189225, from which Norton and Cosper (1985) developed the resistant cultivar "AU-Producer". This cultivar was introduced into the Watermelon Germplasm Bank and is expected to present the same level of resistance of PI 189225, that in turn, presented the same level of resistance of the resistant accessions. Therefore, the AU-Producer can be used to develop watermelon resistant lines to both pathogens, namely: gummy stem blight and powdery mildew.

Borges (1997) has identified the powdery mildew resistance found in the source as monogenic and dominant and, therefore, the F1 hybrids between watermelon resistant lines and lines from susceptible cultivars (Figure 1) are powdery mildew resistant. However, it will be necessary to determine the mode of inheritance of gummy stem blight resistance in the identified sources of resistance to guide the future strategies.

Fifty accessions from the Watermelon Germplasm Bank were also evaluated for reaction to three different viruses, namely: papaya ring spot virus – strain watermelon (PRSV-w); watermelon mosaic virus 2 (WMV-2) and zucchini yellow mosaic virus (ZYMV). In greenhouse experiments, seed samples were planted in sterilized soil, using four plants per pot. A leaf sample of each accession was collected for test in the enzyme linked immunosorbent assay (ELISA) using specific antiserum for their respective viruses. Five accessions from *C. lanatus*, *C. lanatus* var. *citroides* and *C. colocynthis*, were resistant to the three viruses.

## II. Genetic analysis

Apart from identifying sources of resistance to powdery mildew, gummy stem blight and virus, which are mostly governed by major genes, potential parents were studied to get the basic information about gene action on some agronomic traits such as flowering date, prolificacy, fruit weight and sugar content. These

characters are relevant to the selection of potential inbred lines for hybrid synthesis.

For this purpose, seven contrasting accessions (two commercial cultivars – Crimson Sweet and Charleston Gray; one introduction – New Hampshire Midget; and four accessions from local populations – CPATSA 91-043, CPATSA 91-028, CPATSA 87-019 and CPATSA 91-071) were intercrossed in a complete diallel scheme including reciprocals. The parents and 21  $F_1$  hybrids and their reciprocals were evaluated in a field experiment, using a randomized complete block design with four replications. The characters evaluated were: number of days from transplanting to appearance of the first female flower (DFF); number of fruits per plant (NFP); fruit weight (FW); total soluble solids (TSS) and number of seeds per fruit (SN). All data were recorded at plant basis and averaged per plot (row of six plants). The Griffing (1956a, 1956b) analysis was performed using the fixed model. The analysis included parents,  $F_1$ 's and their reciprocals. Parent means indicate that they are contrasting genotypes in most of the characters analyzed, especially for prolificacy and sugar content.

These contrasting genotypes can be used in a watermelon breeding program with different objectives. For example, the CPATSA 87-019 and the CPATSA 91-043 genotypes can be used to increase prolificacy, which, in turn, if managed with fruit weight and plant density, can be used to obtain watermelon lines of high productivity in fruit yield. On the other hand, flesh color and sugar content from the accessions presented low values. However, commercial cultivars can be used to improve these characters.

Studies have shown that the additive variances were prevalent in the parents analyzed rather than the non-additive variances. It was also found significant genetic correlation among the characters analyzed although allowing selection of relevant characters to the watermelon breeding (Ferreira, 1996). Therefore, crosses between selected pair of parents followed by selfing and appropriate backcrossing can be used to obtain watermelon lines for synthesis of superior watermelon hybrids.

In the process of hybrid development, selfing for

several generations needs to be performed. Despite the cucurbitaceous family being reported as not affected by selfing (Allard, 1960) the behavior of a segregating population between a cross of CPATSA 87-019 with Crimson Sweet was examined and found that some progenies suffered inbreeding depression while other progenies were much less affected (Ferreira, 2000). The segregating population of the same cross was also used to estimate the natural outcrossing rate, which was 76,5%. This indicates that the population practices a mixture of selfing and outcrossing for reproduction, with implications for breeding strategies such as recurrent selection, since the progress of selection will be a function of the additive variance, as well as, a function of the covariance between additive and dominance effects (Ferreira, 2000).

### III. Line development and evaluation

In order to develop watermelon hybrids, contrasting populations must be chosen. In this study they are broadly designated population A and B (Figure 1). For diploid hybrids, the two populations used to develop the lines must be diploids whereas for triploid hybrids the contrasting populations must be diploid and tetraploid. Diploid lines were derived from three basic progenies, L2, L7 and L9 (population A), and the others were derived from the commercial cultivars Perola, Sugar Baby and Charleston Gray (population B). The tetraploid lines were obtained from the population A after chromosome duplication and from introduction of the accession CT3. The lines were evaluated *per se* (general combining ability) and in hybrid combinations (specific combining ability).

To develop seedless watermelons, which are triploid hybrids, a set of tetraploid lines need to be produced to be crossed with diploid lines as source of pollen (Mohr, 1986). The first step is to produce tetraploid plants, which, in turn, require duplication of the chromosome number of the selected diploid genotypes and, then, identification of the tetraploid plants among the progeny of the treated seed lot.

Two powdery mildew resistant lines (L7 and L9) were selected and 100 seeds from each were treated with a 0.2% colchicine solution for 24

hours in a *Petri* dish, in the dark. The seeds were planted in plastic bags in a greenhouse. The available plants from the two lines (eleven from L7 and three from L9) were submitted to progeny testing in order to identify tetraploid plants. The leaf chloroplast number in guard cells were recorded as well as morphological characters (leaf width and length in cm; leaf width/leaf length ratio; leaf petiole and vine diameter in mm; internode length in cm; and seed number per fruit). Three plants from L7 (L7-10, L7-27 and L7-28) and two plants from L9 (L9-20 and L9-24) were tetraploids identified by the low seed number per fruit compared with the diploid lines.

Later, a new powdery mildew resistant line, L2, was submitted to the same process of polyploidization. From then on, the watermelon breeding program had three tetraploid progenies in order to develop tetraploid lines.

For diploid hybrids, one set of lines was derived from three basic progenies L2, L7 and L9 and another was derived from the commercial cultivars Perola, Sugar Baby and Charleston Gray (Figure 1).

#### **A. Selection of diploid lines from population A**

Twelve partially inbred lines derived from powdery mildew resistant diploid lines with different degrees of prolificacy and fruit size were planted at the Embrapa Experimental Station of Bebedouro at Petrolina-PE in the year 2000, using furrow irrigation. 104 selfed lines were obtained (Table 1). The yield per plant ranged from 6.6 to 34 kilograms and the sugar content was between 10 and 13° Brix. Several plants produced two fruits and the plants set female flowers for one week, 33 days after transplanting, when artificial pollinations were performed. A sample of 31 selfed lines was selected in order to increase line homozygosity. The experiment was carried out in the same Experimental Station and the selfed lines presented a percentage of prolific plants of 20% (standard deviation = 15,8%) which indicated that the set of lines is different for this character.

Sugar content was above 10°Brix and fruit weight ranged from five to fourteen kilograms. The lines set fruits between the 33<sup>th</sup> and the 41<sup>th</sup> days after transplantation, and the artificial pollination continued for one week (around five days for several sets of lines) after female flowering (Table 1). The selection was primarily for plants that set fruit in the first pollination, or at least, for plants that set fruits in the first five days of female flowering, since this character can be relevant for commercial hybrid seed production through artificial pollination.

The commercial cultivars Perola, Sugar Baby and Charleston Gray present good fruit quality (sugar content above 10 °Brix and red flesh) but high susceptibility to powdery mildew and other watermelon diseases. Some selfed lines (population B) from these commercial varieties were obtained from seed samples from the Watermelon Germplasm Bank. These lines when crossed with powdery mildew resistant lines (population A) can produce powdery mildew resistant hybrid combinations.

#### **B. Selection of tetraploid lines from Charleston Tetra # 3**

The CT3 accession was first multiplied. Seeds were selfed and a very low fruit setting was observed. This accession is susceptible to powdery mildew, but, has sugar content above 10°Brix; red flesh; rind uniformity around the fruit; early flowering and medium vines for plant density, whenever necessary. In 2001, eleven selfed progenies were planted at the Embrapa Experimental Station of Bebedouro at Petrolina-PE. Fruit setting percentage for the CT3 population was 21%. However, 21 plants set fruits at the first artificial pollination and 33 when pollination took place during the five days of female flowering. 61% of the selfed lines had more than 100 seeds per fruit, which is a satisfactory performance, suggesting that the population has improved its ability to set fruits and seeds when artificially pollinated.

Despite the favorable results with the selection of tetraploid lines from CT3, which, in turn, can produce a reasonable and diversified number of triploid hybrids when crossed with diploid lines

**Table 1** - Range of characters for twelve sets of partially inbred lines of watermelon derived from L2, L7 and L9. Embrapa Experimental Station, Petrolina-PE. 2000.

| Set of lines and the number of selfed lines for each set | Range                |                  |             |                              |                                  |
|--|----------------------|------------------|-------------|------------------------------|----------------------------------|
|  | Yield per plant (kg) | Earliness (days) | Prolificacy | Total soluble solids (°Brix) | Number of days under pollination |
| Set # 1 (10)   | 10.3 a 27.6          | 38 a 42          | 1 a 2       | 10 a 12.8                    | 1 a 9                            |
| Set # 2 (11)   | 11.5 a 28.2          | 33 a 40          | 1 a 2       | 11 a 12.6                    | 1 a 4                            |
| Set # 3 (12)   | 7.0 a 24.7           | 33 a 41          | 1 a 2       | 10 a 12                      | 1 a 7                            |
| Set # 4 (5)  | 11.0 a 24.8          | 35 a 40          | 1 a 2       | 10 a 12.8                    | 1 a 6                            |
| Set # 5 (8)  | 11.0 a 34.6          | 34 a 40          | 1 a 3       | 10.4 a 12                    | 1 a 7                            |
| Set # 6 (3)  | 6.6 a 27.7           | 34 a 39          | 1 a 2       | 11.0 a 11.2                  | 1 a 6                            |
| Set # 7 (14)   | 9.3 a 27.2           | 33 a 41          | 1 a 2       | 10.8 a 12.6                  | 1 a 7                            |
| Set # 8 (10)   | 6.7 a 16.6           | 34 a 40          | 1           | 10.4 a 13.5                  | 1 a 6                            |
| Set # 9 (16)   | 8.5 a 32.1           | 33 a 39          | 1 a 3       | 10.0 a 12.4                  | 1 a 5                            |
| Set # 10 (7)   | 9.4 a 25.9           | 34 a 41          | 1 a 2       | 10.2 a 12.2                  | 1 a 5                            |
| Set # 11 (3)   | 15.6 a 24.9          | 34 a 41          | 1 a 2       | 11 a 13                      | 1 a 5                            |
| Set # 12 (5)   | 7.3 a 32.5           | 39 a 41          | 1 a 4       | 10 a 11                      | 2 a 5                            |

selected from L2, L7 and L9, it was necessary to broaden the genetic basis of the tetraploid lines in the program of watermelon breeding to give more flexibility to the fruit and plant characters for prospective triploid hybrids. As mentioned previously, triploid hybrids need to fit both the farmers' preference, particularly in regards to good seeds of lower cost, and the consumers' preference, who tend to choose smaller fruits of good uniformity and quality.

### C. Selection of tetraploid lines from population A

As described previously, a set of tetraploid lines were obtained by using colchicine in some sets of watermelon advanced lines (L2, L7 and L9). However, the duplication of the chromosomes in the lines had correlated response to some characters relevant to the breeding program such as prolificacy, less number of seeds per fruit, seed germination and fruit setting. They were later compared with the diploid version, but yield per plant and sugar content were similar to the diploid phase. Therefore, among the characters to be improved in the tetraploid lines, fruit setting, earliness and seed germination were primarily focused. Considering that the range for most of the characters in the available lines was narrow, a sample of the tetraploid lines was crossed with lines of the CT3 population which is much earlier and presents reasonable fruit setting when compared with the tetraploid lines from L2, L7 and L9. Two generations of selfing and selection were carried out during the year 2000 and early

2001.

The percentage of good seedlings ranged from 0 to 55% in the original set of tetraploid lines and from 17 to 96% in the latest generation of selfing, showing an improvement in this character. Diploid lines are normally selfed from the 33<sup>rd</sup> to 38<sup>th</sup> days after transplanting whereas the original set of tetraploid lines was selfed during two or more weeks, from the 38<sup>th</sup> to 56<sup>th</sup> days after transplanting. The last set of selected lines was selfed 39<sup>th</sup> to 44<sup>th</sup> days after transplanting with some progress for earliness. Fruit setting in the original set of tetraploid lines (L7 and L9) was 3 and 6% and produced 41 to 50 seeds per fruit (Souza, 2000). After two selection cycles among 100 selfed lines, more than 50% had 100 seeds per fruit while some of them produced more than 200 seeds per fruit.

Lines, however, need to be selected for specific combining ability during their development process. This can be done, by extending the concept used in prolific maize as recommended by Hallauer (1967) to watermelon hybrid development.

The diversification of triploid hybrids can be accomplished by using different diploid populations. For instance, in the Watermelon Germplasm Bank, there are accessions with good fruit characteristics and different fruit sizes, such as Sugar Baby, Perola, Charleston Gray and other types of smaller fruits. They can all be used to derive lines to be paired with the tetraploid lines from L2, L7 and L9, in order to produce

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triploid hybrids resistant to powdery mildew and different fruit patterns.

#### **D. Evaluation of lines for specific combining ability**

The specific combining ability of the lines selected from the A and B populations was estimated in an experiment in which 36 powdery mildew resistant watermelon selfed lines from the latest selfing generation were planted along with diploid lines from Perola and Charleston Gray, and CT3 tetraploid lines under drip irrigation at the Embrapa's Bebedouro Experimental Station at Petrolina-PE, in the year 2001. A selected pair of plants, one from the powdery mildew resistant lines and other from the commercial cultivar Perola was crossed and the two plants were selfed. Seventeen combinations were obtained. The same procedure was done with the commercial cultivar Charleston Gray and CT3 and a set of seven combinations was performed for the former and eleven for the latter. The hybrid combinations plus three checks were tested in a field experiment, in plots of eight plants in a row at the same Experimental Station, under drip irrigation. The following characters were evaluated: average fruit weight (FW); total soluble solids (TSS); fruit length (FL) and diameter (FD); fruit length/fruit diameter ratio; hollow heart - HH (scale of scores: 0 – without hollow heart; 1 – light flesh breaking; 2 – deep flesh breaking); seed number per fruit (SN)/fruit weight (FW) ratio. Yield per plant was obtained from each plot's total fruit production averaged by the total number of fruits per plot. Weights are expressed in kilograms; length and diameter in cm; and, sugar content in °Brix degrees.

Sugar content in all hybrid combinations was above twelve °Brix, except in some combinations such as 1, 10 and 14 with Perola and 21 and 22 with Charleston Gray, that had 11.4 to 11.9 °Brix (Table 2), showing that the lines were very well selected for this character.

Yield per plant ranged from 8 to 15 kg, showing a clear effect of the combination of different lines. Lines from combinations 7 and 9 showed good specific combining ability for this character. A potential production above 50 t/ha per hectare,

almost double the potential of the available commercial cultivar in the São Francisco valley is estimated. A second level of plant yield is 13 kg, which had good yield potential as well. Several hybrid combinations present this yield level. The lines involved in these hybrid combinations need to be exploited in the next cycle of selection, synthesizing as many hybrid combinations as possible in order to select the best pair of lines to produce the desirable hybrids. However, other characters need to be considered in the final selection of the lines.

The hollow heart was present in almost all hybrid combinations in which L9 was a parent in the diploid combinations. The triploid hybrids had hollow heart, first because the triploid hybrids are prone to hollow heart, and second, because the parent CT3 may tend to induce this problem. However, the number of hybrid combinations with CT3 was very low. Thus, a large number of crosses between CT3 and the diploid lines from population A are necessary in order to analyze the hollow heart problem in triploid hybrids. The tetraploid line L9 showed a general combining ability effect to increase hollow heart in triploid hybrids, but the same line had different specific combining ability effect when crossed with different parents since one combination presented a negative effect for hollow heart, i. e., it reduced the hollow heart in hybrid combinations (Souza, 2000). Therefore, there is an indication that this character present genetic variation among the lines under selection which needs to be focussed in future selections.

Fruit weight ranged from 6.5 to almost 13 kg, which means that if plant density is adjusted, particularly in the triploid hybrids, there is a range of powdery mildew resistant fruit patterns that can be recommended for the large fruit market and also for supermarket chains. However, the triploid hybrids had smaller fruits, probably due the small fruit size of the CT3 parent. These hybrids had less vigor and can be used with higher plant density to increase yield per hectare as well as decrease fruit size to adjust to supermarket demand. Parents of the hybrid 27 need to be analyzed in more detail for yield potential despite the presence of some hollow heart.



**Table 2** - Performance of diploid and triploid hybrid combinations and commercial watermelon cultivars, for different traits<sup>1/</sup>. Embrapa Experimental Station, Petrolina-PE. 2001.

| Parent identification  | Plant yield (kg) | Fruit weight (kg) | TSS (°Brix) | SN/FW | FL/FD | HH  |
|------------------------|------------------|-------------------|-------------|-------|-------|-----|
| 1, L7, P <sup>2/</sup> | 13.2             | 10.9              | 11.9        | 53    | 1.05  | 0   |
| 2, L7, P               | 11.9             | 11.2              | 12.3        | 64    | 1.09  | 0   |
| 3, L7, P               | 11.7             | 12.8              | 12.1        | 66    | 1.21  | 0   |
| 4, L7, P               | 10.3             | 10.6              | 12.3        | 70    | 1.09  | 0   |
| 5, L7, P               | 10.3             | 12.0              | 12.2        | 61    | 1.10  | 0   |
| 6, L2, P               | 10.1             | 12.1              | 12.5        | 57    | 1.07  | 0   |
| 7, L2, P               | 15.7             | 12.6              | 12.6        | 60    | 1.08  | 0   |
| 8, L2, P               | 10.2             | 9.1               | 12.0        | 63    | 1.07  | 0   |
| 9, L9, P               | 15.1             | 10.1              | 12.1        | 70    | 1.08  | 1   |
| 10, L9, P              | 12.0             | 9.0               | 11.8        | 76    | 1.08  | 1   |
| 12, L9, P              | 11.9             | 10.0              | 12.2        | 63    | 1.09  | 1   |
| 13, L9, P              | 10.7             | 10.6              | 12.4        | 81    | 1.03  | 1   |
| 14, L9, P              | 9.6              | 10.4              | 11.8        | 64    | 1.07  | 2   |
| 15, L9, P              | 12.5             | 9.8               | 12.3        | 68    | 1.08  | 1   |
| 16, L7, P              | 11.2             | 11.4              | 12.3        | 59    | 1.08  | 0   |
| 17, L7, P              | 8.8              | 9.8               | 12.7        | 62    | 1.07  | 0   |
| 18, L2, CG             | 13.6             | 12.1              | 12.1        | 63    | 1.50  | 0   |
| 19, L2, CG             | 10.1             | 10.9              | 12.2        | 57    | 1.51  | 1   |
| 20, L2, CG             | 11.3             | 11.8              | 12.0        | 68    | 1.44  | 0   |
| 21, L2, CG             | 11.7             | 9.7               | 11.7        | 87    | 1.39  | 0   |
| 22, L9, CG             | 10.8             | 9.3               | 11.4        | 80    | 1.48  | 1   |
| 23, L9, CG             | 11.5             | 9.7               | 12.0        | 83    | 1.50  | 1   |
| 24, L7, CG             | 11.8             | 12.3              | 12.0        | 75    | 1.55  | 0   |
| 25, L7, CT3            | 9.6              | 6.7               | 12.3        | 0,8   | 1.05  | 1   |
| 26, L7, CT3            | 11.1             | 6.5               | 12.5        | 1,2   | 1.02  | 1   |
| 27, L7, CT3            | 13.1             | 8.1               | 12.8        | 2,2   | 1.01  | 1   |
| 28, L7, CT3            | 13.3             | 8.4               | 12.6        | 1,9   | 1.02  | 1   |
| 29, L7, CT3            | 9.6              | 8.1               | 12.6        | 3,6   | 1.03  | 1   |
| 30, L2, CT3            | 8.0              | 7.3               | 12.3        | 1,7   | 1.01  | 1   |
| 31, L2, CT3            | 11.5             | 7.8               | 12.7        | 3,0   | 1.00  | 2   |
| 32, L2, CT3            | 10.0             | 6.9               | 12.6        | 2,0   | 1.00  | 1   |
| 33, L2, CT3            | 9.7              | 7.7               | 12.5        | 2,0   | 1.00  | 1   |
| 34, L9, CT3            | 10.3             | 7.8               | 12.0        | 1,0   | 1.03  | 1   |
| 35, L9, CT3            | 10.6             | 7.1               | 12.8        | 8,0   | 1.02  | 1   |
| Crimson Sweet          | 8.9              | 10.7              | 12.1        | 68    | 1.15  | 1   |
| Pérola                 | 8.7              | 9.0               | 10.8        | 72    | 1.09  | 0   |
| Charleston Gray        | 8.7              | 10.8              | 10.9        | 68    | 2.11  | 0   |
| Mean                   | 11.1             | 9.8               | 12.2        | 48    | 1.17  | 0,6 |
| Standard deviation     | 1.74             | 1.81              | 0.5         | 31    | 0.23  | 0,6 |

<sup>1/</sup> PY – plant yield, fruit weight – FW; total soluble solids – TSS; seed number (SN)/fruit weight (FW) ratio; fruit length (FL)/fruit diameter (FD) ratio and hollow heart – HH;

<sup>2/</sup> P – L7, L2 and L9 – diploid lines; P – diploid line from Perola; CG – diploid line from Charleston Gray; CT3 – tetraploid line from Charleston Tetra Number 3 and the number of the respective hybrid combination.

As for seed index, triploid hybrids presented a very low number of seeds per kilogram of fruit and can be commercialized as such. In fact, several fruits were either completely seedless or had less than ten seeds per fruit. Moreover, if late harvesting can present seedless fruits, early female flowering may be removed in order to

either reduce or prevent the problem.

Perola and CT3 hybrids had a round shape (fruit length/fruit diameter around 1,0) and blocky shape in its hybrids with Charleston Gray.

#### **EXPERIMENTAL HYBRIDS**

The watermelon breeding program at the Embrapa Semi-Arido Research Center has several diploid and tetraploid lines which were extensively evaluated for general combining ability, under irrigation, in the São Francisco valley. Some diploid lines resistant to powdery mildew, especially those originated from L2 and L7 crossed with specific diploid lines from Perola and Charleston Gray, can produce good diploid hybrids with large round and blocky fruits ready for the watermelon market. Diploid lines from Sugar Baby or other small-fruited accessions from the Germplasm Bank can be used to synthesize hybrids with small fruits.

Triploid experimental hybrids (seedless fruits) can be produced by crossing specific diploid lines resistant to powdery mildew with tetraploid lines from CT3. The fruits are round shaped, smaller and the plants (powdery mildew resistant) can be managed at higher plant densities in order to allow greater percentage of fruits for supermarket chains and the external market. Experimental hybrids will be available next year.

## NEW BREEDING TOOLS

Considering the availability of several accessions of different genetic backgrounds in the Watermelon Germplasm Bank, it will be necessary to use molecular data to establish a core collection with identified morphological traits and major disease resistance genes relevant to watermelon breeding (Brown, 1989). RAPD markers have been used in watermelon (Ferreira, 2000; Levi et al., 2000). A watermelon core collection can be stored for long term conservation as well as for future breeding programs.

Another research action uses molecular markers to help the selection of watermelon lines resistant to *Didymella bryoniae* and to the three major viruses, namely PRSV-w, WMV-2 and ZYMV. Therefore, different set of lines, resistant to different biotic stresses will be developed which can be used to identify molecular markers associated to watermelon diseases by bulk segregant analysis (Michelmore et al., 1991). This method has been successfully used to identify ZYMV resistant melon plants (Danin-Poleg et al., 2000).

Finally, the reciprocal recurrent selection exhaustively used in maize breeding (Hallauer and Miranda Filho, 1982) needs to be adjusted to

be used in the watermelon breeding program. Plants from contrasting populations (A – tetraploid and B - diploid) are planted in the same field. During the pollination period, each plant from the two populations are selfed, keeping an accurate identification of the plants. After the fruit setting of selfings, crosses are performed. Pollen from diploid plants is transported to the stigma of tetraploid plants that need to be prolific. From practical experience, the watermelon prolific plants, after one fruit set by selfing can quite easily set another fruit by crossing, thus the method can be applied to the watermelon breeding. The remnant selfed seed is stored in a cold chamber while the crosses are evaluated in the field, in replicated trials. From the performance of their crosses in the field, tetraploid lines are selected to continue the selection. The process continues until a desirable degree of homozygosity is reached. Using irrigation, one cycle can be completed in one year.

Watermelon crop in Brazil is expected to attract future breeders able to combine classical plant breeding with molecular tools in order to produce well adapted watermelon hybrids (ecologically and economically) for the internal and external markets thus improving the Brazilian watermelon agricultural business.

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## RESUMO

**Recursos genéticos e melhoramento genético da melância na Embrapa Semi-Arid**  
Os recursos genéticos e melhoramento genético

da melancia na Embrapa semi-árido usados para estabelecer o programa de melhoramento de melancia na Embrapa Semi-Árido foram descritos, bem como, o programa de melhoramento com seus objetivos, metodologias e alguns resultados. Também foi mostrada a estratégia de manejo dos recursos genéticos no Banco de Germoplasma de melancia e no programa de melhoramento. A seleção para resistência a doenças, características de planta e fruto foram descritas e alguns resultados relevantes foram apresentados. Algumas combinações híbridas diplóides e triplóides foram obtidas e avaliadas. Algumas delas apresentaram boas perspectivas para serem usadas como híbridos experimentais a serem testados em áreas de produtores. Novas metodologias de melhoramento para produzir novas gerações de híbridos de melancia resistentes a doenças e bem adaptados tanto para o mercado interno como para o mercado externo foram discutidas.

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