

INHERITANCE AND NATURE OF RESISTANCE TO FUSARIUM WILT IN WATERMELON

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ABSTRACT

Two crosses were made between different watermelon cultivars, i.e. Charleston Gray X Baby Sugar and Crimson Sweet X Baby Sugar as well as there reciprocal crosses, in order to study the inheritance and nature of resistance to fusarium wilt disease. The F_1 hybrid showed high resistance to the disease. The ratios of resistant to susceptible plants in the F_2 and BC_1 populations (backcross to the susceptible parent) were 3 : 1 and 1: 1, respectively. The earliness and total yield/plant were inherited quantitatively. The nature of dominance for earliness and total yield/plant ranged from partial to over dominance in both crosses. The estimates of broad sense heritability for earliness and total yield/ plant ranged from intermediate to above intermediate, while those of the narrow sense heritability ranged from low to intermediate. With regard to number of gene pairs differentiating the two parental cultivars for earliness ranged from 1 to 3 and for total yield/plant from 1 to 5 pairs. Plant reaction to fusarium wilt disease were negatively correlated with each of earliness, fruit length, diameter and weight and total yield/plant. Moreover, there were highly significant positive correlations between plant reaction to fusarium wilt disease and each of reducing, non-reducing and total sugars. Also, negative correlation with each of total, free and congested phenols in the cross Crimson Sweet X Sugar Baby was found. The combined effect of plant disease reaction, number of branches/plant, fruit set percentage and fruit length, diameter and weight on total yield/plant was highly significant.

INTRODUCTION

Fusarium wilt disease of watermelon caused by *Fusarium oxysporum* f. sp. *niveum* (E. F. Sm.) Snyder & Hans., is one of the most serious production problems confronting watermelon growers throughout the world. Once a field is infested, the fusarium wilt pathogen may survive for many years and seriously limit watermelon production in those fields. Resistant varieties and long rotation are the only control methods now used by watermelon growers. Genetic resistance has consistently proven to be the most effective and efficient means of control (ELmstrom and Hopkins, 1981; Hopkins and ELmstrom, 1984).

ELmstrom and Hopkins (1981); Martyn and Netzer (1991); Zhang et al (1995); Zhou and Zhou (1995); Gu et al (1996); Fenny et al (1998); Young et al (1998); Xiao et al (1999); Yucel et al (1999); Xiao et al (2000); Hawkins et al (2001); Zhang et al (2002 a); Zhang et al (2002 b); Swiader et al. (2002); Michail et al. (2003) and Zhou and Everts (2003) mentioned that highly genetic differences were observed between the different *Citrullus lenatus* genotypes concerning resistance to fusarium wilt disease.

Xiao *et al* (2000) made intergeneric crosses between lines D3-1 and D3-2 of bottle gourd (*Lagenaria siceraria*) which are highly resistant to wilt disease of watermelon caused by *Fusarium oxysporum* and watermelon cultivar Sugar Baby which is susceptible. The F₁ hybrid showed high resistance to the disease. The ratios of resistance to susceptibility the Bc₁ (backcross to the susceptible parent-Sugar Baby) and the F₂ populations were 1: 1 and 3:1, respectively.

Yu *et al* (1995) showed that the inheritance of resistance fitted the additive-dominance model, whereas the additive effect was major and the susceptibility was partially dominant. On the other hand, Xiao *et al* (2000) mentioned that resistance to fusarium wilt was dominant and simply inherited which was controlled by a mono-gene or mono-segment DNA. Chemical constituents of watermelon plants, *i.e.*, total phenols and sugars (reducing, non-reducing and total) varies between resistant and susceptible plants concerning on powdery mildew of melon (Merghany, 1989); fusarium wilt and downy mildew of cucumber (Abd El Hafez *et al.*, 1990; Fang *et al.*, 1994). In addition Abd El Hafez *et al.* (1990) found a negative strong correlation between the degree of susceptibility and total phenols and strong positive correlation between the degree of infection and soluble and non-soluble sugars in their study on the inheritance of downy mildew resistance in cucumber. Badr and Mohamed (1998) found that, leaves of resistant male parent of cucumber contained higher phenols and lower sugars contents than any of the susceptible female parents. The objectives of this research were to study the inheritance of resistance to fusarium wilt disease in watermelon plants and reveal the nature of resistance. Such information is important when designing a breeding program for developing new watermelon cultivars that are resistant to fusarium wilt disease.

MATERIAL AND METHODS

This research was conducted in the experimental field and greenhouse of the Department of Horticulture, College of Agriculture-Moshtohor, Zagazig University, Benha Branch, during the summer seasons of 2000, 2001 and 2002.

Individual plants of cultivars Crimson Sweet, Sugar Baby and Charleston Gray, which belong to *Citrullus lanatus*, were selfed for two generations during summer seasons before starting this research. Watermelon cultivars Charleston Gray and Crimson Sweet are known to be resistant to the fusarium wilt disease, while, Sugar Baby is known to be susceptible (ELmstrom and Hopkins, 1981). Seeds of these cultivars were obtained from the germplasm preservation laboratory, Faculty of Agriculture-Moshtohor, Department of Horticulture, Moshtohor, Kalubia, Egypt. The following crosses were made between the different parental germplasm in the summer season of 2000: Crimson Sweet X Sugar Baby, Charleston Gray X Sugar Baby, Sugar Baby X Crimson Sweet and Sugar Baby X Charleston Gray.

Seeds of the parental genotypes and F_1 's were planted on March 25, 2001 in the field. Plants of the F_1 populations were selfed to obtain F_2 seeds and the crosses between the different parental genotypes were repeated, as the previous year, to obtain enough seeds for the different F_1 populations. In addition, the backcross populations i.e., Bc_1 and Bc_2 , were obtained by crossing plants of each F_1 hybrid with its respective parents. Seeds of the parental genotypes, F_1 , F_2 and backcrosses were kept until the next season to evaluate the different populations in the field.

Seeds of the different populations of each cross were planted in the field on March 28, 2002, for evaluating the plants of each population individually. The experimental design used was randomized complete block design with three replications. Each replicate contained one ridge for each of the parental genotypes and their F_1 plants, four ridges for F_2 plants and two ridges for plants of each backcross populations. Seeds were sown in hills on one side of each ridge of four-meter length and 2.0 meters wide, with two seeds per hill at 40 cm apart. All other agriculture practices, i.e., irrigation, fertilization, weed control, ...etc., were followed as in the district.

Wilt disease studies:

Samples of naturally infected of plants collected from the Exp. Farm, Fac. Agric., Moshtohor, Zagazig Univ., were used for isolation. Infected plants were surface sterilized with 5% sodium hypochloride solution for 2 minutes, re-washed several time in sterilized distilled water, and then dried between sterilized filter papers. Small portions of infected tissues were cut, plated on potato dextrose agar medium (PDA) and incubated at 25 °C for 3-5 days. The resultant fungus was isolated and purified using the hyphal tip and/or the single spore methods (Hawker, 1950). The obtained fungus was identified as *Fusarium oxysporum* according to Barnett & Hunter (1972) and confirmed by Fungal Taxonomy Dept., Plant Pathology Institute, ARC, Egypt. The pathogenicity of the obtained fungus was verified on number of inbred lines, i.e., (susceptible to fusarium wilt disease) and plants under greenhouse conditions.

Greenhouse experiment:

Plastic pots (20 cm dim) each containing 3 Kg sterilized clay loamy soil (1 sand: 2 clay (w:w) were used in this study. The potted soil was infested at the rate of 3 % (w/w) by 2-weeks old cultures of *Fusarium oxysporum* grown for 2 weeks on corn meal-sand medium at 25°C (Riker and Riker 1936), thoroughly mixed, watered and left for two weeks under the greenhouse conditions. Untreated natural soil as well as un-infested sterilized soil were served as controls. Pots were planted with healthy surface sterilized watermelon seeds of an inbred lines using 3 seeds per pot. Three pots were used for each particular treatment.

Percentage of pre-emergence damping-off was calculated 15 days after sowing while % post-emergence damping-off and % healthy survived seedlings were also determined after 45 days.

Field experiment:

Watermelon germplasm were tested in field soil naturally infested with the watermelon fusarium wilt fungus.

Percentage of disease incidence was recorded five times starting 15 days from sowing periodically every 3 days and calculated as disease index. The final one was recorded in the results using a scale containing 6 grades suggested by Perry (1962) to illustrate the differences between the various grades of susceptibility:

Grade: 0 : Apparently healthy plants.

1 : Plants with net chlorosis of cotyledonary leaves.

2 : Plants with yellowing and browning of cotyledonary leaves.

3 : Plants with yellowing, browning and chlorosis of the first true leaf.

4 : Plants with dropping of cotyledonary leaves and yellowing in the first foliage leaves with slight brown colour.

5 : Plants with complete death of all leaves whether dropped or not and had the black colour.

The equation used for estimating disease incidence was as follows:

$$\text{Disease index} = \frac{(n_0 \times X_0 + (n_1 \times 1) \dots + (n_5 \times 5))}{n \times c} \times 100$$

Where:

n = No of plants in each grade.

c = number of grade as modified from Perry (1962).

The following characters affected by the degree of resistance to wilt disease were recorded for the individual plants of the different populations of each cross: Earliness of flowering, fruit set percentage, number of branches, fruit weight, total yield/plant and fruit length and diameter.

Total phenols present in plant leaves were estimated and presented as ml/100 gm fresh weight according to the method described by Snell and Snell (1953).

Total sugars content of leaves of individual plants was determined using the method described by Flood and Priestly (1973).

Genetic statistical analysis:

The frequency distribution for the different characters in the F₂ population of the different crosses was used to determine the mode of the inheritance according to the method suggested by Briggs and Knowles (1977).

Analysis of variance and calculations of the mean and its standard error, total variance and correlation coefficients were performed according to the methods described by Briggs and Knowles (1977). The chi-square test was applied to reveal the mode of inheritance of the qualitative characters according to the method described by Strickberger (1976).

The nature of dominance for the studied quantitative characteristics was determined by the value of the potence ratio of gene set (P) calculated by the formula reported by Smith (1952)

$$\text{Potence ratio (P)} = \frac{F_1 - M.P.}{1/2(P_2 - P_1)}$$

Where:

F₁ = F₁mean., M. P. = Mid-parent mean., P₁ = the smaller parent mean. And P₂ = the larger parent mean.

The following formula suggested by Allard (1960) was used to

calculate the broad sense heritability (BSH) estimate for the different quantitative characters.

$$BSH = \frac{VF_2 - (VF_1 + VP_1 + VP_2) / 3}{VF_2} \times 100$$

Narrow sense heritability (NSH) was estimated using the formula described by Mather and Jinkes (1971):

$$NSH = \frac{2VF_2 - (VBc_1 + VBc_2)}{VF_2} \times 100$$

Whereas:

VF1 = variance of the first generation, VF2 = variance of the second generation, VP1 = variance of the first parent, VP2 = variance of the second parent, VBc1 = variance of the first backcross and VBc2 = variance of the second backcross.

The minimum number of gene pairs differentiating the two parents was estimated using the following method given by Castle and Wright (1921):

$$N = \frac{N}{8(VF_2 - VF_1)} D^2$$

Where:

N = minimum number of gene pairs by which the parental differ, D = Mean of larger parent - Mean of smaller parent, VF₂ = variance of F₂ population and VF₁ = variance of F₁ population.

RESULTS AND DISCUSSION

Greenhouse experiment:

The parental cultivars Charleston Gray and Crimson Sweet were highly resistant to fusarium wilt disease, While Sugar Baby showed high susceptibility (Table, 1).

Table (1): Mean values of wilt disease index, estimates for some watermelon crosses under greenhouse and field conditions.

Cross	Population	Wilt disease index %		T. Test
		Green-house	Field	
Charleston Gray X Sugar Baby	P ₁	8.30	4.83	0.302
	P ₂	100.0	86.67	0.817
	F ₁	9.3	7.33	0.158
Sugar Baby X Charleston Gray	P ₁	100.0	86.67	0.817
	P ₂	8.30	4.83	0.302
	F ₁	10.67	9.50	0.049
Crimson Sweet X Sugar Baby	P ₁	11.0	6.50	0.305
	P ₂	100.0	86.67	0.817
	F ₁	13.7	10.83	0.223
Sugar Baby X Crimson Sweet	P ₁	100.0	86.67	0.817
	P ₂	11.0	6.50	0.305
	F ₁	15.3	15.00	0.028

The F₁ hybrids for all crosses were highly resistant. The differences between plant reaction means of each P₁, P₂ and F₁ of both crosses in the field and greenhouse experiments were not significant. This means that evaluation of different populations for fusarium wilt disease in the greenhouse is a dependable method for evaluation. These results indicate that this parental germplasm possess different gene for resistance to fusarium wilt disease. In this regard, Barnes (1972) in field and greenhouse studies determined that field and greenhouse resistance was categorized as follows: highly resistance, moderately resistance, slightly resistance and susceptible.

Field experient:

Fusarium wilt disease reaction:

Data presented in Table (2) show that, plants of Charleston Gray and Crimson Sweet were resistance to fusarium wilt disease, while plants of Sugar Baby were highly susceptible.

Table (2): Frequency distribution and segregation for plant reaction to Fusarium wilt in parents, F₁, F₂, BC₁, BC₂ generations in some watermelon crosses.

Generations	Frequency distribution and segregation for plant reaction (%)					Total No. of plants	R	S	Ratio	X ²
	20	40	60	80	100					
Charleston Gray (P ₁)	27	3	-	-	-	30	30	-		
Sugar Baby (P ₂)	-	-	-	-	30	30	-	30		
F ₁	28	2	-	-	-	30	30	-		
F ₂	34	19	17	14	36	120	84	36	3:1	1.6 n.s.
BC ₁ (F ₁ x P ₁)	47	13	-	-	-	60	60	-		
BC ₂ (F ₁ x P ₂)	21	8	-	-	31	60	29	31	1:1	0.06 n.s.
Sugar Baby (P ₁)	-	-	-	-	30	30	-	30		
Charleston Gray (P ₂)	27	3	-	-	-	30	30	-		
F ₁	26	3	1	-	-	30	30	-		
F ₂	35	24	13	19	29	120	91	29	3:1	0.04 n.s.
BC ₁ (F ₁ x P ₁)	17	14	3	-	26	60	34	26	1:1	1.06 n.s.
BC ₂ (F ₁ x P ₂)	55	5	-	-	-	60	60	-		
Crimson Sweet (P ₁)	24	6	-	-	-	30	30	-		
Sugar Baby (P ₂)	-	-	-	-	30	30	-	30		
F ₁	22	7	1	-	-	30	30	-		
F ₂	35	19	21	18	27	120	93	27	3:1	0.4 n.s.
BC ₁ (F ₁ x P ₁)	48	12	-	-	-	60	60	-		
BC ₂ (F ₁ x P ₂)	26	4	-	1	29	60	31	29	1:1	0.06 n.s.
Sugar Baby (P ₁)	-	-	-	-	30	30	-	30		
Crimson Sweet (P ₂)	24	6	-	-	-	30	30	-		
F ₁	27	3	-	-	-	30	30	-		
F ₂	68	10	3	5	34	120	86	34	3:1	0.71 n.s.
BC ₁ (F ₁ x P ₁)	14	13	8	-	25	60	35	25	1:1	1.66 n.s.
BC ₂ (F ₁ x P ₂)	52	8	-	-	-	60	60	-		

n.s.: not significant.

Differences among *Citrullus lanatus* germplasm concerning their resistance to fusarium wilt disease have been reported by El mstrom and Hopkins (1981); Martyn and Netzer (1991); Zhang *et al* (1995); Zhou and Zhou (1995); Gu *et al* (1996); Fenny *et al* (1998); Young *et al* (1998); Xiao *et al* (1999); Yucel *et al* (1999); Xiao *et al* (2000); Hawkins *et al* (2001); Zhang *et al.* (2002 a); Zhang *et al.* (2002 b); Swiader *et al.* (2002); Michail *et al.* (2003) and Zhou and Everts (2003). All F₁ plants were high resistant to the disease indicating the dominance of resistance plants. The results are in agreement with those obtained by Xiao *et al* (2000); Swiader *et al.* (2002) and Zhang *et al.* (2002 a) they found that F₁ hybrid had high resistance to the disease. F₂ populations segregated according to 3 resistant to 1 susceptible. When F₁ plants were backcrossed to the susceptible parent, the progeny segregated to the ratio of 1 resistant to 1 susceptible, while when backcrossed to resistant parent, the progeny exhibited resistance. These results showed that resistance to fusarium wilt disease was a kind of dominant inheritance controlled by a single gene pair. These results are in accordance with those reported by Xiao *et al* (2000) who found that the ratios of resistance to susceptibility of the Bc₁, which F₁ was backcrossed with the susceptible parent-Sugar Baby, and the F₂, populations were 1 : 1 and 3 : 1, respectively. Also, Yu *et al* (1995) showed that the inheritance of resistance confirmed the additive-dominance model. The additive effect was major and the susceptibility was partially dominant. Moreover, Xiao *et al* (2000) mentioned that resistance to fusarium wilt was a kind of dominant inheritance controlled by a mono-gene or mono-segment DNA.

Earliness of flowering:

Differences in earliness were detected among the parental watermelon cultivars (Table,3). The cultivar Baby Sugar had the highest number of days to the first flower anthesis (82.47 day), followed by cv. Charleston Gray (73.70 day) and cv. Crimson Sweet (54.30 day). The variability in number of days to the first flower anthesis observed among the different parental watermelon germplasm could be very useful in breeding programs for watermelon earliness.

The frequency distribution of the F₁, F₂, Bc₁ and Bc₂ plants shown in Table (3) indicated quantitative inheritance pattern for earliness in the crosses Charleston Gray X Baby Sugar, Baby Sugar X Charleston Gray, Crimson Sweet X Baby Sugar and Baby Sugar X Crimson Sweet.

Concerning nature of dominance, earliness showed partial dominance ($p=0.03$ and 0.75) in the crosses Charleston Gray X Baby Sugar and Crimson Sweet X Baby Sugar, respectively. Meanwhile, over dominance were detected in the crosses Sugar Baby X Charleston Gray and Sugar Baby X Crimson Sweet (Table, 4). The differences in these results may be due to that earliness was inherited quantitatively.

The broad sense heritability estimates were 60.86%, 69.09%, 63.37% and 73.91%. Meanwhile, the narrow sense heritability were 27.87%, 27.52%, 30.39% and 22.72% for the crosses Charleston Gray X Baby Sugar, Baby Sugar X Charleston Gray, Crimson Sweet X Baby Sugar and Baby Sugar X Crimson Sweet, respectively (Table, 4). Thus, selection would be non-effective in the four crosses with regard to this character.

Table (3): Frequency distribution for earliness in different population for some watermelon crosses.

Population	Upper class limits (days)										Total No. of plants	Mean \pm SE	Variance
	50	60	70	80	90	100	110	120					
Charleston Gray (P ₁)	-	-	11	7	12	-	-	-	-	-	30	73.70 \pm 1.73	142.99
Sugar Baby (P ₂)	-	-	-	8	23	-	-	-	-	-	30	82.47 \pm 1.73	32.04
F ₁	-	-	6	7	17	-	-	-	-	-	30	78.23 \pm 1.73	54.91
F ₂	1	8	4	20	47	28	10	2	-	-	120	85.51 \pm 0.86	110.67
BC1 (F ₁ x P ₁)	-	-	2	16	24	17	1	-	-	-	60	84.37 \pm 1.22	96.22
BC2 (F ₁ x P ₂)	-	-	-	15	22	15	8	-	-	-	60	86.97 \pm 1.22	94.28
LSD 0.05												13.36	
0.01												20.24	
Sugar Baby (P ₁)	-	-	-	8	23	-	-	-	-	-	30	82.47 \pm 1.55	32.04
Charleston Gray (P ₂)	-	-	11	7	12	-	-	-	-	-	30	73.70 \pm 1.55	142.99
F ₁	-	-	13	10	7	-	-	-	-	-	30	72.73 \pm 1.55	70.56
F ₂	-	-	3	30	60	24	1	2	-	-	120	83.64 \pm 0.78	157.00
BC1 (F ₁ x P ₁)	-	1	9	19	13	15	3	-	-	-	60	81.03 \pm 1.10	134.56
BC2 (F ₁ x P ₂)	-	-	1	28	26	5	-	-	-	-	60	80.17 \pm 1.10	136.24
LSD 0.05												9.01	
0.01												15.19	
Crimson Sweet (P ₁)	4	26	-	-	-	-	-	-	-	-	30	54.30 \pm 1.75	21.34
Sugar Baby (P ₂)	-	-	-	8	23	-	-	-	-	-	30	82.47 \pm 1.75	32.06
F ₁	-	-	6	8	16	-	-	-	-	-	30	79.00 \pm 1.75	102.21
F ₂	2	1	4	24	49	17	16	7	-	-	120	87.23 \pm 0.87	141.61
BC1 (F ₁ x P ₁)	-	-	8	6	20	22	4	-	-	-	60	86.13 \pm 1.23	120.56
BC2 (F ₁ x P ₂)	-	-	-	9	43	8	-	-	-	-	60	84.58 \pm 1.23	119.62
LSD 0.05												13.51	
0.01												20.47	
Sugar Baby (P ₁)	-	-	-	8	23	-	-	-	-	-	30	82.47 \pm 1.49	32.04
Crimson Sweet (P ₂)	4	26	-	-	-	-	-	-	-	-	30	54.30 \pm 1.49	21.34
F ₁	-	-	-	-	19	11	-	-	-	-	30	87.70 \pm 1.49	24.90
F ₂	5	4	25	42	31	9	3	1	-	-	120	76.13 \pm 0.75	100.0
BC1 (F ₁ x P ₁)	-	-	5	26	15	14	-	-	-	-	60	80.17 \pm 1.06	89.06
BC2 (F ₁ x P ₂)	-	-	5	24	23	8	-	-	-	-	60	79.60 \pm 1.06	88.2
LSD 0.05												11.56	
0.01												17.51	

With regard to number of the gene pairs differentiating the two parental cultivars for earliness was from 1 to 3 pairs of gene in all crosses under study (Table. 4).

Table (4): Potence ratio, broad (B.S.H.) and narrow sense heritability (N.S.H.) and minimum number of effective gene pairs estimates for the different watermelon crosses.

Characters Crosses	Earliness of flowering				Total yield/plant			
	P. ratio	B.S.H.	N.S.H.	No. of gene pairs	P. ratio	B.S.H.	N.S.H.	No. of gene pairs
Charleston Gray X Sugar Baby	0.03	60.86	27.87	1	1.92	65.73	29.37	1
Sugar Baby X Charleston Gray	-1.22	69.09	27.52	1	1.40	66.10	20.15	1
Crimson Sweet X Sugar Baby	0.75	63.37	30.39	3	2.40	51.87	11.44	2
Sugar Baby X Crimson Sweet	1.37	73.91	22.72	2	0.87	59.77	13.62	5

Total yield per plant:

The results presented in Table (5) show that the parental cultivar Charleston Gray had the highest total yield/plant (8731.67kg) followed by Crimson Sweet (8258.33 kg) and Baby Sugar (4688.33 kg). These results were agreement with those reported by Norton *et al* (1995) and Wang *et al* (1997) they found that there were highly differences between *Citrullus lanatus* cultivars for total yield.

The F1 plants of all crosses were higher than both parents for total yield/plant except in the cross Baby Sugar X Crimson Sweet, which was intermediate between both parents. The potence ratio (p) calculated in the crosses Charleston Gray X Baby Sugar, Baby Sugar X Charleston Gray and Crimson Sweet X Baby Sugar indicated over dominance for high yield/plant, Meanwhile partial dominance for high yield/plant in the cross Baby Sugar X Crimson Sweet (Table, 4).

Total yield/plant was found to be inherited quantitatively, Based on the frequency distribution of this character in the F₂, Bc₁ and Bc₂ populations of all crosses (Table, 5).

The broad sense heritability values for total yield/plant were 65.73%, 66.10%, 51.87% and 59.77%, while the narrow sense heritability values were 29.37%, 20.15%, 11.44% and 13.62% in the crosses Charleston Gray X Baby Sugar, Baby Sugar X Charleston Gray, Crimson Sweet X Baby Sugar and Baby Sugar X Crimson Sweet, respectively, (Table, 4). These results indicated that the environmental variation influenced total yield/plant more than the genetic variation. Based on these results, selection for high total yield/plant in the segregating generations should be performed in replicated experiments.

The number of effective gene pairs controlling total yield/plant ranged from 1 to 5 in all crosses under this study.

Table (5): Frequency distribution for total yield/plant in different populations for some watermelon crosses.

Population	Upper class limite (g)										Total No. of plants	Mean \pm SE	Variance	
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000				11000
Charleston Gray (P ₁)	-	-	-	-	-	4	6	3	6	3	3	5	8731.67 \pm 69	693018.9
Sugar Baby (P ₂)	-	-	-	2	6	19	5	-	-	-	-	-	4688.33 \pm 69	1190804.7
F ₁	-	-	3	2	3	1	4	3	-	1	2	11	10583.33 \pm 69	36863472.0
F ₂	-	2	11	16	11	16	15	12	17	11	8	1	6985.00 \pm 35	43752527.0
BC ₁ (F ₁ x P ₁)	-	-	1	6	9	5	8	9	4	3	6	9	7651.67 \pm 49	42087373.0
BC ₂ (F ₁ x P ₂)	-	1	3	6	1	3	7	8	9	5	5	12	7722.50 \pm 49	32569436.0
L.S.D. 0.05													5372.73	
0.01													8139.23	
Sugar Baby (P ₁)	-	-	-	6	19	5	-	-	-	-	-	-	4688.33 \pm 62	854903.7
Charleston Gray (P ₂)	-	-	-	-	-	4	6	3	6	3	3	5	8731.67 \pm 62	6930108.9
F ₁	-	-	4	-	1	4	1	4	2	2	4	8	9550.0 \pm 62	26126717.0
F ₂	-	3	20	24	12	11	7	16	4	6	17	12	6954.58 \pm 312	23508933.0
BC ₁ (F ₁ x P ₁)	-	1	3	3	15	1	6	3	1	16	4	7	7747.50 \pm 44	23819806.0
BC ₂ (F ₁ x P ₂)	-	-	4	6	13	12	6	4	5	4	1	5	6368.33 \pm 44	18461509.8
L.S.D. 0.05													4830.40	
0.01													7317.64	
Crimson Sweet (P ₁)	-	-	-	-	-	-	9	5	6	10	-	-	8258.33 \pm 63	6568302.6
Sugar Baby (P ₂)	-	-	-	6	19	5	-	-	-	-	-	-	4688.33 \pm 63	1190804.7
F ₁	-	-	-	-	-	1	1	3	5	5	15	-	10751.67 \pm 63	12438389.0
F ₂	-	1	8	2	16	17	12	7	8	30	11	8	8390.42 \pm 31	13988348.0
BC ₁ (F ₁ x P ₁)	-	2	2	8	4	5	9	7	5	6	6	6	7215.0 \pm 44	8254014.1
BC ₂ (F ₁ x P ₂)	-	-	3	3	8	-	11	1	-	13	2	19	9242.5 \pm 44	18122730.0
L.S.D. 0.05													4842.47	
0.01													7335.94	
Sugar Baby (P ₁)	-	-	-	6	19	5	-	-	-	-	-	-	4688.33 \pm 95	1190804.7
Crimson Sweet (P ₂)	-	-	-	-	-	-	9	5	6	10	-	-	8258.33 \pm 95	6568302.6
F ₁	-	-	-	1	9	3	-	2	3	4	1	7	2028.33 \pm 95	3521117.0
F ₂	-	6	9	20	7	8	15	14	6	25	6	5	8101.83 \pm 47	35606760.0
BC ₁ (F ₁ x P ₁)	-	6	7	8	5	1	3	4	2	2	6	16	8088.33 \pm 67	29002318.0
BC ₂ (F ₁ x P ₂)	-	-	1	3	2	2	4	1	2	3	3	39	13393.3 \pm 67	37361923.0
L.S.D. 0.05													7346.38	
0.01													11129.16	

Leaf chemical composition

It is clearly evident from Table (6) that there were highly significant differences between different populations, i.e., P₁, P₂, F₁, F₂, Bc₁ and Bc₂ in the cross Crimson X Sugar Baby for sugars (reducing, non-reducing and total) and phenols (free, conjugate and total) contents of the plant leaves. Leaves of the resistant cultivar Crimson Sweet contained higher phenolic (97.25, 1163.00 and 260.25 mg/100 g f.w.) for free, conjugate and total phenolic, respectively and lower sugars (91.99, 30.84 and 122.83 mg/100 g f.w.) for reducing, non-reducing and total sugars contents, respectively, than the susceptible cultivar Sugar Baby (Table, 6). Whereas, the amounts of both phenolic and sugars contents in leaves of the F₁ plants were intermediate between the two parents.

Sugars leaves content of Bc₂ plants (166.04, 25.29 and 194.21 mg/100 g F.W. for reducing, non-reducing and total sugars, respectively) were higher than that of the Bc₁ plants (107.96, 7.46 and 115.41 mg/100 g f.w. for reducing, non-reducing and total sugars, respectively). On the other hand, phenols leaves content of Bc₂ plants (63.25, 107.75 and 171.00 mg/100 g f.w. for free, conjugate and total phenolic, respectively) were lower than that of the Bc₁ plants (91.03, 145.98 and 237.01 mg/100 g f.w. for free, conjugate and total phenolic, respectively). The differences observed between Bc₁ and Bc₂ populations in the present study could be due to maternal effect. Such information is very useful in breeding programs to improve resistance to fusarium wilt in watermelon.

Biochemical defense in plant might occur through inhibitors present in plant cells or deficiency in nutrients essential for the pathogen. The relatively high sugars content of susceptible plants may serve as a rich source of food for fusarium wilt fungus resulting in higher level of susceptibility. The present results suggested that defense mechanisms of a chemical nature are responsible for the resistance to infection with fusarium wilt disease. These results agree with those obtained by Merghany (1989) on powdery mildew on melon; Abd El-Hafez *et al.* (1990) and Fang *et al.* (1994) on downy mildew in cucumber. Also, Badr and Mohamed (1998) found that, leaves of resistant male parent of cucumber contained higher phenols (free, conjugated and total phenols) and lower sugars (reducing, non-reducing and total sugars) contents than any of the susceptible female parents.

Table 6: Leaf chemical composition of parent, F₁, F₂ BC₁ and BC₂ populations derived from crosses Crimson sweet x Sugar Baby as affected by fusarium wilt disease.

Populations	Sugars (mg/100 g fresh weight)			Phenols (mg/100 g fresh weight)		
	Reducing	Non-reduce	Total	Free	Conjugated	Total
Crimson Sweet (P ₁)	91.99	30.84	122.83	97.25	163.00	260.25
Sugar Baby (P ₂)	268.55	23.07	291.61	39.35	78.24	117.59
F ₁	117.19	15.29	132.48	80.78	127.61	208.39
F ₂	114.62	15.05	131.87	88.38	199.24	287.62
BC ₁ (F ₁ x P ₁)	107.96	7.46	115.41	91.03	145.98	237.01
BC ₂ (F ₁ x P ₂)	166.04	25.29	194.21	63.25	107.75	171.00
L.S.D. at 0.01	60.53	10.42	68.03	27.43	59.22	80.84
0.05	91.70	15.78	103.06	41.56	89.72	122.46

Simple correlation:

Plant reaction to fusarium wilt disease was highly significant negative correlated with each of earliness, fruit length, diameter and weight and total yield/plant in all crosses under study (Table, 7). Moreover, there were highly significant positive correlations between plant reaction to fusarium wilt disease and each of reducing, non-reducing and total sugars, whereas, negative correlation with each of total, free and congested phenols in the cross Crimson Sweet X Baby Sugar. In this respect, Wang *et al* (2002) found that the resistant cultivars maintained relatively lower content of soluble sugar than the susceptible cultivars.

Significant positive correlation was observed between fruit weight and each of number of branches/plant. Moreover, highly significant positive correlations were found between fruit weight and each of earliness, fruit length and diameter and total yield/plant. In addition, there were highly significant positive correlations between fruit weight and each of total, free and congested phenols, whereas negative correlations with each of reducing, non-reducing and total sugars in the cross Crimson Sweet X Baby Sugar was recorded.

Total yield/plant was positively correlated with earliness, fruit length, diameter and weight in the crosses Charleston Gray X Baby Sugar, Baby Sugar X Charleston Gray, Crimson Sweet X Baby Sugar and Baby Sugar X Crimson Sweet. Meanwhile, there were highly significant positive correlations between total yield/plant and each of total, free and conjugated phenols. Moreover negative correlations with each of reducing, non-reducing and total sugars in the cross Crimson Sweet X Baby Sugar.

Multiple correlation:

The mutual effect of the different studied components of total yield/plant which measured by plant disease reaction, number of branches/plant, fruit set percentage and fruit length, diameter and weight was presented in Table (8). The results of the multiple regression analysis indicated significant linear relationship between the combined effect of plant disease reaction, number of branches/plant, fruit set percentage and fruit length, diameter and weight, and the total yield/plant in all studied crosses (Table, 8). The values of R squared (R^2) were 0.647, 0.509, 0.507 and 0.767 which indicates that 64.7%, 50.9%, 50.7% and 76.7% of the variation in total yield/plant observed in the F_2 plants of the crosses under study were related to a real linear relationship between total yield/plant and all characters mentioned above. This result indicated the importance of considering the previously mentioned characters when selecting for high total yield/plant.

Table (7): Coefficient of correlation values (r) of different characters for some watermelon crosses.

Crosses	Characters	1	2	3	4	5	6	7	8	9	10	11	12	13
Charleston Gray X Sugar Baby	2	-0.003												
	3	-0.311	-0.244											
	4	0.009	-0.346	0.384										
	5	-0.326	-0.082	0.320	0.144									
	6	-0.425	0.063	0.385	0.160	0.509								
	7	-0.474	0.210	0.308	0.078	0.531	0.900							
	8	-0.755	-0.016	0.299	0.052	0.218	0.565	0.587						
	9	0.122												
Sugar Baby X Charleston Gray	2	-0.262	-0.347											
	3	0.052	-0.284	0.162										
	4	0.293	0.230	-0.179	0.062									
	5	-0.274	-0.094	0.298	0.050	0.061								
	6	-0.283	0.195	-0.272	0.081	0.629	0.480							
	7	-0.381	0.159	0.293	0.199	0.269	0.216	0.388						
	8	0.130												
	9	-0.295	-0.350											
Crimson Sweet X Sugar Baby	2	0.051	-0.355	0.291										
	3	-0.243	-0.375	0.549	0.026									
	4	-0.224	-0.426	0.541	0.044	0.970								
	5	-0.373	0.227	0.678	0.033	0.927	0.917							
	6	-0.450	0.043	0.531	0.158	0.391	0.325	0.480						
	7	-0.940	-0.128	0.301	-0.066	0.174	0.145	0.307	0.381					
	8	-0.691	-0.081	0.179	-0.026	0.195	0.188	0.245	0.266	0.594				
	9	-0.913	-0.130	0.303	-0.065	0.160	0.131	0.300	0.385	0.982	0.454			
Sugar Baby X Crimson Sweet	2	0.951	0.113	-0.314	0.077	-0.257	-0.235	-0.372	-0.462	-0.913	-0.734	-0.877		
	3	0.453	0.043	-0.223	0.081	-0.370	-0.321	-0.379	-0.452	-0.288	-0.291	-0.295	0.490	
	4	0.906	0.103	-0.283	0.056	-0.250	-0.231	-0.351	-0.463	-0.855	-0.710	-0.820	0.959	0.495
	5	-0.244												
	6	-0.260	0.126											
	7	-0.036	-0.215	0.162										
	8	-0.378	0.245	0.357	0.077									
	9	-0.394	0.097	0.422	0.077	0.641								
Sugar Baby X Crimson Sweet	2	-0.440	0.232	0.435	0.007	0.791	0.701							
	3	-0.497	0.430	0.307	0.220	0.663	0.548	0.808						
	4													
	5													
	6													
	7													
	8													
	9													

Characters with the coefficient as follow:

- 1: wilt disease, 2: number of branches, 3: earliness, 4: fruit set percentage, 5: fruit length, 6: fruit diameter, 7: fruit weight, 8: yield/plant, 9: total phenol, 10: free phenol, 11: conjugated phenol, 12: reducing sugars, 13: non-reducing sugars and 14: total sugars.

Table (8): Multiple regression coefficients between total yield/plant and other characters in some watermelon crosses.

Crosses	Involved indepent variables	R-Square	Multiple R	Significance
Charleston Gray X Sugar Baby	Wilt disease			
	No. of branches			
	Fruit set percentage			
	Fruit length	0.647	0.805	**
	Fruit diameter			
	Fruit weight			
Sugar Baby X Charleston Gray	Wilt disease			
	No. of branches			
	Fruit set percentage			
	Fruit length	0.509	0.714	**
	Fruit diameter			
	Fruit weight			
Crimson Sweet X Sugar Baby	Wilt disease			
	No. of branches			
	Fruit set percentage			
	Fruit length	0.507	0.712	**
	Fruit diameter			
	Fruit weight			
Sugar Baby X Crimson Sweet	Wilt disease			
	No. of branches			
	Fruit set percentage			
	Fruit length	0.767	0.876	**
	Fruit diameter			
	Fruit weight			

** : Significant at 1% level of significance

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توريث وطبيعة المقاومة لمرض الذبول الفيوزاريومي في البطيخ

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تم إجراء التهجين بين أصناف مختلفة من البطيخ مثل شارلستون جراى X البيبي شوجر والكريمسون اسويت X البيبي شوجر وكذلك أيضا الهجن العكسية وذلك لدراسة توريث وطبيعة المقاومة لمرض الذبول الفيوزاريومي في البطيخ. أظهرت نباتات الجيل الأول مقاومة عالية لهذا المرض. وقد كانت نسبة انعزال النباتات المقاومة إلى النباتات الحساسة في نباتات الجيل الثاني وفي التهجين الرجعي لنباتات الجيل الأول مع الأب الحساس 3: 1 و 1: 1 على التوالي، وكانت صفات التبرير في الإزهار والمحصول الكلي للنبات تورث كميًا. تراوحت طبيعة توريث صفات التبرير في الإزهار والمحصول الكلي للنبات بين سيادة جزئية إلى فوق السيادة وذلك في الهجن التي تحت الدراسة. تقدير درجة التوريث بمعناها الواسع لصفات التبرير في الإزهار والمحصول الكلي للنبات تراوحت ما بين متوسطة إلى فوق متوسطة - بينما درجة التوريث بمعناها الضيق تراوحت ما بين منخفضة إلى متوسطة. عدد أزواج الجينات التي تتحكم في صفة التبرير في الإزهار تراوحت بين زوج إلى ثلاث أزواج - أما بالنسبة لمحصول النبات الكلي تراوحت بين زوج إلى خمسة أزواج من الجينات.

رد فعل النبات تجاه مرض الذبول الفيوزاريومي كان مرتبط ارتباطًا سالبًا عاليًا المعنوية مع كل من التبرير في الإزهار - طول وقطر ووزن الثمرة ومحصول النبات الكلي. بينما كانت هناك علاقة موجبة عالية المعنوية بين رد فعل النبات للمرض مع كل من محتوى النبات من السكريات المختزلة والغير مختزلة والكلية - بينما العلاقة كانت سالبة مع كل من الفينولات الكلية والحررة والمرتبطة وذلك في الهجين كريمسون اسويت X البيبي شوجر. هناك علاقة خطية عالية المعنوية بين تأثير الصفات الآتية مجتمعة على محصول النبات الكلي وهي رد فعل النبات للمرض - عدد أفرع النبات - نسبة العقد - طول وقطر ووزن الثمرة.