GENETIC STUDIES ON TOMATO

By

AHMED MOHAMMED ALY MAHMOUD
B.Sc. Agric. Sci. (Horticulture), Fac. Agric., Cairo Univ., 1999
M.Sc. Agric. Sci. (Vegetable Crops), Fac. Agric., Cairo Univ., 2004

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APPROVAL SHEET

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ABSTRACT

Studies were conducted during the period from 2005 to 09 at Agricultural Experiment Station (AES) of the Faculty of Agriculture, Cairo University, Giza, Egypt as a first step for a local tomato breeding program to TYLCV-resistance. Ninety-two domestic and wild tomato accessions were evaluated for TYLCV resistance under field conditions during the 2005, 2006 and 2007 fall plantings. A graft-inoculation experiment was conducted for detection of TYLCV in symptomless plants of some of the evaluated accessions and selected as best sources for resistance. Based on performance over three evaluation seasons, all of the evaluated accessions of *S. chessmaniae*, *S. chilense*, *S. chmielewskii*, *S. habrochaites*, *S. neorickii*, and *S. pennellii* and most of the evaluated accessions of *S. peruvianum* showed low TYLCV mean scores. Evaluated *S. pimpinellifolium* accessions showed a wide range of reaction to TYLCV infection. Sixteen accessions exhibited resistance to TYLCV. None of the evaluated accessions of both *S. lycopersicum* and *Solanum sp.* appeared resistant to TYLCV. Meanwhile, 2 accessions of both *S. lycopersicum* (LYC 179/83 and LYC 32/83) and *Solanum sp.* (PIs 126915 and 205017) appeared promising as some of their plants were symptomless. These plants were selected and re-evaluated. The tolerance of progenies of selected plants of accessions was reconfirmed. Grafting experiment revealed that all evaluated symptomless plants of accessions *S. pennellii* LA 716 and *S. peruvianum* LAs 107, 1474, 1677, 2157, and 2172 and PIs 128652 and 270435 were not virus carries. These accessions are considered resistant. According to the results obtained from the evaluation trials, *S. chmielewskii* LA 1317; *S. habrochaites* LA 1777 and PI 390662; a selection of *S. lycopersicum* var. *flammatum* LYC 179/83; *S. neorickii* LA 1326; *S. pimpinellifolium* PIs 211840 and 407543; and a selection of *Solanum sp.* PI 205017 were chosen to study the inheritance of TYLCV resistance. Resistance derived from *S. chmielewskii* LA 1317 was found to be controlled by 2 pairs of genes with partial dominance of resistance over susceptibility, while, resistance derived from *S. habrochaites* LA 1777 and PI 390662; *S. neorickii* LA 1326; and *S. pimpinellifolium* PIs 211840 and 407543 was found to be controlled by 3 pairs of genes with partial dominance of resistance over susceptibility. BSH estimates were 84.93, 71.30, 74.75, 75.4, 70.6 and 68.9 %, respectively. Meanwhile, resistance derived from selections of *S. lycopersicum* var. *flammatum* and *Solanum sp.* was found to be controlled by 8 and 6 pairs of genes, respectively, with partial dominance of resistance over susceptibility. BSH estimates were 60.8 and 65.6 %, respectively. Selections of *S. lycopersicum* accessions LA 3845 (P_1), LA 3846 (P_2), LYC 32/83 (P_3) and LYC 179/83 (P_4); *S. pimpinellifolium* PI 211840 (P_5) and selections of *Solanum sp.* accessions PIs 126915 (P_6) and 205017 (P_7) having high tolerance to TYLCV and accepted fruit quality characters, were selected for use in a half diallel crossing program to study the possibility of producing tolerant × tolerant F_1s. The additive gene action played the major role in the inheritance of all studied characters except fruit ascorbic acid content and fruit pH value. P_1 and P_2 proved to be general good combiners for early yield (EY), total yield (TY), average fruit weight (AFW) and fruit pH value, while P_4 proved to be a general good combiner for EY, TY and AFW. The crosses $P_1 \times P_2$, $P_1 \times P_4$, $P_2 \times P_4$ and $P_5 \times P_6$ were the best combinations for EY, TY and AFW.

Key words: Tomato, *Solanum lycopersicum* L., Tomato yellow leaf curl virus, Resistance, Tolerance, Evaluation, Inheritance, Combining ability.

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LIST OF ABBREVIATIONS

AAC	:	Ascorbic acid content.
AES	:	Agricultural experiment station.
AFW	:	Average fruit weight.
AVRDC	:	Asian vegetable research and development center.
BSH	:	Broad sense heritability.
ELISA	:	Enzyme-linked immunosorbent assay.
EU	:	Experimental unit.
EY	:	Early yield.
FSI	:	Fruit shape index.
GCA	:	General combining ability.
P	:	Potence ratio.
RCBD	:	Randomized complete block design.
SCA	:	Specific combining ability.
TA	:	Titratable acidity.
TLCV	:	Tomato leaf curl virus.
ToLCV-[Ban4]	:	Tomato leaf curl virus, Bangalore isolate 4, India.
TSS	:	Total soluble solids.
TY	:	Total yield.
TYLCD	:	Tomato yellow leaf curl disease.
TYLCTHV-[2]	:	Tomato yellow leaf curl virus, Thailand isolate.
TYLCV	:	Tomato yellow leaf curl virus.
TYLCV-Is	:	Tomato yellow leaf curl virus Israel.
TYLCV-Sar	:	Tomato yellow leaf curl Sardinia virus.

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INTRODUCTION

The cultivated tomato, *Solanum lycopersicum* L. (formerly *Lycopersicon esculentum* Mill.), is a worldwide-grown vegetable crop and the focus of a large agricultural industry. In Egypt, tomato is the leading vegetable crop. It's acreage reached 571844 feddan in 2008 yielding 9.2 million tons with an average of 16.1 tons / feddan*.

Tomato is subject to infection with several fungal, bacterial, viral, and mycoplasmal pathogens, which threaten it's cultivation and productivity. Tomato yellow leaf curl disease (TYLCD) is one of the most devastating diseases of cultivated tomatoes in tropical and subtropical regions, including Egypt. Yield losses ranged between 28.4% to 92.3% and reached 100% in some reports, according to the age of the plant at the time of infection and environmental conditions (Czosnek and Laterrot 1997; Makkouk and Laterrot, 1983; Nour-El Din *et al.*, 1969; Picó *et al.* 1999). The disease is induced by a number of *Begomovirus* species (family Geminiviridae), among them, *Tomato yellow leaf curl virus* (TYLCV), which is widely spread worldwide (Moriones and Novas-Castillo, 2000; Fauquet and Stanley, 2005).

First TYLCD symptoms on tomato plants appear 2-4 weeks after inoculation and become fully developed after a period of up to 2 months (Ioannou 1985; Credi *et al.*, 1989). The type and severity of symptoms vary according to virus isolate, host genetic background, environmental conditions, and growth stage and physiological condition of the tomato plant at the time of infection. Tomato plants

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affected by the virus are severely stunted, shoots are erect, and leaflets are much smaller than normal and abnormal in shape. The leaflets that appear soon after infection are cupped downwards and inwards; leaves developing later are strikingly chlorotic, mis-shapen and show an upwards curling of the margin of the leaflets. Young, early infected plants, are usually unfruitful because of severe flower shedding. Thus, yield reduction is higher when plants are infected at early stages of development. Infection at later growth stages drastically reduces production of new fruits. Infected plants produce fewer and smaller fruits. Fruits set before infection tend to ripen normally (Nitzany, 1975; Ioannou, 1985).

TYLCD was first reported in late 1930s in Isreal, in association with outbreaks of the whitefly *B. tabaci* (Antignus and Cohen, 1994). From the early 1960s, the disease has quickly spread in Middle East, Southern Asia, Eastern and Western Africa, the Mediterranean Basin, Western Europe, Australia, Western Hemisphere (Dominican Republic, Cuba, Jamaica, Brazil, Puerto Rico, and Bahamas), and was reported locally in Mexico and the USA (Czosnek *et al.,* 1990; Czosnek and Laterrot, 1997; Polston *et al.*, 1999; Moriones and Navas-Castillo, 2000; Brown and Idris, 2006; Rojas *et al.*, 2007). The rapid and widespread outbreaks of the disease were due to several reasons, foremost was the spread of bio-type B of the whitefly (Polston *et al.*, 1999).

TYLCV is transmitted to plants naturally by the whitefly (*Bemisia tabaci* Genn. and *B. argentifollii* (*B. tabaci* biotype B); Homoptera: *Aleyrodidae*), but not transmitted by the greenhouse

whitefly (*Trialeurodes vaporariorum*), and it is persistent and circulative but not transmitted to the insect's progeny (Cohen and Nitzany, 1966). Once the whitefly vector feeds on an infected host plant and acquires the virus, viral transmission can occur within 17-24 hours, and may continue for the life span of the vector. Immature nymphs are able to acquire the virus and transmit it at the adult stage (Caciagl *et al.*, 1995). TYLCV is not transmitted mechanically. No cases of seed transmission have been documented. TYLCV, as other viruses that afflict tomato, is graft-transmitted (Hassan *et al.*, 1982).

Under Egyptian conditions *B. tabaci* flourishes from April through November, with a peak from August through October. Henceforth, TYLCD is most severe in crops transplanted during summer and early autumn, when vector population is high (Shaheen, 1983).

The management of TYLCD in tomato is difficult, expensive, and with limited options. Various strategies have been pursued to control the disease and decrease losses, mostly emphasizing vector control, although only a few are frequently effective and some cannot be used in all climates and locations (Cohen and Antignus, 1994; Polston and Anderson, 1997). Often control efficiency is not sufficient and economic losses are incurred. Pesticides are reasonably effective in reducing vector population, which can reach very high levels, but complete eradication of the whitefly as a virus vector is rarely attained. Furthermore, there are concerns that the vector may develop pesticide resistance and the intense application of pesticides may have deleterious effects on the environment (Picó *et al.*, 1996). Physical

barriers such as fine-mesh screens have been used in the Mediterranean Basin to protect crops (Cohen and Antignus, 1994). Recently, UV-absorbing plastic sheets and screens have been shown to inhibit entry of whiteflies into greenhouse. Furthermore, filtration of UV light was shown to hinder the whitefly dispersal activity and, consequently, reduce virus spread (Antignus *et al.*, 2001). However, adoption of physical barriers adds to production costs and these screens create problems of shading, overheating, and high relative humidity. Therefore, the best way to reduce yield losses inflected by TYLCD and to reduce the spread of the virus is by the use of virus-resistant tomato cvs, as their use is perhaps the easiest, safest, most practical, and best environment-friendly method for controlling this viral disease (Hassan and abdel-Ati, 1999; Lapidot and Friedmann, 2002; Picó *et al.*, 1996). Therefore, breeding for TYLCD resistance has been one of the most important goals of tomato breeding.

As a first step in a local breeding program, the present study was conducted to:

1. Evaluate the level of resistance to TYLCV under Egyptian conditions of several domesticated and wild tomato accessions and select resistant ones.
2. Study the mode of inheritance of TYLCV resistance in some resistant tomato accessions.
3. Study the possibility of producing tomato hybrids resistant to TYLCV.

REVIEW OF LITERATURE

1. Sources of resistance/tolerance to TYLCD in tomato genotypes

Studies on screening tomatoes for resistance/tolerance to TYLCD have been carried out by several workers. The literature is somewhat confusing regarding the tolerance/resistance reaction of domestic and wild tomato accessions to TYLCV. Early literature, i.e., up to about 1980, refers to 'resistance', while later literature, i.e., from about 1980 to nearly 1991, refers to 'tolerance' to the virus. Recently, i.e., since about 1991, the term high 'resistance' was used with reference to the reaction of some wild accessions. With this understanding in mind, I present this literature review on the subject.

The Early efforts to identify sources of resistance to TYLCD within the domesticated tomato (*S. lycopersicum*) in India (Nariani and Vasudera, 1963), the Sudan (Abdel-Al *et al.*, 1973), Israel (Pilowsky and Cohen, 1974), Egypt (El-Hammady *et al.*, 1976), Lebanon (Makkouk, 1976), Jordan (Abu-Gharbieh *et al.*, 1978), and Saudia Arabia (Mazyad *et al.*, 1979) were unfruitful, as they revealed lack of resistance to the disease in tomato cvs. Meanwhile, some cvs showed slight susceptibility (tolerance) such as Early Pak 7, Pearl Harbour (El-Hammady *et al.*, 1976); 73T16 (Makkouk, 1976); and Peto CVF, Castlex 17, South Callorina T3691, Suh Artic, VFN 19 and Homested (Abu-Gharbieh *et al.*, 1978). However, resistance to the disease was reported in a number of accessions of *S. chilense* (Pilowsky and Cohen, 1974), *S. habrochaites* (formerly *L. hirsutum*) (Pilowsky, 1976), and *S. peruvianum* (formerly *L. peruvianum*) (El-Hammady *et al.*, 1976;

Nariani and Vasudera, 1963; Pilowsky and Cohen, 1974). Also, tolerance to TYLCD was reported in *S. pimpinellifolium* (formerly *L. pimpinellifolium*) LA 121 which reacted as a symptomless host in Israel (Pilowsky and Cohen, 1974) and Jordan (Makkouk, 1978). Thus, it was necessary to screen the tomato wild species for potential sources of resistance to TYLCD.

Varma *et al.* (1980) evaluated 6 lines of 3 tomato wild species and 80 tomato cvs for resistance to TLCV (TYLCV) under natural field inoculation conditions with whitefly, and found that *S. corneliomuelleri* (formerly *L. glandulosum*) and *S. peruvianum* were highly resistant. Meanwhile, *S. lycopersicum* EC104395 was found to be tolerant to TYLCV, contracting mild symptoms very late after germination, and giving the highest yield when compared with other tomato cvs.

Hassan *et al.*(1982) evaluated 118 tomato cvs and breeding lines and 26 accessions of 4 wild tomato species, *viz.*, *S. galapahense* (formerly *L. cheesmanii* f. *minor*), *S. habrochaites, S. peruvianum,* and *S. pimpinellifolium*, for TYLCV resistance under field conditions of heavy viruliferous whitefly infestation. All tested commercial tomato cvs and breeding lines were highly susceptible, though 6 cvs exhibited slight susceptibility, *viz.*, P.E.D., Pusa Ruby, Large Red Cherry, Castlemart, MM-Nova, and Sioux. All tested accessions of *S. galapagense* LA 1401; *S. habrochaites* LAs 386, 1295, 1352, 1393, and 1691; *S. habrochaites* f. *glabratum* LAs 1252 and 1624; *S. peruvianum* LA 372, LA 452, LA 462, LA 1274, LA 1333, LA 1373, and CMV sél. INRA, and *S. peruvianum* f. *humifusum* LA 385 were highly resistant. None of the tested plants exhibited TYLCV symptoms

and grafting experiments indicated that none carried the virus within 12 weeks of grafting. Accessions of *S. pimpinellifolium* varied in their reactions; LAs 121, 1579, 1589, and 1690 were segregating, while all tested plants of LAs 411, 1256, 1370, 1583, and 1634 exhibited severe symptoms. Grafting experiments indicated the presence of TYLCV in all symptomless plants of *S. pimpinellifolium*.

Mazyad *et al.* (1982) found that *S. galapagense* LA 1401, *S. habrochaites* LA 386, and *S. peruvianum* CMV sél. INRA remained free of TYLCV even after prolonged exposure to natural vector inoculation for nearly an entire year. Progenies of symptomless virus carrier plants of *S. pimpinellifolium* LAs 121, 373, and 1690 continued to segregate in this character. Resistance to vector transmission in *S. peruvianum* CMV sél INRA was broken when inoculations were made at high temperatures (mostly over 42° C during day time). Plants of this accession were susceptible to graft inoculations but they were symptomless.

According to Geneif (1984), accessions *S. pimpinellifolium* LAs 1478 and 1582; *S. peruvianum* LAs 111 and 1369; and *S. habrochaites* LAs 386, 1223, and 1347 were consistently free of any symptoms of TYLCV. Most of the lines of *S. lycopersicum* var. *cerasiforme* showed moderate infection.

Ioannou (1985) evaluated 29 open-pollinated and 22 hybrid tomato cvs, 9 lines of 4 wild tomato species, *viz., S. chilense*, *S. habrochaites*, *S. peruvianum*, and *S. pimpinellifolium*, and introduced breeding lines derived from crosses between resistant wild species and the cultivated tomato for TYLCV resistance under greenhouse

inoculation conditions. The test included also 10 tomato cvs, 2 lines of *S. habrochaites*, 4 lines of *S. peruvianum*, and the introduced breeding lines derived from crosses between resistant wild species and the cultivated tomato under natural field conditions. Generally, all tested tomato cvs were highly susceptible. All tested lines of *S. chilense* (NIS-27-3), *S. habrochaites* (LAs 386 and 1777), and *S. peruvianum* (CMV sél. INRA, 84 LC-1, LA 372, and PI 365956) were highly resistant. *S. pimpinellifolium* LA 121 and the introduced breeding lines derived from crosses between these resistant species and the cultivated tomato were designated as tolerant rather than resistant.

Yassin (1985) reported resistance to TYLCV in *S. pimpinellifolium* LA 1582. According to the Asian Vegetable Research and Development Center (AVRDC) report for year 1985 (AVRDC, 1987) resistance to the Taiwan-TYLCV isolate was found in 8 cultivated and wild tomato lines, with *S. peruvianum* INRA Sél (VL 115) and *S. lycopersicum* VL 81 and VL 82 being the most resistant.

Reaction to TLCV (TYLCV) was studied by Banerjee and Kalloo (1987b) in 122 tomato cvs, lines and wild accessions in field, screenhouse and greenhouse conditions over 2 years. *S. habrochaites* f. *glabratum* B 6013 and *S. habrochaites* f. *typicum* LA 1904 were highly resistant in all 3 environments, as were accessions of *S. peruvianum*. The *S. pimpinellifolium* accession A 1921 was free of TYLCV symptoms for the first 90 days. Of the *S. lycopersicum* varieties, Ace 99 was the least susceptible, while AC 142, Collection No. 2, Kalyanpur Angurlata, and H 5101 had low incidence of TLCV (TYLCV) infection.

Kasrawi *et al.* (1988) evaluated 16 accessions of three wild tomato species, *viz.*, *S. habrochaites*, *S. peruvianum*, and *S. pimpinellifolium*, and 55 commercial tomato hybrids and cvs for TYLCV resistance. All commercial hybrids and cvs were highly susceptible. Accessions of *S. hirsutum*, *S. habrochaites* f. *glabratum*, and *S. pimpinellifolium* showed a wide range of reaction. Those of *S. peruvianum* (INRA, LA 372, LA 462, LA 1274, LA 1333, and LA 1373) and *S. peruvianum* f. *humifusum* exhibited very high levels of resistance.

Collections of *S. habrochaites* and *S. peruvianum* showed a high degree of resistance to TLCV (TYLCV) (Bisht *et al.*, 1989). Also, resistance to TYLCV was found in *S. pimpinellifolium* Hirsute and LA 1478 (Kasrawi, 1989), *S. habrochaites* LA 386, LA 1777, PI 390513, PI 390658, and PI 390659; and *S. peruvianum* PI 127830 and PI 127831 (Saikia and Muniyappa, 1989).

Rowell *et al.* (1989) found through evaluating tomato lines collected by AVRDC and local cvs in Cambodia for resistance to TYLCV, that the AVRDC lines showed the greatest resistance to the virus, especially CL-1131-0-0-43-8-1.

AVRDC (1990) reported that none of 5 wild accessions of *S. pimpinellifolium*, *S. habrochaites*, and *S. lycopersicoides* showed resistance to TYLCV when screened using a double grafting method.

Pilowsky and Cohen (1990) indicated that the accession *S. peruvianum* PI 126935 was tolerant to TYLCV.

Hassan *et al.* (1991) evaluated 1720 tomato accessions, one of *S. galapagense*, one of *S. lycopersicum* var. *cerasiforme*, 20 of *S.*

lycopersicum × *S. pimpinellifolium*, 10 of *S. habrochaites*, one of *S. habrochaites* f. *glabratum*, one of unspecified tomato hybrid, one of *S. pennellii*, 12 of *S. peruvianum*, one of *S. lycopersicum* × *S. peruvianum*, 27 of *S. pimpinellifolium*, and one of *S. pimpinellifolium* hirsute for TYLCV resistance under field conditions in Al-Ain, United Arab Emirates during the 1988/1989 and 1989/1990 autumn plantings. Most symptomless and slightly susceptible and some of the moderately susceptible accessions in the first year trial were re-evaluated in the second year. In the first trial, 90.09%, 9.27%, 0.47% and 0.17% of the *S. lycopersicum* accessions were, respectively, highly susceptible, moderately susceptible (to different degrees), slightly susceptible, and symptomless. Respective percentages of the wild accessions were 42.1% (mostly of the *S. lycopersicum* × *S. pimpinellifolium* hybrids), 15.8%, 1.3% and 1.3% (mostly of *S. habrochaites* and *S. peruvianum*). In the second year trial, only 2 *S. peruvianum* PIs 390670 and 390687 remained symptomless, while all other re-evaluated accessions showed various degrees of susceptibility. Based on performance in both years of the study, the following accessions were selected from the germplasm evaluated as the best sources of tolerance to infection with TYLCV: *S. lycopersicum* PIs 365923, 365925 and 390648; *S. habrochaites* PI 390662; *S. peruvianum* PIs 390669, 390670, 390681, and 390687; and *S. pimpinellifolium* PIs 407543 and 407546.

Muniyappa *et al.* (1991) screened 1201 tomato cvs, breeding lines and accessions of tomato species for TYLCV resistance under field conditions. Two lines of *S. habrochaites* (PIs 390658 and 390659) and two lines of *S. peruvianum* (PIs 127830 and 127831) were resistant

to TYLCV infection. These accessions did not produce any leaf curl symptoms either in the field or after inoculation with viruliferous whiteflies.

Zakay *et al.* (1991) screened 32 tomato accessions representing 5 tomato species for resistance to TYLCV. The screened genotypes were examined for the presence of viral DNA and symptoms development at 2-week intervals. Tomato cvs harbored the virus and developed symptoms. Accessions of the wild species *S. pimpinellifolium*, *S. habrochaites,* and *S. peruvianum* showed variation in their response to infection. Accession *S. chilense* LA 1969 presented the highest level of resistance: only two of 58 plants contained viral DNA and none developed symptoms.

Channarayappa *et al.* (1992) evaluated more than 1200 tomato cvs, breeding and wild lines for resistance to TLCV (TYLCV) under field conditions. All *S. lycopersicum* accessions were susceptible to TYLCV. Three lines of *S. habrochaites* and one of *S. peruvianum* showed apparent resistance to TYLCV.

Davino *et al.* (1992) conducted a greenhouse evaluation trial on tomato F_1 hybrids Turguesa, Samar, Arletta, Rita and Mereto, which are known to be TYLCV – resistant, and cvs M46, M47, and M48, and cherry-type tomato variety RS9020 for TYLCV infection. Variety RS9020 showed the lowest number of TYLCV infected plants and the highest yield.

Ioannou (1992) conducted field trials on 52 cvs and 10 tomato lines and failed to establish any useful resistance to TYLCV, but tolerance or partial resistance was found in several tomato species,

especially the accessions *S. peruvianum* CMV sél INRA and *S. pimpinellifolium* Hirsute.

Among 42 tomato genotypes tested for TYLCV resistance over two years under plastichouse conditions, Abou-Jawdah *et al.* (1996) found resistance in *S. chilense* LA 1969.

Mahanta *et al.* (1998) evaluated 23 tomato cvs over two seasons for TLCV (TYLCV) infection. Cvs BT-3, Arka Alok, and Arka Abha were free of TYLCV.

Picó *et al.* (1998) evaluated 9 hybrids and 3 cvs of tomato, 4 accessions of *S. peruvianum*, and 4 accessions of *S. chilense* for TYLCV resistance based either on natural or artificial inoculations. Hybrid cvs F3524, F3522, Fiona, and Ty-King showed the highest level of resistance. Wild accessions *S. chilense* LA 1963 and LA 1969 had the highest level of resistance under different conditions, whereas the other wild accessions, especially *S. peruvianum* PI 126944 and *S. chilense* were promising.

Abou-Jawdah *et al.* (1999) evaluated 67 tomato lines, and identified several lines as promising for resistance to TYLCV. Relative virus concentration was determined in three tolerant and two susceptible cvs selected based on the severity of symptoms observed in field tests. Ty-King, DRW3093, DRW3098, and Fiona were the most promising cvs under heavy inoculum pressure. They produced, significantly, higher yields than susceptible controls. They were followed by CLX 3752, RS 8990, S&G 143 and Ty-Carla, which had significantly low disease severity indices and higher yields than the susceptible controls. It was noted that Ty-King was the most resistant

line and did not display obvious symptoms. Virus concentration in most, but not all, tolerant tomato lines were significantly lower than in the susceptible line.

Giordano *et al.* (1999) evaluated 31 accessions representing four tomato species, *viz.*, *chilense, lycopersicum, peruvianum*, and *pimpinellifolium*, for resistance to TYLCV with bipartite genome from Brasilia-DF. The screened genotypes were examined for the presence of viral DNA and for symptom development during 28 days after inoculation. Resistant genotypes were found in *S. peruvianum* CNPH-784, CNPH-786, and CNPH-787, *S. chilense* LA 1967, *S. pimpinellifolium* LA 1342 and *S. lycopersicum* line 17-2-3 (F_5 Ty-King), line 9-2-1 (F_5 Ty-King), Chiltichiltylc 95, Multichiltylc 95 and TY-52. Most of the resistant genotypes harbored the virus without showing symptoms. On the other hand, *S. chilense* LA 1967 showed no disease symptom and the presence of viral DNA was detected in only one out of 10 inoculated plants.

Picó *et al.* (1999) evaluated 9 *S. chilense* accessions, *viz.*, LAs 1932, 1938, 1959, 1960, 1961, 1968, 1969, 1971, and 2884 and 4 interspecific F_1 hybrids derived from crosses between *S. lycopersicum* and *S. chilense*, *viz.*, LAs 1932, 1938, 1960 and 1971, which were obtained by using the pollen mixture technique, against TYLCV. Viral DNA accumulation, which is more discriminatory than symptomatology when assaying wild tomato species, allowed the accession *S. chilense* LA 2884 to be discarded since it accumulated considerably more viral DNA than the other *S. chilense* accessions, also reaching 100% infection. All F_1 hybrids exhibited a high level of

resistance similar to that of the resistant parent, although differences appeared among them in symptom severity and viral accumulation.

Singh *et al.* (1999a, b) found that cvs H-24 and H-36 were resistant to TLCV (TYLCV) as they showed a very low disease incidence. Also cvs Pusa Ruby, Pusasheetal, and Pusa Gaurav, were the most promising for high yield.

In one of AVRDC's research efforts to define resistance to TYLCV, twenty-four cultivated and wild tomatoes reported as resistant to TYLCV and 14 inbred lines developed by AVRDC using H-24 as the TYLCV resistance source were screened at AVRDC's Asian Regional Center (AVRDC-ARC), Kamphaengsaen, during the dry season of 2000. Resistance assessment was based on visible symptoms and virus detection by DNA hybridization with a Thailand TYLCV strain probe on leaves collected from 10 symptomless plants per entry. Out of the 24 resistance sources tested at AVRDC-ARC, only seven entries showed highly to moderate resistance, *viz.*, *S. chilense* LA 1932; TLCV(271/1x26)-1 (resistance source from H-24); FL505 (resistance source from *S. chilense* LA 1969, Tyking, and Fiona); *S. habrochaites* LA 1777; H-24; FL619 (resistance source from *S. chilense* LA 1932 and LA 2779); and FL699sp (resistance source from *S. chilense* LA 1938). Resistance source H-24 and AVRDC inbred lines (with H-24 as resistance source) showed high to moderate resistance. However, the percentage of symptomless plants carrying the virus varied widely from line to line. Nevertheless, 9 of the 14 tested lines had similar or better resistance than the resistant parent H-24 at AVRDC-ARC. In a second trial that was undertaken in collaboration

with Limagrain and East-West Seed companies, in Thailand and the Philippines, respectively, 10 lines were screened during the dry season of 2000 and resistance was assessed according to visual symptoms 60 days after transplanting. Multilocation screening showed that lines identified as resistant at AVRDC-ARC might not be suitable in other areas. This screening confirmed the high level of location-specificity of TYLCV resistance. Among them, H-24 was highly susceptible in the Philippines and at the Limagrain's station in Thailand. TY-52, Gempride, and FLA505 displayed similar resistance instability (AVRDC, 2000).

Twenty-five tomato lines and varieties from America, Middle East, India and Taiwan with reported resistance to TYLCV were evaluated for resistance to TYLCV at AVRDC- ARC, Nakhon Pathom, Thailand. TLCV(271/1x26)-1 and two wild accessions, *viz*., *S. chilense* LA 1392 and *S. habrochaites* LA 1777 did not show any TYLCV symptom. However, the last two did not bear fruits. Five other accessions had lesser TYLCV incidence than the control and may be used in incorporating virus resistance to commercially acceptable varieties. The experiment showed lack of a significant correlation between TYLCV incidence or severity and yield or agronomic characteristics (Lieu, 2000).

Using *Agrobacterium*-mediated inoculation, Picó *et al*., (2000) identified several new resistant sources to TYLCV in an extraordinarily variable tomato wild gene pool collected from Ecuador and Peru. This screening assay revealed high susceptibility within *S. lycopersicum* and *S. pennellii*, but the existence of different levels of resistance within *S.*

pimpinellifolium and *S. habrochaites*. Agroinoculation allowed the selection of 4 *S. pimpinellifolium* (UPV-16953, UPV-16990, UPV-16991 and UPV-17049) and 2 *S. habrochaites* (UPV-16910 and UPV-16911) accessions with higher level of resistance.

Pilowsky and Cohen (2000) evaluated 25 wild species accessions in the greenhouse for resistance to the whitefly-borne TYLCV. A high level of resistance was detected in 7 of 9 accessions of *S. peruvianum* and in all 5 accessions of *S. chilense* tested. In contrast, plants of 7 accessions of *S. habrochaites* and 3 of 4 accessions of *S. pimpinellifolium* were highly susceptible. Plants of accession *S. pimpinellifolium* CIAS27 showed moderate resistance to the virus.

Razvi *et al.* (2000) reported that cvs Fiona, Ty-King, and Top 21 showed a high degree of resistance to TLCV (TYLCV), whereas, cv. Meghana was tolerant when the TYLCV infection level was high but still recorded good yield. Hussein and Mansour (2001) evaluated 12 tomato hybrid cvs, and reported high resistance in E445, Drw8001, Saria, DRW8006, DRW8003, W322F1, DRW8009, and DRW8005, whereas E446 and DRW004 were moderately resistant, and 146-92 and Antares were the least resistant. Also, Sajeed *et al.* (2002) found that the cultivar Punjab Chhuhara was the most resistant to TYLCV followed by Sel-7.

Nainar and Pappiah (2002a, b) evaluated 72 *S. lycopersicum* lines and 20 accessions of *S. galapagense*, *S. chilense*, *S. habrochaites*, *S. peruvianum*, and *S. pimpinellifolium* against TLCV (TYLCV) infection. Generally, all lines of *S. lycopersicum* were susceptible to the virus. Among the wild accessions, 6 were susceptible, 7 were

moderately susceptible, 5 were moderately resistant, and 2 were resistant. Two resistant accessions, *viz., S. pimpinellifolium* IIHR 1942 and *S. habrochaites* LE 1118 did not exhibit infection up to 75 days after transplanting.

In a study conducted by Maruthi *et al.* (2003) to evaluate reaction of wild and domesticated tomatoes for resistance to tomato yellow leaf curl virus Israel (TYLCV-Is) and tomato leaf curl virus from Bangalore isolate 4, India (ToLCV-[Ban4]) to find sources of resistance to both viruses. A total of 34 tomato genotypes resistant/tolerant to TYLCV-Is were evaluated for resistance to ToLCV-[Ban4] under glasshouse and field conditions at the University of Agricultural Sciences, Bangalore, India. Resistance was assessed by criteria like disease incidence, symptom severity and squash-blot hybridization. All the tomato genotypes inoculated with ToLCV-[Ban4] by the whitefly vector *B. tabaci* produced disease symptoms. In some plants of the lines 902 and 910, however, the virus was not detected by hybridization. The tomato genotypes susceptible to ToLCV-[Ban4] by whitefly-mediated artificial inoculation were also found susceptible to the virus under natural field conditions. However, there were substantial differences between genotypes in disease incidence, spread, symptom severity and crop yield. Despite early disease incidence, many genotypes produced substantially higher yields than the local hybrid, Avinash-2. Sixteen tomato genotypes from India resistant/tolerant to ToLCV-[Ban4] were also tested for TYLCV-Is resistance at the Hebrew University of Jerusalem, Rehovot, Israel. Accessions of wild species *S. habrochaites* LA 1777 and PI 390659

were the best sources of resistance to both viruses. Lines 902 and 910, which were resistant to TYLCV-Is, were only tolerant to ToLCV-[Ban4] and accession *S. peruvianum* CMV Sel. INRA, resistant to ToLCV-[Ban4], was only tolerant to TYLCV-Is.

In a study by Qaryouti *et al.* (2003), forty-nine accessions of tomato land races collected from local farmers during 1983-95 were evaluated for TYLCV susceptibility during the 2001/02 season in Ghour Al-Safi, Jordan. The accessions 971b, 951, 952, 989 and 968 had no visible TYLCV symptoms with fruit yields ranging from 39.5 to 45.1 t/ha. Yields of 5 other accessions, *viz*., 975, 976, 979, 981, and 991 ranged from 52 to 59 t/ha with slight TYLCV symptoms, indicating good source for further TYLCV resistance studies.

Mahmoud (2004) evaluated 73 wild and domestic tomato accessions, *viz*., one accession of *S. chilense*, 2 of *S. chmielewskii*, 23 of *S. lycopersicum* var. *cerasiforme*, 10 of *S. lycopersicum* var. *esculentum*, 3 of *S. habrochaites* f. *glabratum*, 8 of *L. habrochaites* f. *hirsutum*, one of *S. pennellii,* and 25 of *S. pimpinellifolium* for TYLCV resistance under field conditions. Based on performance in both years of the study, all evaluated accessions of *S. chilense*, *S. lycopersicum* var. *cerasiforme*, *S. lycopersicum* var. *esculentum*, and *S. habrochaites* f. *glabratum* were susceptible. However, the accessions *S. chmielewskii* LA 1317; *S. habrochaites* f. *hirsutum* LAs 1393 and 1777 and PIs 126445 and 390662; *S. pennellii* LA 716; and *S. pimpinellifolium* LAs 121, 722, 1258, 1478, and 1633 and PIs 212408, 407544, and 407555 exhibited resistance to TYLCV infection.

Castro *et al.* (2005) evaluated 12 tomato advanced breeding lines derived from *L. chilense* and partially resistant to *Tomato yellow leaf curl Sardinia virus* (TYLCV-Sar) for their resistance to the species from Israel (TYLCV-Is). Two assays were carried out in two consecutive years, using agroinoculation and whitefly-mediated inoculation, respectively. Symptom severity, percentage of infection, and viral DNA accumulation (using molecular hybridization) were measured. In the first assay, the 12 breeding lines were agroinoculated with both virus species. Resistance to TYLCV-Sar was confirmed for the 12 breeding lines, but only 6 of them showed resistance to TYLCV-Is. During the second assay these six breeding lines were whitefly-inoculated with TYLCV-Is. All lines showed high levels of partial resistance to TYLCV-Is consisting of attenuation and delay in time of symptom development and reduction in virus accumulation when compared with the susceptible control. Three of these lines even accumulated significantly lower amounts of viral DNA than the resistant controls 'Anastasia' and 'Boludo' hybrids. These lines also display good horticultural traits, appropriate for the protected growing system and for the fresh market requirements. These advanced breeding lines are base material for developing commercial hybrids highly resistant to TYLCV-Sar and TYLCV-Is.

Samarajeewa *et al.* (2005) screened 14 tomato germplasm accessions, including wild (*S. cheesmaniae*, *S. habrochaites*, *S. peruvianum* and *S. pimpinellifolium*) and commercial types for resistance to TYLCV to identify the possible sources of resistance genes to be transferred to cultivated tomato and identify a putative

molecular marker for resistance. Only *S. habrochaites* showed high resistance to the disease. Susceptible Marglobe was crossed with *S. habrochaites* in both directions to transfer the resistant genes. The crossing was successful only when Marglobe was used as the mother plant. F_1 and F_2 progenies were obtained and screened for resistance using whiteflies. The resistant plants had more trichomes on leaves and stems than the susceptible plants.

A tomato field screening was conducted by Chakraborty *et al.* (2005) against TYLCD to identify the source of resistance for future multiplication, genetic improvement and cultivation in the plains of West Bengal, India. Fifty-three hybrid cultivars and lines were selected and screened under natural field conditions. None of the lines or hybrids was free from the disease. Very low or low disease incidences were found in hybrids and lines like BSS-422 (9.63%), TH-010848 (10.03%) and TH-01462 (10.07%).

Alegbejo and Banwo (2006) found, when evaluated 16 tomato cvs for resistance to local strains of TLCV (TYLCV) at Samaru, Northern Guinea Savanna, during the 1998/99 and 1999/2000 dry seasons that, 5 cvs were moderately resistant, 9 were moderately susceptible, while 2 were highly susceptible. Most of the cultivars were high yielding (46-55 t/ha) and had good fruit size (4.8-6.0 cm × 2.8-4.1 cm).

Muqit *et al.* (2006) evaluated 15 tomato cvs for resistance to TYLCV under natural field condition in Bangladesh for two consecutive years (2003-04 and 2004-05). None of the varieties tested

were resistant to TYLCV. Only 4 varieties, namely, BINA-3, BARI-1, BARI-2 and BARI-11, were found to be moderately resistant.

In a study conducted by Chomdej *et al.* (2007) to screen and breed a new resistant cultivar to Thailand isolate (TYLCTHV-[2]), sixteen-tomato accessions from the AVRDC, Taiwan were screened for resistance. The accessions expressing the resistant genotypes were then crossed to the TYLCV-susceptible female parent, Seeda3 (SD3), to generate F_1 progenies. Tomato parents and their F_1 progenies were inoculated with TYLCTHV-[2] at 3 weeks old using whitefly as the inoculation vector. Disease response of the plants was rated according to the incidence and severity of the development of viral yellowing and curling symptoms. The presence of viral protein in the inoculated plants was confirmed by Enzyme-Linked Immunosorbent Assay (ELISA). AVRDC tomato parental lines FLA591-15, H24, CLN2443C, TLB111, TLB111-F6-4-1, and TLB130-F6-3-1, and F_1 progenies of SD3 × TLB130-F6-3-1 expressed little or no symptom at all at one month after inoculation. Serological detection by ELISA readings correlated perfectly with physical observation of the genotype.

Abdel-Ati (2008) evaluated 9 accessions of *S. lycopersicum*, 4 of *S. lycopersicum* var. *cerasiforme*, one of *S. peruvianum* × *S. lycopersicum*, 11 of *S. habrochaites*, 13 of *S. peruvianum*, and 17 of *S. pimpinellifolium*. None of the evaluated accessions of *S. lycopersicum* and *S. lycopersicum* var. *cerasiforme* was resistant to TYLCV. *S. peruvianum* × *S. lycopersicum* PI 306812, *S. habrochaites* LA 1777, *S. peruvianum* PIs 390669, 390670 and 390682, and TMV sél INRA and

S. pimpinellifolium PIs 407544 sels A and C showed apparent resistance to TYLCV infection.

Azizi *et al.* (2008) assessed 134 accessions of *S. lycopersicum* and six accessions of *S. peruvianum* for resistance to an Iranian isolate of TYLCV. Plants were inoculated using whiteflies and the reaction of plants was evaluated based on either disease symptoms or viral DNA amplification. All accessions of *S. lycopersicum* had demonstrated various degrees of disease symptoms. However, all six accessions of *S. peruvianum* were resistant and remained symptomless. Phenotypic evaluation was confirmed by amplification of a 670bp TYLCV DNA fragment in all tested accessions of *S. lycopersicum*. Based on both phenotypic and molecular evaluations, no accession provided complete resistance to TYLCV, whereas nine accessions were assessed as tolerant. The high level of resistance noted in whitefly inoculated accessions of *S. peruvianum* was not observed in graft inoculated plants of these accessions. The TYLCV DNA fragment was detected five weeks post inoculation when plants were inoculated by grafting. These results suggested that accessions of *S. peruvianum* may be merely resistant to vector inoculation of TYLCV.

2. Genetics of resistance/tolerance

The number of genes that were found controlling resistance to TYLCV varied among studies due to the following reasons:

1. Different source of resistance (Hassan *et al.*, 1984b, Hassan and Abdel-Ati, 1999; Mahmoud, 2004).
2. Different species and isolates of the virus in different geographical areas (Maruthi *et al.*, 2003; Castro *et al.*, 2005).

3. Variation in reaction to TYLCV within some accessions, especially, in those of *S. pimpinellifolium* (Hassan *et al.*, 1982; Hassan and abdel-Ati, 1999, Mahmoud, 2004; Abdel-Ati, 2008).

a. Resistance/tolerance derived from *S. chilense*

Michelson *et al.* (1994) and Zamir *et al.* (1994) reported that TYLCV tolerance derived from LA 1969 was controlled by one major partially dominant gene, named *Ty-1*, and mapped to chromosome 6, and two modifier genes mapped to chromosomes 3 and 7.

Ji and Scott (2006) and Ji *et al.* (2007) reported that resistance derived from accession LA 2779 was controlled by one partially dominant gene, termed *Ty-3*, and mapped to chromosome 6 near to the gene *Ty-1*.

Also, Ji *et al.* (2008 and 2009) mapped a new TYLCV-resistance locus, termed *Ty*-4, on the long arm of chromosome 3 in advanced breeding lines derived from the resistant accession LA 1932.

Vidavsky *et al.* (1998) indicated that tolerance derived from accession *S. peruvianum* EC104395 was controlled by 3 genes with no dominance effect.

b. Resistance/tolerance derived from *S. galabagense*

A recessive and/or polygenic resistance has been derived from accession LA 1401 of *S. galabagense* (Hassan *et al.*, 1984b) and NSH was low, being 44%.

c. Resistance/tolerance derived from *S. habrochaites*

Resistance derived from *S. habrochaites* LA 386 was dominant and controlled by more than one gene (Hassan *et al.*, 1984b), while that

from *S. habrochaites* f. *glabratum* B 6013 was dominant, but controlled by 2 epistatic genes segregating in the F_2 into 13 resistant : 3 susceptible (Banerjee and Kalloo, 1987a). Hanson *et al.* (2000), mapped resistance gene named *Ty-2* in this accession at the end of the chromosome 11.

Vidavsky and Czosnek (1998) studied the inheritance of resistance and tolerance to TYLCV in two lines (BC_1F_4) that were derived from a cross between F_1 (*S. habrochaites* LA 386 × LA 1777) and *S. lycopersicum*. Tolerance was controlled by a dominant major gene and resistance by two to three additive recessive genes.

Nainar and Pappiah (2002c) found that resistance in *S. habrochaites* was controlled by three recessive genes.

Mahmoud (2004) found that resistance derived from accession *S. habrochaites* f. *glabratum* PI 126445 was controlled by two recessive genes, and BSH was 76.3%.

d. Resistance/tolerance derived from *S. pennellii*

Hassan and Abdel-Ati (1999) and Mahmoud (2004) found that tolerance derived from accession *S. pennellii* LA 716 is controlled by 4 recessive genes, and BSH estimation was moderate, being 70.4% and 82.8% in the two studies, respectively.

e. Resistance/tolerance derived from *S. peruvianum*

Resistance derived from accession *S. peruvianum* PI 126935 was found to be recessive and controlled by 5 genes (Pilowsky and Cohen, 1990). Additionally, resistance derived from accessions PI 126926, PI 126930, PI 390681, and LA 441 was controlled by three

genes, one with partial dominance and the others recessive (Friedmann *et al.*, 1998).

Recently, Anbinder *et al.* (2009) found that TYLCV resistance in TY-172, originating from resistant lines PI 126926, PI 126930, PI 390681, and LA 441, was controlled by a major quantitative trait locus (QTLs), termed *Ty-5*, and mapped to chromosome 4, in addition to four other minor QTLs that originated from resistant or susceptible parents, and mapped to chromosome 1, 7, 9, and 11.

f. Resistance/tolerance derived from *S. pimpinellifolium*

Results of genetic studies on tolerance derived from the species *S. pimpinellifolium* are often contradictory.

Most of the previous studies showed that resistance is monogenic with complete dominance in accessions LA 121, LA 1582 (Yassin, 1985 and 1987), LA 1478 (Geneif, 1984), and Hirsute-INRA in which the symbol *Tylc* was proposed (Kasrawi, 1989); incomplete dominance in A 1921 (named *Tlc*) (Banerjee and Kalloo, 1987a) and LA 121 (Pilowsky and Cohen, 1974); and recessive in accessions Hirsute (Vidavsky *et al.*, 1998) and UPV16991 (Castro *et al.*, 2007). However, in a few studies resistance was quantitatively inherited with partial dominance gene action in accessions LAs 121 and 722 (Mahmoud, 2004) or partially recessive gene action in accessions LA 121 and LA 373 (Hassan *et al.*, 1984a) or with some dominance (Kasrawi and Mansour, 1994). Hassan and Abdel-Ati (1999) found that resistance derived from accessions PIs 407543 and 407544 was controlled by 3 genes with complete dominance and from PI 407555 by 3 genes with partial dominance. In another study, Mahmoud (2004)

found that resistance derived from accession LA 1478 is controlled by 2 genes with partial dominance.

Broad sense heritability (BSH) for TYLCV resistance was estimated by Hassan and Abdel-Ati (1999) as 61.4%, 50.2% and 59.7% for PIs 407543, 407544, and 407555, respectively and by Mahmoud (2004) as 72.2%, 45.0%, and 80.8% for LAs 121, 722, and 1478, respectively. Meanwhile, narrow sense heritability (NSH) was estimated as 52%, 27% (Hassan *et al.*, 1984a), 46.1%, 28.5% and 33.0% (Hassan and Abdel-Ati, 1999), respectively, for LA 121, LA 373, PI 407543, PI 407544, and PI 407555.

3. Breeding efforts to produce resistant or tolerant cvs

No resistance to TYLCV was found in cultivated *S. lycopersicum* (Picó *et al.*, 1999; Pilowsky and Cohen, 2000), but some cvs showed low susceptibility to infection (Hassan *et al.*, 1991; Laterrot, 1993). Therefore, breeding programs have been based mainly on the transfer of resistance genes from accessions of wild species into the domesticated tomato. Attention was particulary given to *S. galapagense*, *S. chilense*, *S. habrochaites*, *S. pennellii*, *S. peruvianum*, and *S. pimpinellifolium*. The urgency to solve the TYLCV problem led to satisfactory introgression of TYLCV-resistance genes from some of these wild relatives. However, progress in breeding has been relatively slow, due to the following reasons:

1. The complicated genetics of resistance to TYLCV, which probably explains why the cultivars and breeding lines developed are most often not as protected as wild species

(Vidavsky and Czosnek, 1998; Hassan and Abdel-Ati, 1999; Mahmoud, 2004).

2. The unavailability of a simple and reliable method for assessment of resistance (Lapidot and Friedmann, 2002; Lapidot *et al.*, 2006).
3. The different response of various sources of resistance against different TYLCV isolates from different geographical areas (Maruthi *et al.*, 2003; Castro *et al.*, 2005).
4. Difficulties in interspecific crosses between wild species, especially between each of *S. chilense* and *S. peruvianum* and cultivated tomato.
5. Agronomic traits that must be recovered from susceptible tomato cultivars to satisfy consumer preferences and industrial demand.

After more than 20 years of breeding efforts in research centers, universities, and seed companies, advanced breeding lines with high levels of resistance from *S. peruvianum*, *S. chilense*, *S. habrochaites*, *S. pimpinellifolium*, and *S. galapagense* have been developed by different breeding teams and are used extensively to breed high quality F_1 hybrids. In addition, a number of resistant F_1 hybrids have been released for commercial production by several seed companies.

The following review represents the efforts of tomato breeders to transfer the resistance genes from resistant wild species to cultivated tomato to produce cultivars and breeding lines resistant to TYLCV.

a. Resistance introgressed from *S. peruvianum*

Resistance in this species, which is quantitative and recessive, allows delay of the onset of symptoms and reduces the accumulation of viral DNA (Rom *et al.*, 1993) or non-appearance of symptoms (Friedman *et al.*, 1998).

In Egypt, Hassan *et al.* (1987) developed a resistant breeding line from an interspecific cross of *S. lycopersicum* cv. Mortelglan × CMV sél INRA (PI 126926 × PI 128648–6).

A breeding program initiated in 1977 at the Volcani Center in Israel for transfer of resistance genes from accession PI 126935 to cultivated tomato, resulted in the commercial hybrid TY-20 in 1988 (Pilowsky and Cohen, 1990). Resistance in this hybrid delays symptoms expression and viral DNA accumulation in infected plants, resulting in acceptable yields. Subsequently, highly resistant breeding lines, *viz.*, TY-172, TY-197, TY-198, and TY-536 were developed from accessions PI 126926, PI 126930, PI 390681, and LA 441 (Friedmann *et al.*, 1998; Lapidot *et al.*, 1997)

Genes from *S. peruvianum* are presently deployed in commercially grown hybrids that have provided good resistance to TYLCV (Czosnek, 2007).

b. Resistance introgressed from *S. chilense*

Resistance genes carried in introgressions from *S. chilense* are important in several breeding programs around the world (Mejía *et al.*, 2005; Pinón *et al.*, 2005; Scott, 2001; Scott *et al.*, 1996; Zakay *et al.*, 1991).

Michelson *et al.* (1994) and Zakay *et al.* (1991) reported high resistance to TYLCV, which reduces the accumulation of the virus and its transmission in plants with no appearance of symptoms, from some accessions of this species, particularly accession LA 1969. Introgression of TYLCV resistance from LA 1969 was also carried out in breeding programs worldwide (Chiang *et al.*, 1994; Laterrot & Moretti, 1994; Zamir *et al.*, 1994). Resistance has been introgressed into the cultivated tomato from LA 1969 by some private seed companies and the resistance is located in a chromosome 6 region that includes *Ty-1* and possibly another linked resistance locus (Czosnek, 2007).

Czosnek *et al.* (1993) developed a TYLCV-tolerant line, *viz.*, FA4, which was a BC_2F_4 line from *S. lycopersicum* × *S. chilense* LA 1969. Also, Zamir *et al.* (1994) produced tolerant tomato cv. TY-52, which carried the gene *Ty-1* that was transferred from accession LA 1969.

The Chiltylc 92 is a BC_1F_2 population derived from self-pollination of the cross ((Momor verte × LA 1969) × Tropiva 3). Selection and subsequent backcrosses to the hybrids Ty-king and Fiona led to the development of Chiltylc 93 and Chiltylc 94, respectively (Laterrot & Moretti, 1994).

Vidavsky *et al.* (1998) produced breeding lines chil 1 (tolerant - free of symptoms) and chil 2 (moderate tolerant - slight symptoms) from LA 1969.

Gómez *et al.* (2004) produced four resistant lines; *viz.*, LD 3, LD 4, LD 5 and LD 6, by an interspecific cross between LA 1969 with tomato followed by four backcrosses to tomato.

Picó *et al.* (1999), through a backcrossing program (5-7 backcross generations) conducted on the first-generation hybrids *S. lycopersicum* × *S. chilense* accessions LA 1932 and LA 1938, produced 6 breeding lines (UPV Ty-1, 3, 6, 9, 17 and 35) with high resistance to the virus. These lines under high inoculum pressure conditions suffered only 30 to 40% yield loss relative to non-infected control plants, and also exhibited appropriate horticultural characteristics for the fresh market tomato industry, and were considered good base material for obtaining commercial hybrids highly resistant to TYLCV.

Currently, several commercial breeding programs are using resistance genes from *S. chilense* and horticulturally acceptable cultivars are being marketed. Among these cultivars are Anastasia, Boludo, Carmencita, Titrit, Llanero, Tygress (Czosnek, 2007), DRW 5833, DRW 8137, and FLA565 (Pietersen and Smith, 2002).

c. Resistance introgressed from *S. habrochaites*

Zakay *et al.* (1991) examined wild tomato species *S. chilense*, *S. habrochaites*, *S. peruvianum*, and *S. pimpinellifolium* for viral DNA and symptom expression following inoculation with TYLCV. Approximately 85 days after inoculation, all inoculated species were infected and had detectable levels of viral DNA, but *S. chilense* and *S. habrochaites* remained symptomless and with low levels of viral DNA.

Vidavsky and Czosnek (1998) selected TYLCV-resistant plants from LA 386 and LA 1777, and these plants were crossed to produce a

highly resistant F_1 population, which was used in crosses with *S. lycopersicum*. The resulting tolerant interspecific F_1 plants were backcrossed to the cultivated tomato. Through a series of self pollinations and phenotypic selection for resistance to TYLCV, plants with immunity and tolerance were generated and produced several resistant (902 and 910) and tolerant lines (901-1, 901-2, 906-7, 908, 913). The line 902 had been used in the production of the hybrid FAVI9 which was an important source of resistance in many breeding programs in Guatemala (Mejía *et al.*, 2002 and 2005) and some countries in the Middle East (Maruthi *et al.*, 2003). Also, it has been used in producing other hybrids, *viz.*, FAVI13, FAVI15, FAVI17, and FAVI18 (Vidavsky and Czosnek, 1998).

Mejia *et al.* (2002) selected F_6 resistant lines from line FAVI-9, *viz.*, F_6-2211 and F_6-5221, under natural conditions in Guatemala, where four begomoviruses occur. These lines were crossed with a high yielding line but susceptible to begomoviruses, *viz.*, HC7880. The experimental hybrids H1 (F6-2211 × HC7880) and H2 (F6-5221 × HC7880) showed mild viral symptoms, which indicated that resistance is dominant. These hybrids yielded about three times the susceptible cv. Marina.

In India, Kalloo and Banerjee (1990b) developed breeding line H24 from accession *S. habrochaites* f. *glabratum* B6013, in addition to 5 other breeding lines, *viz.*, H2, H11, H17, H23, and H36. "H24" which has been shown to carry the resistance gene *Ty-2* (Hanson *et al.*, 2000&2006). "H24" confers specific tolerance to some, but not all isolates of TYLCV/ToLCV. It is tolerant to TYLCV/ToLCV strains in

Taiwan, northern Vietnam, South India, and Israel but susceptible to TYLCV strains from northern India, Thailand, and the Philippines. *Ty-2* resistance gene was the initial source of resistance used in tomato breeding program at the AVRDC and has been extensively exploited by some seed companies in Asia and elsewhere. It has been used in producing new highly resistant tomato cvs, such as TLB111, and TLB130, and TLB182 (Muniyappa *et al.*, 2002).

Using resistance to TYLCTHV-[2] in accession L6112, Chomdej *et al.* (2008) selected resistant BC_1F_1 lines, *viz.*, 04T105-7, 04T105-1, 04T105-10, 04T109-4 and 04T104-1, which showed TYLCV resistance comparable to that of the parental line L60112. However, several unfavorable characteristics were expressed regarding fruit size, color and shape, for these lines.

d. Resistance introgressed from *S. pimpinellifolium*

Even though resistance has been detected in various accessions of this wild species, it has not become a major source of resistance genes in current breeding programs.

Kalloo and Banerjee (1990a) developed 4 tolerant breeding lines (LCP-2, and LCP-3, LCP-9, and LCP-22) through transfer of resistance gene from accession A 1921 into tomato cvs HS 101, HS 102, and Punjab Chhuhara.

The Pimpertylc population was created by crossing *S. pimpinellifolium* plants from accessions hirsute-INRA and LA 1478 (Laterrot, 1992), which had been selected for resistance in different countries.

Czosnek *et al.* (1993) developed a TYLCV-tolerant line, *viz.*, FA 119, which was a BC_3F_4 line from *S. lycopersicum* × *S. pimpinellifolium*.

Vidavsky *et al.* (1998) produced two breeding lines, *viz.*, pim-1 (tolerant - free of symptoms) and pim-2 (moderately tolerant - mild symptoms and late) through transfer of resistance genes of accession Hirsute.

A breeding program was developed from an initial *S. lycopersicum* × *S. pimpinellifolium* UPV16991 cross (Castro *et al.*, 2007). This first cross was followed by several selfing generations. Selection for resistance to TYLCV and Tomato yellow leaf curl Sardinia virus (TYLCSV) was carried out for plants of each generation. One partially resistant F_6 plant, named L102, was chosen to form a family to study the genetic control of resistance to TYLCV.

e. Resistance introgressed from *S. galapagense*

This species has not been a significant source of resistance in breeding programs as like other species. In Egypt, a moderately resistant breeding line (line 44) was derived from introgression of resistance genes from *S. galapagense* with the commercial cv. Pakmor B (Moustafa and Nakhla, 1990).

f. Pyramiding of TYLCV-resistance genes

Despite efforts undertaken by different research groups, there are no immune commercial plant materials available. Most of the cultivars and breeding lines available today present variable degrees of tolerance to some, but not all isolates of TYLCV, they are either

symptomless or present mild symptoms, and have relatively good yields and fairly good fruit quality.

Pyramiding the chromosomal regions associated with resistance in the lines from different origins will improve the degree of resistance to TYLCV and will broaden the resistance against a wider range of begomoviruses. The strategy followed to incorporate high levels of begomovirus resistance in common bean, strictly through intraspecific recombination and pyramiding of different resistance traits found in diverse gene pools of *Phaseolus vulgaris*, confirms the feasibility of this approach (Blair *et al.*, 1993). However, there are both direct and circumstantial evidence indicating the existence of adequate genetic variability in the primary and secondary gene pools of most cultivated species. This genetic variability can be exploited within and between cultivated species and their relatives. Interspecific hybridization in tomato can be practiced not only in search of resistance to begomoviruses, but to other pathogens and pests as well (Debouck, 1991). In the case of tomato, it is evident that the cultivars with some degree of TYLCV resistance, also exhibit resistance to distinct bipartite begomoviruses infecting tomato in the Americas and in Asia (Muniyappa *et al.*, 1991; Piven *et al.*, 1995).

The combination of classical breeding together with molecular markers linked to the different sources of resistance will be required in order to facilitate the pyramiding of the resistance genes. It will help the breeder to distinguish between the different sources of resistance and to combine all TYLCV-resistance genes available from the five

main resistance sources in use, *S. chilense*, *S. habrochaites*, *S. galapagense*, *S. peruvianum*, and *S. pimpinellifolium*.

Breeding tomato cultivars for resistance consisted of introgressing the resistance traits from one of the wild tomato species into the domesticated tomato. However, it appears that each breeding program has resistant germplasm with a general combining ability with other resistant sources. In most cases, these lines present excellent agronomical traits (such as yield, fruit size, color, firmness, shelf life, etc.). By combining lines originating from different resistant wild tomato sources, one may shorten the time for breeding commercially valuable tomato resistant to TYLCV, with higher levels of resistance and higher yields than each of the resistant parents (Vidavski *et al.*, 2008).

Kasrawi and Mansour (1994) found that interespecific hybrids obtained from crosses between *S. pimpinellifolium*, *S. peruvianum*, and *S. habrochaites* show different patterns of segregation upon TYLCV inoculation, suggesting the existence of different, complementary genes.

In a breeding project in the Mediterranean region, Laterrot (1990 &1992) and Laterrot and Moretti (1996) produced some TYLCV-resistant lines, *viz.*, Chepertylcv-92 and Pimpertylc J-13, through bulking of resistance genes from species *S. galapagense*, *S. peruvianum* and *S. pimpinellifolium*.

In one of AVRDC's research efforts, a study was conducted for pyramiding of TYLCV-resistant genes, *viz.*, *Ty-1* (source *S. chilense*) and *Ty*-2 (source *S. habrochaites*) into tomato. Their results indicate

that the incorporation of various resistant resources can provide better resistance (AVRDC, 2000).

Moustafa *et al.* (2005) used 7 true-breeding tomato lines having high resistance to TYLCV and good fruit quality characters, *viz.*, line one (Fiona: F_7 7-1), line 2 (Tyking : F_7 2-2), line 3 (F_1 Fiona × F_1 Tyking: F_6 3-1), line 4 (F_1 Fiona × F_1 Tyking : F_6 4-4), line 5 (Chiltylc 93: F_7 2-2-1), line 6 (Chiltylc 93: F_7 2-2-3), and line 7 (Chiltylc 94: F_6 5-4), to produce 8 hybrids, *viz.*, Line 1× Line 6, Line 3 × Line 5, Line 3 × Line 7, Line 4 × Line 6, Line 5 × Line 1, Line 5 × Line 2, Line 5 × Line 6, and Line 5 × Line 7. These hybrids were evaluated along with their parents and two controls, i.e., cv. Castlerock and the hybrid E 448 (Al-Qods). All evaluated lines showed high level of TYLCV resistance than cv. Castlerock. All evaluated hybrids showed high level of TYLCV resistance, and all of them were not significantly different from the check hybrid E 448.

Tomato genotypes with resistance to begomoviruses derived from different wild species were evaluated in Guatemala. Selection of individual plants for several generations resulted in breeding lines with high levels of resistance. Lines with resistance from *S. habrochaites* were Gh1, Gh3, and Gh13 (selected from hybrid Favi 9) and line Gh2 (from hybrid Favi 12). Lines with resistance from *S. peruvianum* were Gper11 (selected from breeding line TY198) and Gper12 and Gper19 (from breeding line TY197). Lines with resistance from *S. chilense* were Gc9 and Gc16 (selected from breeding lines FLA595-2 and FLA658-2BK, respectively). Line Gpimper10 was selected from segregating population Pimper J-13 with resistance derived from *S.*

pimpinellifolium and *S. peruvianum*. Crosses among resistant lines resulted in higher levels of resistance for F_1 populations than crosses between resistant and susceptible lines. Improved breeding lines with begomovirus resistance have been selected from these hybrids (Mejía *et al.*, 2005).

Vidavski *et al.* (2006) reported that the highest level of resistance was obtained from an F_1 902 × TY-172. Unfortunately, there are no confirmed markers for the resistance loci associated with these two sources, but preliminary data indicate that *Ty-3* gene is likely to be one gene associated with these lines. With the availability of PCR-based markers for the three mapped TYLCV resistance genes including *Ty-1*, *Ty-2*, and *Ty-3*, it is promising and relatively facile to bring these genes together in a single genotype to reach the maximum level of resistance. However, since *Ty-1* and *Ty-3* loci are linked, a crossover between them will be required to obtain the resistant alleles in cvs. Hybrid breeding may be one avenue to join the resistant alleles in heterozygous condition. A diallel analysis of different resistance sources did show improved resistance, when different loci were combined heterozygously.

The diallel experiments conducted by Vidavski *et al.* (2008) with sources of begomovirus resistance from Fla-595 (*S. chilense*), TY-172 (*S. peruvianum*), Pim-Hir (*S. pimpinellifolium*), and 902 (*S. habrochaites*) provided evidence that pyramiding of genes will contribute to hybrids with high levels of resistance.

Castro *et al.* (2008) evaluated the level of resistance in plants which combined *S. pimpinellifolium* UPV16991-derived resistance and

the *Ty-1* gene, both in heterozygosis. Most of the hybrids between S. *pimpinellifolium* and *S. chilense*-derived resistant lines exhibited milder symptoms than heterozygotes of either *S. pimpinellifolium* or *S. chilense* derived resistance. In some of the hybrids, viral accumulation was also lower than in respective heterozygotes. Our results support the utility of resistance derived from UPV16991 combined with the *Ty-1* gene in increasing levels of resistance to TYLCD in tomato hybrids.

g. Inheritance of TYLCV resistance in true-breeding resistant tomato lines

Abdel-Ati *et al.* (2005) studied the inheritance of TYLCV resistance in true-breeding tomato lines, *viz.*, line 1 (Fiona: F_7 7-1), 2 (Tyking: F_7 2-2), 4 (F_1 Fiona × F_1 Tyking: F_6 4-4), and 7 (Chiltylc 94: F_7 5-4), in addition to the susceptible cv. Castlerock. Four susceptible × resistant crosses were made. The genetic populations of each cross, *i.e.*, parents, F_1, F_1r, F_2, and backcrosses to both parents were evaluated for TYLCV resistance. There were no significant differences between F_1 and F_1r populations in all crosses, indicating no maternal effect for TYLCV resistance. Two types of dominance were observed for TYLCV resistance in the 4 susceptible × resistant crosses, *viz.*, partial dominance for TYLCV susceptibility in 3 crosses and no dominance for TYLCV resistance in the cross Castelrock × line 4. Minimum number of genes estimated to control TYLCV resistance ranged from 2 to 4 pairs in the susceptible × resistant crosses. BSH estimated for TYLCV resistance ranged from 67.7 % to 74.6% in the four studied crosses.

Mazyad *et al.* (2007) studied the inheritance of TYLCV resistance in line Favi-9, which is derived from *S. habrochaites*, through crossing it as male with 5 TYLCV susceptible tomato cvs, *viz.*, Edkawy, Castlerock, Peto 86, Marmmande, and Strain B as females. Low negative values of potence ratio (ranged between -0.11 to -0.30) were estimated indicating that TYLCV tolerance behaved as partial recessive toward resistant parent. The BSH estimates were high for the crosses Peto-86 × Favi-9, Castlerock × Favi-9 and Marmmande × Favi-9, being 88.38%, 83.27% and 75.64%, respectively. BSH estimates for the two remaining crosses were low, indicating that there is a minor role for the environment on this trait except in crosses Edkawy × Favi-9 and Strain-B × Favi-9. The estimate of minimum number of genes controlling this trait ranged between one to two pairs.

Chomdej *et al.* (2007) found that the resistance to TYLCTHV-2 in AVRDC resistant lines H-24, FLA591-15 and FLA456-4 was incompletely dominant.

4. Production and genetic evaluation of TYLCV resistant/tolerant tomato F_1s

Development of F_1 hybrid dates back to first observation on heterosis in tomato (Hedrick and Booth, 1968). Parents with the best breeding values should be identified prior to the initiation of any breeding program. To determine suitable parents of a cross for the development of a cultivar, combining abilities [General (GCA) and specific combining ability (SCA)] analysis is an ideal technique (Arunachalam, 1976; Baker, 1978). GCA is the average effect of a

parent on the phenotype of its progeny and is equivalent to its breeding value (Kearsey and Pooni, 1996; Lynch and Walsh, 1998).

a. TYLCV resistance/tolerance

A limited literature is available pertaining to combining ability analysis for TYLCV-resistance trait. In general, the results of Dharmatti et al. (1999) and Mazyad *et al.* (2007) indicated the role of non-additive gene action in inheritance of TYLCV-resistance, while results of Prabuddha *et al.* (2008) indicated the importance of additive gene action for this trait. Meanwhile, Hazra and Nath (2008) reported in early autumn season overwhelming revelation of additive genetic component for resistance, whereas in autumn-winter season both additive and dominance gene effects were equally important, seemingly manifesting complicated inheritance of resistance.

Dharmatti *et al.* (1999) noticed high heterosis in crosses with parents having high GCA. Also, Mazyad *et al.* (2007) found that better parent heterosis (heterobeltiosis) values ranged from 112.7 to 128.7. These results mean manifestation of hybrid vigor towards the better parent.

Prabuddha *et al.* (2008) found that line LA 3948 was a good general combiner for TYLCV resistance and whitefly resistance, while the tester Nandi was found to be a good general combiner for whitefly resistance parameters. The cross Nandi × LA 3948 exhibited maximum yield coupled with TLCV and whitefly resistance.

Vidavski *et al.* (2008) selected 6 TYLCV-resistant tomato lines, in which resistance was introgressed from different wild tomato species, and crossed them with each other and with a susceptible line in

a non-reciprocal diallel crossing. The highest level of resistance was achieved by combining together the resistant lines 72-PER (TY-172, derived from *S. peruvianum*) and HAB (H-902, derived from *S. habrochaites*). The 72-PER × HAB hybrid showed a low disease severity index, gave a good yield (9.3 kg/plant), and presented the lowest TYLCV-induced yield loss compared to non-infected plants (46%). Surprisingly, hybrids with the less resistant line PIM (PIMHIR, derived from *S. pimpinellifolium*), showed a high level of resistance when combined with HAB, CHIL (Fla-595-2, derived from *S. chilense*), or 72-PER, and all showed a higher level of resistance than PIM itself, or than the hybrid PIM × susceptible B-117. The combination of the resistant lines emphasized the role of major dominant gene in HAB and CHIL lines. Moreover, it showed a surprising combining ability between PIM and 72-PER.

b. Early fruit yield

Analysis of variance for combining ability of early yield (EY) indicated that mean squares due to GCA and SCA were significant for EY (Mohamed and El-Shabasi, 2003; Dharamveer *et al.*, 2005). Also, Yang *et al.* (2006) reported that mean square due to GCA was more significant for EY.

Mahendrakar *et al.* (2005) postulated that the ratio of GCA:SCA variance indicated that a non-additive genetic component was predominant for EY.

Most of the previous studies showed positive heterosis for EY. Significant positive heterosis of EY based on best-parent value was reported by Babu (1978) and Reddy and Mathai (1979). Kumar *et al.*

(1995) observed 41.6% positive heterosis over superior parents for EY. Bhnan (1998) found that most hybrids expressed positive heterosis for EY. Mohamed and El-Shabasi (2003) found that 6 out of 10 F_1 hybrids showed the highest estimates of heterosis and SCA effects.

c. Total fruit yield

Significant mean sequares due to GCA and SCA have been reported for total yield (TY) (Makesh *et al.*, 2002a; Sharma *et al.*, 2002; Mohamed and El-Shabasi, 2003). Significant estimates in GCA and SCA variances have been reported by Ali *et al.* (1989), Bhatt *et al.* (2001b), and Cheema *et al.* (2003). Both additive and non-additive gene effects were involved in the inheritance of TY (Makesh *et al.*, 2002b; Dhaliwal *et al.*, 2002).

Reports are available on non-additive gene action (Dharmatti *et al.*, 2001; Chadha *et al.*, 2001). The majority of the researchers described non-additive gene action being more pronounced for genetic determination of TY as a mode of inheritance (Kryuchkov *et al.*, 1992; Srivastava *et al.*, 1998; Dhaliwal, 2000; Thakur and Joshi, 2000; Bhatt *et al.*, 2001 a&b; Roopa *et al.*, 2001; Kaur *et al.*, 2004; Dhaliwal *et al.*, 2004; Mahendrakar *et al.*, 2005; Singh and Singh, 2005). Additionally, the involvement of additive as well as non-additive gene action have been reported in the inheritance of TY (Natarajan, 1992; Surjan *et al.*, 1999; Makesh *et al.*, 2002a). The magnitude of additive gene action was higher than the non-additive one (Surjan *et al.*, 1999), or lower (Dhankhar and Dhankhar, 2002). Preponderance of additive type gene action has been reported (Kalloo *et al.*, 1974; Garg *et al.*, 2007&2008).

High heterosis has been observed in crosses involving parents with high GCA status (Dharmatti *et al.*, 2001). The specific combining estimates of most of crosses were related to the general combining ability gene effects of their parents and the best cross combination in all characters involved at least one parent with high GCA effect (Thakur and Joshi, 2000; Kumar *et al.*, 1997). On the contrary, the best cross combination did not necessarily involve good general combiner as their parents (Sharma *et al.*, 1999). Maximum heterosis has been achieved by successful combination of high SCA and GCA effects (Kryuchkov *et al.*, 1992).

Positive heterosis for TY has been shown in all hybrids produced by Bhnan (1998), and 58.5% heterosis has been reported by Hegazi *et al.* (1995). Also, positive significant heterosis of 41.97%, 157.84% and 28.94%, respectively, over the high parent, the better parent, and commercial control have been indicated (Bhatt *et al.*, 2001b).

Concerning the number of combinations depicting heterosis, 38 crosses out of 45 showed heterosis over their best parents, two of them by 117.7 and 138% (Diaz and Miksh, 1985). Mandal *et al.* (1992) reported that 11 out of 17 hybrids evaluated showed significant heterosis for TY. Sidhu and Singh (1993) found that the estimates of heterosis in 55 hybrids were significant in 11 of them and ranged from 23.8 to 71.7%. Also, Bora *et al.* (1993) found significant heterosis for TY over the better parent in 11 out of 19 hybrids evaluated. Heterobeltiosis for TY have been recorded after crossing 10 genotypes in a half diallel fashion (Fageria *et al.*, 2001). Out of 40 F_1s, 6 (15%)

showed good specific combining ability for TY (Chadha *et al.*, 2001). According to line × tester analysis, 16 F_1s out of 34 (47%) showed heterobeltiosis (Joshi and Thakur, 2003). Also, 7 crosses out of 28 exhibited significant heterobeltiosis (Thakur *et al.*, 2004). Significant heterosis for TY was found under open and greenhouse environment over mid-parent point and higher parent (Bhatt *et al.*, 2004).

d. Average fruit weight

Preference for a given size and weight of tomato varies among consumers and depends to some extent on the desired use of the tomato fruits. The range of fruit size and weight varies among cultivars starting from cherry types (15 g) to beef steak types (450 g) (Ho and Hewit, 1982).

Highly significant GCA and SCA mean squares have been reported for average fruit weight (AFW), however, the GCA mean square values were higher than SCA indicating prevalence of wide variability and a high degree of additive variance (Sharma *et al.*, 2002; Pratta *et al.*, 2003). Significant GCA and SCA variances have been reported (Chandrasekhar and Rao, 1989; Ali *et al.*, 1989).

Both additive and non-additive gene effects were found important in the inheritance of AFW (Natarajan, 1992; Dhaliwal *et al.*, 2002; Makesh *et al.*, 2002b; Cheema *et al.*, 2003; Ali *et al.*, 1989), but the magnitude of additive gene effect was more (Surjan *et al.*, 1999) and prevailed (Kumar *et al.*, 1997; Pratta *et al.*, 2003; Garg *et al.*, 2007 and 2008). On the contrary, GCA/SCA ration indicated the greater role of non-additive gene effects (Roopa *et al.*, 2001; Dhaliwal *et al.*, 2004). Heritability estimates and genetic advance were high for AFW.

Some hybrids showed positive heterosis, others had no heterotic effect and others had negative heterosis. Heterosis over better parent (52%), mid parent (90%) and control (81%) has been recorded (Akhilesh and Lal, 2004). Positive heterosis has been also recorded (Araujo and Campos, 1991; Kumar *et al.*, 1995). Concerning number of combinations evincing heterosis, 9 crosses out of 28 (32%) exhibited varying degrees of heterosis (Thakur *et al.*, 2004). However, negative heterobeltiosis was reported (Bhnan, 1998; Fageria *et al.*, 2001). On the contrary, Diaz and Mikcsh (1985) didn't observe any heterosis for AFW for 45 F_1 hybrids evaluated.

e. Fruit shape index

Tomato cultivars differ greatly in fruit shape, as fruits may be spherical, oblate, oblong, cylindrically elongated or pear like. Fruit shape index (FSI) is the ratio between fruit length and fruit diameter. Fruit length is the polar diameter, while fruit width is the equatorial diameter.

Significant GCA and SCA mean squares have been reported (Mohamed and El-Shabasi, 2003). Garg *et al.* (2007 and 2008) and Chadha *et al.* (2002) indicated from a line × tester analysis the importance of additive gene effect for FSI, while, results of Sharma *et al.* (2007) and Singh and Singh (2005) indicated the preponderance of non-additive genetic component for this character. Also, Joshi and Kohli (2006) reported that the ratio of additive to dominance variance indicated the predominance of non-additive gene actions.

Significant positive heterosis of FSI based on mid-parent values was reported in only 5 out of 45 hybrids, and high-parent heterosis

ranged from 7.36 to 30.89% (Abd-Allah, 1995). Also, Hegazi *et al.* (1995) found that 4 out of 21 F_1 hybrids showed positive heterosis for FSI over their high parents. Meanwhile, negative heterosis was evident in most of hybrids tested by Youssef (1997) and Bhnan (1998).

The Heritability estimates in narrow sense was observed low for FSI, indicating that direct selection for these traits may be ineffective as the trait was largely governed by dominant genes (Joshi and Kohli, 2006).

f. Ascorbic acid content

Analysis of variance for combining ability indicated that mean squares due to GCA and SCA were significant for ascorbic acid content (AAC) (Gaikwad *et al.*, 2002; Makesh *et al.*, 2002a; Mohamed and El-Shabasi, 2003; Yang *et al.*, 2007).

From a line × tester analysis, the non-additive genetic variance was predominant for AAC (Kumar *et al.*, 1997; Dhatt *et al.*, 2001; Roopa *et al.*, 2001; Garg *et al.*, 2007 and 2008). Also, Joshi and Kohli (2006) and Kumar *et al.* (1997) reported, from a diallel analysis, that the ratio of additive to dominance variance indicated the predominance of non-additive gene actions for AAC. Meanwhile, Makesh *et al.* (2002a) and Bhatt *et al* (2001b and 2004) reported that additive and non-additive gene effects had significant effects on the inheritance of AAC. However, the degree of dominance (σ^2g/σ^2s) revealed the prevalence of a non-additive gene effect (Bhatt *et al.*, 2001a). Also, Bhatt *et al.* (2004) found that the proportion of GCA × environment interaction variance was greater than that of the SCA × environment

variance estimates, and additive genetic variances were more sensitive than non-genetic variances to changing environments.

Positive high significant heterosis was found for ascorbic acid, being 16.68, 54.57 and 161.33% over the top parent, better parent and commercial control, respectively (Bhatt *et al.*, 2001b). Six out of 10 F_1 hybrids showed the highest heterosis estimates and SCA effects (Mohamed and El-Shabasi, 2003). Also, Bhnan (1998) found that some hybrids gave positive heterosis, while others gave negative heterosis for this trait. On the contrary, Chen and Zhao (1990) found that heterosis for ACC was non-significant.

Environmental interactions indicated that environment had a significant role in the expression of ACC (Sharma et al. 2006). Yang *et al.* (2007) found that the broad and narrow heritabilities of AAC were low. Also, Joshi and Kohli (2006) found that heritability estimates in narrow sense was low for ACC. Thus, the direct selection for these traits may be ineffective as the trait was largely governed by dominant genes (Joshi and Kohli, 2006).

g. Fruit pH value

The mean squares due to GCA and SCA were highly significant for fruit pH trait (Sharma *et al.*, 2002; Chishti *et al.*, 2008) and mean squares value for GCA was higher than SCA, indicating the prevalence of wide variability and a high degree of additive variance (Sharma *et al.*, 2002). In a line × tester analysis, importance of additive gene effect has been revealed (Dhatt *et al.*, 2001; Garg *et al.*, 2007), and both of additive and non-additive gene effects have been revealed (Dhaliwal *et al.*, 2003b).

Most of the first cross hybrids produced an average pH value either too close to the mid-parental value or deviated towards the smaller parental pH value (Khalaf-Allah *et al.*, 1985). In a study involving 20 hybrid combinations, 13 F_1 showed negative transgressive heterosis, whereas positive transgressive heterosis was observed in 2 F_1s (Chen and Zhao, 1990).

h. Fruit titratable acidity

Analysis of variance for combining ability indicated that mean squares due to GCA and SCA were significant for fruit titratable acidity (TA) (Chandrasekhar and Rao, 1989; Gunasekera and Perera, 1999; Dhaliwal *et al.*, 2001; Alwis *et al.*, 2005; Pandey *et al.*, 2006; Yang *et al.*, 2007), and this result indicated the importance of both additive and non-additive genetic components. Gaikwad *et al.* (2002) found in a line × tester analysis of variance for combining ability that variances due to the lines used and the line × tester interactions were non-significant for TA, whereas the variance due to the testers used were significant.

The magnitude of GCA and SCA variance indicated the importance of additive as well as non-additive gene action (Dhaliwal *et al.*, 2003a; Sharma *et al.*, 2006) or with predominance of non-additive action for TA (Pandey *et al.*, 2006). In a line × tester analysis, the non-additive genetic variance was predominant for TA (Kumar *et al.*, 1997; Dhatt *et al.*, 2001; Garg *et al.*, 2007 and 2008). Meanwhile, Gunasekera and Perera (1999) and Yang *et al* (2007) reported that the additive genetic variance was predominant for TA. The result of a line × tester analysis conducted by Gunasekera and Perera (1999) indicated that

heterobeltiosis for TA was evident. Hayman's analysis of variance indicated significant additive genetic variation as well as dominance. Possible epistatic effects were also observed for TA. Overdominance was not observed in TA indicating that heterobeltiosis was due to dispersion of genes in the parents. Although these results indicated that superior hybrids could be selected for TA, the significant additive genetic variance and the absence of overdominance indicate that equally good or even better inbred lines could be obtained from these hybrids in future improvement programmes.

SCA effects were significant and positive in 7 crosses for TA (Chandrasekhar and Rao, 1989).

SCA effects for most crosses were related to the GCA effects of their parents, and the best cross combinations for TA trait involved at least one parent with high GCA effects. Hence high GCA effects can be used as criteria in selection of desirable parents for heterosis breeding when processing characters (Kumar *et al.*, 1997).

Positive heterosis was found in some of the F_1 hybrids evaluated for TA (Babu, 1978; Patil and Patil, 1988; Abd-Allah, 1995; Youssef, 1997; Bhnan, 1998).

Environmental interactions indicated that environment had a significant role in the expression of TA (Sharma *et al.*, 2006). The broad and narrow heritabilities of TA were low (Yang *et al.*, 2007).

i. Total soluble solids

The efforts to develop varieties for higher fruit solids have not been easy because of the existence of a negative relationship between yield and solids contents. Also, successful selection for high solids

progeny in a segregating population is difficult due to the environmental impact on this character (Allen Stevenes and Rick, 1986).

Stoner and Thompson (1966) used an eight parents diallel with four large and four small fruited tomato lines to study the inheritance of solids in tomato fruit. Their results indicated the existence of dominant genes for high solids and showed that these genes can have rather large effect. Mean square due to GCA and SCA were significant (Makesh *et al.*, 2002a). GCA and SCA variances were high and significant, indicating the importance of both additive and non-additive gene action as has been reported by Dhaliwal *et al.* (1999&2003a) and Bhatt *et al.* (2001b). Meanwhile, non significant GCA and SCA variances were reported by Cheema *et al.* (2003). Variance due to lines and testers and line × tester interaction were non significant (Gaikwad *et al.*, 2002). As both GCA and SCA effects were significant, this indicated the importance of pure line and heterosis breeding (Dhaliwal *et al.*, 1999). The ratio of σ^2_s / σ^2_g indicated a greater role of none-additive gene effects (Dhaliwal *et al.*, 2004). Since non-additive gene action is dominant, heterosis breeding is recommended (Kumar *et al.*, 1997; Kalloo *et al.*, 1974). Additive and non-additive gene effects have been observed while non-additive gene effects were more pronounced (Dhaliwal *et al.*, 2000). The prominent role of non-additive effects was observed with over dominance toward higher total soluble solids (TSS) (Thakur and Kohli, 2005).

In some studies, all F_1 hybrids evaluated surpassed their parents in TSS and showed positive heterosis (Khalil, 1979; Conti *et al.*, 1990).

In other studies, only some of the studied hybrids showed positive heterosis (Babu, 1978; Sonone *et al.*, 1981; Patil and Patil, 1988). Positive, highly significant heterosis of 25.97, 11.93 and 19.02% over the top, better, and commercial control, respectively, have been recorded for TSS (Bhatt *et al.*, 2001b). High heterosis was observed over better parent (19.20%), mid parent (22.90%) and the control (35.50%) (Akhilesh and Lal, 2004). Also, Bhnan (1998) found that some hybrids gave positive heterosis, while others gave negative heterosis for this trait. In 2 out of 28 F_1 hybrids (7%), significant positive heterosis for TSS (23.19% and 15.93%) have been recorded (Patgaonkar *et al.*, 2003). Zhou and Xu (1990) reported that 3 F_1 hybrids showed positive transgressive heterosis, whereas, negative transgressive heterosis was observed in 6 others. On the contrary, Khalil *et al.* (1988) and Chen and Zhao (1990) found that heterosis for TSS content was non-significant.

5. Evaluation of TYLCV resistant/tolerant tomato genotypes for yield and fruit quality

a. Yield

Varma *et al.* (1980) evaluated some tomato cvs under field and greenhouse conditions for TYLCV (Indian strain) resistance and yield. Resistant tomato line EC 104395 gave the highest yield over other tested cvs.

Moustafa and Nakhla (1990) developed two TYLCV-resistant tomato lines, *viz.*, 44 and 53. Both lines produced reasonable yield of tomato fruits with good horticultural characteristics under conditions of natural field infection.

According to Hassan *et al.* (1991) visual field observation indicated good yielding potential in 17 tomato PIs, *viz.*, 406868, 432946, 432947, 433116, 433145, 433171, 433191, 435339, 451963, 451970, 451983, 451985, 452015, 452020, 452025, 466915, and 466917. These PIs were relatively heavy yielders in spite of the widespread severe infection with TYLCV in the field trail which included 1720 *S. lycopersicum* accessions.

Moustafa and Hassan (1993) evaluated 17 true-breeding tomato cvs reported to be tolerant to TYLCV, and 4 recently released TYLCV-tolerant hybrids for yield, quality, and virus tolerance in comparison with the locally grown cv. Castlerock. Results obtained showed that the hybrids TY-20, BB 234, BB 235, and Typhoon were significantly higher yielding than cv. Castlerock under conditions of heavy natural infection.

The effect of TYLCV on total yield and yield components of various resistant F_1 tomato cvs and new breeding lines was studied by Lapidot et al. (1997). The evaluated genotypes were inoculated with TYLCV by means of whitefly vector in the first-true leaf stage. Non-inoculated plants of the same cultivar or line served as controls. There were substantial differences among the different entries tested in the extent of yield loss relative to the corresponding non-inoculated control plants. Plants of TY-172 and TY-197 suffered the least relative yield loss and exhibited the highest level of resistance.

Picó *et al.* (1999) selected six advanced breeding lines (UPV TY 1, 3, 6, 9, 17, and 53) that exhibited a high level of resistance to TYLCV-Sr. Under high inoculum pressure, these lines suffered only

30-40% yield reduction relative to non-infected control plants, compared with 90 -95% yield losses in susceptible controls.

Vidavski *et al.* (2008) evaluated several TYLCV-resistant lines that originated from different wild tomato progenitors. PIM (originated from *S. pimpinellifolium*) and 72-PER (originated from *S. peruvianum*) yielded better than the susceptible cultivar (respectively 8.8, 7.7 and 5.2 kg/plant), while HAB (originated from *S. habrochaites*) and CHIL (originated from *S. chilense*) had yields similar to those of susceptible line B-117 (respectively 4.3, 5.4 and 5.2 kg/plant). The hybrids between the resistant lines and the susceptible one yielded better than susceptible.

b. Fruit quality

1. Average fruit weight

Moustaf and Nakhla (1990) developed 6 tomato lines tolerant to TYLCV and evaluated them in replicated field trial under natural conditions of TYLCV infection. Two lines, *viz.*, 44 and 51 produced fruits similar in weight to the commercial variety UC 97-3. Fruit weight of another line (53) was statistically close to fruit weight of the commercial variety Peto 86. The other lines (25, 35, and 47) produced small fruits.

Moustafa and Hassan (1993) evaluated 17 true-breeding tomato cvs reported to be tolerant to TYLCV, and 4 TYLCV-tolerant hybrids for fruit quality in comparison with cv. Castlerock. Hybrids were not significantly different from cv. Castlerock in AFW in the two summer seasons in which TYLCV symptoms were generally low as in 1991, or

nil as in 1992. In theses plantings, five of the true breeding cvs evaluated, *viz.*, Campbell, Columbia, Roza, Slava, and Campbell 1138, had larger fruits than cv. Castlerock in 1991, but these differences were not observed in 1992. On the contrary, data obtained in the fall seasons varied in the two years of the study. Weight of fruits of the four hybrids evaluated were significantly larger than that of cv. Castlerock in 1991 but was similar in 1992. None of the other evaluated true-breeding cvs had larger fruits than cv. Castlerock in either of the fall seasons.

Lapidot *et al.* (1997) studied the effect of TYLCV on fruit weight under the conditions of artificial inoculation in the new breeding lines TY-172 and TY-197; the tolerant commercial cvs 8484, 3761, Fiona, and Tyking; and the susceptible control cv. 5656. There was nearly any reduction in fruit weight in infected plants of lines TY-172 and TY-197 and cvs Fiona and Tyking, while there was clear reduction in fruit weight in infected plants of cvs 3761 and 8484, and no fruits were produced from infected plants of the susceptible control cv. 5656.

Using *S. habrochaites* LA 1777 and LA 386 as sources of TYLCV resistance in a breeding programme, Vidavsky and Czosnek (1998) produced a stable BC_1F_4 resistant line (902) and another stable BC_1F_4 tolerant line (908). Both lines had good horticultural characteristics and produced 80 to 120 g red fruit.

2. Total soluble solids

Moustafa and Nakhla (1990) bred six tomato lines having superior TYLCV tolerance and yield. These lines were evaluated in replicated field trails. Data obtained showed that two tolerant lines, *viz.*, 47 and 51 exhibited high percentage of TSS, being 5.3% and 5.4%,

respectively. The other lines and commercial varieties showed inferior percentages.

Moustafa and Hassan (1993) evaluated 17 true-breeding tomato cvs reported to be tolerant to TYLCV, and 4 TYLCV-tolerant hybrids, for yield, quality, and virus tolerance in comparison with cv. Castlerock. There was no significant difference observed between cv. Castlerock and any of the evaluated cvs, including hybrids, in fruit TSS content.

MATERIALS AND METHODS

These studies were conducted during the period from 2005 to 2009 at the Agricultural Experiment Station (AES) of the Faculty of Agriculture, University of Cairo, Giza, Egypt.

1. Screening for resistance

Ninety-two domestic and wild tomato accessions were evaluated for TYLCV resistance under field conditions at AES of the Faculty of Agriculture, University of Cairo, Giza, Egypt during the 2005/2006, 2006/2007 and 2007/2008 fall plantings. Accessions in the first trial included one of *S. cheesmaniae*, one of *S. chilense*, 3 of *S. chmielewskii*, 9 of *S. habrochaites*, 24 of *S. lycopersicum*, 2 of *S. neorickii*, 2 of *S. pennellii*, 22 of *S. peruvianum*, 20 of *S. pimpinellifolium*, and 4 of *Solanum sp.* Accessions which received mean disease score < 1.9 in the first trial were re-evaluated in the two subsequent trials. The latter trails also included selections from 1st year trail made on 2 accessions of *S. lycopersicum*, 1 of *S. pimpinellifolium*, and 2 of *Solanum sp.* and also selections of 2 accessions of *S. lycopersicum* which were previously selected by the auther (unpublished). Additionally, 2 accessions of *Solanum sp.* were evaluated in the second season only. All tomato accessions used in these studies are presented in Table 1. Seeds of the LAs, LYCs, and PIs were kindly provided by the Tomato Genetic Resources Center, University of California, Davis; the Institut für Pflanzengenetik und Kulturpfianzenforschung, Genebank, Gatersleben, Germany; and the USDA through Dr. Charles Block (Plant Introduction Station, Ames,

Table 1. List of domesticated and wild tomato accessions evaluated for TYLCV resistance.

Species[z]	Accession[y]
S. chessmaniae	PI 379035
S. chilense	LA 2931
S. chmielewskii	LA 1028 LA 1317 PI 379030
S. habrochaites	LA 1347 LA 1393 LA 1731 LA 1777 PI 126445 PI 365907 PI 379013 PI 390513 PI 390662
S. lycopersicum	LA 3845 cv. NC EBR-5 sel[x] LA 3846 cv. NC EBR-6 sel
S. lycopersicum var. *amplipinnatum*	LYC 328/90 cv. Quedlinburger Frühe Liebe
S. lycopersicum var. *bukasovii*	LYC 68/02
S. lycopersicum var. *cerasiforme*	LYC 196/81 cv. Bubjekosoko
S. lycopersicum var. *colombianum*	LYC 69/90
S. lycopersicum var. *commune*	LYC 180/81 cv. Pierette LYC 182/81 cv. Russische
S. lycopersicum var. *cordiforme*	LYC 356/89 cv. Ochsenherz
S. lycopersicum var. *densifolium*	LYC 224/89 cv. Immun LYC 255/02 cv. Oktjabrenok
S. lycopersicum var. *finiens*	LYC 222/79 cv. Mingerzahn St 55
S. lycopersicum var. *flammatum*	LYC 179/83 cv. Ohnegleichen
S. lycopersicum var. *grandifolium*	LYC 215/02 cv. Red Jaquet
S. lycopersicum var. *incarnatum*	LYC 353/85 cv. Berner Rosen
S. lycopersicum var. *mikadofolium*	LYC 91/94 cv. Mikado Scharlachrote
S. lycopersicum var. *oviforme*	LYC 71/81 cv. König Humbert
S. lycopersicum var. *persicoides*	LYC 140/02 cv. Weißbehaart
S. lycopersicum var. *perspicuum*	LYC 355/02 cv. Dwarf Champion
S. lycopersicum var. *pluriloculare*	LYC 396/83 cv. Jupilee Orange

Continued

Table 1. Continued.

Species[z]	Accession[y]
S. lycopersicum var. *pygmaeum*	LYC 217/79 cv. Karzelek Pulawski
S. lycopersicum var. *pyriforme*	LYC 32/ cv. Gelbe 07
S. lycopersicum var. *scopigerum*	LYC 29/79 cv. Lena
S. lycopersicum var. *speciosum*	LYC 186/79 cv. Viktor
S. lycopersicum var. *subviride*	LYC 121/83 cv. Hellfrucht
S. lycopersicum var. *violaceum*	LYC 137/94 cv. Ponderosa Purpurviolette
S. neorickii	LA 1326 LA 2201
S. pennellii	LA 716 LA 1303
S. peruvianum	LA 107 LA 372 LA 462 LA 1274 LA 1333 LA 1474 LA 1677 LA 2157 LA 2172 LA 2744 LA 3220 PI 126435 PI 126444 PI 126935 PI 127831 PI 128648 PI 128652 PI 128653 PI 128655 PI 212407 PI 270435 PI 306811 CNV sél INRA
S. pimpinellifolium	LA 121 LA 722 LA 1256 LA 1258 LA 1342 LA 1478

Continued

Table 1. Continued.

Species[z]	Accession[y]
S. pimpinellifolium (Contd.)	LA 1633
	LA 2182
	LA 2656
	LA 2854
	PI 126927
	PI 126947
	PI 211838
	PI 211840
	PI 212408
	PI 340905 cv. Cervena Kapha
	PI 379023
	PI 407543
	PI 407544
	PI 407555
Solanum sp.	LA 4135
	PI 112835
	PI 126915
	PI 205016
	PI 205017
	PI 568258
	PI 568259
S. lycopersicum	Cstlerock (control)

[z]Former scientific names: ***Lycopersicon chessmanii*** for ***Solanum chessmaniae***, ***L. chilense*** for ***S. chilense***, ***L. chmielewskii*** for ***S. chmielewskii***, ***L. hirsutum*** for ***S. habrochaites***, ***L. esculentum*** for ***S. lycopersicum***, ***L. parvifolrum*** for ***S. neorickii***, ***L. pennellii*** for ***S. pennellii***, ***L. peruvianum*** for ***S. peruvianum***, ***L. pimpinellifolium*** for ***S. pimpinellifolium***, and ***Lycopersicon sp.*** for ***Solanum sp.***

[y]Accession: All LAs were the courtesy of the University of California, Davis, USA; the LYCs were the courtesy of the Institut für Pflanzengenetik und Kulturpfianzenforschung, Genebank, Gatersleben, Germany; the PIs were kindly provided by the USDA through Dr. Charles Block (Plant Introduction Station, Ames, Iowa); ***S. peruvianum*** CMV sél INRA was provided by Dr. H. Laterrot, INRA, Montfavet, France; and the commercial cv. Castlerock (control) was obtained from Sun Seeds Company, USA.

[x]sel: a selection from the indicated accession.

Iowa), respectively; while *S. peruvianum* CMV sél INRA was provided by Dr. H. Laterrot, INRA, Montfavet, France. Seeds of the commercial cv. Castlerock (control) were obtained from Sun Seeds Company, USA.

Seeds of these accessions were sowed in each of the three fall seasons on the first of September in speedling trays filled with mixture enriched with macro and micro elements of peatmoss and vermiculate (1:1). Five week-old seedlings were field-transplanted in a randomized complete block design (RCBD) with three replicates. Each experimental unit (EU) consisted of 1 row; 1.2 m wide × 4.5 m long (EU area = 5.4 m^2). Plants were set 50 cm apart and subjected to the common agricultural practices.

a. TYLCV inoculation

1. whitefly-mediated inoculation

Virus infection was enhanced by natural viruliferous whitefly infestation in the nursery and in field plots (Fig. 1). No insecticides were applied to encourage heavy infestation.

Fig. 1. Whitefly population was high during the screening period.

Data on TYLCV resistance was recorded for individual plants 3 months after transplanting on a 1-4 scale (Fig. 2), depending on the

severity of TYLCV symptoms as follows: 1: no symptoms appearing on the plant, 2: slight symptoms on plant top, 3: moderate symptoms, and 4: severe symptoms on the entire plant. Individual plant ratings of each accession were added and divided by the number of evaluated plants to obtain the corresponding mean disease score. Data obtained were statistically analyzed and mean comparisons were based on Duncan's multiple range test (Waller and Duncan, 1969).

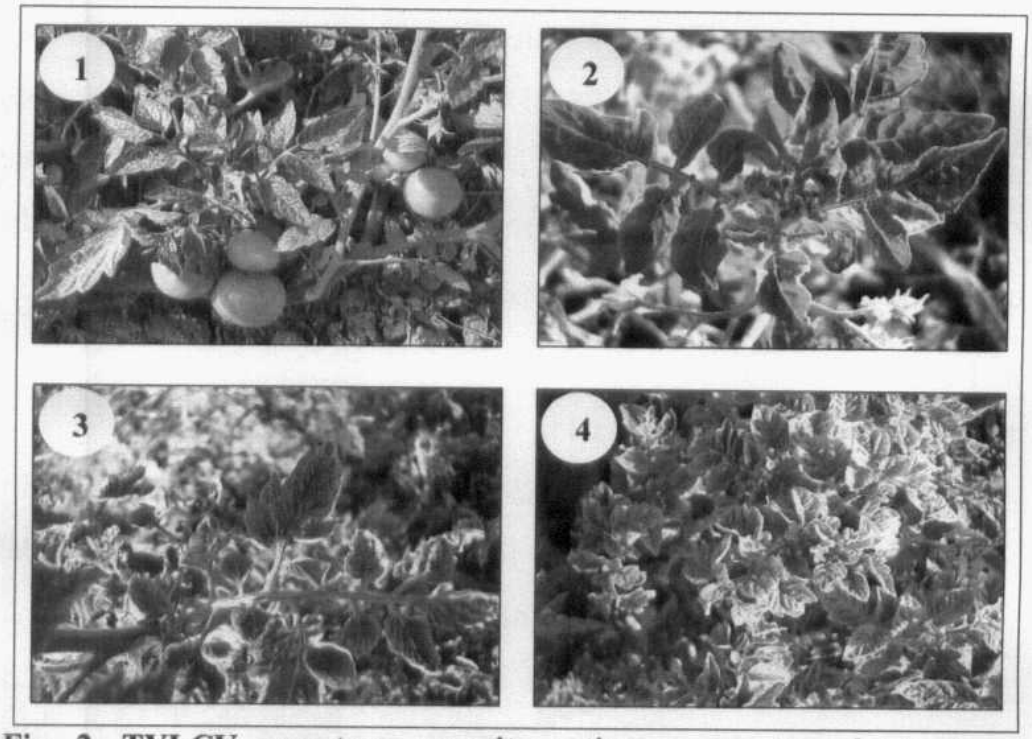

Fig. 2. TYLCV symptoms severity rating on tomato plants. 1, no symptoms appearing on the plant; 2, slight symptoms on the plant top; 3, moderate symptoms; and 4, severe symptoms on the entire plant.

2. Graft-inoculation

The graft-inoculation experiment was conducted from January to May 2008 under tunnels covered with plastic net for detection of TYLCV in symptomless plants of some of the evaluated tomato accessions, especially those which were completely symptomless in the

third evaluation season, and selected as best sources for resistance. Healthy seedlings of cv. Castlerock were used as scions and rooted cuttings from symptomless plants of evaluated tomato accessions were used as rootstocks (Fig. 3).

The seeds of 'Castlerock' were sown on the first of January in speedling trays filled with mixture enriched with macro and micro elements of peatmoss and vermiculate (1:1). The stocks were prepared as stem cuttings and were rooted in pots filled with the same mixture. Cleft grafting was applied with accessions of *Solanum sp.* and *S. lycopersicum*, but, tongue grafting was applied with *S. habrochaites*, *S. pennellii*, *S. peruvianum*, and *S. pimpinellifolium* (Fig. 3). Grafts were examined 2, 4, 6, 8, 10, and 12 weeks after grafting for the development of TYLCV symptoms on the susceptible scion, i.e. cv. Castlerock.

2. Genetic studies

According to results obtained from the evaluation trials, *S. chmielewskii* LA 1317; *S. habrochaites* LA 1777 and PI 390662; a selection of *S. lycopersicum* var. *flammatum* LYC 179 / 83 cv. Ohnegleichen; *S. neorickii* LA 1326; *S. pimpinellifolium* PI 211840 and PI 407543 and a selection of *Solanum sp.* PI 205017, which were characterized as resistant accessions, were chosen to study the inheritance of TYLCV resistance. These eight accessions were crossed, as male parents, with TYLCV susceptible tomato cv. Castlerock in the 2006/2007 winter planting in the greenhouse at AES. In the 2007/2008

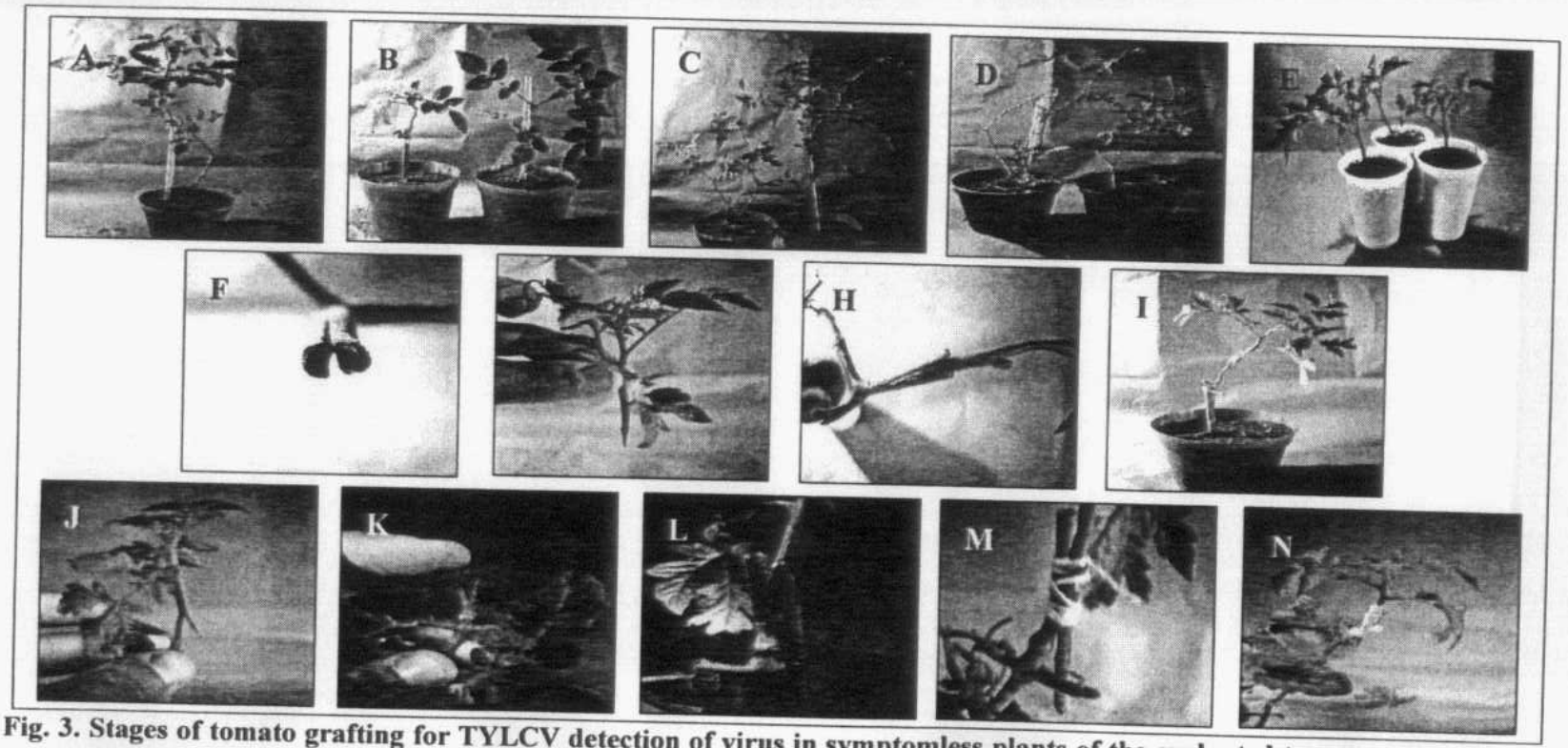

Fig. 3. Stages of tomato grafting for TYLCV detection of virus in symptomless plants of the evaluated tomato accessions. A-D, rootstocks (root cuttings) of accessions *Solanum sp.* PI 126915; *S. habrochaites* PI 390662, *S. neorickii* LA 1326, and *S. peruvianum* CMV sél INRA; E, scions (seedlings) of cv. Castlerock; F-I, stages of cleft grafting used with *S. lycopersicum* and *Solanum sp*; and L-N, stages of tongue grafting used with *S. habrochaites*, *S. pennellii*, *S. peruvianum*, and *S. pimpinellifolium*.

winter planting, F_1 plants of the eight crosses were planted for selfing to obtain F_2 seeds.

Seeds of genetic populations of each cross, i.e., P_1, P_2, F_1, and F_2 were sowed in speedling trays filled with mixture enriched with macro and micro elements of peatmoss and vermiculate (1:1) on the first of September 2008 and seedlings were field-transplanted at AES on 7 October 2008 for evaluation for TYLCV resistance under natural conditions of whitefly infestation. Populations of each cross were planted in a RCBD with 3 replicates. Each EU consisted of 1.2 m wide × 4.5 m long beds depending on the genetic population planted and its seed supply. All plants received common agricultural practices without using insecticides.

The severity of TYLCV symptoms was determined as previously described (sect. 1 part a. 1). Data obtained were used in calculating the following genetic parameters:

a. Potence ratio

Potence ratio (P) was used to determine the direction of dominance according to Smith (1952) as follows:

$$P = \frac{\overline{F_1} - \overline{MP}}{½ (\overline{P_2} - \overline{P_1})}$$

Where: $\overline{F_1}$ = First generation mean.

$\overline{P_1}$ = Mean of the smaller parent

$\overline{P_2}$ = Mean of the larger parent.

MP = Mid parent value =½ $(\overline{P_1} + \overline{P_2})$.

The absence of dominance was assumed when the difference between the parents was significant and $\overline{F_1}$ – **MP** was not significant. Complete dominance was assumed when P equaled to or did not differ from ±1.0. Meanwhile, partial dominance was considered when P was between +1.0 and -1.0, but was not equal to zero. Over dominance (Heterosis) was assumed when P exceeded ± 1.0.

b. The minimum number of genes controlling the character

The minimum number of genes was calculated using Castle-Wright equation (Castle and Wright, 1921) as follows:

$$N = \frac{D^2}{8(V_{F_2} - V_{F_1})}$$

Where: **N** = Number of genes controlling the character.

D = Difference between parental means.

V_{F_1} & V_{F_2} = Variances of the F_1 and F_2 populations, respectively.

c. Broad sense heritability

Broad sense heritability (BSH) was calculated using the equation:

$$BSH = \left(\frac{V_G}{V_P}\right) \times 100$$

Where: V_G = Genetic variance which was calculated by subtracting the environmental variance (V_E) from phenotype variance (V_P).

V_P = V_{F_2}.

V_E = Environmental variance which was calculated as the

geometric mean of the non-segregating populations, i.e., parents and F_1 (Allard, 1960).

3. Production and Evaluation of the F_1s

a. Production of the F_1s

Based on the results of the evaluation trails, 2 selections of *S. lycopersicum* accessions LA 3845 (P_1) and LA 3846 (P_2); one selection of *S. lycopersicum* var. *pyriforme* LYC 32/83 (P_3); one selection of *S. lycopersicum* var. *flmmatum* LYC 179/83 (P_4); and 2 selections of *Solanum sp.* accessions PI 126915 (P_5) and PI 205017 (P_6), and one accession of *S. pimpinellifolium* PI 211840 (P_7), having high tolerance to TYLCV and accepted fruit quality characters were selected for use in a half diallel crossing program to produce tolerant × tolerant F_1s. Also, 6 susceptible tomato cvs, *viz.*, Ace 55VF (P_8), Castlerock (P_9), Marmande (P_{10}), Sioux (P_{11}), Super Strain B (P_{12}) and Yellow Peach FS-3 (P_{13}), were selected for use in another crossing program with previous tolerant lines (line × tester) to produce tolerant × susceptible F_1s. The F_1 seeds were produced during the winter and summer seasons of 2008.

b. Evaluation of F_1s and parental lines

Produced tolerant × tolerant F_1s and their parents and tolerant × susceptible F_1s and their parents were evaluated in the fall season of 2008 / 2009 in two different trails. Seeds of the F_1 hybrids and their parents along with the cvs Castlerock and 802 F_1, as controls, were sown in speedling trays filled with mixture enriched with macro and

micro elements of peatmoss and vermiculate (1:1) on the first of September 2008 and transplanted on mid of October 2008.

A RCBD with three replicates was used. Each plot consisted of three rows; each row was 1.2 m wide and 4.5 m long (plot area = 16.2 m^2). Plants were set 50 cm apart and subjected to the recommended agricultural practices without insecticide spraying.

c. Characters measured

The following characters were studied:

1. Level of TYLCV resistance

The severity of TYLCV symptoms was determined as previously described (sect. 1 part a. 1).

2. Yield components

a. Early yield per plant. EY was measured as the yield of the first three pickings.

b. Total yield per plant. TY was measured as total weight of all harvested fruits at the red-ripe stage.

3. Fruit quality

a. Physical characters

1. **Average fruit weight.** AFW was determined as the mean weight of twenty fruits chosen randomly from each plot in the second and third pickings.
2. **Fruit shape index.** FSI was calculated as the ration between fruit length (polar diameter) and fruit diameter (equatorial diameter) of 20 fruits / plot. Oval fruits shape is usually considered for a ratio of 1.2 or more, round shape for a ratio of

0.95-1.20, and oblate shape for a ratio less than 0.95 (Yeager, 1937).

b. Chemical constituents

1. **Total soluble solids.** TSS was determined in at least 10 fruits from each plot using a hand refractometer.
2. **pH value.** pH was determined by immersing the glass electrode of a pH meter into juice extracted from a 200 g fruit sample per plot.
3. **Titratable acidity.** TA was ascertained using 0.1 N NaOH solution and phenolphthalein as indicator (AOAC, 1990).
4. **Ascorbic acid content:** AAC was determined using 2, 6 dichlorophenol endophenol dye (AOAC, 1990).
5. **Fruit color.** Fruit color was measured in rip fruits of parents; crosses having the parent P_3, which is characterized by yellow fruits; and cv. control. Fruit contents of both lycopene and β-carotene were determined (AOAC, 1990).

d. Statistical analysis

1. Tolerant × tolerant F_1s

Before subjecting the data to combining ability analysis, an ordinary analysis of variance was performed to determine the significance of genotypic differences and to compare between genotypes (parents and F_1 hybrids) and the control (Steel and Torrie, 1984). Also, data were analyzed according to Griffing's approach of diallel analysis (Singh and Choudhary, 1977). In the present study the parents were selected based on their reaction to TYLCD for making

tolerant × tolerant crosses and only parents and one set of F_1s were used (half diallel). Therefore, Method II and Model-I was used.

a. Combining ability analysis

Assuming no differences among the direct and reciprocal crosses, the mean performance of a cross (x_{AB}) should be equal to $GCA_A + GCA_B + SCA_{AB}$. The GCA_A and GCA_B is the general combining ability of the A and B parents and performance of a cross of A and B is expected to be equal to the sum ($GCA_A + GCA_B$) of general combining ability of their parents. However, the actual performance of the cross may be different from this sum by an amount equal to SCA. In terms of gene action, the differences in GCA are due to additive genetic variance and additive × additive type of epistasis, whereas SCA estimates non-additive genetic variance. The data have been arranged by pooling the observations from three replications and finally taking their means hence each genotype is represented by one observation. Various statistical equations used in combining ability studies were as follows:

$$\text{SS due to GCA} = \frac{1}{n+2}\left[\sum(Y_{i.}+Y_{ii})^2 - \frac{4}{n}Y^2_{..}\right]$$

$$\text{SS due to SCA} = \sum\sum Y^2_{..} - \left[\left(\frac{1}{n+2}\sum(Y_{i.}+Y_{ii})^2\right) + \left(\frac{2}{(n+1)(n+2)}\right)Y^2_{.}\right]$$

Check; Treatment SS = r (SS due to GCA + SS due to SCA)

b. Genetic components

The estimates of genetic components are obtained as under:

1. Component due to GCA:

$$\delta_g^2 = \frac{2}{n+2}(M_g - M_s)$$

2. Component due to SCA:

$$\delta_s^2 = M_s - \grave{M}_e$$

Where $\delta_e^2 = \acute{M}_e$

3. Ratio of gca variance to sca variance:

$$\delta_g^2 / \delta_s^2$$

4. Estimation of GCA effects:

$$g_i = \frac{1}{n+2}\left[\sum(Y_{i.}+Y_{ii}) - \frac{2}{n}Y_{..}\right]$$

5. Estimation of SCA effects:

$$s_i = Y_{ij} - \frac{1}{n+2}(Y_{i.}+Y_{ii}+Y_{.j}+Y_{jj}) + \frac{2}{(n+1)(n+2)}Y_{..}$$

6. Standard Errors:

$$S.E.(g_i) = \left[(n-1)\delta^2_e/n(n+2)\right]^{1/2}$$

$$S.E.(s_{ii}) = \left[(n^2+n+2)\delta^2_e/(n+1)(n+2)\right]^{1/2}$$

$$S.E.(g_i - g_j) = \left[2\delta^2_e/(n+2)\right]^{1/2}$$

$$S.E.(s_{ij}) = \left[n\,(n-1)\delta^2_e/(n+1)(n+2)\right]^{1/2}$$

$$S.E.(s_{ii} - s_{jj}) = \left[2\,(n-2)\delta^2_e/(n+2)\right]^{1/2}$$

$$S.E.(s_{ij} - s_{ik}) = \left[2\,(n+1)\delta^2_e/(n+2)\right]^{1/2}$$

$$S.E.(s_{ij} - s_{kl}) = \left[2\,n\delta^2_e/(n+2)\right]^{1/2}$$

ANOVA for combining ability analysis in model-I method-II

Source	d.f.	M.S.	E.M.S. Model-I
GCA	p-1	M_g	$\delta^2_e + \delta^2_s + (n+2)\,\delta^2_g$
SCA	[p(p-1)]/2	M_s	$\delta^2_e + \delta^2_s$
Error	(g-1)(r-1)	M_e	δ^2_e

Where: p, number of parents; g, number of genotypes (parents and crosses) and r, number of replication.

c. Estimation of heterosis

The percent increase (+) or decrease (-) of a cross over better parent was calculated to determine heterotic effects for all characters. Estimate of heterosis over the better parent (heterobeltiosis) was calculated using the following equation (Sinha and Khanna, 1975):

$$\textbf{Better parent heterosis} = \frac{\overline{F_1} - \overline{B_P}}{\overline{B_P}} \times 100$$

Where:

$\overline{F_1}$: Mean of the first hybrid generation.

$\overline{B_P}$: Mean of the better parent in a particular F_1 cross.

2. Tolerant × susceptible F_1s

Before subjecting the data to combining ability analysis, analysis of variance was performed to determine the significance of genotypic difference and comparing the genotypes (parents and F_1 hybrids) with the control (Steel and Torrie, 1984). Data were analyzed according to Line × Tester analysis (Singh and Choudhary, 1977).

a. Genetic components

Estimates of genetic components were obtained as follows:

1. **Estimation of GCA effects for lines:**

$$g_i = \frac{x_{i...}}{tr} - \frac{x_{..}}{ltr}$$

2. **Estimation of GCA effects for testers:**

$$g_t = \frac{x_{.j.}}{lr} - \frac{x_{...}}{ltr}$$

3. **Estimation of SCA effects:**

$$s_{ij} = \frac{x_{ij.}}{r} - \frac{x_{i..}}{tr} - \frac{x_{.j.}}{lr} + \frac{x_{...}}{ltr}$$

Where: l = number of lines.

t = number of testers.

r = number of replicates.

4. Standard Errors:

$$\textbf{S.E(gca for line)} = (M_e/rt)^{1/2}$$

$$\textbf{S.E(gca for tester)} = (M_e/rl)^{1/2}$$

$$\textbf{S.E(sca effects)} = (M_e/r)^{1/2}$$

$$\textbf{S.E}(g_i - g_j)\ \textbf{line} = (2\,M_e/rt)^{1/2}$$

$$\textbf{S.E}(g_i - g_j)\ \textbf{tester} = (2\,M_e/rl)^{1/2}$$

$$\textbf{S.E}(s_{ij} - s_{kl}) = (2\,M_e/r)^{1/2}$$

b. Estimation of heterosis

The percent increase (+) or decrease (-) of a cross over better parent was calculated to determine heterotic effects for all characters. Estimate of heterosis over the better parent (heterobeltiosis) was calculated as previously described (sect. 3 part d.1.c).

RESULTS AND DISCUSSION

1. Screening for resistance

Data obtained on TYLCV resistance in the 2005/2006 fall planting of evaluated domesticated and wild tomato accessions are presented in Table 2. The evaluated tomato accessions showed a wide range of response to TYLCV infection with significant differences among them. The cultivar Castlerock (control) was severally susceptible as it's mean score was 3.98 (Fig.4).

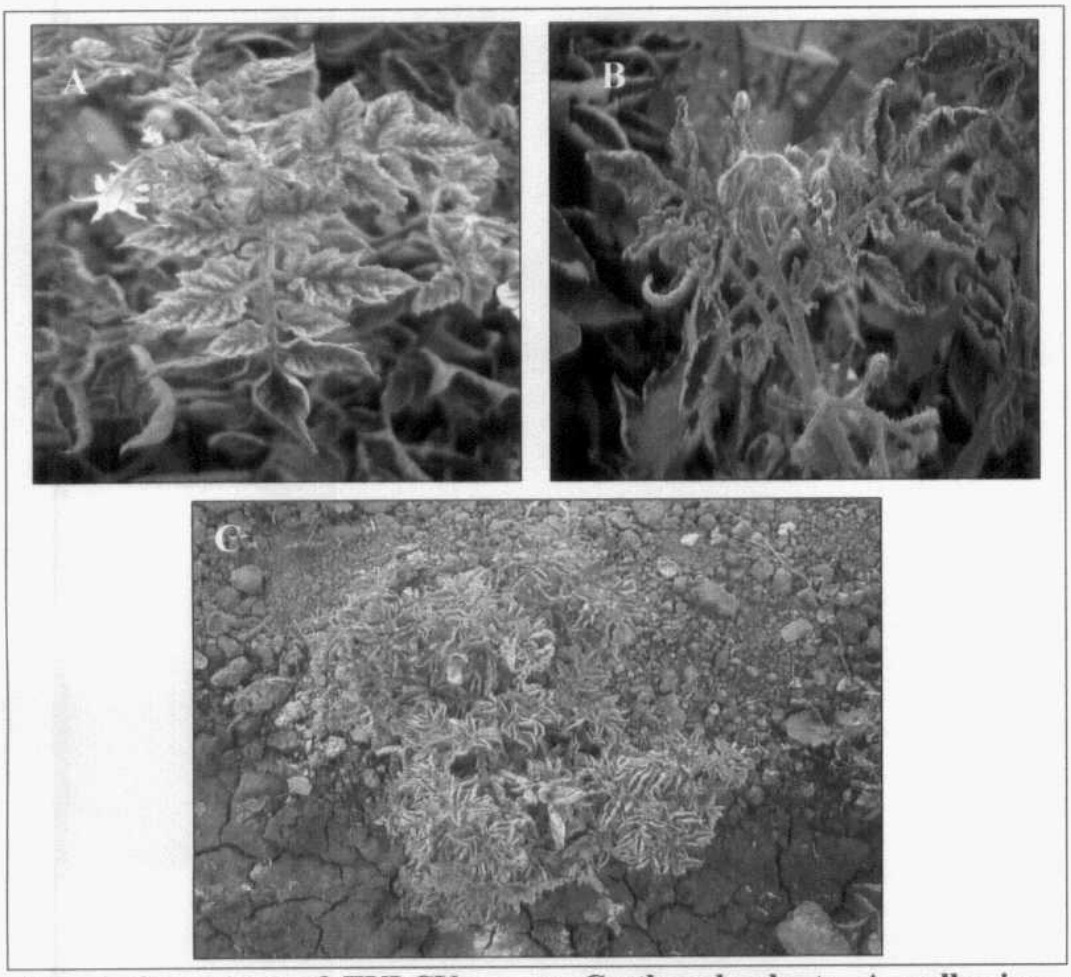

Fig. 4. Symptoms of TYLCV on cv. Castlerock plants. A, yellowing, curling and leaf mis-shaping; B, arrows point to flower abortion; and C, severe symptoms accompanied with stunting.

Table 2. Evaluation for TYLCV resistance in plants of domesticated and wild tomato accessions in the 2005/2006 fall planting.

Species[z]	Accession	Frequency of TYLCV disease score[y]				Total No. of plants	Mean score[x]
		1	2	3	4		
S. chessmaniae	PI 379035	8	4	0	0	12	1.33 g-k
S. chilense	LA 2931	1	1	0	0	2	1.50 f-k
S. chmielewskii	LA 1028	5	5	0	0	10	1.53 f-k
	LA 1317	21	0	0	0	21	1.00 k
	PI 379030	2	2	1	0	5	1.67 f-k
S. habrochaites	LA 1347	10	1	0	0	11	1.07 k
	LA 1393	11	0	0	0	11	1.00 k
	LA 1731	6	0	1	0	7	1.33 g-k
	LA 1777	12	1	0	0	13	1.11 k
	PI 126445	22	1	0	0	23	1.03 k
	PI 365907	6	1	1	0	8	1.83 e-i
	PI 379013	16	0	0	0	16	1.00 k
	PI 390513	23	3	0	0	26	1.11 k
	PI 390662	21	0	0	0	21	1.00 k
S. lycopersicum var. *amplipinnatum*	LYC 328/90	0	0	1	27	28	3.97 a
S. lycopersicum var. *bukasovii*	LYC 68/02	0	0	0	24	24	4.00 a
S. lycopersicum var. *cerasiforme*	LYC 196/81	0	0	0	29	29	4.00 a
S. lycopersicum var. *colombianum*	LYC 69/90	0	0	0	29	29	4.00 a
S. lycopersicum var. *commune*	LYC 180/81	0	0	0	24	24	4.00 a
	LYC 182/81	0	0	0	21	21	4.00 a
S. lycopersicum var. *cordiforme*	LYC 356/89	0	0	0	26	26	4.00 a
S. lycopersicum var. *densifolium*	LYC 224/89	0	0	0	30	30	4.00 a
	LYC 255/02	0	0	0	28	28	4.00 a
S. lycopersicum var. *finiens*	LYC 222/79	0	0	0	29	29	4.00 a
S. lycopersicum var. *flammatum*	LYC 179/83	1	1	2	22	26	3.77 a
S. lycopersicum var. *grandifolium*	LYC 215/02	0	1	2	21	24	3.80 a
S. lycopersicum var. *incarnatum*	LYC 353/85	0	0	0	16	16	4.00 a

Continued

Table 2. Continued.

Species[z]	Accession	Frequency of TYLCV disease score[y] 1	2	3	4	Total No. of plants	Mean score[x]
S. lycopersicum var. *mikadofolium*	LYC 91/94	0	0	0	21	21	4.00 a
S. lycopersicum var. *oviforme*	LYC 71/81	0	0	0	21	21	4.00 a
S. lycopersicum var. *persicoides*	LYC 140/02	0	0	0	23	23	4.00 a
S. lycopersicum var. *perspicuum*	LYC 355/02	0	0	0	25	25	4.00 a
S. lycopersicum var. *pluriloculare*	LYC 396/83	0	0	0	28	28	4.00 a
S. lycopersicum var. *pygmaeum*	LYC 217/79	0	0	0	28	28	4.00 a
S. lycopersicum var. *pyriforme*	LYC 32/83	2	0	0	22	24	3.80 a
S. lycopersicum var. *scopigerum*	LYC 29/79	0	0	1	23	24	3.96 a
S. lycopersicum var. *speciosum*	LYC 186/79	0	0	0	24	24	4.00 a
S. lycopersicum var. *subviride*	LYC 121/83	0	0	0	26	26	4.00 a
S. lycopersicum var. *violaceum*	LYC 137/94	0	0	0	19	19	4.00 a
S. neorickii	LA 1326	23	4	0	0	27	1.17 i-k
	LA 2201	6	1	1	0	8	1.50 f-k
S. pennellii	LA 716	5	0	0	0	5	1.00 k
	LA 1303	4	3	0	0	7	1.33 g-k
S. peruvianum	LA 107	14	0	0	0	14	1.00 k
	LA 372	20	2	0	0	22	1.08 k
	LA 462	26	2	0	0	28	1.07 k
	LA 1274	0	4	2	1	7	2.63 b-d
	LA 1333	19	0	0	0	19	1.00 k
	LA 1474	7	0	0	0	7	1.00 k
	LA 1677	8	0	0	0	8	1.00 k
	LA 2157	14	0	0	0	14	1.00 k
	LA 2172	23	0	0	0	23	1.00 k
	LA 3220	10	3	1	4	18	1.97 e-g
	PI 126435	18	2	0	0	20	1.21 i-k
	PI 126444	27	3	1	0	31	1.25 i-k
	PI 126935	24	5	0	0	29	1.17 i-k
	PI 127831	25	0	0	0	25	1.00 k

Continued

Table 2. Continued.

Species[z]	Accession	Frequency of TYLCV disease score[y] 1	2	3	4	Total No. of plants	Mean score[x]
S. peruvianum (Contd.)	PI 128648	23	3	0	0	26	1.13 jk
	PI 128652	26	0	0	0	26	1.00 k
	PI 128653	21	1	0	0	22	1.06 k
	PI 128655	20	0	0	1	21	1.17 i-k
	PI 212407	4	2	0	0	6	1.25 i-k
	PI 270435	22	0	0	0	22	1.00 k
	PI 306811	24	7	2	0	33	1.25 i-k
	CMV sél INRA	21	0	0	0	21	1.00 k
S. pimpinellifolium	LA 121	23	0	0	0	23	1.00 k
	LA 722	22	3	0	0	25	1.11 k
	LA 1256	16	8	2	1	27	1.55 f-k
	LA 1258	8	12	4	1	25	1.95 e-g
	LA 1342	17	5	0	0	22	1.24 i-k
	LA 1478	11	2	2	0	15	1.50 f-k
	LA 1633	21	4	2	0	27	1.34 g-k
	LA 2182	24	7	0	1	32	1.31 g-k
	LA 2656	19	4	1	0	24	1.22 i-k
	LA 2854	0	10	3	5	18	2.79 bc
	PI 126927	5	14	5	1	25	2.07 d-f
	PI 126947	19	6	1	0	26	1.32 g-k
	PI 211838	21	5	0	0	26	1.21 i-k
	PI 211840	28	0	0	0	28	1.00 k
	PI 212408	21	5	1	0	27	1.26 h-k
	PI 340905	8	18	6	0	32	1.93 e-h
	PI 379023	11	8	7	0	26	1.81 e-j
	PI 407543	20	3	0	0	23	1.15 i-k
	PI 407544	25	0	0	0	25	1.00 k
	PI 407555	21	0	0	0	21	1.00 k
Solanum sp.	PI 112835	0	0	5	19	24	3.85 a
	PI 126915	3	4	11	0	18	2.36 c-e
	PI 205016	0	0	11	0	11	3.00 b
	PI 205017	3	6	6	5	20	2.81 bc
S. lycopersicum	Cstlerock (control)	0	0	1	28	29	3.96 a

[z]Former scientific names: *Lycopersicon chessmanii* for *Solanum. chessmaniae*, *L. chilense* for *S. chilense*, *L. chmielewskii* for *S. chmielewskii*, *L. hirsutum* for *S. habrochaites*, *L. esculentum* for *S. lycopersicum*, *L. parvifolrum* for *S. neorickii*, *L. pennellii* for *S. pennellii*, *L. peruvianum* for *S. peruvianum*, *L. pimpinellifolium* for *S. pimpinellifolium*, and *Lycopersicon sp.* for *Solanum sp.*

[y]Disease scores: 1, symptomless; 2, slight; 3, moderate, and 4, severe symptoms.

[x]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

None of the evaluated accessions of both *S. lycopersicum* and *Solanum sp.* appeared resistant to TYLCV as their mean scores ranged from 2.36 to 4.00. These results confirm previous reports by Nariani and Vasudera (1963), Abdel-Al *et al.* (1973), Pilowsky and Cohen (1974), El-Hammady *et al.* (1976), Makkouk (1976), Abu-Garbieh *et al.* (1978), Mazyad *et al.* (1979), Hassan *et al.* (1982 and 1991), Ioannou (1985b), Banerjee and Kalloo (1987b), and Channarayappa *et al.* (1992), Mahmoud (2004), and Abdel-Ati (2008) concerning the general lack of TYLCV resistance in *S. lycopersicum*. Meanwhile, 2 accessions of both *S. lycopersicum* (var. *flammatum* LYC 179 /83 and var. *pyriforme* LYC 32 / 83) and *Solanum sp.* (PIs 126915 and 205017) appeared promising as some of their plants were symptomless. One plant of each of these accessions was selected, and their progenies were re-evaluated in the following evaluation seasons.

All of the evaluated accessions of *S. chessmaniae* (PI 379035), *S. chilense* (LA 2931), *S. chmielewskii* (LAs 1028 and 1317; and PI 379039), *S. habrochaites* (LAs 1347, 1393, 1731, and 1777; and PIs 126445, 365907, 379013, 390513, and 390662), *S. neorickii* (LAs 1326 2201), and *S. pennellii* (LAs 716 and 1303) showed low TYLCV mean scores, i. e., resistant, and ranged from 1.00 to 1.83. Therefore, these accessions were re-evaluated in the following evaluation seasons.

Most of the evaluated accessions of *S. peruvianum* showed low TYLCV mean scores, i. e., resistant, and ranged from 1.10 to 1.25. They were re-evaluated in the following trials. These accessions were LAs, 107, 372, 462, 1333, 1474, 1677, 2157, and 2172; PIs 126435, 126444, 126935, 127831, 128648, 128652, 128653, 128655, 212407,

270435, and 306811; and CMV sél INRA. Meanwhile, the other two evaluated accessions of *S. peruvianum* LAs 1274 and 3220 had mean scores of 2.63 and 1.97, respectively.

Sixteen out of the 20 evaluated *S. pimpinellifolium* accessions exhibited high levels of resistance, as their mean scores ranged from 1.00 to 1.81, and thus, they were re-evaluated in the following evaluation seasons. These accessions were LAs 121, 722, 1256, 1342, 1478, 1633, 2182, and 2656; and PIs 126947, 211838, 211840, 212408, 379023, 407543, 407544, and 407555. Other evaluated *S. pimpinellifolium* accessions had mean scores ranging from 1.97 to 2.79. TYLCV symptoms in *S. pimpinellifolium* plants were yellow leaf curl without stunting, while the plants exhibited vigorous vegetative growth. No differences were observed in the amount of vegetative growth between plants showing TYLCV symptoms (yellow leaf curl) and symptomless plants.

Data obtained on TYLCV resistance in the 2006/2007 and 2007/2008 fall plantings of evaluated domesticated and wild tomato accessions are presented in Tables 3 and 4. The evaluated tomato accessions showed a wide range of response to TYLCV infection with significant differences among them.

The tolerance of progenies of selected plants of accessions *S. lycopersicum* var. *flammatum* LYC 179/83 and *S. lycopersicum* var. *pyriforme* LYC 32/83 and of accessions *Solanum sp.* PIs 126915 and 205017 was reconfirmed (Fig. 5A-D). Mean scores of their progenies ranged from 1.05 to 1.19 and 1.00 to 1.14 in the second and third evaluation seasons, respectively. Likewise, selections of

Table 3. Evaluation for TYLCV resistance in plants of domesticated and wild tomato accessions in the 2006/2007 fall planting.

Species[z]	Accession	Frequency of TYLCV disease score[y]				Total No. of plants	Mean score[x]
		1	2	3	4		
S. chessmaniae	PI 379035	15	7	1	0	23	1.40 g-i
S. chilense	LA 2931	8	4	0	0	12	1.28 hi
S. chmielewskii	LA 1028	18	4	4	0	26	1.41 g-i
	LA 1317	22	3	2	0	27	1.23 hi
	PI 379030	8	3	1	0	12	1.66 e-h
S. habrochaites	LA 1347	19	2	2	0	23	1.25 hi
	LA 1393	20	1	0	0	21	1.04 i
	LA 1731	13	3	3	0	19	1.47 f-i
	LA 1777	21	0	0	0	21	1.00 i
	PI 126445	20	0	0	0	20	1.00 i
	PI 365907	4	7	3	0	14	1.91 ef
	PI 379013	16	0	0	0	16	1.00 i
	PI 390513	17	6	0	0	23	1.23 hi
	PI 390662	16	1	0	0	17	1.06 i
S. lycopersicum	LA 3845 sel[w]	20	8	0	0	28	1.28 hi
	LA 3846 sel	21	9	0	0	30	1.29 hi
S. lycopersicum var. *flammatum*	LYC 179/83	3	3	3	24	33	3.52 b
	LYC 179/83 sel	15	1	0	0	16	1.05 i
S. lycopersicum var. *pyriforme*	LYC 32/83	3	0	2	22	27	3.57 b
	LYC 32/83sel	17	4	0	0	21	1.19 hi
S. neorickii	LA 1326	20	6	2	0	28	1.34 g-i
	LA 2201	10	8	5	0	23	1.83 e-g
S. pennellii	LA 716	5	0	0	0	5	1.00 i
	LA 1303	4	3	0	0	7	1.33 hi
S. peruvianum	LA 107	17	0	0	0	17	1.00 i
	LA 372	21	7	1	0	29	1.25 hi
	LA 1274	25	3	1	0	29	1.15 hi
	LA 1333	19	0	0	0	19	1.00 i
	LA 1474	12	0	0	0	12	1.00 i
	LA 1677	21	0	0	0	21	1.00 i
	LA 2157	13	0	0	0	13	1.00 i
	LA 2172	33	0	0	0	33	1.00 i
	PI 126435	13	6	1	0	20	1.43 f-i
	PI 126444	23	5	0	0	28	1.20 h-i
	PI 126935	19	9	0	0	28	1.29 hi
	PI 127831	21	0	0	0	21	1.00 i
	PI 128648	25	4	1	0	30	1.18 hi
	PI 128652	22	0	0	0	22	1.00 i

Continued

Table 3. Continued.

Species[z]	Accession	Frequency of TYLCV disease score[y] 1	2	3	4	Total No. of plants	Mean score[x]
S. peruvianum (Contd.)	PI 128653	16	3	0	0	19	1.14 hi
	PI 128655	26	0	0	1	27	1.25 hi
	PI 212407	13	3	2	0	18	1.31 hi
	PI 270435	31	0	0	0	31	1.00 i
	PI 306811	18	5	1	0	24	1.30 hi
	CNV sél INRA	18	0	0	0	18	1.00 i
S. pimpinellifolium	LA 121	20	0	0	0	20	1.00 i
	LA 722	27	5	1	0	33	1.17 hi
	LA 1256	12	4	3	0	19	1.23 hi
	LA 1342	16	3	1	0	20	1.24 hi
	LA 1478	18	6	0	0	24	1.30 hi
	LA 1633	17	6	1	1	25	1.44 f-i
	LA 2182	15	7	2	2	26	1.62 e-h
	LA 2656	15	7	1	0	23	1.42 g-i
	LA 2656 sel	13	0	0	0	13	1.00 i
	PI 126947	18	4	5	0	27	1.49 e-i
	PI 211838	17	7	2	0	26	1.39 g-i
	PI 211840	27	1	0	0	28	1.03 i
	PI 212408	22	2	3	0	27	1.24 hi
	PI 379023	16	10	10	2	38	1.96 e
	PI 407543	19	8	4	0	31	1.52 e-i
	PI 407544	29	0	0	0	29	1.00 i
	PI 407555	31	0	0	0	31	1.00 i
Solanum sp.	LA 4135	0	4	14	16	34	3.36 bc
	PI 126915	3	7	7	9	26	2.89 d
	PI 126915 sel	19	2	0	0	21	1.07 i
	PI 205017	4	8	12	15	39	3.02 cd
	PI 205017 sel	18	1	0	0	19	1.06 i
	PI 568258	0	9	12	24	45	3.34 bc
	PI 568259	0	0	0	25	25	4.00 a
S. lycopersicum	Cstlerock (control)	0	0	0	44	44	4.00 a

[z]Former scientific names: *Lycopersicon chessmanii* for *Solanum. chessmaniae*, *L. chilense* for *S. chilense*, *L. chmielewskii* for *S. chmielewskii*, *L. hirsutum* for *S. habrochaites*, *L. esculentum* for *S. lycopersicum*, *L. parvifolrum* for *S. neorickii*, *L. pennellii* for *S. pennellii*, *L. peruvianum* for *S. peruvianum*, *L. pimpinellifolium* for *S. pimpinellifolium*, and *Lycopersicon sp.* for *Solanum sp.*

[y]Disease scores: 1, symptomless; 2, slight; 3, moderate, and 4, severe symptoms.

[x]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

[w]sel: a selection from the indicated accession.

Table 4. Evaluation for TYLCV resistance in plants of domesticated and wild tomato accessions in the 2007-2008 fall planting.

Species[z]	Accession	Frequency of TYLCV disease score[y] 1	2	3	4	Total No. of plants	Mean score[x]
S. chessmaniae	PI 379035	14	2	1	0	17	1.18 d-k
S. chilense	LA 2931	11	2	0	0	13	1.12 g-k
S. chmielewskii	LA 1028	15	5	1	0	21	1.32 c-k
	LA 1317	18	1	4	0	23	1.39 c-j
	PI 379030	12	4	0	0	16	1.31 c-k
S. habrochaites	LA 1347	14	4	1	0	19	1.33 c-k
	LA 1393	15	2	0	0	17	1.11 h-k
	LA 1731	15	7	1	0	23	1.38 c-j
	LA 1777	15	0	0	0	15	1.00 k
	PI 126445	16	0	0	0	16	1.00 k
	PI 365907	8	4	3	0	15	1.49c-g
	PI 379013	15	0	0	0	15	1.00 k
	PI 390513	15	3	2	0	20	1.31 c-k
	PI 390662	15	3	0	0	18	1.15 f-k
S. lycopersicum	LA 3845 sel[w]	16	4	0	0	20	1.21 c-k
	LA 3846 sel	21	5	0	0	26	1.16 e-k
S. lycopersicum var. *flammatum*	LYC 179/83	6	2	0	24	32	3.34 b
	LYC 179/83 sel	18	1	0	0	19	1.07jk
S. lycopersicum var. *pyriforme*	LYC 32/83	4	1	2	22	29	3.50 b
	LYC 32/83sel	19	3	0	0	22	1.14 f-k
S. neorickii	LA 1326	17	4	1	0	22	1.26 c-k
	LA 2201	10	4	3	0	17	1.50 c-f
S. pennellii	LA 716	3	0	0	0	3	1.00 k
	LA 1303	2	1	0	0	3	1.25 c-k
S. peruvianum	LA 107	16	0	0	0	16	1.00 k
	LA 372	12	4	1	0	17	1.40 c-j
	LA 1274	17	5	1	0	23	1.31 c-k
	LA 1333	16	0	0	0	16	1.00 k
	LA 1474	17	0	0	0	17	1.00 k
	LA 1677	23	0	0	0	23	1.00 k
	LA 2157	19	0	0	0	19	1.00 k
	LA 2172	18	0	0	0	18	1.00 k
	PI 126435	11	4	1	0	16	1.41 c-j
	PI 126444	17	5	0	0	22	1.23 c-k
	PI 126935	18	6	3	0	27	1.44 c-i
	PI 127831	23	0	0	0	23	1.00 k

Continued

Table 4. Continued.

Species[z]	Accession	Frequency of TYLCV disease score[y] 1	2	3	4	Total No. of plants	Mean score[x]
S. peruvianum (Contd.)	PI 128648	19	4	6	0	29	1.53 cd
	PI 128652	24	0	0	0	24	1.00 k
	PI 128653	14	3	0	0	17	1.20 c-k
	PI 128655	10	1	2	0	13	1.28 c-k
	PI 212407	16	2	0	0	18	1.13 g-k
	PI 270435	22	0	0	0	22	1.00 k
	PI 306811	11	3	1	0	15	1.33 c-k
	CNV sél INRA	26	0	0	0	26	1.00 k
S. pimpinellifolium	LA 121	33	0	0	0	33	1.00 k
	LA 722	15	4	2	0	21	1.35 c-k
	LA 1256	23	6	1	0	30	1.26 c-k
	LA 1342	16	4	4	0	24	1.46 c-h
	LA 1478	14	5	0	0	19	1.21 c-k
	LA 1633	16	4	4	0	24	1.55 c
	LA 2182	13	3	1	2	19	1.52 c-e
	LA 2656	15	7	0	0	22	1.32 c-k
	LA 2656 sel	27	0	0	0	27	1.00 k
	PI 126947	19	7	5	0	31	1.55 cd
	PI 211838	15	10	1	0	26	1.47 c-h
	PI 211840	16	2	0	0	18	1.07 jk
	PI 212408	15	6	1	0	22	1.34 c-k
	PI 379023	15	4	1	1	21	1.40 c-j
	PI 407543	15	5	3	0	23	1.41 c-j
	PI 407544	33	0	0	0	33	1.00 k
	PI 407555	34	0	0	0	34	1.00 k
Solanum sp	PI 126915	5	1	2	19	27	3.30 b
	PI 126915 sel	20	2	0	0	22	1.08 i-k
	PI 205017	3	2	5	15	25	3.31 b
	PI 205017 sel	9	0	0	0	9	1.00 k
S. lycopersicum	Cstlerock (control)	0	0	3	44	47	3.94 a

[z]Former scientific names: *Lycopersicon chessmanii* for *Solanum. chessmaniae*, *L. chilense* for *S. chilense*, *L. chmielewskii* for *S. chmielewskii*, *L. hirsutum* for *S. habrochaites*, *L. esculentum* for *S. lycopersicum*, *L. parvifolrum* for *S. neorickii*, *L. pennellii* for *S. pennellii*, *L. peruvianum* for *S. peruvianum*, *L. pimpinellifolium* for *S. pimpinellifolium*, and *Lycopersicon sp.* for *Solanum sp.*

[y]Disease scores: 1, symptomless; 2, slight; 3, moderate, and 4, severe symptoms.

[x]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

[w]sel: a selection from the indicated accession.

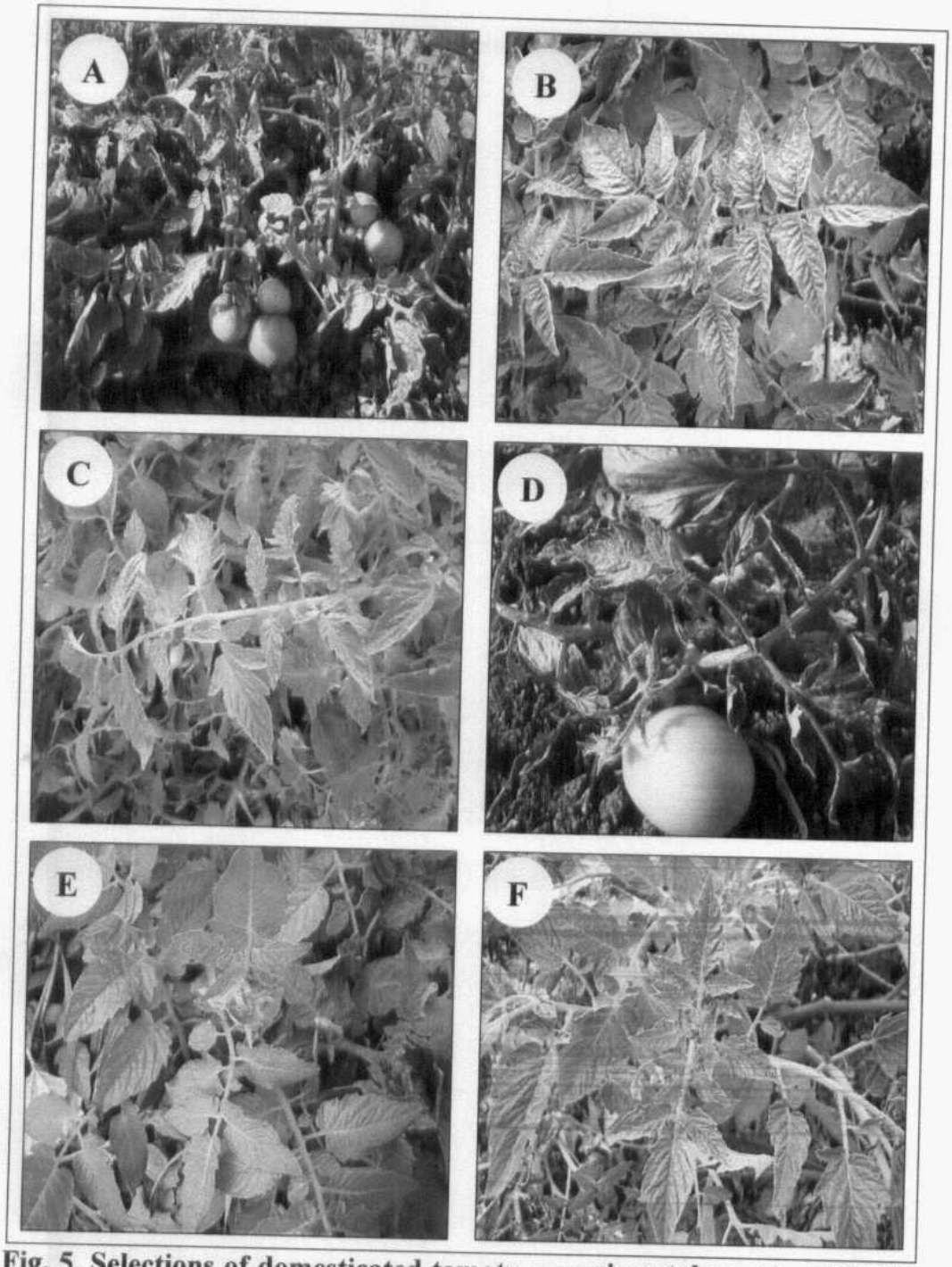

Fig. 5. Selections of domesticated tomato accessions tolerant to TYLCV. A, selection of *S. lycopersicum* var. *flammatum* LYC 179/83; B, selection of *S. lycopersicum* var. *pyriforme* LYC 32 / 83; C and D, selections of *S. lycopersicum* LA 3845 and LA 3846, respectively; and E and F, selections of *Solanum sp.* PIs 126915 and PI 205017, respectively.

S. lycopersicum LAs 3845 and 3846, which were evaluated through the second and third evaluation seasons, showed tolerance to TYLCV (Fig. 5 E-F), and their mean scores were, respectively, 1.28 and 1.29 in the second season and 1.21 and 1.16 in the third season. These findings are significant to the tomato breeder who looks for tolerant sources to TYLCV in domestic tomato germplasm.

In the two seasons, all of the re-evaluated accessions of *S. chessmaniae*, *S. chilense*, *S. chmielewskii*, *S. habrochaites*, *S. neorickii*, *S. pennellii*, and *S. peruvianum* showed low TYLCV mean scores that ranged from 1.00 to 1.91 (Fig. 6). The accessions *S. habrochaites* LA 1777, PI 126445, and PI 379013; *S. pennellii* LA 716; and *S. peruvianum* LAs 107, 1333, 1474, 1677, 2157, and 2172, PIs 127831, 128652, and 270435, and CMV sél INRA were free of any TYLCV symptoms. Results obtained on the reaction of *S. chilense* agree with those of Pilowsky and Cohen (1974 and 2000), Ioannou (1985), Zakay *et al.* (1991), Abou-Jawdah *et al.* (1996), Giorando *et al.* (1999) and Samarajeewa *et al.* (2005) who reported a high level of TYLCV resistance in *S. chilense* accessions, whereas, the present results partially agree with those of Picó *et al.* (1998), who found that *S. chilense* accessions LA 1963 and LA1969 out of 4 accessions evaluated showed a high level of resistance. On the contrary, Mahmoud (2004) found susceptibility to TYLCV in *S. chilense* PI 251313. Results obtained on *S. chmielewskii* confirm previous report by Mahmoud (2004).

Results obtained on *S. pennellii* confirm previous reports by Hassan and Abdel-Ati (1999) and Mahmoud (2004).

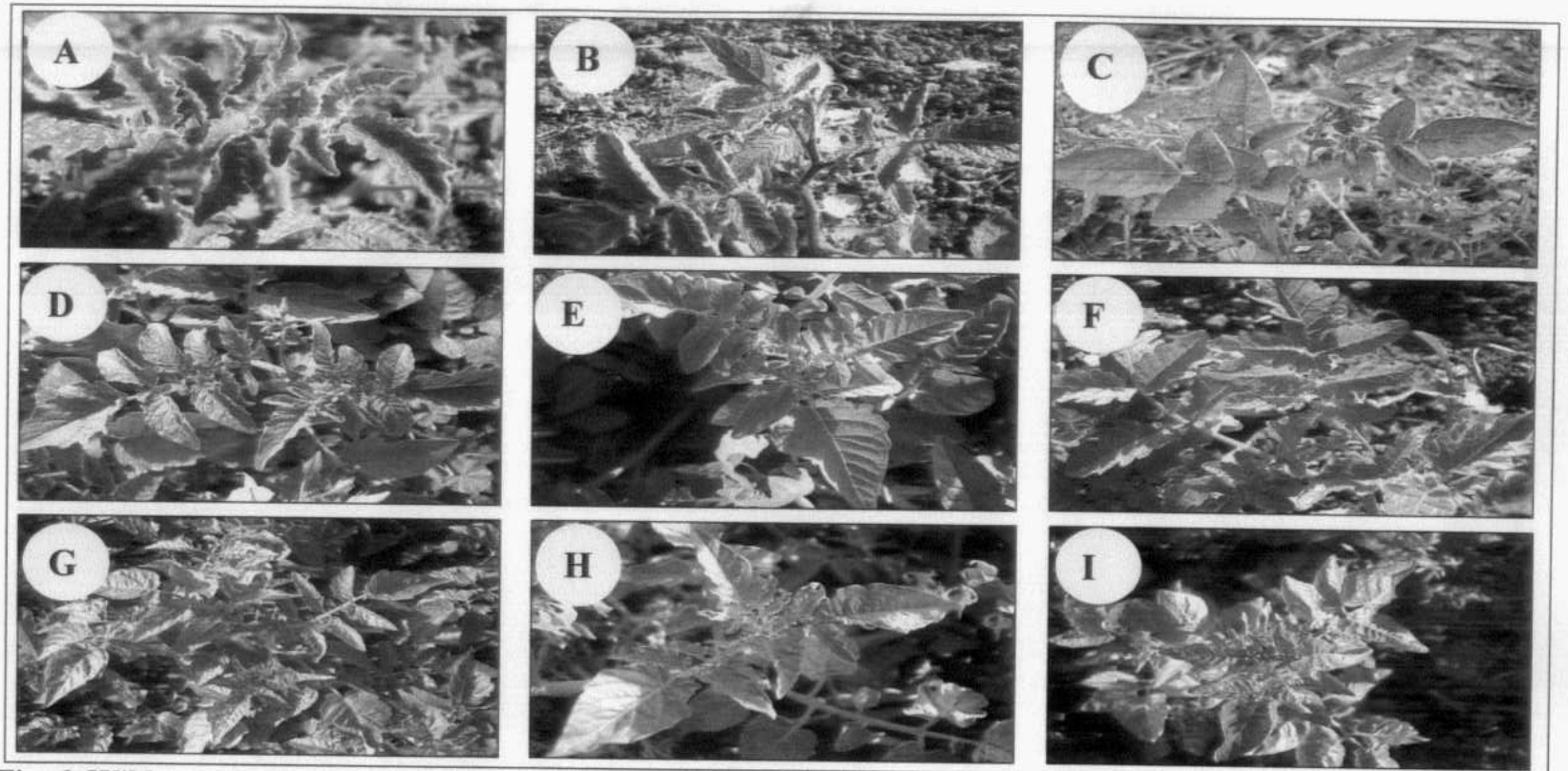

Fig. 6. Wild tomato accessions resistant to TYLCV. A-B, *S. habrochaites* PIs 126445 and 390662, respectively; C, *S. neorickii* LA 1326, D-F, *S. peruvianum* LA 107, PI 127831 and CMV sél INRA, respectively; G-H, *S. pimpinellifolium* PIs 211840 and 407544; and I, a selection of *S. pimpinellifolium* LA 2656.

Results on *S. habrochaites* are in agreement with those of Hassan *et al.* (1982 and 1991), Mazyad *et al.* (1982), Geneif (1984), Ioannou (1985), Siakia and Myniyappa (1989) and Muniyappa *et al.*, (1991) who found a high level of TYLCV resistance in the evaluated *S. habrochiates* accessions, whereas the present results partially agree with those of Kasrawi *et al.* (1988) and Mahmoud (2004) who found that accessions of *S. habrochaites* showed a wide range of reaction.

Results on *S. peruvianum* confirm those obtained by Hassan *et al.* (1982, 1991), Pilowsky and Cohen (1990), Friedmann *et al.*, (1998), and Lapidot *et al.*, (1997) who found a high level of TYLCV resistance in the evaluated *S. peruvianum* accessions.

The present results on *S. cheesmaniae* and *S. neorickii* accessions are the first record of their reaction to TYLCV.

In both seasons, the re-evaluated accessions of *S. pimpinellifolium* showed low TYLCV mean scores that ranged from 1.00 to 1.96. Accessions LAs 121 and 2656 sel and PIs 407544 and 407555 were free of any TYLCV symptoms. Generally, our results on *S. pimpinellifolium* are in agreement with those of Hassan *et al.* (1982), Kasrawi (1989) and Mahmoud (2004) who found that *S. pimpinellifolium* accessions showed a wide range of reaction to TYLCV infection. Meanwhile, they partially agree with those of Pilowsky and Cohen (1974), Geneif (1984), and Hassan and Abdel-Ati (1999) who reported resistance to TYLCV in the evaluated *S. pimpinellifolium* accessions.

Grafting experiment revealed that all evaluated symptomless plants of accessions *S. pennellii* LA 716 and *S. peruvianum* LAs 107,

1474, 1677, 2157, and 2172 and PIs 128652 and 270435 were not virus carriers, as scions of 'Castlerock' grafted on them remained free of any TYLCV symptoms during the course of the experiment which lasted for 12 weeks after grafting (Table 5). These accessions are considered resistant. On the contrary, variable reactions, i.e., some grafts proved positive and others negative for virus presence, were found in symptomless plants of accessions *S. habrochaites* LAs 1393 and 1777 and PIs 379013 and 390662; *S. peruvianum* LA 1333, PI 127831, and CMV sél INRA; and *S. pimpinellifolium* LA 121 and PIs 211840, 407544, and 407555. Meanwhile, all grafts proved positive for virus presence in symptomless plants of *S. lycopersicum* LYCs 179/83 sel and 32/83 sel, and *Solanum sp.* PIs 126915 sel and 205017 sel. Accessions having low mean disease scores whose grafts were completely or partially positive to virus presence may be considered tolerant to TYLCV infection.

2. Genetics of resistance

Data obtained on TYLCV resistance of parental, F_1, and F_2 populations of the crosses between cv. Castlerock, as a female parent, and each of *S. chmielewskii* LA 1317; *S. habrochaites* LA 1777 and PI 390662; *S. lycopersicum* var. *flammatum* LYC 179/83 sel; *S. neorickii* LA 1326; *S. pimpinellifolium* PIs 211840 and 407543; and *Solanum sp.* PI 205017 sel, as male parents, are presented in Table 6, while quantitative genetic parameters obtained for the same crosses are presented in Table 7.

Table 5. Detection of TYLCV symptoms on scions of healthy 'Castlerock' when grafted on rootstock of selected symptomless plants of some domestic and wild tomato accessions.

Species[z]	Accession	No of grafted plants	Number of grafts in which TYLCV symptoms were detected (+) or not detected (-) after lapsed period (in weeks) after grafting											
			2		4		6		8		10		12	
			-	+	-	+	-	+	-	+	-	+	-	+
S. habrochaites	LA 1393	9	9	0	9	0	8	1	8	1	7	2	7	2
	LA 1777	7	7	0	7	0	7	0	6	1	5	2	5	2
	PI 379013	8	8	0	8	0	8	0	5	2	4	3	4	3
	PI 390662	10	10	0	10	0	8	2	8	2	7	3	7	3
S. lycopersicum var. *flammatum*	LYC 179/83 sel[y]	9	9	0	7	2	5	4	2	7	0	9	0	9
S. lycopersicum var. *pyriforme*	LYC 32/83 sel	7	7	0	5	2	3	4	0	7	0	7	0	7
S. pennellii	LA 716	3	3	0	3	0	3	0	3	0	3	0	3	0
S. peruvianum	LA 107	9	9	0	9	0	9	0	9	0	9	0	9	0
	LA 1333	6	6	0	6	0	5	1	5	1	5	1	5	1
	LA 1474	7	7	0	7	0	7	0	7	0	7	0	7	0
	LA 1677	9	9	0	9	0	9	0	9	0	9	0	9	0
	LA 2157	5	5	0	5	0	5	0	5	0	5	0	5	0
	LA 2172	7	7	0	7	0	7	0	7	0	7	0	7	0
	PI 127831	7	7	0	7	0	7	0	6	1	6	1	6	1
	PI 128652	3	3	0	3	0	3	0	3	0	3	0	3	0
	PI 270435	6	6	0	6	0	6	0	6	0	6	0	6	0
	CMV sél INRA	12	12	0	12	0	10	2	10	2	9	3	9	3
S. pimpinellifolium	LA 121	12	11	1	9	3	6	6	6	6	3	9	3	9
	PI 211840	10	9	1	7	3	7	3	5	5	4	6	7	3
	PI 407544	11	9	2	7	4	7	4	3	8	3	8	3	8
	PI 407555	9	9	0	9	0	8	1	7	2	5	4	5	4
Solanum sp.	PI 126915 sel	10	10	0	7	3	4	6	2	8	0	9	0	9
	PI 205017 sel	6	6	0	4	2	4	2	2	4	1	5	0	6

[z]Former scientific names: *Lycopersicon hirsutum* for *Solanum habrochiates*, *L. esculentum* for *S. lycopersicum*, *L. pennellii* for *S. pennellii*, *L. peruvianum* for *S. peruvianum*, *L. pimpinellifolium* for *S. pimpinellifolium*, and *Lycopersicon sp.* for *Solanum sp.*

[y]sel: a selection from the indicated accession.

Table 6. Distribution, mean, and variance of TYLCV disease scores of parental, F_1, and F_2 populations of the crosses between cv. Castlerock and some selected resistance accessions.

Population	Frequency of TYLCV disease score[z] 1	2	3	4	Total No. of plants	Mean $\bar{X} \pm S_{\bar{X}}$	Variance (σ^2)
Castlerock × *S. chmielewskii* LA 1317							
Castlerock	0	0	2	14	16	3.88 ± 0.09	0.12
LA 1317	9	0	0	0	9	1.00 ± 0.00	0.00
F_1	5	9	4	0	18	1.94 ± 0.17	0.53
F_2	24	11	8	12	55	2.15 ± 0.16	1.46
Castlerock × *S. habrochaites* LA 1777							
Castlerock	0	0	2	14	16	3.88 ± 0.09	0.12
LA 1777	7	1	0	0	8	1.13 ± 0.13	0.13
F_1	5	8	3	1	17	2.00 ± 0.21	0.75
F_2	7	11	13	15	46	2.78 ± 0.16	1.15
Castlerock × *S. habrochaites* PI 390662							
Castlerock	0	0	2	14	16	3.88 ± 0.09	0.12
PI 390662	11	0	0	0	11	1.00 ± 0.00	0.00
F_1	11	3	3	0	17	1.53 ± 0.19	0.64
F_2	9	14	12	6	41	2.37 ± 0.16	0.99
Castlerock × *S. lycopersicum* var. *flammatum* LYC 179/83 sel[y]							
Castlerock	0	0	2	14	16	3.88 ± 0.09	0.12
LYC 179/83 sel	14	5	0	0	19	1.26 ± 0.10	0.20
F_1	6	10	12	5	33	2.48 ± 0.17	0.95
F_2	5	9	13	19	46	3.00 ± 0.15	1.07
Castlerock × *S. neorickii* LA 1326							
Castlerock	0	0	2	14	16	3.88 ± 0.09	0.12
LA 1326	11	0	0	0	11	1.00 ± 0.00	0.00
F_1	7	8	5	2	22	2.09 ± 0.21	0.94
F_2	9	11	7	18	45	2.76 ± 0.18	1.42
Castlerock × *S. pimpinellifolium* PI 211840							
Castlerock	0	0	2	14	16	3.88 ± 0.09	0.12
PI 211840	13	2	0	0	15	1.13 ± 0.09	0.12
F_1	9	5	15	3	32	2.38 ± 0.18	1.02
F_2	9	8	8	21	46	2.89 ± 0.18	1.43
Castlerock × *S. pimpinellifolium* PI 407543							
Castlerock	0	0	2	14	16	3.88 ± 0.09	0.12
PI 407543	8	1	0	0	9	1.11 ± 0.11	0.11
F_1	5	7	9	2	23	2.35 ± 0.19	0.87
F_2	7	8	13	15	43	2.84 ± 0.17	1.19

Continued

Table 6. Continued

Population	Frequency of TYLCV disease scores[z] 1	2	3	4	Total No. of plants	Mean $\bar{X} \pm S_{\bar{X}}$	Variance (σ^2)
Castlerock × *Solanum sp.* PI 205107 sel							
Castlerock	0	0	2	14	16	3.88 ± 0.09	0.12
PI 205107 sel	15	2	0	0	17	1.12 ± 0.08	0.11
F_1	11	15	7	5	38	2.16 ± 0.16	1.00
F_2	5	8	9	15	37	2.92 ± 0.18	1.19

[z]Disease scores: 1, symptomless; 2, slight; 3, moderate; and 4, severe symptoms.
[y]sel: a selection from the indicated accession.

Table 7. Quantitative genetic parameters obtained for the TYLCV resistance character from crosses between cv. Castlerock and some selected resistant accessions.

Cross	Parameter: Potence ratio	No. of genes	BSH (%)
Castlerock × *S. chmielewskii* LA 1317	-0.35	1.11	84.93
Castlerock × *S. habrochaites* LA 1777	-0.37	2.36	71.30
Castlerock × *S. habrochaites* PI 390662	-0.63	2.96	74.75
Castlerock × *S. lycopersicum* var. *flmmatum* LYC 179/83 sel[z]	-0.06	7.15	60.75
Castlerock × *S. neorickii* LA 1326	-0.24	2.16	75.35
Castlerock × *S. pimpinellifolium* PI 211840	-0.09	2.30	70.63
Castlerock × *S. pimpinellifolium* PI 407543	-0.10	3.00	68.91
Castlerock × *Solanum sp.* PI 205107 sel	-0.25	5.01	65.55

[z]sel: a selection from the indicated accession.

a. Resistance derived from *S. chmielewskii*

In the cross Castlerock × LA 1317, parents were highly significantly different in TYLCV mean scores. F_1 mean was very close to that of the resistant parent. F_2 plants were widely distributed between their respective parents with a mean score very close to the mid parental value.

The low negative P value (-0.35) indicated partial dominance of resistance to TYLCV over susceptibility. Resistance to TYLCV was found to be controlled by two pairs of genes. Estimate of BSH in this cross was high, being 84.93 %.

The present result on the inheritance of TYLCV-resistance in *S. chmielewskii* accessions is being reported for the first time.

b. Resistance derived from *S. habrochaites*

In each of the two studied crosses which involved *S. habrochaites* accessions LA 1777 and PI 390662, parents of each cross were highly significantly different in their TYLCV mean scores. F_1 means were intermediate between their respective parents with a tendency towards the resistant parent, especially in the cross Castlerock × PI 390662. F_2 plants were widely distributed between their respective parents with a slight tendency towards the mid parental value (Table 6).

In each of the two studied crosses, the low negative P values (-0.37 and -0.63, respectively) indicated partial dominance of resistance to TYLCV over susceptibility. These results are in agreement with those obtained by Hassan *et al.* (1984b) and Banerjee and Kalloo (1987a) who reported that TYLCV resistance was dominant over susceptibility, but contradict those obtained by Vidavsky and Czosnek (1998) and Mahmoud (2004) who found that TYLCV resistance was a recessive trait.

Minimum number of genes estimated to control TYLCV resistance in the crosses Castlerock × LA 1777 and Castlerock × PI 390662 were 3 pairs as estimated by Castle-Wright

equation. Those results coincide with those obtained by Nainar and Pappiah (2002c) who estimated 3 paris of genes to control this character. Meanwhile, Vidavsky and Czosnek (1998) reported that TYLCV resistance was controlled by 2 to 3 pairs of genes. Also, Banerjee and Kallo (1987a) found that resistance in *S. habrochaites* was controlled by 2 pairs of genes.

Estimates of BSH for the crosses Castlerock × LA 1777 and Castlerock × PI 390662 were moderately high, being 71.30 % and 74.75 %, respectively (Table 7). These results agree with those obtained by Mahmoud (2004) who found that BSH was 76.3 % for the cross Castlerock × PI 126445.

c. Resistance derived from *S. lycopersicum*

In the cross Castlerock × *S. lycopersicum* var. *flmmatum* LYC 179/83 sel, parents were highly significantly different in TYLCV mean score. F_1 mean was intermediate between the two parents with a slight tendency towards the resistant parent. F_2 plants were widely distributed between their respective parents with a tendency towards the susceptible one.

The very low negative P value (-0.06) indicated partial dominance of resistance to TYLCV over susceptibility. These results are in agreement with those of Chomdej *et al.* (2007) who found that the resistance to TYLCTHV-2 in AVRDC resistant lines, *viz.*, H24, FLA591-15, and FLA456-4, was incompletely dominant. Meanwhile, Mazyad *et al.* (2007) found that resistance derived form resistant tomato line Favi-9, was partially recessive.

Also, Abdel-Ati *et al.* (2005) found two types of dominance for TYLCV-resistance in 4 susceptible × resistant crosses, *viz.*, partial dominance for TYLCV-susceptibility in 3 crosses and no dominance in one.

Resistance to TYLCV in *S. lycopersicum* var. *flmmatum* LYC 179 / 83 sel was found to be controlled by 8 pairs of genes.

Mazyad et al. (2007) found that resistance derived from tomato line Favi-9 is controlled by one to 2 pairs of genes, while, Abdel-Ati *et al.* (2005) found that resistance derived from resistant tomato inbred lines is controlled by 2 to 4 pairs of genes.

Estimate of BSH in this cross was moderate, being 60.43 %. This result was in accordance with those obtained by Abdel-Ati *et al.* (2005) who estimated BSH ranging from 67.7 to 74.6 % in four tomato resistant inbred lines. Mazyad *et al.* (2007) estimated BSH as 55.76%, 59.31%, 75.64%, 83.27%, and 88.38% for crosses between the resistant tomato line Favi-9 and cvs. Edkawy, Strain B, Marmmande, Castle Rock, and Peto 86, respectively.

d. Resistance derived from *S. neorickii*

In the cross Castlerock × LA 1326, parents were highly significantly different in TYLCV mean score. F_1 mean was intermediate between the two parents with a slight tendency towards the resistant parent. F_2 plants were widely distributed between their respective parents with a slight tendency towards the susceptible parent.

The low negative P value (-0.24) obtained indicated partial dominance of resistance to TYLCV over susceptibility. Resistance to TYLCV was found to be controlled by 3 pairs of genes. Estimate of BSH in this cross was moderately high, being 75.03%.

The present result on the inheritance of TYLCV-resistance in *S. neorickii* accessions is being reported for the first time.

e. Resistance derived from *S. pimpinellifolium*

In each of the two studied crosses which involved *S. pimpinellifolium* accessions PIs 211840 and 407543, parents of each cross were highly significantly different in their TYLCV mean scores. F_1 means were intermediate between their respective parents with a slight tendency towards the resistant parent. F_2 plants were widely distributed between their respective parents with a slight tendency towards the susceptible one (Table 6).

In each one of the two studied crosses, the low negative P values indicated partial dominance for TYLCV-resistance over susceptibility. These results are in agreement with those obtained by Pilowsky and Cohen (1974), Banerjee and Kalloo (1987a), and Hassan and Abdel-Ati (1999) in accessions LA 121, LA 1921, and PI 407555, respectively. On the contrary, complete dominance for TYLCV resistance was reported by Geneif (1984), Yassin (1985 and 1987), Kasrawi (1989), and Hassan and Abdel-Ati (1999) in accessions LA 1478; LA 1582; Hirsute-INRA; PIs 407543 and 407544, respectively. Recessiveness for TYLCV resistance was reported by Hassan *et al.* (1984a), Castro *et al.*

(2007), and Vidavsky *et al.* (1998) in accessions LA 121, LA 373; UPV 16991; and Hirsute, respectively.

Minimum number of genes estimated to control TYLCV resistance in the crosses Castlerock × PI 211840 and Castlerock × PI 407543 was 3 pairs as estimated by Castle-Wright equation. These results agree with previous reports which estimated the number of genes controlling TYLCV tolerance/resistance derived from *S. pimpinellifolium* PIs 407543, 407544, and 407555 as 3 pairs (Hassan and Abdel-Ati, 1999).

Estimates of BSH for the crosses Castlerock × PI 211840 and Castlerock × PI 407543 were moderate, being 69.08 % and 65.55 %, respectively (Table 7). These results partially agree with those obtained by Hassan and Abdel-Ati (1999) who found that BSH ranged from 50.2% to 61.4% in accessions PIs 407543, 407544, and 407555.

f. Resistance derived from *Solanum sp.*

In the cross Castlerock × PI 205107 sel, parents were highly significantly different in TYLCV mean score. F_1 mean was intermediate between the two parents with a slight tendency towards the resistant parent. F_2 plants were widely distributed between their respective parents with a tendency towards the susceptible parent.

The low negative P value (-0.25) indicated partial dominance of resistance to TYLCV over susceptibility. Resistance to TYLCV was found to be controlled by 6 pairs of genes. Estimate of BSH in this cross was moderate, being 65.55 %.

3. Production and evaluation of the F_1s

a. Evaluation of tolerant × tolerant F_1s and their parents

Based on the results of the evaluation trails, *S. lycopersicum* accessions LA 3845 sel (P_1) and LA 3846 sel (P_2); *S. lycopersicum* var. *pyriforme* LYC 32/83 sel (P_3); *S. lycopersicum* var. *flmmatum* LYC 179/83 sel (P_4); *S. pimpinellifolium* PI 211840 (P_5); and *Solanum sp.* accessions PI 126915 sel (P_6) and PI 205017 sel (P_7), having high tolerance to TYLCV and accepted fruit quality characters, were selected for use in a half diallel crossing program to produce tolerant × tolerant F_1s. As presented in the materials and methods, 7 tolerant parents were compared with the highly susceptible cv. Castlerock, while tolerant × tolerant F_1s were compared with the highly tolerant cv. 802 F_1.

1. Evaluation for TYLCV tolerance

Data obtained on TYLCV mean score in 2008/2009 fall planting of tolerant × tolerant F_1s and their parents and the controls are presented in Table 8. All evaluated parents showed high level of TYLCV tolerance with significant differences among them. All evaluated parents were significantly more tolerant to TYLCV than cv. Castlerock. Also, all of them, except P_1, P_2 and P_3, were not significantly different in TYLCV mean score from the control cv. 802 F_1.

All evaluated F_1 hybrids showed high level of TYLCV tolerance (most of their plants were symptomless) and their mean scores of TYLCV infection ranged from 1.07 to 1.50 with significant differences among them and also between them and the control cv. 802 F_1.

Table 8. Reaction of seven TYLCV-tolerant tomato lines and their F_1s to TYLCV in the 2008/2009 fall planting.

Population[z]	Frequency of TYLCV disease score[y]				Total No. of plants	Mean score[x]
	1	2	3	4		
Parents						
P_1	26	5	7	0	38	1.50 b
P_2	28	11	3	0	42	1.40 b-d
P_3	26	8	4	0	38	1.43 b-d
P_4	14	5	0	0	19	1.26 b-g
P_5	13	2	0	0	15	1.13 d-g
P_6	20	2	0	0	22	1.08 e-g
P_7	25	8	0	0	33	1.23 b-g
Castlerock (Control)	0	0	2	14	16	3.86 a
Tolerant × tolerant F_1s						
$P_1 \times P_2$	36	4	3	0	43	1.20 b-g
$P_1 \times P_3$	27	5	3	0	35	1.32 b-f
$P_1 \times P_4$	26	4	4	0	34	1.33 b-f
$P_1 \times P_5$	30	3	2	0	35	1.18 c-g
$P_1 \times P_6$	26	3	4	0	33	1.32 b-f
$P_1 \times P_7$	32	4	5	0	41	1.30 b-g
$P_2 \times P_3$	28	13	3	0	44	1.43 b-d
$P_2 \times P_4$	29	10	5	0	45	1.47 bc
$P_2 \times P_5$	32	5	6	0	43	1.40 b-d
$P_2 \times P_6$	33	5	5	0	43	1.35 b-f
$P_2 \times P_7$	33	7	5	0	45	1.37 b-e
$P_3 \times P_4$	31	7	4	0	42	1.34 b-f
$P_3 \times P_5$	29	5	8	0	42	1.50 b
$P_3 \times P_6$	33	4	7	0	44	1.36 b-e
$P_3 \times P_7$	29	13	5	0	47	1.49 b
$P_4 \times P_5$	29	10	4	0	43	1.42 b-d
$P_4 \times P_6$	31	8	4	0	43	1.36 b-e
$P_4 \times P_7$	33	7	4	0	44	1.34 b-f
$P_5 \times P_6$	37	1	5	0	43	1.26 b-g
$P_5 \times P_7$	37	4	0	0	41	1.09 e-g
$P_6 \times P_7$	41	3	0	0	44	1.07 fg
802 F_1 (Control)	49	1	0	0	50	1.02 g

[z]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; and P_7: *Solanum sp.* PI 205017 sel.

[y]Disease scores: 1, symptomless; 2, slight; 3, moderate, and 4, severe symptoms.

[x]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

The highest level of TYLCV tolerance was noted in the hybrids $P_6 \times P_7$ and $P_5 \times P_7$, which scored 1.07 and 1.09, respectively, followed by the hybrids $P_1 \times P_2$, $P_1 \times P_5$, $P_1 \times P_7$ and $P_5 \times P_6$, with mean scores ranging from 1.18 to 1.30, without significant differences among them. As compared to the control, these 6 hybrids were not significantly different in TYLCV mean score from the control cv. 802 F_1.

2. Evaluation for yield and fruit characters

a. Early yield per plant

Data obtained on EY/plant for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 9. Significant differences were observed among parents, and between parents and the control cv. Castlerock. P_1 and P_2 produced the highest EY, being 0.94 and 0.88 kg/plant, respectively, without significant differences between them, followed by P_4. The control cv. Castelrock produced the lowest EY/plant, being 0.12 kg/plant.

With regard to the evaluated hybrids, the highest significant EY/plant was produced by hybrid $P_1 \times P_4$, followed by hybrid $P_2 \times P_4$ without significant differences between them. The hybrid $P_1 \times P_2$ ranked third in this respect. These three hybrids were significantly superior compared to the control hybrid. Also, all evaluated hybrids were significantly higher in total yield than cv. Castlerock.

b. Total yield per plant

Data obtained on TY/plant for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 9. Significant differences were observed among parents, and between parents and the control cv. Castelrock. All evaluated parents were significantly superior

compared to cv. Castlerock. The highest significant TY/plant was produced by P_1 and P_4. The control cv. Castelrock produced the lowest TY, being 0.73 kg/plant.

Regarding TY/plant of the evaluated hybrids, the control hybrid 802 produced the highest significant TY/plant (4.96 kg/plant) over all evaluated parents and hybrids. The hybrids $P_1 \times P_4$ and $P_1 \times P_2$ were, significantly, the second in this respect, being 4.52 and 4.39 kg/plant, respectively, without significant differences between them, followed by the hybrid $P_2 \times P_4$. Also, all evaluated hybrids were significantly higher in TY/plant than cv. Castlerock.

c. Average fruit weight

Data obtained on AFW for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 9. Significant differences were observed among parents, and between parents and the control cv. Castelrock. The parent P_1 produced the highest significant AFW among all evaluated parents. It was followed by P_4, P_2, and cv. Castlerock without significant differences among them. Fruits of the parents P_3 (*S. lycopersicum* var. *pyriforme*), P_5 (*S. pimpinellifolium*), P_6, and P_7 (*Solanum sp.*) were of the cherry type. Their AFW ranged from 9.76 to 19.35 g.

The control cv. 802 F_1 produced the highest significant AFW, being 136 g, over all evaluated parents and hybrids. Hybrids $P_2 \times P_4$ and $P_1 \times P_4$ were the second in this respect, being 93.15 and 92.71 g, respectively, without significant differences between them, followed by the hybrid $P_1 \times P_2$ (89.78 g) with significant differences among them. AFW of the remaining evaluated hybrids ranged from 4.64 to 37.56 g.

Table 9. Mean performance of seven TYLCV-tolerant tomato lines and their F_1s in total yield, early yield, average fruit weight, and fruit shape index in the 2008/2009 fall planting[z].

Population[y]	Early yield (kg/plant)		Total yield (kg/plant)		Average fruit weight (g)		Fruit shape index (L/D)	
Parents								
P_1	0.94	d	3.46	de	96.07	b	1.25	c
P_2	0.88	de	3.10	f-i	87.14	d	1.32	a
P_3	0.29	no	2.27	kl	11.49	j	1.01	f
P_4	0.82	ef	3.55	d	89.35	d	0.84	l
P_5	0.20	op	1.63	m	9.76	jk	1.02	f
P_6	0.21	op	1.66	m	19.35	i	0.98	gh
P_7	0.21	op	1.77	m	16.79	i	0.97	h
Castlerock (control)	0.12	p	0.73	n	86.81	d	0.97	h
Tolerant × tolerant F_1s								
$P_1 \times P_2$	1.57	b	4.39	bc	89.78	d	1.29	b
$P_1 \times P_3$	0.90	de	3.61	d	34.42	e-g	1.12	d
$P_1 \times P_4$	1.70	a	4.52	b	92.71	c	1.05	e
$P_1 \times P_5$	0.79	ef	3.00	h-j	31.65	gh	1.14	d
$P_1 \times P_6$	0.80	ef	3.24	e-h	34.63	e-g	1.12	d
$P_1 \times P_7$	0.80	ef	3.35	d-g	33.86	fg	1.12	d
$P_2 \times P_3$	0.81	ef	3.11	f-i	30.58	h	1.14	d
$P_2 \times P_4$	1.65	ab	4.21	c	93.15	c	1.05	e
$P_2 \times P_5$	0.68	gh	2.83	ij	31.98	gh	1.15	d
$P_2 \times P_6$	0.67	gh	2.74	j	36.26	ef	1.12	d
$P_2 \times P_7$	0.73	fg	2.92	h-j	34.30	fg	1.12	d
$P_3 \times P_4$	0.82	ef	3.36	d-f	32.17	gh	0.89	j
$P_3 \times P_5$	0.44	kl	2.15	kl	7.20	kl	0.95	hi
$P_3 \times P_6$	0.45	kl	2.13	kl	10.80	j	0.93	i
$P_3 \times P_7$	0.48	jk	2.40	k	9.61	jk	0.94	i
$P_4 \times P_5$	0.55	ij	3.04	g-i	33.72	fg	0.88	jk
$P_4 \times P_6$	0.60	hi	3.12	f-i	37.56	e	0.86	kl
$P_4 \times P_7$	0.54	ij	3.19	e-h	36.08	ef	0.86	kl
$P_5 \times P_6$	0.37	l-n	2.08	l	11.35	j	0.86	kl
$P_5 \times P_7$	0.39	k-m	2.09	l	10.35	j	0.86	kl
$P_6 \times P_7$	0.33	mn	2.30	kl	4.64	l	0.84	l
802 F_1 (control)	1.24	c	4.96	a	136.00	a	1.00	fg

[z]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

[y]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; and P_7: *Solanum sp.* PI 205017 sel.

All these hybrids had at least one parent of P_3, P_5, P_6, and P_7 which are characterized by their small fruits.

d. Fruit shape index

Data obtained on FSI for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 9. Significant differences were observed between the genotypes evaluated for FSI. Results showed that the parents P_1 and P_2 produced oval fruits, meanwhile, parents P_3, P_5, P_6 and P_7 and the check cv. Castlerock produced round fruits. The parent P_4 was the only one that produced oblate fruits.

Hybrid $P_1 \times P_2$ was the only one which produced oval fruits having a FSI of 1.29. The remaining hybrids produced round or oblate fruits.

e. Ascorbic acid content

Data obtained on AAC for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 10. Significant differences were observed among parents, and between parents and the control cv. Castelrock. P_3 had the highest significant AAC (28.19 mg/100 g fresh fruit) among the evaluated parents. Other evaluated parents, except P_1 and P_7, were significantly higher in this character than cv. Castlerock.

The highest significant AAC value was produced by hybrid $P_3 \times P_5$ (38.12 mg/100 g fresh fruit) with significant differences from all other evaluated F_1 hybrids, including the control cv. 802 F_1. It was followed, respectively, by hybrids $P_3 \times P_6$, $P_4 \times P_5$, $P_4 \times P_6$, and $P_3 \times P_7$. It is worthy of mention to indicate that these five top hybrids in AAC

Table 10. Mean performance of seven TYLCV-tolerant tomato lines and their F_1s in fruit chemical characters in the 2008/2009 fall planting[z].

Population[y]	Ascorbic acid content (mg/100 g fresh fruit)		pH value		Titratable acidity (mg citric acid/100 g fresh fruit)		TSS (%)		β-carotene content (mg/100 g fresh fruit)		Lycopene content (mg/100 g fresh fruit)	
Parents												
P_1	19.15	p	4.03	o	0.44	r	4.14	h	0.45	e	2.19	c
P_2	21.45	m	3.97	p	0.41	st	4.04	h	0.51	d	1.91	e
P_3	28.19	f	4.32	d-f	0.57	o	5.87	c	1.62	a	0.43	i
P_4	22.73	k	4.26	g-i	0.48	q	4.14	h	0.44	ef	1.95	e
P_5	24.03	i	4.23	h-l	0.97	c	6.06	b	0.40	fg	2.49	a
P_6	23.25	j	4.35	b-d	0.93	d	5.87	c	0.38	gh	2.46	a
P_7	19.37	p	4.41	b	0.95	d	6.06	b	0.35	h	2.31	b
Castlerock (control)	20.96	n	4.25	g-j	0.53	p	4.00	h	0.46	e	2.10	d
Tolerant × tolerant F_1s												
$P_1 \times P_2$	17.05	u	4.04	o	0.39	t	3.68	i				
$P_1 \times P_3$	19.88	o	4.22	h-l	0.47	q	4.50	fg	0.62	bc	1.18	g
$P_1 \times P_4$	17.59	t	4.19	j-n	0.43	rs	3.73	i				
$P_1 \times P_5$	18.14	s	4.17	l-n	0.65	j-l	4.59	fg				
$P_1 \times P_6$	17.81	st	4.24	g-k	0.64	k-m	4.50	fg				
$P_1 \times P_7$	16.18	v	4.27	f-h	0.63	k-m	4.59	fg				
$P_2 \times P_3$	20.85	n	4.19	k-n	0.44	r	4.46	g	0.64	b	1.05	h
$P_2 \times P_4$	18.56	r	4.16	mn	0.39	t	3.68	i				

Continued

Table 10. Continued[z].

Population[y]	Ascorbic acid content (mg/100 g fresh fruit)	pH value	Titratable acidity (mg citric acid/100 g fresh fruit)	TSS (%)	β-carotene content (mg/100 g fresh fruit)	Lycopene content (mg/100 g fresh fruit)
$P_2 \times P_5$	19.10 pq	4.14 n	0.62 mn	4.54 fg		
$P_2 \times P_6$	18.77 qr	4.21 i-m	0.60 n	4.46 g		
$P_2 \times P_7$	17.15 u	4.23 g-k	0.62 l-n	4.55 fg		
$P_3 \times P_4$	21.39 m	4.34 c-e	0.47 q	4.51 fg	0.62 bc	1.07 h
$P_3 \times P_5$	38.12 a	4.32 de	0.72 g	6.09 b	0.60 bc	1.31 f
$P_3 \times P_6$	36.05 b	4.38 bc	0.70 h	6.01 b	0.60 bc	1.30 f
$P_3 \times P_7$	30.91 d	4.41 b	0.69 hi	6.08 b	0.59 c	1.23 g
$P_4 \times P_5$	31.80 c	4.29 e-g	0.67 ij	5.20 e		
$P_4 \times P_6$	31.73 c	4.36 b-d	0.64 k-m	5.11 e		
$P_4 \times P_7$	29.47 e	4.38 bc	0.65 jk	5.13 e		
$P_5 \times P_6$	22.22 l	4.34 c-e	0.81 f	5.37 d		
$P_5 \times P_7$	20.88 n	4.36 b-d	0.83 e	5.46 d		
$P_6 \times P_7$	25.18 g	3.99 op	1.04 a	6.80 a		
802 F_1 (control)	24.38 h	4.56 a	1.01 b	4.64 f	0.42 ef	2.27 b

[z]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.
[y]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; and P_7: *Solanum sp.* PI 205017 sel.

had at least one of their parents as P_3, P_5, or P_6, which had the highest significant values of AAC among the evaluated parents.

f. Fruit pH value

Data obtained on fruit pH value for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 10. Significant differences were observed among parents, and between parents and the control cv. Castelrock. P_2 had the lowest significant fruit pH value (3.97). Meanwhile, P_3, P_6, and P_7 were significantly higher in this trait than cv. Castlerock.

Control cv. 802 F_1 had the highest fruit pH value, and was significantly different from all other evaluated parents and hybrids. Hybrids $P_6 \times P_7$ and $P_1 \times P_2$ had the lowest fruit pH values (3.99 and 4.03, respectively) without significant differences among them.

g. Fruit titratable acidity

Data obtained on fruit TA for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 10. Significant differences were observed among parents, and between parents and the check cv. Castelrock. The parent P_5 produced the highest fruit TA (0.97 mg citric acid/100 g fresh fruit), followed by P_6 and P_7 with significant differences between them.

$P_6 \times P_7$ had the highest significant TA content among all evaluated genotypes. It was followed by the control cv. 802 F_1, $P_5 \times P_7$, and $P_5 \times P_6$.

h. Fruit total soluble solids content

Data obtained on TSS for the genotypes evaluated in 2008/2009 fall planting are presented in Table 10. Significant differences were

noted among parents, and between parents and the control cv. Castelrock. P_5 and P_7 gave the highest significant TSS content (6.06%) among all evaluated parents, followed by P_3 and P_6 (5.87 %). Other evaluated parents produced fruits having TSS content non-significantly different from the control cv. Castlerock.

The highest significant TSS content among hybrids was produced by $P_6 \times P_7$, followed by $P_3 \times P_5$, $P_3 \times P_6$ and $P_3 \times P_7$, without significant differences between these three hybrids. All evaluated hybrids were significantly superior in TSS compared to cv. Castlerock, except, hybrids $P_1 \times P_2$, $P_1 \times P_4$, and $P_2 \times P_4$. Also, 9 out of the 21 evaluated hybrids significantly surpassed the control cv. 802 F_1 in TSS, which was not significantly different from 7 other hybrids.

i. Fruit pigments content

Fruit pigments were measured as β-carotene and lycopene contents, and measured in ripe fruits of the 7 parents and crosses having P_3 which produces yellow fruits and also measured in the control cvs. Data obtained on fruit β-carotene and lycopene contents in the 2008/2009 fall planting are presented in Table 10. There were significant differences among parents and the check cv. Castlerock in fruit β-carotene and lycopene contents. The parent P_3 had, significantly, the highest β-carotene content (1.62 mg/100 g fresh fruit) and the lowest lycopene content (0.43 mg/100 g fresh fruit) among all evaluated parents and hybrids. Parents P_7 and P_6 had, significantly, the lowest β-carotene content without significant differences between them, followed by P_5. At the same time, P_5 and P_6 had the highest

significant lycopene content (2.49 and 2.46 mg/100 g fresh fruit, respectively), followed by P_7.

There were significant differences among hybrids in β-carotene and lycopene contents. F_1s were close to that of the lower parent in β-carotene content, and intermediate between the two parents in lycopene content.

3. Diallel analysis

a. Variation and mean performance of parents and hybrids

Data obtained on various studied characters under TYLCV-infection for tomato genotypes evaluated in the 2008/2009 fall planting are presented in Table 11. Significant differences were found among the evaluated genotypes for all studied characters.

Mean squares of the studied genotypes and their components (parents and F_1s) for the studied characters under TYLCV-infection are presented in Table 12.

Mean squares for genotypes, parents, and hybrids were highly significant ($P \leq 0.01$) for all studied traits, except, TYLCV mean score character which was significant ($P \leq 0.05$) for genotypes and non-significant for both parents and hybrids (Table 12).

The parents versus hybrids (P vs H) component was highly significant for all studied characters except TYLCV mean score which was non-significant.

b. Combining ability analysis

Combining ability means the capacity of parent to produce different progeny with different genetic make up and change phenotype

Table 11. Mean performance of seven TYLCV-tolerant tomato lines and their twenty one F_1s of various studied characters in the 2008/2009 fall planting[z].

Population[y]	TYLCV mean score[x]	Early yield (kg/plant)	Total yield (kg/plant)	Average fruit weight (g)	Fruit shape index (L/D)	TSS (%)	pH value	Titratable acidity (mg citric acid/100g fresh fruit)	Ascorbic acid content (mg/100g fresh fruit)
Parents									
P_1	1.50 a	0.94 c	3.46 cd	96.07 a	1.25 c	4.14 g	4.03 op	0.44 q	19.15 p
P_2	1.40 a-c	0.88 de	3.10 ef	87.14 d	1.32 a	4.04 g	3.97 q	0.41 rs	21.45 m
P_3	1.42 a-c	0.29 m	2.27 j-l	11.49 o	1.01 h	5.87 c	4.32 de	0.57 o	28.19 f
P_4	1.26 a-e	0.82 ef	3.55 c	89.35 c	0.84 op	4.14 g	4.26 fg	0.48 p	22.73 j
P_5	1.13 c-e	0.20 n	1.63 m	9.76 o	1.02 h	6.06 b	4.23 gh	0.97 b	24.03 h
P_6	1.08 de	0.21 n	1.66 m	19.35 m	0.98 i	5.87 c	4.35 cd	0.93 c	23.25 i
P_7	1.23 a-e	0.21 n	1.77 m	16.79 n	0.97 i	6.06 b	4.41 ab	0.95 c	19.37 p
Tolerant × tolerant F_1s									
$P_1 \times P_2$	1.20 a-e	1.57 b	4.39 ab	89.78 c	1.29 b	3.68 h	4.04 o	0.39 s	17.05 t
$P_1 \times P_3$	1.32 a-e	0.90 cd	3.61 c	34.42 fg	1.12 ef	4.50 f	4.22 hi	0.47 p	19.88 o
$P_1 \times P_4$	1.33 a-e	1.70 a	4.52 a	92.71 b	1.05 g	3.73 h	4.19 j-l	0.43 qr	17.59 s
$P_1 \times P_5$	1.18 b-e	0.79 f	3.00 fg	31.65 j-l	1.14 de	4.59 f	4.17 lm	0.65 ij	18.14 r
$P_1 \times P_6$	1.32 a-e	0.80 f	3.24 de	34.63 fg	1.12 f	4.50 f	4.24 gh	0.64 jl	17.81 s
$P_1 \times P_7$	1.29 a-e	0.80 f	3.35 cd	33.86 gh	1.12 f	4.59 f	4.27 fg	0.63 j-l	16.18 u
$P_2 \times P_3$	1.43 a-c	0.81 e-f	3.11 e-f	30.58 l	1.14 de	4.46 f	4.19 j-l	0.44 q	20.85 n
$P_2 \times P_4$	1.47 ab	1.65 a	4.21 b	93.15 b	1.05 g	3.68 h	4.16 mn	0.39 s	18.56 q
$P_2 \times P_5$	1.40 a-c	0.68 g	2.83 hi	31.98 ij	1.15 d	4.54 f	4.14 n	0.62 mn	19.10 p
$P_2 \times P_6$	1.35a-e	0.67 g	2.74 i	36.26 ef	1.12 f	4.46 f	4.21 ij	0.60 n	18.77 q

Continued

Table 11. Continued[z].

Population[y]	TYLCV mean score[x]	Early yield (kg/plant)	Total yield (kg/plant)	Average fruit weight (g)	Fruit shape index (L/D)	TSS (%)	pH value	Titratable acidity (mg citric acid/100 g fresh fruit)	Ascorbic acid content (mg/100 g fresh fruit)
Tolerant × tolerant F_1s (Contd.)									
$P_2 \times P_7$	1.37 a-d	0.73 g	2.92 gh	34.30 fg	1.12 f	4.55 f	4.23 gh	0.62 lm	17.15 t
$P_3 \times P_4$	1.34 a-e	0.82 e-f	3.36 cd	32.17 hi	0.89 l	4.51 f	4.34 d	0.47 p	21.39 m
$P_3 \times P_5$	1.49 a	0.44 ij	2.15 j-l	7.20 p	0.95 j	6.09 b	4.32 de	0.72 f	38.12 a
$P_3 \times P_6$	1.36 a-e	0.45 ij	2.13 j-l	10.80 o	0.93 j	6.01 b	4.38 ab	0.70 g	36.05 b
$P_3 \times P_7$	1.49 a	0.48 i	2.40 j	9.61 o	0.94 j	6.08 b	4.41 a	0.69 gh	30.91 d
$P_4 \times P_5$	1.42 a-c	0.55 h	3.04 fg	33.72 gh	0.88 lm	5.20 e	4.29 ef	0.67 hi	31.80 c
$P_4 \times P_6$	1.36 a-e	0.60 h	3.12 e-f	37.56 e	0.86 no	5.11 e	4.36 cd	0.64 j-l	31.73 c
$P_4 \times P_7$	1.34 a-e	0.54 h	3.19 de	36.08 ef	0.86 mn	5.13 e	4.38 ab	0.65 ij	29.47 e
$P_5 \times P_6$	1.26 a-e	0.37 l	2.08 l	11.35 o	0.86 mn	5.37 d	4.34 d	0.81 e	22.22 l
$P_5 \times P_7$	1.10 de	0.39 j-l	2.09 l	10.35 o	0.86 mn	5.46 d	4.36 cd	0.83 d	20.88 n
$P_6 \times P_7$	1.07 e	0.33 lm	2.30 j-l	4.64 q	0.84 p	6.80 a	3.99 pq	1.04 a	25.18 g

[z]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

[y]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; and P_7: *Solanum sp.* PI 205017 sel.

[x]Disease scores: 1, symptomless; 2, slight; 3, moderate, and 4, severe symptoms.

Table 12. Mean squares from analysis of variance of a 7 × 7 half diallel crosses of tomato for various characters.

Character	Mean squares					
	Replications df = 3	Genotypes df =27	Parents (P) df = 6	Hybrids (H) df = 20	P vs H df = 1	Error df = 54
TYLCV mean score	0.003^{ns}	0.047*	0.037^{ns}	0.019^{ns}	0.025^{ns}	0.0232
Early yield per plant	0.011**	0.482**	0.187**	0.237**	1.062**	0.0014
Total yield per plant	0.201**	1.840**	2.216**	1.584**	4.716**	0.0234
Average fruit weight	8.537**	2751.791**	2534.508**	1014.550**	2287.714**	1.6481
Fruit shape index	0.002**	0.060**	0.043**	0.026**	0.030**	0.0002
TSS	0.010^{ns}	2.258**	1.492**	1.024**	1.089**	0.0071
pH value	0.016**	0.047**	0.041**	0.019**	0.010**	0.0006
Titratable acidity	0.002**	0.102**	0.101**	0.037**	0.045**	0.0002
Ascorbic acid content	0.097*	110.096**	14.341**	68.126**	7.329**	0.0260

*Significant ($P \leq 0.05$), **highly significant ($P \leq 0.01$) and ^{ns} non-significant.

when combined with another parent. General combining ability (GCA) provides mainly an estimate of additive gene action. Specific combining ability (SCA) refers to the performance of two particular lines in a particular cross combination and it thus reflects non-additive type of gene action (Griffing, 1956).

As presented in materials and methods, combining ability analysis was performed for parents with their F_1s using Model I method II (Singh and Choudhary, 1977). Each analysis was conducted only when significant differences were found among the tested genotypes. Therefore, the genotypic variances were partitioned into their components, i.e., GCA and SCA for the studied characters, except TYLCV mean score. The mean squares due to GCA and SCA for the studied characters are presented in Table 13.

Highly significant mean squares for GCA and SCA were recorded for all studied characters. These results proved that both additive and non-additive gene effects are playing an important role in operating the heredity of all studied traits.

Higher values of variance due to GCA (δ^2_g) than variance due to SCA (δ^2_s) and δ^2_g/δ^2_s ratio was more than one for all studied characters, except pH value and AAC, suggesting preponderance of additive gene action for these characters. Meanwhile, higher values of δ^2_s than δ^2_g and δ^2_g/δ^2_s ratio was less than one for pH value and AAC, indicating that non-additive variance prevailed in genetic determination of these characters.

Results obtained on EY partially agree with the findings of Yang *et al.* (2006) who reported that mean square due to GCA was more

Table 13. Analysis of variance for combining ability of a 7 × 7 half diallel crosses for various characters in tomato.

Characters	Mean squares			δ^2_g	δ^2_s	δ^2_e	$\delta^2_g : \delta^2_s$	δ^2_A	δ^2_D
	GCA df = 6	SCA df = 21	Error df = 54						
Early yield per plant	0.547**	0.051**	0.0014**	0.055	0.049	0.0014	1.12	0.110	0.049
Total yield per plant	2.387**	0.106**	0.0234**	0.253	0.083	0.0234	3.05	0.507	0.083
Average fruit weight	3764.166**	103.877**	1.648**	406.699	102.229	1.6481	3.98	813.398	102.229
Fruit shape index	0.085**	0.002**	0.0002**	0.009	0.001	0.0002	9.00	0.019	0.001
TSS	2.966**	0.121**	0.007**	0.316	0.114	0.0071	2.77	0.632	0.114
pH value	0.045**	0.007**	0.001**	0.004	0.007	0.0006	0.57	0.008	0.007
Titratable acidity	0.145**	0.002**	0.0002**	0.016	0.002	0.0002	8.00	0.032	0.002
Ascorbic acid content	84.182**	23.130**	0.026**	6.784	23.104	0.0260	0.29	13.567	23.104

**Highly significant (P ≤ 0.01).

significant for EY. Meanwhile, Mahendrakar *et al.* (2005) reported that non-additive genetic component was predominant for EY.

The present results on TY character confirm those obtained by Kalloo *et al.* (1974) and Garg *et al.* (2007 and 2008) who reported preponderance of additive type of gene action for EY. Also, Surjan *et al.* (1999) reported that the magnitude of additive gene action was higher than the non-additive one. On the contrary, involvement of non-additive gene action has been reported for the inheritance of TY (Kryuchkov *et al.*, 1992; Srivastava *et al.*, 1998; Dhaliwal, 2000; Thakur and Joshi, 2000; Bhatt *et al.*, 2001 a&b; Dharmatti *et al.*, 2001; Chadha *et al.*, 2001; Roopa *et al.*, 2001; Kaur *et al.*, 2004; Dhaliwal *et al.*, 2004; Mahendrakar *et al.*, 2005; Singh and Singh, 2005).

Regarding AFW character, results obtained confirm previous reports by Kumar *et al.* (1997), Surjan *et al.* (1999), Sharma *et al.* (2002), Pratta *et al.* (2003), Pratta *et al.* (2003), and Garg *et al.* (2007&2008). On the contrary, Roopa *et al.* (2001) and Dhaliwal *et al.* (2004) reported that GCA/SCA ratio indicated a greater role for non-additive gene effects.

Results obtained on FSI character are in agreement with those of Chadha *et al.* (2002) and Garg *et al.* (2007 and 2008) and disagree with those of Singh and Singh (2005) and Sharma *et al.* (2007) who indicated a preponderance of non-additive genetic component for this character.

Results obtained on TA are in agreement with those of Gunasekera and Perera (1999) and Yang *et al.* (2006 and 2007) who reported that the additive genetic variance was predominant for this

character, but present results do not confirm those of Kumar *et al.* (1997), Dhatt *et al.* (2001), and Garg *et al.* (2007 and 2008) who reported that the non-additive genetic variance was predominant in this character.

Results obtained on TSS% partially agree with those of Dhaliwal *et al.* (2000), who found that additive and non-additive gene effects have been observed, but non-additive gene effects were more pronounced. Also, Kumar *et al.* (1997), Dhaliwal *et al.* (2004), and Thakur and Kohli (2005) found a greater role for non-additive gene effects in this character.

Result obtained for pH value partially agree with Singh *et al.* (1998) and Dhaliwal *et al.*, (2003) who reported the involvement of additive and non-additive effects in the inheritance of this character.

Result obtained on AAC are in agreement with those of Kumar *et al.* (1997), Bhatt *et al.* (2001a), Dhatt *et al.* (2001), Roopa *et al.* (2001), Joshi and Kohli (2006), and Garg *et al.* (2007&2008), who reported the importance of non-additive gene action in the inheritance of this character.

c. General combining ability effects

General combining ability effects (g_i) for parental genotypes in F_1's are presented in Table 14.

Results indicated that GCA effects of three parents, *viz.*, P_1, P_2 and P_4 were positive and highly significant for TY/plant. Also, these parents recorded positive and highly significant GCA effects for EY/plant and AFW. For FSI, P_1 and P_2 recorded positive and highly significant GCA effects.

Table 14. General combining ability (GCA) effects for different characters of tomato in a 7 × 7 half diallel cross.

Parent[z]	Early yield per plant	Total yield per plant	Average fruit weight	Fruit shape index	Ascorbic acid content	pH value	Titratable acidity	TSS
P_1	0.32**	0.65**	22.71**	0.13**	-4.43**	-0.08**	-0.11**	-0.66**
P_2	0.25**	0.36**	20.62**	0.15**	-3.39**	-0.12**	-0.14**	-0.70**
P_3	-0.13**	-0.21**	-17.45**	-0.02**	4.30**	0.06**	-0.05**	0.40**
P_4	0.21**	0.59**	22.14**	-0.10**	1.24**	0.03**	-0.10**	-0.46**
P_5	-0.22**	-0.53**	-17.67**	-0.04**	1.50**	0.02**	0.13**	0.40**
P_6	-0.22**	-0.47**	-14.54**	-0.06**	1.49**	0.03**	0.13**	0.47**
P_7	-0.21**	-0.38**	-15.82**	-0.06**	-0.71**	0.06**	0.14**	0.55**
S.E. (g_i)	±0.007	±0.027	±0.229	±0.002	±0.029	±0.004	±0.002	±0.002
S.E. (g_j - g_i)	±0.010	±0.042	±0.349	±0.003	±0.044	±0.007	±0.003	±0.003

**Highly significant and ($P \leq 0.01$).

[z]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; and P_7: *Solanum sp.* PI 205017 sel.

The GCA effects of four parents, *viz.*, P_3, P_4, P_5, and P_6 were positive and highly significant for AAC.

Parents P_1 and P_2 exhibited negative and highly significant (favorable) GCA effects for fruit pH value.

For TA, P_5, P_6 and P_7 recorded positive and highly significant GCA effects. For TSS %, these parents in addition to P_3 recorded highly significant positive GCA effects.

The GCA effects are mainly attributable to additive and additive × additive interactions, which are fixable. Therefore, parents with high GCA may be recommended for utilization in genetic improvement in tomato through varietal breeding.

According to these results, P_1 and P_2 proved to be general good combiners for EY/plant, TY/plant, AFW, FSI, and fruit pH value. On the other hand, P_4 proved to be a general good combiner for EY/plant, TY/plant and AFW.

d. Specific combining ability effects

The specific combining ability (SCA) effects of F_1 cross combinations are presented in Table 15.

For EY/plant, crosses $P_1 \times P_2$, $P_1 \times P_4$, $P_2 \times P_4$, $P_5 \times P_6$, and $P_6 \times P_7$ recorded positive highly significant SCA effects.

Five out 21 crosses, *viz.*, $P_1 \times P_2$, $P_1 \times P_3$, $P_1 \times P_4$, $P_2 \times P_4$ and $P_6 \times P_7$, recorded high significant positive SCA effects and three crosses, *viz.*, $P_1 \times P_6$, $P_1 \times P_7$ and $P_5 \times P_6$ recorded significant positive SCA effects for TY/plant.

For AFW, crosses $P_1 \times P_2$, $P_1 \times P_4$, $P_2 \times P_4$, $P_3 \times P_5$, $P_3 \times P_6$, $P_3 \times P_7$, $P_5 \times P_6$, and $P_5 \times P_7$ recorded high significant positive SCA

Table 15. Specific combining ability (SCA) effects for different characters of tomato in 21 crosses.

Cross[z]	Early yield per plant	Total yield per plant	Average fruit weight	Fruit shape index	Ascorbic acid content	pH	Titratable acidity	TSS
$P_1 \times P_2$	0.306**	0.49**	8.35**	-0.0053ns	1.76**	-0.0034ns	-0.001ns	0.07**
$P_1 \times P_3$	0.006ns	0.27**	-8.94**	-0.0064ns	-3.09**	-0.0012ns	-0.004ns	-0.22**
$P_1 \times P_4$	0.476**	0.38**	9.76**	0.0003ns	-2.32**	0.0014ns	0.001ns	-0.13**
$P_1 \times P_5$	-0.004ns	-0.02ns	-11.50**	0.0199**	-2.03**	-0.0008ns	-0.006ns	-0.13**
$P_1 \times P_6$	-0.001ns	0.17*	-11.64**	0.0225**	-2.35**	0.0503**	-0.015*	-0.28**
$P_1 \times P_7$	-0.001ns	0.18*	-11.13**	0.0218**	-1.79**	0.0503**	-0.033**	-0.28**
$P_2 \times P_3$	-0.015ns	0.07ns	-10.69**	-0.0053ns	-3.17**	0.0003ns	-0.009ns	-0.21**
$P_2 \times P_4$	0.485**	0.36**	12.29**	-0.0186**	-2.40**	-0.0005ns	-0.012ns	-0.13**
$P_2 \times P_5$	-0.054**	0.10ns	-9.07**	0.0110ns	-2.11**	-0.0027ns	-0.008ns	-0.13**
$P_2 \times P_6$	-0.062**	-0.04ns	-7.91**	0.0036ns	-2.44**	0.0484**	-0.031**	-0.28**
$P_2 \times P_7$	-0.009ns	0.04ns	-8.60**	0.0029ns	-1.87**	0.0484**	-0.019**	-0.27**
$P_3 \times P_4$	0.035ns	0.08ns	-10.63**	-0.0064ns	-7.26**	-0.0016ns	-0.012ns	-0.41**
$P_3 \times P_5$	0.089**	-0.01ns	4.22**	-0.0168*	9.21**	0.0029ns	0.012ns	0.31**
$P_3 \times P_6$	0.091**	-0.08ns	4.68**	-0.0108ns	7.16**	0.0473**	-0.018*	0.17**
$P_3 \times P_7$	0.118**	0.09ns	4.78**	-0.0082ns	4.21**	0.0473**	-0.038**	0.15**
$P_4 \times P_5$	-0.144**	0.08ns	-8.86**	-0.0068ns	5.96**	-0.0012ns	0.003ns	0.29**
$P_4 \times P_6$	-0.089**	0.10ns	-8.15**	-0.0075ns	5.89**	0.0499**	-0.034**	0.13**
$P_4 \times P_7$	-0.155**	0.08ns	-8.35**	-0.0016ns	5.83**	0.0499**	-0.024**	0.07**
$P_5 \times P_6$	0.109**	0.18*	5.46**	-0.0712**	-3.87**	0.0477**	-0.090**	-0.47**
$P_5 \times P_7$	0.119**	0.10ns	5.74**	0.0686**	-3.01**	0.0477**	-0.071**	-0.46**
$P_6 \times P_7$	0.064**	0.25**	-3.10**	-0.0727**	1.29**	-0.3412**	0.126**	0.81**
S.E. (s_i)	±0.020	±0.079	±0.665	±0.007	±0.083	±0.013	±0.007	±0.006
S.E. ($s_{ij} - s_{ki}$)	±0.027	±0.110	±0.925	±0.009	±0.116	±0.018	±0.009	±0.008

*Significant ($P \leq 0.05$), **highly significant ($P \leq 0.001$) and ns non-significant.

[z]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; and P_7: *Solanum sp.* PI 205017 sel.

effects.

Regarding to FSI, 4 F_1 crosses, namely $P_1 \times P_5$, $P_1 \times P_6$, $P_1 \times P_7$ and $P_5 \times P_7$, exhibited highly significant positive SCA effects.

For AAC, 8 crosses, *viz.*, $P_1 \times P_2$, $P_3 \times P_5$, $P_3 \times P_6$, $P_3 \times P_7$, $P_4 \times P_5$, $P_4 \times P_6$, $P_4 \times P_7$, and $P_6 \times P_7$, had highly significant positive SCA effects. Also, these crosses had highly significant positive SCA effects for TSS%.

With respect to fruit pH value, only one cross ($P_6 \times P_7$) recorded negative (favorable) and high significant SCA effects. Also, this cross recorded high significant positive SCA effects of TA content.

SCA involves non-additive effects and additive × dominance and dominance × dominance interactions, which are non-fixable or non-heritable and are of significance in hybrid breeding only. So, SCA effects are useful to predict the potential of a particular cross in exploiting heterosis.

Based on results obtained for SCA effects, cross $P_1 \times P_2$ was the best combination for EY/plant, TY/plant, AFW, AAC, and TSS. Meanwhile, crosses $P_1 \times P_4$, $P_2 \times P_4$ and $P_5 \times P_6$ were the best combinations for EY/plant, TY/plant and AFW, while, cross $P_6 \times P_7$ was the best combination for EY/plant, TY/plant, fruit pH value, TA and TSS.

e. Heterosis estimations

The percent increase (+) or decrease (-) of a cross over the better parent was calculated to determine heterotic effects for all traits. Data on estimates of heterosis over the better parent (heterobeltiosis) for the studied characters are presented in Table 16.

Table 16. Estimates of heterobelotiosis percentage for the studied characters of 21 crosses.

Cross[z]	TYLCV mean score	Early yield	Total yield	Average fruit weight	Fruit shape index	TSS	pH value	Titratable acidity	Ascorbic acid content
$P_1 \times P_2$	-14.29^{ns}	67.02*	26.88*	-6.55*	-2.27*	-11.11*	1.76*	-11.36*	-20.51*
$P_1 \times P_3$	-7.70^{ns}	-4.26^{ns}	4.34^{ns}	-64.17*	-10.40*	-23.34*	4.71*	-17.54*	-29.48*
$P_1 \times P_4$	5.56^{ns}	80.85*	27.32*	-3.50*	-16.00*	-9.90*	3.97*	-10.42*	-22.61*
$P_1 \times P_5$	4.42^{ns}	-15.96*	-13.29*	-67.06*	-8.80*	-24.26*	3.47*	-32.99*	-24.51*
$P_1 \times P_6$	22.22^{ns}	-14.89*	-6.36^{ns}	-63.95*	-10.40*	-23.34*	5.21*	-31.18*	-23.40*
$P_1 \times P_7$	5.69^{ns}	-14.89*	-3.18^{ns}	-64.75*	-10.40*	-24.26*	5.96*	-33.68*	-16.47*
$P_2 \times P_3$	2.14^{ns}	-7.95^{ns}	0.32^{ns}	-64.91*	-13.64*	-24.02*	5.54*	-22.81*	-26.04*
$P_2 \times P_4$	16.67^{ns}	87.50*	18.59*	4.25*	-20.45*	-11.11*	4.79*	-18.75*	-18.35*
$P_2 \times P_5$	23.89^{ns}	-22.73*	-8.71*	-63.30*	-12.88*	-25.08*	4.28*	-36.08*	-20.52*
$P_2 \times P_6$	25.00^{ns}	-23.86*	-11.61*	-58.39*	-15.15*	-24.02*	6.05*	-35.48*	-19.27*
$P_2 \times P_7$	11.38^{ns}	-17.05*	-5.81*	-60.64*	-15.15*	-24.92*	6.55*	-34.74*	-20.05*
$P_3 \times P_4$	6.35^{ns}	0.00^{ns}	-5.35^{ns}	-64.00*	-11.88*	-23.17*	1.88*	-17.54*	-24.12*
$P_3 \times P_5$	32.74*	51.72*	-5.29^{ns}	-37.34*	-6.86*	0.50^{ns}	2.13*	-25.77*	35.23*
$P_3 \times P_6$	25.93^{ns}	55.17*	-6.17^{ns}	-44.19*	-7.92*	2.39*	1.39*	-24.73*	27.88*
$P_3 \times P_7$	21.14^{ns}	65.52*	5.73^{ns}	-42.76*	-6.93*	0.33^{ns}	2.08*	-27.37*	9.65*
$P_4 \times P_5$	25.66^{ns}	-32.93*	-14.37*	-62.26*	-13.73*	-14.19*	1.42*	-30.93*	32.33*
$P_4 \times P_6$	25.93^{ns}	-26.83*	-12.11*	-57.96*	-12.24*	-12.95*	2.35*	-31.18*	36.47*
$P_4 \times P_7$	8.94^{ns}	-34.15*	-10.14*	-59.62*	-11.34*	-15.35*	2.82*	-31.58*	29.65*
$P_5 \times P_6$	16.67^{ns}	76.19*	25.30*	-41.34*	-15.69*	-11.39*	2.60*	-16.49*	-7.53*
$P_5 \times P_7$	-3.54^{ns}	85.71*	18.08*	-38.36*	-15.69*	-9.90*	3.07*	-14.43*	-13.11*
$P_6 \times P_7$	-0.93^{ns}	57.14*	29.94*	-76.02*	-14.29*	12.21*	-8.28*	9.47*	8.30*

*Significant ($P \leq 0.05$) and ^{ns} non-significant.

[z] P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; and P_7: *Solanum sp.* PI 205017 sel.

For TYLCV mean score character, the better-parent have the smaller value. Concerning heterobeltiosis for TYLCV resistance, only 4 hybrids, *viz.*, $P_1 \times P_2$, $P_1 \times P_3$, $P_5 \times P_7$ and $P_6 \times P_7$, gave desired negative heterobeltiosis, but without significant differences from their respective better-parents. Other evaluated hybrids exhibited positive heterobeltiosis, but without significant differences between them and their respective better-parents, except the hybrid $P_3 \times P_5$, where its mean score was significantly greater than its better-parent.

For EY/plant, 9 out of the 21 evaluated hybrids exhibited heterobelotiosis with significant differences between them and their respective better-parents. Hybrids $P_2 \times P_4$, and $P_5 \times P_7$, gave the highest heterobeltiosis percentage (87.50 and 85.71, respectively).

Data on heterobeltiosis for TY/plant indicated that 6 out the 21 evaluated hybrids gave significant positive heterobelotiosis, *viz.*, $P_1 \times P_2$, $P_1 \times P_4$, $P_2 \times P_4$, $P_5 \times P_6$, $P_5 \times P_7$ and $P_6 \times P_7$, with the hybrids $P_6 \times P_7$, $P_1 \times P_4$ and $P_1 \times P_2$ having the highest heterobelotiosis percentages (29.94, 27.32 and 26.88, respectively).

As regarding heterobelotiosis for AFW, only one hybrid out of 21 hybrids, *viz.*, $P_2 \times P_4$, significantly surpassed it's respective better-parent in this trait.

Data obtained on heterobelotiosis for TSS indicated that only 2 hybrids, *viz.*, $P_3 \times P_6$ and $P_6 \times P_7$, showed positive significant heterobelotiosis (2.39 and 12.21, respectively).

Only one hybrid out of the 21 hybrids, *viz.*, $P_6 \times P_7$, exhibited significant negative heterobelotiosis (-8.28%) for fruit pH trait. Also,

for fruit TA trait, this hybrid exhibited significant positive heterobelotiosis (9.47%).

For fruit AAC, 7 out of the 21 evaluated hybrids exhibited significant heterobelotiosis, *viz.*, $P_3 \times P_5$, $P_3 \times P_6$, $P_3 \times P_7$, $P_4 \times P_5$, $P_4 \times P_6$, $P_4 \times P_7$ and $P_6 \times P_7$. Hybrids $P_4 \times P_6$, $P_3 \times P_5$ and $P_4 \times P_5$ gave the highest heterobelotiosis percentages (36.47, 35.23 and 32.33, respectively).

b. Evaluation of tolerant × susceptible F_1s and their parents

Seven TYLCV-tolerant tomato lines and 6 susceptible tomato cvs, *viz.*, Ace 55VF, Castlerock, Marmande, Sioux, Super Strain B and Yellow Peach FS-3 were selected for use in another crossing program (line × tester) for producing tolerant × susceptible F_1s. The cultivar Castlerock was used as a control for comparing parents, and the cultivar 802 F_1 was used for comparing the produced hybrids.

1. Evaluation for TYLCV tolerance

Data obtained on TYLCV mean score in 2008/2009 fall planting for tolerant × susceptible F_1s and their parents along with the controls are presented in Table 17. All evaluated tolerant parents showed high level of TYLCV tolerance with significant differences among them. Also, these tolerant parents were significantly more tolerant to TYLCV than the susceptible parents. Four out of the 7 TYLCV-tolerant lines, *viz.*, P_4, P_5, P_6, and P_7, were non significantly different in TYLCV-tolerance from the control hybrid.

All evaluated F_1 hybrids showed moderate level of TYLCV tolerance (some of their plants were symptomless) and their mean scores for TYLCV infection ranged from 2.17 in the hybrid $P_7 \times P_9$ to

Table 17. Reaction of thirteen TYLCV-tolerant and susceptible tomato lines and their F_1s to TYLCV in the 2008/2009 fall planting.

Population[z]	Frequency of TYLCV disease score[y] 1	2	3	4	Total No. of plants	Mean score[x]
Tolerant parents						
P_1	26	5	7	0	38	1.50 p
P_2	28	11	3	0	42	1.40 pq
P_3	26	8	4	0	38	1.43 p
P_4	14	5	0	0	19	1.26 p-r
P_5	13	2	0	0	15	1.13 qr
P_6	20	2	0	0	22	1.08 r
P_7	25	8	0	0	33	1.23 p-r
Susceptible parents						
P_8	0	3	6	26	35	3.65 ab
P_9 (Control)	0	0	2	14	16	3.86 a
P_{10}	0	1	4	29	34	3.84 a
P_{11}	0	3	15	23	41	3.52 b
P_{12}	3	8	19	22	52	3.16 c
P_{13}	0	1	10	25	36	3.70 ab
Toleant × tolerant F_1s						
$P_1 \times P_8$	14	7	15	14	50	2.56 e-m
$P_1 \times P_9$	14	13	14	9	50	2.36 m-o
$P_1 \times P_{10}$	14	4	6	16	40	2.60 e-m
$P_1 \times P_{11}$	14	5	12	13	44	2.55 e-n
$P_1 \times P_{12}$	15	7	14	12	48	2.48 h-n
$P_1 \times P_{13}$	14	9	11	15	49	2.53 e-n
$P_2 \times P_8$	15	7	6	14	42	2.45 i-o
$P_2 \times P_9$	15	15	11	8	49	2.25 no
$P_2 \times P_{10}$	15	6	5	16	42	2.52 e-n
$P_2 \times P_{11}$	15	8	9	13	45	2.45 i-o
$P_2 \times P_{12}$	16	10	12	12	50	2.40 k-o
$P_2 \times P_{13}$	15	7	8	14	44	2.48 h-n
$P_3 \times P_8$	14	11	11	14	50	2.50 f-n
$P_3 \times P_9$	14	13	9	8	44	2.25 no
$P_3 \times P_{10}$	14	10	12	16	52	2.57 e-m
$P_3 \times P_{11}$	14	5	11	13	43	2.54 e-n
$P_3 \times P_{12}$	15	9	12	12	48	2.43 j-o
$P_3 \times P_{13}$	14	11	13	16	54	2.57 e-m
$P_4 \times P_8$	7	15	16	14	52	2.73 d-j
$P_4 \times P_9$	6	10	12	5	33	2.40 k-o
$P_4 \times P_{10}$	7	12	15	16	50	2.81 d-f
$P_4 \times P_{11}$	7	12	16	16	51	2.78 d-h
$P_4 \times P_{12}$	11	10	11	12	44	2.54 e-n
$P_4 \times P_{13}$	7	12	14	14	47	2.75 d-i

Continued

Table 17. Continued.

Population[z]	Frequency of TYLCV disease score[y] 1	2	3	4	Total No. of plants	Mean score[x]
Toleant × tolerant F_1s (Contd.)						
$P_5 \times P_8$	7	10	18	14	49	2.80 d-g
$P_5 \times P_9$	9	5	15	3	32	2.38 l-o
$P_5 \times P_{10}$	7	15	11	16	49	2.73 d-j
$P_5 \times P_{11}$	7	10	11	13	41	2.73 d-j
$P_5 \times P_{12}$	9	11	11	12	43	2.59 e-m
$P_5 \times P_{13}$	7	7	14	19	47	2.96 cd
$P_6 \times P_8$	11	8	13	18	50	2.75 d-i
$P_6 \times P_9$	11	4	11	14	40	2.71 d-k
$P_6 \times P_{10}$	11	10	9	16	46	2.65 e-m
$P_6 \times P_{11}$	11	6	10	20	47	2.83 de
$P_6 \times P_{12}$	12	5	11	12	40	2.58 e-m
$P_6 \times P_{13}$	11	8	9	18	46	2.73 d-j
$P_7 \times P_8$	14	6	4	15	39	2.52 e-n
$P_7 \times P_9$	11	15	7	5	38	2.17 o
$P_7 \times P_{10}$	14	5	3	16	38	2.57 e-m
$P_7 \times P_{11}$	14	6	8	13	41	2.49 g-n
$P_7 \times P_{12}$	15	9	11	12	47	2.42 j-o
$P_7 \times P_{13}$	14	5	11	18	48	2.69 d-l
802 F_1 (Control)	49	1	0	0	50	1.02 r

[z]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; P_7: *Solanum sp.* PI 205017 sel.; P_8: cv. Ace 55VF; P_9: Castlerock; P_{10}: Marmande; P_{11}: Sioux; P_{12}: Super Strain B; and P_{13}: Yellow Peach FS-3.

[y]Disease scores: 1, symptomless; 2, slight; 3, moderate, and 4, severe symptoms.

[x]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

2.83 in the hybrid $P_6 \times P_{11}$ with significant differences among them and also between them and the control cv. 802 F_1.

2. Evaluation for yield and fruit characters

a. Early yield per plant

Data obtained on EY/plant for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 18. Significant differences were observed among tolerant parents and also among susceptible parents. The tolerant parents P_1 and P_2 produced the highest EY without significant differences between them, followed by P_4. The susceptible parent P_9 produced the highest early yield (0.20 kg/plant) among the susceptible parents.

With regard to the evaluated hybrids, the highest EY was produced by the hybrids $P_1 \times P_{12}$, $P_1 \times P_{13}$, $P_4 \times P_8$, $P_4 \times P_9$ and $P_4 \times P_{11}$ without significant differences among them, but with significant differences from the control cv. 802 F_1, which gave the highest EY among all evaluated genotypes.

b. Total yield per plant

Data obtained on TY/plant for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 18. Significant differences were observed among tolerant parents and also among susceptible parents. Yield of susceptible parents was affected by TYLCV-infection and scored significantly low yield compared with the tolerant parents. Total yield/plant of tolerant parents ranged from1.63 to 3.55 kg. Meanwhile, it ranged from 0.69 to 1.16 kg in susceptible ones.

Table 18. Mean performance of thirteen TYLCV-tolerant and susceptible tomato lines and their F_1s in total yield, early yield, average fruit weight and fruit shape index in the 2008/2009 fall planting[z].

Population[y]	Early yield (kg/plant)	Total yield (kg/plant)	Average fruit weight (g)	Fruit shape index (L/D)
Tolerant parents				
P_1	0.94 b	3.46 b	96.07 e	1.25 b
P_2	0.88 c	3.10 c	87.14 g	1.32 a
P_3	0.29 jk	2.27 d	11.49 x	1.01 i
P_4	0.82 d	3.55 b	89.35 fg	0.84 tu
P_5	0.20 l-p	1.63 h-l	9.76 x	1.02 i
P_6	0.21 l-o	1.66 h-k	19.35 v	0.98 j
P_7	0.21 l-o	1.77 f-i	16.79 w	0.97 jk
Susceptible parents				
P_8	0.15 o-q	0.95 r-t	109.00 c	0.87 q-t
P_9	0.12 q	0.73 uv	86.81 gh	0.97 j-l
P_{10}	0.20 l-p	0.97 p-t	71.47 j	0.67 B
P_{11}	0.14 pq	0.69 v	123.80 b	0.93 m-o
P_{12}	0.14 pq	0.94 st	89.97 f	1.01 i
P_{13}	0.17 m-q	1.16 n-s	103.80 d	0.79 wx
Tolerant × susceptible F_1s				
$P_1 \times P_8$	0.31 j	1.91 e-g	65.63 k	1.16 f
$P_1 \times P_9$	0.34 h-j	1.80 e-i	58.52 no	1.20 de
$P_1 \times P_{10}$	0.38 g-i	1.90 e-g	53.62 p	1.06 h
$P_1 \times P_{11}$	0.37 gi	1.76 f-i	70.37 j	1.20 de
$P_1 \times P_{12}$	0.50 e	1.98 ef	59.53 no	1.24 c
$P_1 \times P_{13}$	0.48 ef	2.22 d	63.95 kl	1.20 de
$P_2 \times P_8$	0.41 g	1.75 g-i	64.74 k	1.16 f
$P_2 \times P_9$	0.37 h-i	1.76 f-i	63.00 k-m	1.10 g
$P_2 \times P_{10}$	0.37 g-i	1.51 k-m	57.41 o	1.19 de
$P_2 \times P_{11}$	0.30 j	1.44 lm	50.76 q	1.06 h
$P_2 \times P_{12}$	0.39 g-i	1.51 k-m	69.62 j	1.18 ef
$P_2 \times P_{13}$	0.35 h-j	1.62 i-l	58.45 no	1.21 d
$P_3 \times P_8$	0.21 l-o	1.32 mn	40.86 s	0.88 q-s
$P_3 \times P_9$	0.23 l-n	1.44 lm	39.18 s	0.85 s-u
$P_3 \times P_{10}$	0.18 l-p	1.14 n-s	34.40 t	0.93 no
$P_3 \times P_{11}$	0.20 l-p	1.20 no	28.20 u	0.79 wx
$P_3 \times P_{12}$	0.20 l-p	1.18 n-q	46.03 r	0.92 op

Continued

Table 18. Continued[z]

Population[y]	Early yield (kg/plant)	Total yield (kg/plant)	Average fruit weight (g)	Fruit shape index (L/D)
Tolerant × susceptible F_1s (contd.)				
$P_3 \times P_{13}$	0.23 l-n	1.32 mn	35.05 t	0.95 k-n
$P_4 \times P_8$	0.49 e	1.85 e-h	77.37i	0.73 zA
$P_4 \times P_9$	0.53 e	2.00 e	77.23 i	0.71 A
$P_4 \times P_{10}$	0.42 fg	1.73 g-j	68.70 j	0.78 wx
$P_4 \times P_{11}$	0.48 e	1.80 e-i	63.12 k-m	0.65 B
$P_4 \times P_{12}$	0.33 ij	1.53 j-m	84.31 h	0.76 xy
$P_4 \times P_{13}$	0.40 gh	1.84 e-i	70.92 j	0.80 vw
$P_5 \times P_8$	0.21 l-o	1.03 o-t	47.52 r	0.89 p-r
$P_5 \times P_9$	0.22 l-n	1.20 no	45.41 r	0.85 s-u
$P_5 \times P_{10}$	0.16 n-q	0.89 tu	38.82 s	0.94 l-o
$P_5 \times P_{11}$	0.20 l-p	1.03 o-t	32.90 t	0.80 w
$P_5 \times P_{12}$	0.19 l-p	1.05 o-t	53.70 p	0.92 op
$P_5 \times P_{13}$	0.18 l-p	1.06 o-t	39.89 s	0.96 j-m
$P_6 \times P_8$	0.21 l-n	1.19 n-p	54.31 p	0.83 uv
$P_6 \times P_9$	0.22 l-n	1.21 no	52.36 pq	0.80 w
$P_6 \times P_{10}$	0.19 l-p	1.03 o-t	44.80 r	0.89 p-r
$P_6 \times P_{11}$	0.19 l-p	1.05 o-t	38.65 s	0.74 yz
$P_6 \times P_{12}$	0.17 m-q	0.96 p-t	61.06 mn	0.86 r-t
$P_6 \times P_{13}$	0.19 l-p	1.13 n-s	46.64 r	0.89 pq
$P_7 \times P_8$	0.23 lm	1.19 n-p	54.10 p	0.83 uv
$P_7 \times P_9$	0.25 kl	1.34 mn	52.10 pq	0.78 wx
$P_7 \times P_{10}$	0.22 l-n	1.16 n-r	45.46 r	0.87 q-t
$P_7 \times P_{11}$	0.21 l-o	1.04 o-t	38.83 s	0.73 zA
$P_7 \times P_{12}$	0.19 l-p	0.96 q-t	61.24 l-n	0.85 s-u
$P_7 \times P_{13}$	0.20 l-p	1.08 o-t	46.26 r	0.89 p-r
802 F_1 (Control)	1.24 a	4.96 a	136.00 a	1.24 c

[z]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

[y]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; P_7: *Solanum sp.* PI 205017 sel.; P_8: cv. Ace 55VF; P_9: Castlerock; P_{10}: Marmande; P_{11}: Sioux; P_{12}: Super Strain B; and P_{13}: Yellow Peach FS-3.

Regarding TY/plant of the evaluated hybrids, the control cv. 802 F_1 produced the highest significant TY/plant compared with all evaluated parents and hybrids. Hybrid $P_1 \times P_{13}$ produced the highest total yield per plant among all evaluated hybrids. Hybrids $P_1 \times P_8$, $P_1 \times P_9$, $P_1 \times P_{10}$, $P_1 \times P_{11}$, $P_4 \times P_8$, $P_4 \times P_9$, $P_4 \times P_{11}$, and $P_4 \times P_{13}$ were the second in this respect without significant differences among them.

c. Average fruit weight

Data obtained on AFW for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 18. Significant differences were observed among tolerant parents and also among susceptible parents. Among all evaluated parents and hybrids, control cv. 802 F_1 produced the highest significant AFW (136 g). The susceptible parent P_{11} was the second in this respect (123.8 g), followed by susceptible parents P_8 and P_{13} (109 and 103.8 g, respectively), with significant differences among them. AFW of the evaluated hybrids ranged from 28.2 g in the hybrid $P_3 \times P_{11}$ to 84.3 g in the hybrid $P_4 \times P_{12}$.

d. Fruit shape index

Data obtained on FSI for the genotypes evaluated in the 2008/2009 fall planting are presented in Table 18. Significant differences were observed between the genotypes evaluated for FSI. Results showed that parents P_1 and P_2 produced oval fruits, meanwhile, parents P_3, P_5, P_6, P_7, P_9, P_{11}, and P_{12} produced round fruits. Parents P_4, P_8, P_{10} and P_{13} produced oblate fruits.

Four hybrids out of them and the control cv. 802 F_1 produced oval fruits with FSI ranging from 1.20 in hybrids $P_1 \times P_9$ and $P_1 \times P_{11}$ to

1.24 in hybrid $P_1 \times P_{12}$. Meanwhile, 10 hybrids produced round fruits with FSI ranging from 0.95 in hybrid $P_3 \times P_{13}$ to 1.19 in hybrid $P_2 \times P_{10}$. The remaining hybrids produced oblate fruits having FSI ranging from 0.94 in hybrid $P_5 \times P_{10}$ to 0.65 in hybrid $P_4 \times P_{11}$.

e. Ascorbic acid content (AAC)

Data obtained on AAC in the 2008/2009 fall planting for the evaluated genotypes are presented in Table 19. Significant differences were observed among tolerant parents and also among susceptible parents. Parent P_3 produced the highest significant AAC among evaluated parents. Other evaluated parents had AAC ranged from 16.31 to 24.03 mg/100 g fresh fruit in P_{11} and P_5, respectively.

With regard to the evaluated F_1 hybrids, the highest values of AAC were produced by crosses involving P_3 with significant differences from all other evaluated F_1 hybrids, and also from the control cv. 802 F_1. These F_1 hybrids had AAC ranging from 30.25 to 34.45 mg/100g fresh fruit.

f. Fruit pH value

Data obtained on fruit pH value in the 2008/2009 fall planting for the evaluated genotypes are presented in Table 20. Significant differences were observed among tolerant parents and also among susceptible parents. The parent P_2 had the lowest fruit pH value, being 3.97.

Concerning hybrids evaluated the hybrids $P_1 \times P_9$ and $P_2 \times P_9$ produced the lowest significant fruit pH values without significant differences between them, followed by the hybrid $P_2 \times P_8$.

Table 19. Mean performance of thirteen TYLCV-tolerant and susceptible tomato lines and their F_1s in some fruit chemical characters in the 2008/2009 fall planting[z].

Population[y]	Ascorbic acid content (mg/100 g fresh fruit)	pH value	Titratable acidity (mg citric acid/100 g fresh fruit)	TSS (%)	β-carotene content (mg/100 g fresh fruit)	Lycopene content (mg/100 g fresh fruit)
Tolerant parents						
P_1	19.15 yz	4.03 C	0.44 rs	4.14 q	0.45 de	2.19 c
P_2	21.45 t	3.97 D	0.41 t-w	4.04 qr	0.51 c	1.91 fg
P_3	28.19 g	4.32 e-k	0.57 k	5.87 b	1.62 a	0.43 k
P_4	22.73 q	4.26 k-r	0.48 p-q	4.14 q	0.44 d-g	1.95 f
P_5	24.03 n	4.23 o-v	0.97 b	6.06 a	0.40 gh	2.49 a
P_6	23.25 p	4.35 b-h	0.93 c	5.87 b	0.38 hi	2.46 a
P_7	19.37 xy	4.41 bc	0.95 bc	6.06 a	0.35 i	2.31 b
Susceptible Parents						
P_8	17.56 CD	4.12 y-A	0.45 qr	3.80 t-v	0.43 d-g	2.02 e
P_9	20.96 u	4.25 m-t	0.53 lm	4.00 rs	0.46 d	2.10 d
P_{10}	18.36 B	4.32 e-k	0.71 i	4.35 p	0.38 hi	2.19 c
P_{11}	16.31 F	4.27 k-q	0.54 l	4.58 o	0.41 f-h	1.90 fg
P_{12}	17.42 D	4.22 q-v	0.51 l-n	3.90 s-u	0.44 d-f	1.92fg
P_{13}	18.91 zA	4.00 CD	0.40 u-x	3.71 v-x	0.41 f-h	1.86 g
F_1 (Tolerant × Susceptible)						
$P_1 \times P_8$	15.42 H	4.12 zA	0.41 t-w	3.57 y-A		
$P_1 \times P_9$	16.85 E	4.05 BC	0.38 w-y	3.54 y-z		
$P_1 \times P_{10}$	15.75 G	4.18 u-x	0.45 q-s	3.67 w-y		
$P_1 \times P_{11}$	14.89 I	4.22 p-v	0.53 lm	3.82 t-v		
$P_1 \times P_{12}$	15.36 H	4.20 s-x	0.45 qr	3.92 r-t		

Continued

Table 19. Continued[z].

Population[y]	Ascorbic acid content (mg/100 g fresh fruit)	pH value	Titratable acidity (mg citric acid/100 g fresh fruit)	TSS (%)	β-carotene content (mg/100 g fresh fruit)	Lycopene content (mg/100 g fresh fruit)
F_1 (Tolerant × Susceptible) (Contd.)						
$P_1 \times P_{13}$	15.99 G	4.17 v-z	0.45 qr	3.62 x-A		
$P_2 \times P_8$	16.39 F	4.09 AB	0.39 w-y	3.53 zA		
$P_2 \times P_9$	16.95 E	4.03 C	0.36 y	3.49 A		
$P_2 \times P_{10}$	17.81 C	4.16 w-z	0.41 t-w	3.62 x-A		
$P_2 \times P_{11}$	16.72E	4.19 t-x	0.51 m-o	3.78 u-w		
$P_2 \times P_{12}$	15.86 G	4.17 v-z	0.43 r-u	3.88 s-u		
$P_2 \times P_{13}$	16.33 F	4.14 x-A	0.42 s-v	3.58 y-A		
$P_3 \times P_8$	33.40 b	4.27 k-q	0.48 op	4.93 g-j	0.62 b	1.10 ij
$P_3 \times P_9$	32.97 c	4.21 r-w	0.44 rs	4.82 j-l	0.61 b	1.03 j
$P_3 \times P_{10}$	34.45 a	4.33 d-j	0.51 l-n	5.06 fg	0.62 b	1.14 hi
$P_3 \times P_{11}$	30.25 e	4.37 b-f	0.58 k	5.21 c-e	0.60 b	1.18 h
$P_3 \times P_{12}$	30.26 e	4.34 d-j	0.51 m-o	5.33 c	0.61 b	1.05 j
$P_3 \times P_{13}$	31.47 d	4.32 e-k	0.49 n-p	4.98 g-i	0.62 b	1.06 j
$P_4 \times P_8$	18.94 AB	4.24 n-u	0.40 v-x	3.57 y-A		
$P_4 \times P_9$	20.40 v	4.18 u-y	0.38 xy	3.53 y-A		
$P_4 \times P_{10}$	21.02 u	4.30 g-m	0.40 v-x	3.66 w-z		
$P_4 \times P_{11}$	19.77 w	4.34 d-j	0.51 l-n	3.82 t-v		
$P_4 \times P_{12}$	18.70 B	4.31 e-l	0.43 r-t	3.92 r-t		
$P_4 \times P_{13}$	19.49 xy	4.29 i-n	0.43 r-t	3.62 x-A		
$P_5 \times P_8$	22.87 q	4.22 p-v	0.77 fg	4.81 j-l		
$P_5 \times P_9$	23.72 o	4.16 w-z	0.77 fg	4.80 j-l		
$P_5 \times P_{10}$	24.69 l	4.29 i-o	0.83 e	4.86 i-l		

Continued

Table 19. Continued[z].

Population[y]	Ascorbic acid content (mg/100 g fresh fruit)	pH value	Titratable acidity (mg citric acid/100 g fresh fruit)	TSS (%)	β-carotene content (mg/100 g fresh fruit)	Lycopene content (mg/100 g fresh fruit)
F_1 (Tolerant × Susceptible) (Contd.)						
$P_5 \times P_{11}$	22.89 q	4.32 e-k	0.94 c	5.00 gh		
$P_5 \times P_{12}$	22.19 r	4.30 h-n	0.85 de	5.22 c-e		
$P_5 \times P_{13}$	22.75 q	4.27 k-q	0.84 de	4.84 j-l		
$P_6 \times P_8$	26.66 j	4.28 j-p	0.68 j	4.92 h-k		
$P_6 \times P_9$	27.61 h	4.23 r-v	0.69 ij	4.67 m-o		
$P_6 \times P_{10}$	29.17 f	4.35 c-i	0.72 hi	5.01 f-h		
$P_6 \times P_{11}$	27.14 i	4.39 b-d	0.82 e	5.20 de		
$P_6 \times P_{12}$	26.06 k	4.36 b-g	0.75 fg	5.28 cd		
$P_6 \times P_{13}$	26.65 j	4.34 d-j	0.74 gh	4.79 k-m		
$P_7 \times P_8$	21.88 s	4.31 f-m	0.72 hi	4.76 lm		
$P_7 \times P_9$	23.02 pq	4.25 l-s	0.70 ij	4.74 l-n		
$P_7 \times P_{10}$	24.19 mn	4.37 b-e	0.76 fg	4.91 h-k		
$P_7 \times P_{11}$	23.58 o	4.41 b	0.86 d	5.03 f-h		
$P_7 \times P_{12}$	21.48 t	4.39 b-d	0.78 f	5.13 ef		
$P_7 \times P_{13}$	22.43 r	4.36 b-f	0.75 fg	4.82 j-l		
802 F_1 (Control)	24.38 m	4.56 a	1.01 a	4.64 no	0.42 e-g	2.27 b

[z]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

[y]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; P_7: *Solanum sp.* PI 205017 sel.; P_8: cv. Ace 55VF; P_9: Castlerock; P_{10}: Marmande; P_{11}: Sioux; P_{12}: Super Strain B; and P_{13}: Yellow Peach FS-3.

g. Fruit titratable acidity

Data obtained on fruit TA in the 2008/2009 fall planting for the evaluated genotypes are presented in Table 20. Significant differences were observed among tolerant parents and also among susceptible parents. Parents P_5 and P_7 produced the highest fruit TA (0.97 and 0.95 mg citric acid/100 g fresh fruit, respectively) without significant differences between them. These two parents ranked second after the control cv. 802 F_1.

The check F_1 hybrid 802 had the highest significant TA content (1.01 mg citric acid/100 g fresh fruit). Among all evaluated hybrids, the F_1 hybrid $P_5 \times P_{11}$ produced the highest value of TA content (0.94 mg citric acid/100 g fresh fruit) with significant differences for the check F_1 hybrid, but without significant differences for the highest parents P_6 and P_7. It was followed by hybrids $P_5 \times P_{12}$, $P_5 \times P_{13}$, and $P_7 \times P_{11}$ without significant differences between them.

h. Fruit total soluble solids content

Data obtained on TSS in 2008/2009 fall planting for the evaluated genotypes are presented in Table 20. Significant differences were observed among tolerant parents and also among susceptible parents. Parents P_5 and P_7 gave the highest significant TSS content (6.06 %) among all evaluated genotypes, followed by parents P_3 and P_6 (5.87 %).

Concerning hybrids, 22 out of the 42 evaluated hybrids, significantly, surpassed the control cv. in TSS content, with the hybrids $P_3 \times P_{11}$, $P_3 \times P_{12}$, $P_5 \times P_{12}$ and $P_6 \times P_{12}$ having the highest values which ranged from 5.21 % to 5.33%.

i. Fruit pigments content

Fruit pigments were measured as β-carotene and lycopene contents, and measured in ripe fruits of the 13 parents, and also in crosses having P_3 which produces yellow fruits and in the control cvs. Data obtained on fruit β-carotene and lycopene contents in the 2008/2009 fall planting are presented in Table 20. There were significant differences among parents and the check cv. Castlerock in fruit β-carotene and lycopene contents. Parent P_3 had the highest significant β-carotene content (1.62 mg/100 g fresh fruit) and the lowest significant lycopene content (0.43 mg/100 g fresh fruit) among all evaluated parents and hybrids. Parents P_5 and P_6 had the highest significant lycopene content among all evaluated genotypes, being 2.49 and 2.46 mg/100 g fresh fruit, respectively, without significant differences between them.

Regarding the evaluated hybrids, there were significant differences among them in lycopene content, but they were non-significantly different in β-carotene content. F_1 hybrids were intermediate between their respective parents in lycopene content.

3. Line × tester analysis

a. Variation and mean performance of parents and hybrids

Data obtained on various studied characters under TYLCV-infection for tomato genotypes evaluated in the 2008/2009 fall planting are presented in Table 20. Significant differences were found among the evaluated genotypes in all characters studied.

Mean squares of the studied genotypes and their components (parents and F_1's) for the studied characters under TYLCV-infection

Table 20. Mean performance of thirteen TYLCV-tolerant and susceptible tomato lines and their F_1s in TYLCV mean score, yield, and some fruit quality characters in the 2008/2009 fall planting[z].

Population[y]	TYLCV mean score[x]	Early yield (kg/plant)	Total yield (kg/plant)	Average fruit weight (g)	Fruit shape index (L/D)	TSS (%)	pH value	Titratable acidity (mg citric acid/100g fresh fruit)	Ascorbic acid content (mg/100g fresh fruit)
Tolerant parent									
P_1	1.50 p	0.94 a	3.46 a	96.07 d	1.25 b	4.14 p	4.03 B	0.44 s	19.15 xy
P_2	1.40 pq	0.88 b	3.10 b	87.14 f	1.32 a	4.04 pq	3.97 C	0.41 u-x	21.45 s
P_3	1.43 p	0.29 l	2.27 c	11.49 y	1.01 j	5.87 b	4.32 d-j	0.57 k	28.19 g
P_4	1.26 p-r	0.82 c	3.55 a	89 .35 e	0.84 r-t	4.14 p	4.26 j-q	0.48 p-r	22.73 p
P_5	1.13 qr	0.20 n-r	1.63 hi	9.76 y	1.02 j	6.06 a	4.23 n-u	0.97 b	24.03 m
P_6	1.08 r	0.21 n-r	1.66 g-i	19.35 w	0.98 k	5.87 b	4.35 a-g	0.93 c	23.25 o
P_7	1.23 p-r	0.21 n-r	1.77 f-h	16.79 x	0.97 k	6.12 a	4.41 ab	0.95 bc	19.37 wx
Susceptible parent									
P_8	3.65 ab	0.15 tv	0.95 rs	109.00 b	0.87 pq	3.80 s-u	4.12 x-z	0.45 q-s	17.56 BC
P_9	3.86 a	0.12 v	0.73 tu	86.81 f	0.97 k	4.00 qr	4.25 l-s	0.53 lm	20.96 t
P_{10}	3.84 a	0.20 n-r	0.97 p-s	71.47 i	0.67 z	4.35 o	4.32 d-j	0.71 i	18.36 A
P_{11}	3.52 b	0.14 uv	0.69 u	123.80 a	0.93 mn	4.58 n	4.27 j-p	0.54 l	16.31 E
P_{12}	3.16 c	0.14 uv	0.94 s	89.97 e	1.01 j	3.90 r-t	4.22 p-u	0.51 l-n	17.42 C
P_{13}	3.70 ab	0.17 r-u	1.16 m-q	103.80 c	0.79 uv	3.71 u-w	4.00 BC	0.40 v-x	18.91 yz
Tolerant × susceptible F_1s									
$P_1 \times P_8$	2.56 e-m	0.31 kl	1.91 d-f	65.63 k	1.16 f	3.57 x-z	4.12 yz	0.41 t-w	15.42 E
$P_1 \times P_9$	2.36 m-o	0.34 ij	1.80 e-h	58.52 o	1.20 de	3.67 v-w	4.18 t-w	0.38 w-y	16.85 D
$P_1 \times P_{10}$	2.60 e-m	0.38 g-i	1.90 d-f	53.62 p	1.06 i	3.82 s-u	4.22 o-U	0.45 q-s	15.75 F
$P_1 \times P_{11}$	2.55 e-n	0.37 hi	1.76 f-h	70.37 ij	1.20 de	3.92 q-s	4.20 r-w	0.53 lm	14.89 H
$P_1 \times P_{12}$	2.48 h-n	0.50 de	1.98 de	59.53 no	1.24 c	3.62 w-z	4.17 u-y	0.45 qr	15.36 G
$P_1 \times P_{13}$	2.53 e-n	0.48 e	2.22 c	63.95 kl	1.12 g	3.54 x-z	4.05 AB	0.45 qr	15.99 F

Continued

Table 20. Continued[z].

Population[y]	TYLCV mean scores[x]	Early yield (kg/plant)	Total yield (kg/plant)	Average fruit weight (g)	Fruit shape index (L/D)	TSS (%)	pH value	Titratable acidity (mg citric acid/100g fresh fruit)	Ascorbic acid content (mg/100g fresh fruit)
Tolerant × susceptible F_1s									
$P_2 \times P_8$	2.45 i-o	0.41 fg	1.75 f-h	64.74 kl	1.16 f	3.53 yz	4.09 zA	0.39 w-y	16.39 E
$P_2 \times P_9$	2.25 no	0.37 hi	1.76 f-h	63.00 lm	1.10 h	3.49 z	4.03 B	0.42 s-v	16.95 D
$P_2 \times P_{10}$	2.52 e-n	0.37 hi	1.51 i-k	57.41 o	1.19 e	3.62 w-z	4.16 v-y	0.36 y	17.81 B
$P_2 \times P_{11}$	2.45 i-o	0.30 kl	1.44 j-l	50.76 q	1.06 i	3.78 t-v	4.19 s-w	0.41 t-w	16.72 D
$P_2 \times P_{12}$	2.40 k-o	0.39 gh	1.51 i-k	69.62 ij	1.18 e	3.88 r-t	4.17 u-y	0.51 m-o	15.86 F
$P_2 \times P_{13}$	2.48 h-n	0.35 ij	1.62 h-j	58.45 o	1.21 d	3.58 x-z	4.14 w-z	0.43 r-u	16.33 E
$P_3 \times P_8$	2.50 f-n	0.21 n-r	1.32 l-n	40.86 t	0.88 op	4.93 g-j	4.27 j-p	0.48 op	33.40 b
$P_3 \times P_9$	2.25no	0.23 m-o	1.44 j-l	39.18 t	0.85 qr	4.82 j-l	4.21 q-v	0.49 n-p	32.97 c
$P_3 \times P_{10}$	2.57 e-m	0.18 p-t	1.14 n-r	34.40 u	0.93 mn	5.06 fg	4.33 c-i	0.44 rs	34.45 a
$P_3 \times P_{11}$	2.54 e-n	0.20 n-r	1.20 m-o	28.20 v	0.79 uv	5.21 c-e	4.37 a-e	0.51 i-n	30.25 e
$P_3 \times P_{12}$	2.43 j-o	0.20 n-r	1.18 m-o	46.03 rs	0.92 n	5.33 c	4.34 c-i	0.58 k	30.26 e
$P_3 \times P_{13}$	2.57 e-m	0.23 m-o	1.32 l-n	35.05 u	0.95 lm	4.98 g-i	4.32 d-j	0.51 m-o	31.47 d
$P_4 \times P_8$	2.73 d-j	0.49 e	1.85 d-g	77.37 h	0.73 x	3.57 x-z	4.24 m-t	0.40 v-x	18.94 yz
$P_4 \times P_9$	2.40 k-o	0.53 d	2.00 d	77.23 h	0.71 y	3.53 x-z	4.18 t-x	0.43 r-t	20.40 u
$P_4 \times P_{10}$	2.81 d-f	0.42 f	1.73 f-h	68.70 j	0.78 vw	3.66 v-y	4.30 f-l	0.38 xy	21.02 t
$P_4 \times P_{11}$	2.78 d-h	0.48 e	1.80 e-h	63.12 lm	0.65 A	3.82 s-u	4.34 c-i	0.40 v-x	19.77 v
$P_4 \times P_{12}$	2.54 e-n	0.33 jk	1.53 ij	84.31 g	0.76 w	3.92 q-s	4.31 d-k	0.51 l-n	18.70 z
$P_4 \times P_{13}$	2.75 d-i	0.40 f-h	1.84 d-g	70.92 ij	0.80 u	3.62 w-z	4.29 h-m	0.43 r-t	19.49 w
$P_5 \times P_8$	2.80 d-g	0.21 n-r	1.03 o-s	47.52 r	0.89 o	4.81 j-l	4.22 o-u	0.77 fg	22.87 p
$P_5 \times P_9$	2.38 l-o	0.22 m-p	1.20 m-o	45.41 rs	0.85 q-s	4.80 j-l	4.16 v-y	0.84 de	23.72 n
$P_5 \times P_{10}$	2.73 d-j	0.16 su	0.89 st	38.82 t	0.94 lm	4.86 i-l	4.29 h-n	0.77 fg	24.69 l
$P_5 \times P_{11}$	2.73 d-j	0.20 n-r	1.03 o-s	32.90 u	0.80 uv	5.00 gh	4.32 d-j	0.83 e	22.89 p
$P_5 \times P_{12}$	2.59 e-m	0.19 n-s	1.05 o-s	53.70 p	0.92 n	5.22 c-e	4.30 g-m	0.94 c	22.19 q

Continued

Table 20. Continued[z].

Population[y]	TYLCV mean score[x]	Early yield (kg/plant)	Total yield (kg/plant)	Average fruit weight (g)	Fruit shape index (L/D)	TSS (%)	pH value	Titratable acidity (mg citric acid/100g fresh fruit)	Ascorbic acid content (mg/100g fresh fruit)
Tolerant × susceptible F_1s									
$P_5 \times P_{13}$	2.96 cd	0.18 p-t	1.06 o-s	39.89 t	0.96 kl	4.84 j-l	4.27 j-p	0.85 de	22.75 p
$P_6 \times P_8$	2.75 d-i	0.21 n-r	1.19 m-o	54.31 p	0.83 st	4.92 h-k	4.28 i-o	0.68 j	26.66 j
$P_6 \times P_9$	2.71 d-k	0.22 m-p	1.21 m-o	52.36 pq	0.80 uv	4.67 mn	4.23 n-u	0.74 gh	27.61 h
$P_6 \times P_{10}$	2.65 e-m	0.19 o-s	1.03 o-s	44.80 s	0.89 o	5.01 f-h	4.35 b-h	0.69 ij	29.17 f
$P_6 \times P_{11}$	2.83 de	0.19 o-s	1.05 o-s	38.65 t	0.74 x	5.20 de	4.39 a-c	0.72 hi	27.14 i
$P_6 \times P_{12}$	2.58 e-m	0.17 q-u	0.96 q-s	61.06 mn	0.86 pq	5.28 cd	4.36 a-f	0.82 e	26.06 k
$P_6 \times P_{13}$	2.73 d-j	0.19 n-s	1.13 n-r	46.64 rs	0.89 o	4.79 k-m	4.34 c-i	0.75 fg	26.65 j
$P_7 \times P_8$	2.52 e-n	0.23 mn	1.19 m-o	54.10 p	0.83 t	4.76 lm	4.31 e-l	0.72 hi	21.88 r
$P_7 \times P_9$	2.42 j-o	0.25 m	1.34 k-m	52.10 pq	0.78 uv	4.74 lm	4.25 k-r	0.75 fg	23.02 op
$P_7 \times P_{10}$	2.69 d-l	0.22 m-p	1.16 m-p	45.46 rs	0.87 pq	4.91 h-k	4.37 a-d	0.70 ij	24.19 m
$P_7 \times P_{11}$	2.17 o	0.21 n-r	1.04 o-s	38.83 t	0.73 x	5.03 f-h	4.41 a	0.76 fg	23.58 n
$P_7 \times P_{12}$	2.57 e-m	0.19 n-s	0.96 rs	61.24 mn	0.85 q-s	5.13 ef	4.39 a-c	0.86 d	21.48 s
$P_7 \times P_{13}$	2.49 g-n	0.20 n-r	1.08 o-s	46.26 rs	0.89 o	4.82 j-l	4.36 a-e	0.78 f	22.43 q

[z]Values followed by a letter in common are not significantly different at the 0.05 level according to Duncan's multiple range test.

[y]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; P_7: *Solanum sp.* PI 205017 sel.; P_8: cv. Ace 55VF; P_9: Castlerock; P_{10}: Marmande; P_{11}: Sioux; P_{12}: Super Strain B; and P_{13}: Yellow Peach FS-3.

[x]Disease scores: 1, symptomless; 2, slight; 3, moderate, and 4, severe symptoms.

are presented in Table 21. Highly Significant differences between the genotypes were found, and this indicated that the thirteen parents differed from each other in genetic components.

Mean squares for genotypes, parents, and hybrids were highly significant for all the studied traits (Table 21). The parents versus hybrids (P vs H) component was significant for the studied traits TY/plant, AFW, FSI, TSS and AAC. Meanwhile, it was non-significant for TYLCV mean score, EY/plant, pH value and TA.

Highly significant differences were detected among lines and also among testers for all studied traits. The interaction between lines and testers was highly significant for the traits EY/plant, pH value, TA and AAC. Meanwhile, it was non-significant for the characters TYLCV mean score, TY/plant, AFW and TSS.

Higher values of variance due to GCA (δ^2_g) than variance due to SCA (δ^2_s) and δ^2_g/δ^2_s ratio was more than one for the studied traits except EY/plant and fruit pH value characters. These results suggested preponderance of additive gene action.

Higher values of δ^2_s than δ^2_g indicated that non-additive variance prevailed in genetic determination of EY/plant and fruit pH value characters.

b. General combining ability effects

General combining ability effects (g_i) for parental genotypes in F_1's are presented in Table 22.

For TYLCV tolerance character, Parents P_2 and P_9 exhibited negative highly significant GCA effects and were considered the best combiners for this trait, followed by parents P_3, P_7 and P_{12} which

Table 21. Mean squares from analysis of variance of line × tester tomato crosses for various studied characters.

S.V	df	TYLCV mean score	Early yield per plant	Total yield per plant	Average fruit weight	Fruit shape index	TSS	pH value	Titratable acidity	Ascorbic acid content
Replication	2	0.0913*	0.0056**	1.4161**	0.1173**	0.00003**	0.0129**	0.0205**	0.0009**	0.0031**
Genotypes	54	1.0923**	0.0934**	1.0657**	1673.5577**	0.0997**	1.6419**	0.0351**	0.0991**	79.1709**
Parents (P)	12	4.5159**	0.2894**	3.1713**	5009.6982**	0.1627**	2.6767**	0.0590**	0.1339**	32.7386**
Hybrids (H)	41	0.0875**	0.0361**	0.3855**	535.8272**	0.0798**	1.335**	0.0275**	0.0911**	92.0832**
P vs H	1	1.2068^{ns}	0.0885^{ns}	3.6861*	8286.8213*	0.1558*	1.8684*	0.0612^{ns}	0.0088^{ns}	106.9561*
Lines (L)	6	0.2663**	0.2121**	2.3413**	2785.4153**	0.4838**	8.5926**	0.1271**	0.5745**	609.9155**
Testers (T)	5	0.2914**	0.0110**	0.2732**	1036.7143**	0.0736**	0.5856**	0.0730**	0.0555**	17.4576**
L × T	30	0.0177^{ns}	0.0051**	0.013^{ns}	2. 4284^{ns}	0.00009^{ns}	0.0063^{ns}	0.6453**	0.0004**	0.9543**
Error	108	0.0242	0.0004	0.0097	1.6112	0.0001	0.0049	0.0005	0.0002	0.0268
δ^2_g	12	0.0028	0.0012	0.0144	20.5483	0.0031	0.0511	-0.0020	0.0035	3.5136
δ^2_s	41	-0.0022	0.0016	0.0011	0.2724	-0.0002	0.0005	0.2149	0.00005	0.3092
$\delta^2_g : \delta^2_s$		-1.27	0.75	13.09	75.43	-15.50	102.20	-0.01	70.00	11.36
δ^2_A F=0		0.0446	0.0196	0.2306	328.7725	0.0491	0.8181	-0.0315	0.0559	56.2180
δ^2_A F=1		0.0111	0.0049	0.0576	82.1931	0.0123	0.2045	-0.0079	0.0140	14.0545
δ^2_D F=0		-0.0097	0.0063	0.0045	1.0896	-0.00007	0.0018	0.8598	0.0002	1.2367
δ^2_D F=1		-0.0022	0.0016	0.0011	0.2724	-0.00002	0.0005	0.2149	0.00005	0.3092

*Significant ($P \leq 0.05$), **highly significant ($P \leq 0.01$) and ^{ns} non-significant.

Table 22. General combining ability (GCA) effects for different characters of tomato in a line × tester cross.

Parent[z]	TYLCV mean score	Early yield per plant	Total yield per plant	Average fruit weight	Fruit shape index	Ascorbic acid content	pH value	Titratable acidity	TSS
GCA lines									
P_1	-0.055^{ns}	0.110**	0.520**	8.246**	0.235**	-6.777**	-0.099**	-0.143**	-0.722**
P_2	-0.143**	0.077**	0.193**	6.971**	0.222**	-5.810**	-0.130**	-0.170**	-0.767**
P_3	-0.091*	-0.081**	-0.142**	-16.403**	-0.041**	9.646**	0.049**	-0.088**	0.645**
P_4	0.102**	0.153**	0.382**	19.918**	-0.187**	-2.766**	0.019**	-0.158**	-0.722**
P_5	0.135**	-0.096**	-0.363**	-10.651**	-0.035**	0.700**	0.002^{ns}	0.243**	0.510**
P_6	0.143**	-0.093**	-0.310**	-4.054**	-0.091**	4.728**	0.066**	0.146**	0.567**
P_7	-0.091*	-0.071**	-0.281**	-4.027**	-0.103**	0.278**	0.093**	0.170**	0.488**
SE gca lines	±0.037	±0.005	±0.023	±0.299	±0.003	±0.039	±0.005	±0.003	±0.016
SE (g_i-g_j) lines	±0.052	±0.007	±0.033	±0.423	±0.004	±0.055	±0.008	±0.005	±0.023
GCA testers									
P_8	0.048^{ns}	0.007^{ns}	0.056**	4.098**	-0.002^{ns}	-0.264**	-0.037**	-0.041**	-0.111**
P_9	-0.205**	-0.017**	-0.083**	-3.960**	0.044**	1.540**	0.027**	-0.001^{ns}	-0.012^{ns}
P_{10}	0.070*	-0.008*	-0.056**	-9.966**	-0.095**	-0.188**	0.062**	0.090**	0.139**
P_{11}	0.057^{ns}	-0.026**	-0.128**	10.070**	0.028**	-1.136**	0.037**	0.011**	0.257**
P_{12}	-0.075*	0.005^{ns}	0.025^{ns}	-2.728**	0.065**	-0.417**	0.012*	-0.001^{ns}	-0.088**
P_{13}	0.105**	0.039**	0.187**	2.486**	-0.040**	0.465**	-0.100**	-0.058**	-0.184**
SE gca testers	±0.034	±0.004	±0.021	±0.277	±0.003	±0.036	±0.005	±0.003	±0.015
SE (g_i-g_j) testers	±0.048	±0.006	±0.030	±0.392	±0.004	±0.051	±0.007	±0.004	±0.022

*Significant ($P \leq 0.05$), **highly significant ($P \leq 0.01$) and ^{ns} non-significant.

[z] P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; P_7: *Solanum sp.* PI 205017 sel.; P_8: cv. Ace 55VF; P_9: Castlerock; P_{10}: Marmande; P_{11}: Sioux; P_{12}: Super Strain B; and P_{13}: Yellow Peach FS-3.

exhibited negative significant GCA effects.

Results indicated that, GCA effects for the parents P_1, P_2, P_4 and P_{13} were positive and highly significant for TY/plant. Also, these parents, except P_8 recorded positive and highly significant GCA effects for EY/plant. For AFW, the above parents, in addition to, the parent P_{11} recorded positive and highly significant GCA effects.

The GCA effects of six parents, *viz.*, P_3, P_5, P_6, P_7, P_9 and P_{13} were positive and highly significant for AAC.

Parents P_1, P_2, P_8 and P_{13} exhibited negative and highly significant (favorable) GCA effects for fruit pH value. For TA, P_5, P_6, P_7, P_{10} and P_{11} recorded positive and highly significant GCA effects. These 5 parents in addition to P_3 recorded highly significant positive GCA effects for TSS%.

The GCA effects are mainly attributable to additive and additive × additive interactions, which are fixable. Therefore, parents with high GCA may be recommended for utilization in genetic improvement in tomato through varietal breeding.

Based on results obtained for lines, P_1 proved to be a good combiner for EY/plant, TY/plant, AFW and fruit pH value; while, P_2 proved to be a good combiner for TYLCV tolerance, EY/plant, TY/plant and fruit pH value. P_3 was the best combiner for TYLCV tolerance, AAC and TSS. P_4 proved to be a good combiner for EY/plant, TY/plant and AFW. The parents P_5, P_6 and P_7 were the best combiners for AAC, TA and TSS.

Also, based on results obtained for testers, P_8 was a good combiner for TY/plant, AFW and pH value. Meanwhile, P_9 was a good

combiner for TYLCV tolerance and AAC. P_{10} was a good combiner for only two characters, *viz.*, TA and TSS%. Also, P_{11} was a good combiner for the two previous characters in addition to AFW. P_{12} was a good combiner for TYLCV tolerance, while, P_{13} was the good combiner for EY/plant, TY/plant, AFW, AAC and pH value.

Susceptible parents P_9 and P_{12} were good combiner for TYLCV-tolerance character, they may be carrying resistance genes. These genes do not appear in only if they are introgressed to resistant background.

c. Specific combining ability effects

The specific combining ability (SCA) effects of F_1 cross combinations are presented in Table 23.

For TYLCV mean score, one cross out 42 crosses, *viz.*, $P_6 \times P_9$, recorded significant positive SCA effects (unfavorable), meanwhile, other evaluated crosses recorded non-significant positive or negative SCA effects.

Two out 42 crosses, *viz.*, $P_5 \times P_{11}$ and $P_7 \times P_9$, recorded significant positive SCA effects for TY/plant. Also, the previous crosses recorded significant positive SCA for EY/per plant. Meanwhile, crosses $P_1 \times P_{12}$, $P_1 \times P_{13}$, $P_4 \times P_8$, $P_4 \times P_{10}$ and $P_4 \times P_{13}$ recorded highly significant positive SCA effects for this character.

For AFW, the cross $P_7 \times P_{11}$ recorded highly significant positive SCA effect and the cross $P_1 \times P_{10}$ recorded significant positive SCA.

For AAC, 16 out 42 crosses exhibited highly significant or positive SCA effects.

Table 23. Specific combining ability (GCA) effects for different characters of tomato in 42 crosses.

Cross[z]	TYLCV mean scores[y]	Early yield per plant	Total yield per plant	Average fruit weight	Fruit shape index	Ascorbic acid content	pH value	Titratable acidity	TSS
$P_1 \times P_8$	0.004^{ns}	-0.099^{**}	-0.073^{ns}	-0.401^{ns}	-0.0000^{ns}	-0.026^{ns}	0.000^{ns}	0.004^{ns}	-0.005^{ns}
$P_1 \times P_9$	0.051^{ns}	-0.034^{**}	-0.042^{ns}	0.546^{ns}	-0.0062^{ns}	-0.404^{**}	0.000^{ns}	0.006^{ns}	-0.013^{ns}
$P_1 \times P_{10}$	0.019^{ns}	-0.008^{ns}	0.028^{ns}	1.645^{*}	-0.0059^{ns}	0.232^{*}	0.000^{ns}	-0.003^{ns}	-0.007^{ns}
$P_1 \times P_{11}$	-0.023^{ns}	0.003^{ns}	-0.036^{ns}	-1.641^{*}	0.0051^{ns}	0.321^{**}	0.000^{ns}	-0.005^{ns}	-0.023^{ns}
$P_1 \times P_{12}$	0.037^{ns}	0.099^{**}	0.025^{ns}	0.324^{ns}	0.0095^{ns}	0.067^{ns}	0.000^{ns}	0.003^{ns}	0.019^{ns}
$P_1 \times P_{13}$	-0.088^{ns}	0.040^{**}	0.100^{ns}	-0.473^{ns}	-0.0023^{ns}	-0.190^{*}	0.000^{ns}	-0.005^{ns}	0.029^{ns}
$P_2 \times P_8$	-0.112^{ns}	0.005^{ns}	-0.228^{**}	-1.297^{ns}	-0.0058^{ns}	0.941^{**}	-0.030^{*}	-0.016^{*}	-0.050^{ns}
$P_2 \times P_9$	-0.060^{ns}	-0.010^{ns}	-0.334^{**}	-0.572^{ns}	-0.0141^{*}	0.563^{**}	-0.030^{*}	-0.034^{**}	-0.058^{ns}
$P_2 \times P_{10}$	-0.058^{ns}	-0.087^{**}	-0.428^{**}	-1.213^{ns}	-0.0103^{ns}	1.199^{**}	-0.030^{*}	-0.031^{**}	-0.052^{ns}
$P_2 \times P_{11}$	-0.119^{ns}	0.012^{ns}	-0.284^{**}	-2.389^{**}	-0.0117^{ns}	1.288^{**}	-0.030^{*}	-0.032^{**}	-0.068^{ns}
$P_2 \times P_{12}$	-0.040^{ns}	-0.055^{**}	-0.333^{**}	-0.762^{ns}	-0.0143^{*}	1.035^{**}	-0.030^{*}	-0.024^{**}	-0.026^{ns}
$P_2 \times P_{13}$	-0.140^{ns}	-0.067^{**}	-0.355^{**}	-1.422^{ns}	-0.0247^{**}	0.778^{**}	-0.030^{*}	-0.024^{**}	-0.016^{ns}
$P_3 \times P_8$	-0.029^{ns}	-0.007^{ns}	0.0002^{ns}	-0.529^{ns}	-0.0037^{ns}	1.529^{**}	0.000^{ns}	0.018^{*}	-0.011^{ns}
$P_3 \times P_9$	-0.021^{ns}	-0.004^{ns}	-0.046^{ns}	1.077^{ns}	-0.0024^{ns}	0.777^{**}	0.000^{ns}	0.013^{ns}	0.013^{ns}
$P_3 \times P_{10}$	0.026^{ns}	0.004^{ns}	-0.013^{ns}	0.879^{ns}	0.0006^{ns}	-1.691^{**}	0.000^{ns}	-0.012^{ns}	0.010^{ns}
$P_3 \times P_{11}$	0.005^{ns}	0.014^{ns}	0.040^{ns}	-1.325^{ns}	0.0033^{ns}	-0.737^{**}	0.000^{ns}	-0.004^{ns}	0.018^{ns}
$P_3 \times P_{12}$	0.031^{ns}	0.014^{ns}	0.031^{ns}	0.494^{ns}	-0.0036^{ns}	-0.247^{**}	0.000^{ns}	-0.013^{ns}	0.019^{ns}
$P_3 \times P_{13}$	-0.013^{ns}	-0.021^{ns}	-0.013^{ns}	-0.597^{ns}	0.0058^{ns}	0.369^{**}	0.000^{ns}	-0.002^{ns}	-0.049^{ns}
$P_4 \times P_8$	0.009^{ns}	0.040^{**}	0.003^{ns}	-0.338^{ns}	-0.0039^{ns}	-0.517^{**}	0.000^{ns}	0.005^{ns}	-0.005^{ns}
$P_4 \times P_9$	-0.057^{ns}	0.001^{ns}	0.018^{ns}	-0.946^{ns}	-0.0023^{ns}	-0.237^{*}	0.000^{ns}	0.009^{ns}	-0.013^{ns}
$P_4 \times P_{10}$	0.068^{ns}	0.046^{**}	0.069^{ns}	-0.519^{ns}	0.0039^{ns}	0.232^{*}	0.000^{ns}	-0.009^{ns}	-0.007^{ns}
$P_4 \times P_{11}$	0.059^{ns}	-0.088^{**}	-0.134^{*}	0.630^{ns}	-0.0058^{ns}	0.115^{ns}	0.000^{ns}	-0.006^{ns}	-0.023^{ns}
$P_4 \times P_{12}$	-0.051^{ns}	-0.048^{**}	0.026^{ns}	0.039^{ns}	0.0001^{ns}	0.187^{*}	0.000^{ns}	-0.003^{ns}	0.019^{ns}
$P_4 \times P_{13}$	-0.027^{ns}	0.049^{**}	0.018^{ns}	1.134^{ns}	0.0079^{ns}	0.219^{*}	0.000^{ns}	0.005^{ns}	0.029^{ns}
$P_5 \times P_8$	0.050^{ns}	0.007^{ns}	-0.066^{ns}	0.378^{ns}	-0.0011^{ns}	-0.046^{ns}	0.000^{ns}	-0.023^{**}	-0.006^{ns}

Continued

Table 23. Continued.

Cross[z]	TYLCV mean scores	Early yield per plant	Total yield per plant	Average fruit weight	Fruit shape index	Ascorbic acid content	pH value	Titratable acidity	TSS
$P_5 \times P_9$	-0.112^{ns}	-0.015^{ns}	-0.067^{ns}	-0.259^{ns}	0.0030^{ns}	-0.033^{ns}	0.000^{ns}	-0.006^{ns}	-0.047^{ns}
$P_5 \times P_{10}$	-0.037^{ns}	0.017^{ns}	0.040^{ns}	-0.174^{ns}	-0.0009^{ns}	-0.114^{ns}	0.000^{ns}	0.020^{*}	-0.061^{ns}
$P_5 \times P_{11}$	-0.028^{ns}	0.022^{*}	0.133^{*}	0.590^{ns}	0.0001^{ns}	0.142^{ns}	0.000^{ns}	0.006^{ns}	0.037^{ns}
$P_5 \times P_{12}$	-0.033^{ns}	-0.017^{ns}	-0.012^{ns}	-0.421^{ns}	-0.0004^{ns}	-0.017^{ns}	0.000^{ns}	0.010^{ns}	0.012^{ns}
$P_5 \times P_{13}$	0.159^{ns}	-0.014^{ns}	-0.028^{ns}	-0.114^{ns}	-0.0007^{ns}	0.068^{ns}	0.000^{ns}	-0.007^{ns}	0.064^{ns}
$P_6 \times P_8$	-0.006^{ns}	0.012^{ns}	0.034^{ns}	0.572^{ns}	-0.0047^{ns}	-0.294^{**}	0.000^{ns}	-0.012^{ns}	0.054^{ns}
$P_6 \times P_9$	0.207^{*}	0.008^{ns}	0.023^{ns}	-0.876^{ns}	0.0115^{ns}	0.411^{**}	0.000^{ns}	-0.014^{ns}	0.048^{ns}
$P_6 \times P_{10}$	-0.125^{ns}	-0.003^{ns}	0.009^{ns}	-1.023^{ns}	0.0011^{ns}	0.107^{ns}	0.000^{ns}	-0.003^{ns}	0.084^{*}
$P_6 \times P_{11}$	0.061^{ns}	0.005^{ns}	-0.006^{ns}	1.357^{ns}	-0.0012^{ns}	-0.013^{ns}	0.000^{ns}	0.007^{ns}	0.040^{ns}
$P_6 \times P_{12}$	-0.054^{ns}	-0.008^{ns}	0.010^{ns}	-0.272^{ns}	-0.0074^{ns}	-0.144^{ns}	0.000^{ns}	0.007^{ns}	-0.101^{*}
$P_6 \times P_{13}$	-0.083^{ns}	-0.015^{ns}	-0.071^{ns}	0.242^{ns}	0.0008^{ns}	-0.068^{ns}	0.000^{ns}	0.016^{*}	-0.124^{**}
$P_7 \times P_8$	-0.004^{ns}	0.008^{ns}	0.003^{ns}	0.340^{ns}	0.0060^{ns}	-0.619^{**}	0.000^{ns}	-0.002^{ns}	-0.023^{ns}
$P_7 \times P_9$	-0.096^{ns}	0.022^{*}	0.121^{*}	-0.246^{ns}	-0.0029^{ns}	-0.110^{ns}	0.000^{ns}	0.0004^{ns}	0.024^{ns}
$P_7 \times P_{10}$	0.019^{ns}	-0.003^{ns}	-0.032^{ns}	-0.871^{ns}	-0.0021^{ns}	1.002^{**}	0.000^{ns}	0.011^{ns}	-0.010^{ns}
$P_7 \times P_{11}$	-0.044^{ns}	-0.002^{ns}	-0.040^{ns}	1.501^{**}	-0.0033^{ns}	-0.149^{ns}	0.000^{ns}	0.007^{ns}	-0.025^{ns}
$P_7 \times P_{12}$	0.021^{ns}	-0.019^{ns}	-0.073^{ns}	-0.679^{ns}	0.0027^{ns}	0.086^{ns}	0.000^{ns}	-0.007^{ns}	0.013^{ns}
$P_7 \times P_{13}$	0.104^{ns}	-0.006^{ns}	0.022^{ns}	-0.045^{ns}	-0.0003^{ns}	-0.210^{*}	0.000^{ns}	-0.009^{ns}	0.021^{ns}
S.E. (s_i)	±0.090	±0.011	±0.057	±0.733	±0.007	±0.095	±0.013	±0.008	±0.040
S.E. ($s_{ij} - s_{ki}$)	±0.127	±0.016	±0.080	±1.036	±0.010	±0.134	±0.018	±0.012	±0.057

[*]Significant ($P \leq 0.05$), [**]highly significant ($P \leq 0.01$) and [ns] non-significant.

[z]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; P_7: *Solanum sp.* PI 205017 sel.; P_8: cv. Ace 55VF; P_9: Castlerock; P_{10}: Marmande; P_{11}: Sioux; P_{12}: Super Strain B; and P_{13}: Yellow Peach FS-3.

For pH value, crosses of P_2 TYLCV-tolerant parent with all of the susceptible parents recorded negative (favorable) significant SCA effects.

For AAC, three out of 42 crosses, *viz.*, $P_3 \times P_8$, $P_5 \times P_{10}$ and $P_6 \times P_{13}$, recorded significant positive SCA effects.

With respect to the TSS %, only one F_1 cross, *viz.*, $P_6 \times P_{10}$, exhibited significant positive SCA effects.

Based on the obtained results on SCA effects, the crosses $P_7 \times P_9$ and $P_5 \times P_{11}$ were superior in EY/plant and TY/plant.

SCA involves non-additive effects, i,e. additive × dominance and dominance × dominance interactions, which are non-fixable or non-heritable and are of significance in hybrid breeding only. So, SCA effects are useful to predict the potential of particular cross in exploiting heterosis.

d. Heterosis estimations

The percent increase (+) or decrease (-) of a cross over better parent was calculated to determine heterotic effects for all traits. Data on estimates of heterosis over the better parent (heterobeltiosis) for studies traits are presented in Table 24.

For TYLCV mean score trait, the better-parent would have the smaller value. Concerning heterobeltiosis for TYLCV resistance, none of the crosses gave desired negative heterobeltiosis.

Data on heterobelotiosis for total yield per plant indicated that all evaluated hybrids gave negative heterobelotiosis.

For early yield per plant, 6 out of the 42 evaluated hybrids, *viz.*, $P_5 \times P_8$, $P_5 \times P_{13}$, $P_6 \times P_{13}$, $P_7 \times P_8$, $P_7 \times P_9$, and $P_7 \times P_{13}$, exhibited

Table 24. Estimates of heterobelotiosis for some traits of 42 tolerant × susceptible crosses.

Cross[z]	TYLCV mean score	Early yield	Total yield	Average fruit weight	Fruit shape index	TSS	pH value	Titratable acidity	Ascorbic acid content
$P_1 \times P_8$	70.67*	-67.02*	-44.80*	-39.79*	-20.00*	-13.77*	2.23*	-8.89*	-19.48*
$P_1 \times P_9$	57.33*	-63.83*	-47.98*	-39.09*	-17.24*	-11.35*	3.72*	-15.09*	-19.61*
$P_1 \times P_{10}$	73.33*	-59.57*	-45.09*	-44.19*	-26.90*	-12.18*	4.71*	-25.35*	-17.75*
$P_1 \times P_{11}$	70.00*	-60.64*	-49.13*	-43.16*	-17.24*	-14.41*	4.22*	-16.67*	-22.25*
$P_1 \times P_{12}$	65.33*	-46.81*	-42.77*	-38.03*	-14.48*	-12.56*	3.47*	-11.76*	-19.79*
$P_1 \times P_{13}$	68.67*	-48.94*	-35.84*	-38.39*	-22.76*	-14.49*	1.25ns	-13.64*	-16.50*
$P_2 \times P_8$	74.41*	-53.41*	-43.55*	-40.61*	-22.15*	-12.62*	3.02*	-13.33*	-23.59*
$P_2 \times P_9$	60.17*	-57.95*	-43.23*	-39.31*	-26.17*	-13.61*	1.51ns	-12.20*	-20.98*
$P_2 \times P_{10}$	79.39*	-57.95*	-51.29*	-34.12*	-20.13*	-10.40*	4.79*	-22.64*	-16.97*
$P_2 \times P_{11}$	74.41*	-65.91*	-53.55*	-41.75*	-28.86*	-13.10*	5.54*	-28.17*	-22.05*
$P_2 \times P_{12}$	70.85*	-55.68*	-51.29*	-43.76*	-20.81*	-15.28*	5.04*	-20.37*	-26.06*
$P_2 \times P_{13}$	76.54*	-60.23*	-47.74*	-35.03*	-18.79*	-11.39*	4.28*	-17.65*	-23.87*
$P_3 \times P_8$	74.83*	-27.59*	-41.85*	-62.51*	-12.87*	-16.01*	3.64*	-15.79*	18.48*
$P_3 \times P_9$	57.34*	-20.69*	-36.56*	-62.25*	-15.84*	-17.89*	5.25*	-22.81*	16.96*
$P_3 \times P_{10}$	79.72*	-37.93*	-49.78*	-60.37*	-7.92*	-13.80*	1.88*	-10.53*	22.21*
$P_3 \times P_{11}$	77.62*	-31.03*	-47.14*	-60.54*	-21.78*	-11.24*	1.16*	-18.31*	7.31*
$P_3 \times P_{12}$	69.93*	-31.03*	-48.02*	-62.82*	-8.91*	-9.20*	1.64*	-10.53*	7.34*
$P_3 \times P_{13}$	79.72*	-20.69*	-41.85*	-61.04*	-5.94*	-15.16*	2.37*	-14.04*	11.64*
$P_4 \times P_8$	116.13*	-40.24*	-47.89*	-29.02*	-16.09*	-13.77*	2.91*	-16.67*	-16.67*
$P_4 \times P_9$	90.00*	-35.37*	-43.66*	-25.60*	-15.48*	-14.73*	4.50*	-20.83*	-10.25*
$P_4 \times P_{10}$	122.46*	-48.78*	-51.27*	-23.11*	-19.59*	-11.59*	1.18ns	-24.53*	-7.52*
$P_4 \times P_{11}$	120.08*	-41.46*	-49.30*	-29.36*	-22.62*	-12.18*	1.88*	-28.17*	-13.02*
$P_4 \times P_{12}$	101.08*	-59.76*	-56.90*	-31.90*	-18.28*	-14.41*	1.17ns	-20.37*	-17.73*
$P_4 \times P_{13}$	117.71*	-51.22*	-48.17*	-21.17*	-20.79*	-12.56*	1.66*	-15.69*	-14.25*

Continued

Table 24. Continued.

Cross[z]	TYLCV mean score	Early yield	Total yield	Average fruit weight	Fruit shape index	TSS	pH value	Titratable acidity	Ascorbic acid content
$P_5 \times P_8$	147.06*	5.00*	-36.81*	-56.40*	-12.75*	-20.63*	2.43*	-20.62*	-4.83*
$P_5 \times P_9$	110.00*	10.00^{ns}	-26.38*	-56.25*	-16.67*	-20.79*	4.00*	-20.62*	-1.29*
$P_5 \times P_{10}$	140.88*	-20.00*	-45.40*	-55.28*	-7.84*	-19.80*	1.42^{ns}	-14.43*	2.75*
$P_5 \times P_{11}$	140.88*	0.00^{ns}	-36.81*	-53.97*	-21.57*	-17.49*	2.13*	-3.09^{ns}	-4.74*
$P_5 \times P_{12}$	128.53*	-5.00^{ns}	-35.58*	-56.62*	-9.80*	-13.86*	1.65*	-12.37*	-7.66*
$P_5 \times P_{13}$	161.18*	-10.00^{ns}	-34.97*	-55.66*	-5.88*	-20.13*	1.18^{ns}	-13.40*	-5.33*
$P_6 \times P_8$	154.63*	0.00^{ns}	-28.31*	-50.17*	-15.31*	-16.18*	3.88*	-26.88*	14.67*
$P_6 \times P_9$	150.93*	4.76^{ns}	-27.11*	-49.56*	-18.37*	-20.44*	5.75*	-25.81*	18.75*
$P_6 \times P_{10}$	145.37*	-9.52^{ns}	-37.95*	-48.39*	-9.18*	-14.65*	2.35*	-22.58*	25.46*
$P_6 \times P_{11}$	162.04*	-9.52^{ns}	-36.75*	-45.92*	-24.49*	-11.41*	1.62*	-11.83*	16.73*
$P_6 \times P_{12}$	138.89*	-19.05^{ns}	-42.17*	-50.68*	-12.24*	-10.05*	2.11*	-19.35*	12.09*
$P_6 \times P_{13}$	152.78*	-9.52^{ns}	-31.93*	-48.16*	-11.88*	-18.40*	2.84*	-20.43*	14.62*
$P_7 \times P_8$	104.88*	9.52^{ns}	-32.77*	-50.37*	-14.43*	-22.22*	4.61*	-24.21*	12.96*
$P_7 \times P_9$	76.42*	19.05*	-24.29*	-49.81*	-19.59*	-22.55*	6.25*	-26.32*	18.84*
$P_7 \times P_{10}$	108.94*	4.76^{ns}	-34.46*	-47.63*	-10.31*	-19.77*	2.82*	-20.00*	15.41*
$P_7 \times P_{11}$	102.44*	0.00^{ns}	-41.24*	-45.67*	-24.74*	-17.81*	2.08*	-9.47*	21.73*
$P_7 \times P_{12}$	96.75*	-9.52^{ns}	-45.76*	-50.53*	-12.37*	-16.18*	2.81*	-17.89*	10.89*
$P_7 \times P_{13}$	118.70*	-4.76^{ns}	-38.98*	-48.58*	-11.88*	-21.24*	3.32*	-21.05*	15.80*

*Significant ($P \leq 0.05$) and ^{ns} non-significant.

[z]P_1: *S. lycopersicum* LA 3845 sel; P_2: *S. lycopersicum* LA 3846 sel; P_3: *S. lycopersicum* var. *pyriforme* LYC 32/83 sel; P_4: *S. lycopersicum* var. *flmmatum* LYC 179/83 sel; P_5: *S. pimpinellifolium* PI 211840; P_6: *Solanum sp.* PI 126915 sel; P_7: *Solanum sp.* PI 205017 sel.; P_8: cv. Ace 55VF; P_9: Castlerock; P_{10}: Marmande; P_{11}: Sioux; P_{12}: Super Strain B; and P_{13}: Yellow Peach FS-3.

positive heterobelotiosis with significant differences between them and their respective better- parents.

As regard to heterobelotiosis for AFW, FSI, TSS% and TA, all evaluated crosses gave negative heterobelotiosis and they significantly surpassed their respective better-parent in this trait.

Also, for fruit pH all evaluated crosses gave positive heterobelotiosis and they significantly surpassed their respective better-parents.

For fruit ascorbic acid content, 19 out of the 42 evaluated hybrids exhibited positive heterobelotiosis ranging from 1.37 % in the hybrid $P_5 \times P_9$ to 12.73 % in the hybrid $P_6 \times P_9$, with significant differences between them and their respective better-parents.

CONCLUSIONS

Resistance to TYLCV was detected in accessions *S. pennellii* LA 716 and *S. peruvianum* LAs 107, 1474, 1677, 2157, and 2172 and PIs 128652 and 270435. Meanwhile, tolerance to TYLCV was detected in evaluated accessions of *S. cheemaniae, S. chilense, S. chmielewskii, S. neorickii* and *S. habrochaites* and some evaluated accessions of *Solanum sp., S. lycopersicum, S. peruvianum* and *S. pimpinellifolium.* Results obtained on *Solanum sp.* and *S. lycopersicum* are significant to the tomato breeder who looks for tolerant sources to TYLCV in domestic tomato germplasm.

Resistance was partially dominant and controlled in different accessions by 2 to 8 genes. Resistance was slightly affected with environmental condition, as broad sense heritability estimates were moderately high to high and ranged from 60.75 to 84.93 %.

Tolerant parents P_1 and P_2 proved to be general good combiners for EY, TY, AFW, FSI, and fruit pH value. P_4 proved to be a general good combiner for EY, TY and AFW. Tolerant by tolerant crosses $P_1 \times P_2$, $P_1 \times P_4$, $P_2 \times P_4$ and $P_5 \times P_6$ were the best combinations for EY, TY and AFW. Cross $P_6 \times P_7$ was the best combination for EY, TY, fruit pH value, TA and TSS.

SUMMARY

These studies were conducted during the period from 2005 to 2009 at the Agricultural Experiment Station (AES) of the Faculty of Agriculture, University of Cairo, Giza, Egypt as a first step for a local tomato breeding program for TYLCV resistance. The present study was conducted to:

- Evaluate the level of resistance to TYLCV under Egyptian conditions of several domesticated and wild tomato accessions and selected resistant ones.
- Study the mode of inheritance of TYLCV resistance in some resistant tomato accessions.
- Study the possibility of producing tomato hybrids resistant to TYLCV.

1. Screening for resistance

Ninety-two domestic and wild tomato accessions were evaluated for TYLCV resistance under field conditions at AES of the Faculty of Agriculture, University of Cairo, Giza, Egypt during the 2005/2006, 2006/2007 and 2007/2008 fall plantings. The graft-inoculation experiment was conducted for detection of TYLCV in symptomless plants of some of the evaluated tomato accessions, especially those which were completely symptomless in the third evaluation season, and selected as best sources for resistance. Results obtained were as follows:

- None of the evaluated accessions of both *S. lycopersicum* and *Solanum sp.* appeared resistant to TYLCV. Meanwhile, 2 accessions

of both *S. lycopersicum* (var. *flammatum* LYC 179/83 and var. *pyriforme* LYC 32/83) and *Solanum sp.* (PIs 126915 and 205017) appeared promising as some of their plants were symptomless. These plants were selected and re-evaluated. The tolerance of progenies of selected plants was reconfirmed.

- All of the evaluated accessions of *S. chessmaniae* (PI 379035), *S. chilense* (LA 2931), *S. chmielewskii* (LAs 1028 and 1317; and PI 379039), *S. habrochaites* (LAs 1347, 1393, 1731, and 1777; and PIs 126445, 365907, 379013, 390513, and 390662), *S. neorickii* (LAs 1326 and 2201), and *S. pennellii* (LAs 716 and 1303) showed low TYLCV mean scores. Also, most of the evaluated accessions of *S. peruvianum* showed low TYLCV mean scores.
- The accessions *S. habrochaites* LA 1777, PI 126445, and PI 379013; *S. pennellii* LA 716; and *S. peruvianum* LAs 107, 1333, 1474, 1677, 2157, and 2172, PIs 127831, 128652, and 270435, and CMV sél INRA were free of any TYLCV symptoms.
- Evaluated *S. pimpinellifolium* accessions showed a wide range of reaction to TYLCV infection. Sixteen accessions exhibited resistance to TYLCV, *viz.*, LAs 121, 722, 1256, 1342, 1478, 1633, 2182, and 2656; and PIs 126947, 211838, 211840, 212408, 379023, 407543, 407544, and 407555. Accessions LAs 121 and 2656 sel and PIs 407544 and 407555 were free of any TYLCV symptoms.
- Grafting experiment revealed that all evaluated symptomless plants of accessions *S. pennellii* LA 716 and *S. peruvianum* LAs 107, 1474, 1677, 2157, and 2172 and PIs 128652 and 270435 were not virus carries. These accessions are considered resistant.

2. Genetics of resistance

According to the results obtained from the evaluation trials, *S. chmielewskii* LA 1317; *S. habrochaites* LA 1777 and PI 390662; a selection of *S. lycopersicum* var. *flammatum* LYC 179/83; *S. neorickii* LA 1326; *S. pimpinellifolium* PIs 211840 and 407543; and a selection of *Solanum sp.* PI 205017, which were characterized as resistant accessions, were chosen to study the inheritance of TYLCV resistance. Results obtained were as follows:

- Resistance to TYLCV derived from *S. chmielewskii* LA 1317 was found to be controlled by 2 pairs of genes with partial dominance of resistance over susceptibility. BSH estimate was high, being 84.93 %.
- Resistance to TYLCV derived from *S. habrochaites* accessions LA 1777 and PI 390662 was found to be controlled by 3 pairs of genes with partial dominance of resistance over susceptibility. BSH estimates were moderately high, being 71.30 % and 74.75 %, respectively.
- Resistance to TYLCV derived from a selection of *S. lycopersicum* var. *flammatum* LYC 179/83 was found to be controlled by 8 pairs of genes with partial dominance of resistance over susceptibility. BSH estimate was moderate, being 60.43 %.
- Resistance to TYLCV derived from *S. neorickii* LA 1326 was found to be controlled by 3 pairs of genes with partial dominance of resistance over susceptibility. BSH estimate was 75.35 %.

- Resistance to TYLCV derived from *L. pimpinellifolium* accessions PIs 211840 and 407543 was found to be controlled by 3 pairs of genes with partial dominance of resistance over susceptibility. BSH estimates were 70.63 and 68.91 %, respectively.
- Resistance to TYLCV derived from a selection of *Solanum sp.* PI 205107 was found to be controlled by 6 pairs of genes with partial dominance of resistance over susceptibility. BSH estimate was moderate, being 65.55 %.

3. Production and evaluation of tolerant × tolerant F_1s

a. Evaluation of tolerant × tolerant F_1s and their parents

Based on the results of the evaluation trails, selections of *S. lycopersicum* accessions LA 3845 (P_1), LA 3846 (P_2), var. *pyriforme* LYC 32/83 (P_3) and var. *flmmatum* LYC 179/83 (P_4); *S. pimpinellifolium* PI 211840 (P_5); and selections of *Solanum sp.* accessions PI 126915 (P_6) and PI 205017 (P_7) having high tolerance to TYLCV and accepted fruit quality characters, were selected for use in a half diallel crossing program to produce tolerant × tolerant F_1s. The cultivar Castlerock was used as a control for comparing parents, and the cultivar 802 F_1 was used for comparing the produced hybrids. Results obtained were as follows:

- All evaluated parents showed high level of TYLCV tolerance with significant differences among them. Also, all evaluated F_1s showed high level of TYLCV tolerance (most of their plants were symptomless). The highest level of TYLCV tolerance was noted

in the hybrids $P_6 \times P_7$ and $P_5 \times P_7$ followed by the hybrids $P_1 \times P_2$, $P_1 \times P_5$, $P_1 \times P_7$ and $P_5 \times P_6$.

- P_1 and P_2 produced the highest EY/plant followed by P_4. The highest significant EY/plant was produced by hybrid $P_1 \times P_4$, followed by hybrid $P_2 \times P_4$ without significant differences between them. The hybrid $P_1 \times P_2$ ranked third in this respect. These three hybrids were significantly superior compared to the control cv. 802 F_1.
- All evaluated parents were significantly superior compared to cv. Castlerock. The highest significant TY/plant was produced by P_1 and P_4. The control cv. 802 F_1 produced the highest significant TY/plant over all evaluated parents and hybrids. The hybrids $P_1 \times P_4$ and $P_1 \times P_2$ were, significantly, the second in this respect without significant differences between them, followed by hybrid $P_2 \times P_4$.
- The parent P_1 produced the highest significant AFW among all evaluated parents followed by P_4, P_2, and control cv. Castlerock without significant differences among them. The control cv. 802 F_1 produced the highest significant AFW over all evaluated parents and hybrids. Hybrids $P_2 \times P_4$ and $P_1 \times P_4$ were the second in this respect without significant differences between them, followed by the hybrid $P_1 \times P_2$.
- Parents P_1 and P_2 produced oval fruits, while parents P_3, P_5, P_6 and P_7 and the check cv. Castlerock produced round fruits. Parent P_4 was the only one that produced oblate fruits. Hybrid $P_1 \times P_2$ was

the only one which produced oval fruits, while the remaining hybrids produced round or oblate fruits.

- P_3 had the highest significant AAC among the evaluated parents. The highest significant AAC value was produced by hybrid $P_3 \times P_5$ with significant differences from all other evaluated F_1 hybrids, including the control cv. 802 F_1. It was followed, respectively, by hybrids $P_3 \times P_6$, $P_4 \times P_5$, $P_4 \times P_6$, and $P_3 \times P_7$.
- P_2 had the lowest significant fruit pH value. Hybrids $P_6 \times P_7$ and $P_1 \times P_2$ had the lowest significant fruit pH values without significant differences among them.
- P_5 produced the highest fruit TA, followed by P_6 and P_7 with significant differences between them. $P_6 \times P_7$ had the highest significant TA content among all evaluated genotypes. It was followed by the control cv. 802 F_1, $P_5 \times P_7$, and $P_5 \times P_6$.
- P_5 and P_7 gave the highest significant TSS content (6.06%) among all evaluated parents, followed by P_3 and P_6 (5.87 %). The highest significant TSS content among hybrids was produced by $P_6 \times P_7$, followed by $P_3 \times P_5$, $P_3 \times P_6$ and $P_3 \times P_7$, without significant differences between these three hybrids.
- P_3 had, significantly, the highest β-carotene content and the lowest lycopene content among all evaluated parents and hybrids. Parents P_7 and P_6 had, significantly, the lowest β-carotene content without significant differences between them, followed by P_5. At the same time, P_5 and P_6 had the highest significant lycopene content, followed by P_7. F_1s were close to that of the lower parent in β-

carotene content, and intermediate between the two parents in lycopene content.

b. Diallel analysis

- Mean squares for genotypes, parents, and hybrids were highly significant ($P \leq 0.01$) for all studied traits, except, TYLCV mean score character which was significant ($P \leq 0.05$) for genotypes and non-significant for both parents and hybrids. The parents versus hybrids (P vs H) component was highly significant for all studied characters except TYLCV mean score which was non-significant.
- Highly significant mean squares for GCA and SCA were recorded for all studied characters. These results showed that both additive and non-additive gene effects are playing an important role in operating the heredity of all studied traits. Higher values of δ^2_g than δ^2_s and δ^2_g/δ^2_s ratio was more than one for all studied characters, except pH value and AAC, suggesting preponderance of additive gene action for these characters. Meanwhile, higher values of δ^2_s than δ^2_g and δ^2_g/δ^2_s ratio was less than one for pH value and AAC, indicating that non-additive variance prevailed in genetic determination of these characters.
- Parents P_1 and P_2 proved to be general good combiners for EY/plant, TY/plant, AFW, FSI, and fruit pH value. On the other hand, P_4 proved to be a general good combiner for EY/plant, TY/plant and AFW.
- Cross $P_1 \times P_2$ was the best combination for EY/plant, TY/plant, AFW, AAC, and TSS. Meanwhile, crosses $P_1 \times P_4$, $P_2 \times P_4$ and

$P_5 \times P_6$ were the best combinations for EY/plant, TY/plant and AFW, while cross $P_6 \times P_7$ was the best combination for EY/plant, TY/plant, fruit pH value, TA and TSS.

4. Production and evaluation of tolerant × susceptible F_1s

a. Evaluation of tolerant × tolerant F_1s and their parents

Seven TYLCV-tolerant tomato lines and 6 susceptible tomato cvs, *viz.*, Ace 55VF (P_8), Castlerock (P_9), Marmande (P_{10}), Sioux (P_{11}), Super Strain B (P_{12}), and Yellow Peach FS-3 (P_{13}), were selected for use in another crossing program (line × tester) for producing tolerant × susceptible F_1s. Cultivar Castlerock was used as control for comparing parents, and cultivar 802 F_1 was used for comparing the produced hybrids. Results obtained were as follows:

- All evaluated tolerant parents showed high level of TYLCV tolerance with significant differences among them. Also, these tolerant parents were significantly more tolerant to TYLCV than the susceptible parents. All evaluated F_1 hybrids showed moderate level of TYLCV tolerance (some of their plants were symptomless).
- Tolerant parents P_1 and P_2 produced the highest significant EY/plant without significant differences between them, followed by P_4. The susceptible parent P_9 produced the highest early yield among the susceptible parents. The highest significant EY/plant was produced by hybrids $P_1 \times P_{12}$, $P_1 \times P_{13}$, $P_4 \times P_8$, $P_4 \times P_9$ and $P_4 \times P_{11}$ without significant differences among them, but with

significant differences from the control cv. 802 F_1, which gave the highest EY among all evaluated genotypes.

- Yield of susceptible parents was affected by TYLCV-infection and scored significantly low yield compared with the tolerant parents. Control cv. 802 F_1 produced the highest significant TY/plant compared with all evaluated parents and hybrids. Hybrid $P_1 \times P_{13}$ produced the highest total yield per plant among all evaluated hybrids, followed by $P_1 \times P_8$, $P_1 \times P_9$, $P_1 \times P_{10}$, $P_1 \times P_{11}$, $P_4 \times P_8$, $P_4 \times P_9$, $P_4 \times P_{11}$, and $P_4 \times P_{13}$.
- The control cv. 802 F_1 produced the highest significant AFW among all the evaluated germplasm. The susceptible parent P_{11} was the second in this respect, followed by susceptible parents P_8 and P_{13}, with significant differences among them. AFW of the evaluated hybrids ranged from 28.2 g in the hybrid $P_3 \times P_{11}$ to 84.3 g in the hybrid $P_4 \times P_{12}$.
- Parents P_1 and P_2 produced oval fruits, meanwhile, parents P_3, P_5, P_6, P_7, P_9, P_{11}, and P_{12} produced round fruits. Parents P_4, P_8, P_{10} and P_{13} produced oblate fruits. Four hybrids out of them and the control cv. 802 F_1 produced oval fruits, meanwhile, 10 hybrids produced round fruits. The remaining hybrids produced oblate fruits.
- Parent P_3 produced the highest significant AAC among evaluated parents. The highest values of AAC were produced by crosses involving P_3 with significant differences from all other evaluated F_1s, and also from the control cv. 802 F_1.

- Parent P_2 had the lowest fruit pH value. Hybrids $P_1 \times P_9$ and $P_2 \times P_9$ produced the lowest significant fruit pH values without significant differences between them, followed by hybrid $P_2 \times P_8$.
- Parents P_5 and P_7 produced the highest significant fruit TA (0.97 and 0.95 mg citric acid/100 g fresh fruit, respectively) without significant differences between them. These two parents ranked second after the control cv. 802 F_1. Among all evaluated hybrids, $P_5 \times P_{11}$ produced the highest value of TA content with significant differences for the control F_1 hybrid, but without significant differences for the highest parents P_5 and P_7. It was followed by hybrids $P_5 \times P_{12}$, $P_5 \times P_{13}$, and $P_7 \times P_{11}$ without significant differences between them.
- Parents P_5 and P_7 gave the highest significant TSS content (6.06 %) among all evaluated genotypes, followed by parents P_3 and P_6 (5.87 %). Twenty two out of the 42 evaluated hybrids, significantly, surpassed the control cv. in TSS content, with the hybrids $P_3 \times P_{11}$, $P_3 \times P_{12}$, $P_5 \times P_{12}$ and $P_6 \times P_{12}$ having the highest values which ranged from 5.21 % to 5.33%.
- Parent P_3 had the highest significant β-carotene content and the lowest significant lycopene content among all evaluated parents and hybrids. Parents P_5 and P_6 had the highest significant lycopene content among all evaluated genotypes, without significant differences between them. Regarding the evaluated hybrids, there were significant differences among them in lycopene content, but they were non-significantly different in

β-carotene content. F_1 hybrids were intermediate between their respective parents in lycopene content.

b. Line × tester analysis

- Mean squares for genotypes, parents, and hybrids were highly significant for all the studied traits. The parents versus hybrids (P vs H) component was significant for the studied traits TY/plant, AFW, FSI, TSS and AAC. Meanwhile, it was non-significant for TYLCV mean score, EY/plant, pH value and TA.
- Highly significant differences were detected among lines and also among testers for all studied traits. The interaction between lines and testers was highly significant for the traits EY/plant, pH value, TA and AAC. Meanwhile, it was non-significant for the characters TYLCV mean score, TY/plant, AFW and TSS.
- Higher values of δ^2_g than δ^2_s and δ^2_g/δ^2_s ratio was more than one for all studied characters, except EY/plant and pH value, suggesting preponderance of additive gene action for these characters. Meanwhile, higher values of δ^2_s than δ^2_g and δ^2_g/δ^2_s ratio was less than one for EY/plant and pH value, indicating that non-additive variance prevailed in genetic determination of these characters.
- P_1 proved to be a good combiner for TY/plant, EY/plant, AFW and fruit pH value; while P_2 proved to be a good combiner for TYLCV tolerance, EY/plant, TY/plant and fruit pH value. P_3 was the best combiner for TYLCV tolerance, AAC and TSS. P_4 proved to be a good combiner for EY/plant, TY/plant and AFW.

The parents P_5, P_6 and P_7 were the best combiners for AAC, TA and TSS.

- P_8 was a good combiner for TY/plant, AFW and pH value. Meanwhile, P_9 was a good combiner for TYLCV tolerance and AAC. P_{10} was a good combiner for only two characters, *viz*., TA and TSS%. Also, P_{11} was a good combiner for the two previous characters in addition to AFW. P_{12} was a good combiner for TYLCV tolerance, while P_{13} was the good combiner for EY/plant, TY/plant, AFW, AAC and pH value.
- The crosses $P_7 \times P_9$ and $P_5 \times P_{11}$ were superior in EY/plant and TY/plant.

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الملخص العربى

دراسات وراثية على الطماطم

أجريت هذه الدراسة فى محطة التجارب الزراعية بكلية الزراعة جامعة القاهرة خلال الفترة من ٢٠٠٥ إلى ٢٠٠٩ و ذلك كخطوة أولية لبرنامج تربية محلى للطماطم لمقاومة فيرس اصفرار و تجعد الأوراق. استهدفت الدراسة النقاط التالية:

- تقييم مستوى المقاومة لفيرس اصفرار و تجعد أوراق الطماطم فى التراكيب الوراثية للطماطم المنزرعة و البرية و إنتخاب المقاوم منها.
- دراسة وراثة صفة المقاومة للفيرس فى التراكيب المقاومة.
- دراسة مدى إمكانية إنتاج هجن طماطم مقاومة للفيرس.

١ـ التقييم للمقاومة

قيم إثنان و تسعون تركيباً وراثياً من الطماطم المنزرع و البرى تحت ظروف الحقل المفتوح فى محطة التجارب الزراعية، كلية الزراعة، جامعة القاهرة خلال المواسم الخريفية ٢٠٠٦/٢٠٠٥، و ٢٠٠٧/٢٠٠٦، و ٢٠٠٨/٢٠٠٧. أجريت تجربة تقييم من خلال التطعيم لتحديد احتواء النباتات الخالية من أعراض الإصابة ـ لبعض السلالات المقاومة ـ على الفيرس. و كانت النتائج كالآتى:

- كانت جميع السلالات المختبرة من *S. lycopersicum*، و *Solanum sp.* قابلة للإصابة، إلا أن هناك سلالتان من الطماطم (LYC 179/83، و LYC 32/83) و سلالتان من النوع *Solanum sp.* (PI 126915، و PI 205017) ظهر بهم نباتات خالية من أعراض الإصابة فى موسم التقييم الأول. انتخب نبات من كل سلالة من تلك السلالات و قيم نسل كل منهم فأثبت تحمله للإصابة فى المواسم التقييم التالية.
- السلالات المختبرة من *S. chessmaniae* (PI 379035)، و *S. chilense* (LA 2931)، و *S. chmielewskii* (LA 1028، و LA 1317، و PI 379039)، و *S. habrochaites* (LA 1347، و LA 1393، و LA 1777، و PI 126445، و PI 365907، و PI 379013، و PI 390513، و PI 390662)، و *S. neriockii*

(LA 1326، و LA 2201) ، و *S. pennellii* (LA 716، و LA 1303) ، و معظم السلالات المقيمة من النوع *S. peruvianum* أظهرت مقاومة للفيرس.

- السلالات المختبرة من النوع *S. pimpinellifolium* أصيبت بدرجات متفاوتة بالفيرس، و أظهرت السلالات التالية مقاومة للفيرس: LA 121، و LA 722، و LA 1256، و LA 1342، و LA 1478، و LA 1633، و LA 2182، و LA 2656، و PI 126947، و PI 211838، وPI 211840 ، وPI 212408، و PI 379023، و PI 407543، و PI 407544، وPI 407555. كانت نباتات السلالات LA 121، و LA 2656 sel، و PI 407544 ، و PI 407555 خالية من أعراض الإصابة.
- أظهرت تجربة التطعيم أن النباتات الخالية من الإصابة من السلالات LA *S. pennellii* 716، و *S. peruvianum* LA 107، و LA 1474، و LA 1677، و LA 2157، و LA 2172، و PI 128652، و PI 270435 لم تكن حاملة الفيرس؛ لذا..اعتبرت تلك السلالات مقاومة للفيرس.

٢- وراثة المقاومة

اختيرت السلالات LA 1317 من *S. chmielewskii*، وLA 1777 و PI 390662 من *S. habrochaites*، و منتخب من السلالة LYC 179/83 من *S. lycopersicum*، و LA 1326 من *S. neriockii*، و PI 211840 و PI 407543 من *S. pimpinellifolium*، و منتخب من PI 205017 من *Solanum sp.*، التى تميزت بمقاومتها للفيرس لدراسة وراثة صفة المقاومة بها، و كانت النتائج كالتالي:

- وجد أن صفة المقاومة للفيرس المستمدة من السلالة LA 1317 التابعة لـ *S. chmielewskii* يتحكم فى وراثتها زوجان من العوامل الوراثية مع سيادة جزئية لصفة المقاومة على صفة القابلية للإصابة، و قدرت درجة التوريث على النطاق العريض بنحو ٨٤,٩٪.
- وجد أن صفة المقاومة للفيرس المستمدة من سلالتى النوع *S. habrochaites* و هما LA 1777 و PI 390662 يتحكم فى وراثتها ثلاثة أزواج من العوامل الوراثية مع

سيادة جزئية لصفة المقاومة على صفة القابلية للإصابة، و قدرت درجة التوريث على النطاق العريض بنحو ٧١,٣ و ٧٤,٨٪ فى السلالتين، على التوالى.

- وجد أن صفة المقاومة للفيرس المستمدة من السلالة المنتخبة من *S. lycpersicum* LYC 179/83 يتحكم فى وراثتها ثمانية أزواج من العوامل الوراثية مع سيادة جزئية لصفة المقاومة على صفة القابلية للإصابة، و قدرت درجة التوريث على النطاق العريض بنحو ٦٠,٤٪.
- وجد أن صفة المقاومة للفيرس المستمدة من السلالة LA 1326 التابعة لـ *S. neriockii* يتحكم فى وراثتها ثلاثة أزواج من العوامل الوراثية مع سيادة جزئية لصفة المقاومة على صفة القابلية للإصابة، و قدرت درجة التوريث على النطاق العريض بنحو ٧٥,٤٪.
- وجد أن صفة المقاومة للفيرس المستمدة من السلالتين PI 211840 و PI 407543 و التابعتين للنوع *S. pimpinellifolium* يتحكم فى وراثتها ثلاثة أزواج من العوامل الوراثية مع سيادة جزئية لصفة المقاومة على صفة القابلية للإصابة، و قدرت درجة التوريث على النطاق العريض بنحو ٧٠,٦، و ٦٨,٩٪ فى السلالتين، على التوالى.
- وجد أن صفة المقاومة للفيرس المستمدة من السلالة المنتخبة من *Solanum sp.* PI 205107 يتحكم فى وراثتها ستة أزواج من العوامل الوراثية مع سيادة جزئية لصفة المقاومة على صفة القابلية للإصابة، و قدرت درجة التوريث على النطاق العريض بنحو ٦٥,٦٪.

٣- إنتاج و تقييم هجن الجيل الأول الناتجة من تلقيح السلالات المتحملة مع بعضها

أ- تقييم الهجن و آباؤها

بناءً على نتائج تجارب التقييم، انتخبت السلالات التالية المتحملة للإصابة بالفيرس و هى ذات صفات جودة مقبولة، و هى منتخبات من *S. lycopersicum* LA 3845 (P_1)، و LA 3846 (P_2)، و LYC 179/83 (P_3)، و LYC 83/83 (P_4)، و السلالة *S. pimpinellifolium* PI 211840 (P_5)، و منتخبات من *Solanum sp.* PI 126915 (P_6)، و PI 205017 (P_7)، و ذلك لإنتاج هجن متحمل × متحمل من خلال برنامج تهجين

Half-diallel cross، تم مقارنة الآباء بالصنف Castlerock، و الهجن بالصنف F_1 802.
و كانت النتائج كالتالى:

- أظهرت الآباء المقيمه درجة عالية من التحمل للإصابة بالفيرس، و كذلك الهجن، و كان أعلى مستوى من التحمل فى الهجن $P_7 \times P_6$، و $P_7 \times P_5$، تلاهم فى ذلك الهجن $P_1 \times P_2$، و $P_1 \times P_5$، و $P_1 \times P_7$، و $P_6 \times P_5$.
- أنتج الأبوان P_1، و P_2 أعلى محصول مبكر للنبات، تلاهما الأب P_4. كذلك أنتج الهجين $P_1 \times P_4$ معنوياً أعلى محصول مبكر للنبات تلاه فى ذلك الهجين $P_2 \times P_4$ بدون فروق معنويه بينهما، و جاء الهجين $P_1 \times P_2$ فى المرتبة الثالثة. و تفوقت هذه الهجن الثلاثة معنوياً على صنف المقارنة F_1 802.
- تفوقت كل الآباء المقيمة – معنوياً – فى المحصول الكلى للنبات بالمقارنة بالصنف Castlerock، و كان أعلاها – معنوياً - الأبوان P_1 و P_4. أنتج صنف المقارنة F_1 802 – معنوياً - أعلى محصول كلى مقارنة بالآباء و الهجن المقيمة، و جاءت الهجن $P_4 \times P_1$، و $P_1 \times P_2$ فى المرتبة الثانية بدون أختلافات معنويه بينهما، و تلاهما الهجين $P_4 \times P_2$.
- أعطى الأب P_1 أعلى متوسط لوزن الثمرة من بين الآباء المقيمه تلاه الآباء P_4، و P_2، و صنف المقارنة Castlerock. أعطى الصنف الهجينى المقارن أعلى متوسط لوزن الثمرة من بين الآباء و الهجن المقيمه. و جاء الهجينان $P_4 \times P_2$، و $P_4 \times P_1$ فى المرتبة الثانية، تلاهما الهجين $P_2 \times P_1$.
- أنتج الأبوان P_1، و P_2 ثماراً مطاولة، بينما أنتجت الآباء P_3، و P_5، و P_6، و P_7 و صنف المقارنة Castlerock ثماراً كروية، أما الأب P_4 فأنتج ثماراً مبططه. و بالنسبة للهجن، فقد أعطى الهجين $P_2 \times P_1$ ثماراً مطاولة، أما بقية الهجن فبعضها أنتج ثماراً كروية و البعض الأخر أنتج ثماراً مبططة.
- أحتوت ثمار الأب P_3 على أعلى محتوى من حامض الأسكوربيك من بين الآباء المقيمة. أيضاً الهجين $P_3 \times P_5$ أعطى – معنوياً - محتوى عالٍ من حامض الأسكوربيك بالمقارنة بباقى الهجن المقيمه بما فى ذلك صنف المقارنة F_1 802، تلاه فى ذلك الهجن $P_3 \times P_6$، و $P_4 \times P_5$، و $P_4 \times P_6$، و $P_3 \times P_7$.

- تميزت ثمار الأب P_2 – معنوياً – بأقل درجة حموضة للثمار، و كذلك الهجينان $P_6 \times P_7$ ، و $P_1 \times P_2$ كانا أقل الهجن – معنوياً - من حيث درجة حموضة الثمار.
- احتوت ثمار الأب P_5 – معنوياً - على أعلى محتوى للثمار من الحموضة المعايرة، تلاه الأبوان P_6، و P_7 مع وجود فروق معنوية عنه على جميع الطرز الوراثية المقيمة من حيث محتوى الثمار من الحموضة المعايرة. و قد تفوق الهجين $P_6 \times P_7$ - معنوياً - تلاه كلاً من هجين المقارنة، و $P_5 \times P_7$، و $P_5 \times P_6$.
- أنتج الأبوان P_5 و P_7 ثماراً احتوت – معنوياً – على أعلى محتوى للثمار من المواد الصلبة الذائبة الكلية، تلاهما الأبوان P_3، و P_6. أما الهجين $P_6 \times P_7$ فكان أعلى الهجن – معنوياً - من حيث محتوى الثمار من المواد الصلبة الذائبة الكلية، تلاه الهجن $P_3 \times P_5$، و $P_3 \times P_6$، و $P_3 \times P_7$ بدون إختلافات معنوية بينهم.
- كان الأب P_3 أعلى الآباء - معنوياً - من حيث محتوى الثمار من صبغة البيتا كاروتين، و أقلهم – معنوياً - من حيث محتوى الثمار من صبغة الليكوبين، بينما كان الأبوان P_7، و P_6 أقل الآباء - معنوياً - من حيث المحتوى الثمرى من صبغة البيتا كاروتين، و كان الأبوان P_5، و P_6 أعلى الأباء – معنوياً - من حيث المحتوى الثمرى من صبغة الليكوبين. و بالنسبة للهجن فكان محتوى ثمارها من صبغة البيتا كاروتين قريباً من الأب الأقل فى هذه الصفة، بينما كان محتواها من صبغة الليكوبين و سطاً بين الأبوان.

ب- تحليل الداى أليل

- كانت قيم Mean squares للتراكيب الوراثية، و الآباء، و الهجن عالية المعنوية ($P \leq 0.01$) لكل الصفات المدروسة، عدا صفة التحمل لـ TYLCV فكانت معنوية ($P \leq 0.05$) للتراكيب الوراثية و غير معنوية لكل من الآباء و الهجن. و كانت عالية المعنوية للآباء مقارنة بالهجن لكل الصفات المدروسة فيما عدا صفة التحمل لـ TYLCV.
- كانت قيم Mean squares لكل من القدرة العامة على التآلف و القدرة الخاصة على التآلف عالية المعنوية لكل الصفات المدروسة، و يدل هذا على أن التأثيران الإضافى و غير الإضافى للجينات يلعبان دوراً هاماً فى وراثة هذه الصفات. كانت القيم المقدرة لتباين القدرة العامة على التآلف أعلى من تباين القدرة الخاصة على التآلف، و بالتالى زادت النسبة بينهما

عن الواحد لكل الصفات المدروسة فيما عدا صفتى درجة حموضة الثمار، و محتوى الثمار من حامض الأسكوربيك و يدل هذا على أن الفعل الإضافى للجينات ذو تأثير أقوى على وراثة تلك الصفات. أما القيم العاليه لتباين القدرة الخاصة على التآلف بالمقارنة بتباين القدرة العامة على التآلف، و بالتالى قلت النسبة بينهم عن الواحد لصفتى درجة حموضة الثمار، و محتوى الثمار من حامض الأسكوربيك يدل على أن الفعل غير الإضافى للجينات ذو تأثير أقوى على وراثة هاتين الصفتين.

- كان الأبوان P_1، و P_2 أفضل الآباء تآلفاً لصفات المحصول المبكر و الكلى للنبات، و متوسط وزن الثمرة، و دليل شكل الثمرة، و درجة حموضة الثمار. كان الأب P_4 أفضل الآباء تآلفاً لصفات المحصول المبكر والكلى للنبات، و متوسط وزن الثمرة.
- كان الهجين $P_1 \times P_2$ أفضل الهجن لصفات المحصول المبكر والكلى للنبات، و متوسط وزن الثمرة، و محتوى الثمار من حامض الأسكوربيك، و محتوى الثمار من المواد الصلبة الذائبة الكلية. بينما كانت الهجن $P_1 \times P_4$، و $P_2 \times P_4$، و $P_5 \times P_6$ هى أفضل الهجن للمحصول المبكر و الكلى للنبات، و درجة حموضة الثمار، و محتوى الثمار من المواد الصلبة الذائبة الكلية.

٤- إنتاج و تقييم هجن الجيل الأول الناتجة من التلقيح بين السلالات المتحملة و السلالات القابلة للإصابة

أ- تقييم الهجن و آباؤها

لقحت السلالات السبعة المتحملة السابقة الذكر مع ستة أصناف قابلة للإصابة هى 55VF Ace (P_8)، و Castlerock (P_9)، و Marmande (P_{10})، و Sioux (P_{11})، و Super Strain B (P_{12})، و Yellow Peach FS-3 (P_{13}) بنظام line × tester لإنتاج هجن متحمل × قابل للإصابة. تم مقارنة الآباء بالصنف Castlerock، و الهجن بالصنف F_1 802. كانت النتائج كالتالى:

- سجلت الآباء المتحملة متوسطات تقدير للإصابة منخفضة – معنوياً - مقارنة بالأصناف القابلة للإصابة، و أظهرت الهجن المقيمة مستوى متوسط من التحمل للإصابة بالفيرس، حيث كانت بعض نباتاتها خالية من الإصابة.

- أنتج الأبوان P_1، و P_2 أعلى محصول مبكر للنبات بدون فروق معنويه فيما بينهما، تلاهم الأب P_4. أعطى الأب القابل للإصابة P_9 أعلى محصول مبكر بين الأصناف القابلة للإصابة. و كان صنف المقارنة الهجين أعلى الهجن من حيث المحصول المبكر، تلاه الهجن $P_1 \times P_{12}$، و $P_1 \times P_{13}$، و $P_4 \times P_8$، و $P_4 \times P_9$، و $P_4 \times P_{11}$ دون وجود فروق معنوية فيما بينهم.
- تأثر المحصول الكلى للأصناف القابلة للإصابة تأثراً كبيراً بالإصابة بالفيرس، فأعطت محصولاً منخفضاً مقارنة بالسلالات المتحملة، أنتج صنف المقارنة F_1 802 – معنوياً - أعلى محصول مقارنة بالآباء و الهجن معاً، و أعطى الهجين $P_1 \times P_{13}$ أعلى محصول من بين الهجن المقيمه تلاه الهجن $P_1 \times P_8$، و $P_1 \times P_9$، و $P_1 \times P_{10}$، و $P_1 \times P_{11}$، و $P_4 \times P_8$، و $P_4 \times P_9$، و $P_4 \times P_{11}$، و $P_4 \times P_{13}$.
- أعطى صنف المقارنة F_1 802 أعلى متوسط لوزن الثمرة مقارنة بالطرز الوراثية المقيمه، و جاء الأب القابل للإصابة P_{11} فى المرتبة الثانية، تلاه الأبوان القابلان للإصابة P_8، و P_{13}. تراوح متوسط وزن الثمرة للهجن المقيمة من ٢٨,٢ إلى ٨٤,٣ جم.
- أنتج الأبوان P_1، و P_2 ثماراً مطاولة، بينما انتجت الآباء P_3، و P_5، و P_6، و P_7، و P_9، و P_{11}، و P_{12} ثماراً كروية، و انتجت الآباء P_4، و P_8، P_{10}، و P_{13} ثماراً مبططة. أما الهجن، فأنتج أربعة منها ثماراً مطاولة بالإضافة لصنف المقارنة $F_1$802، وأنتج عشرة منها ثماراً كروية، و بقية الهجن أنتجوا ثماراً مبططة.
- كان الأب P_3 أعلى الآباء – معنوياً - من حيث محتوى الثمار من حامض الأسكوربيك، و قد تميزت الهجن التى كان الأب P_3 أحد آبائها بأنها أعطت – معنوياً - أعلى محتوى من حامض الأسكوربيك، مع وجود إختلافات معنويه فيما بينهم و كذلك مع صنف المقارنة F_1 802.
- كان الأب P_2 أقل الآباء – معنوياً - من حيث درجة حموضة الثمار، و كانا الهجينان $P_1 \times P_9$، و $P_2 \times P_9$ أقل الهجن – معنوية – من حيث درجة حموضة الثمار، دون وجود فروق معنويه فيما بينهما، تلاهم فى ذلك الهجين $P_2 \times P_8$.

- أظهرا الأبوان P_5، و P_7 أعلى محتوى للثمار من الحموضة المعايرة، و ذلك بعد صنف المقارنة F_1 802. و بالنسبة للهجن المقيمه، فأعطى الهجين $P_5 \times P_{11}$ أعلى قيمة لمحتوى الثمار من الحموضة المعايرة بدون إختلافات معنوية عن الأبوين السابقين، و تلاه فى ذلك الهجن $P_5 \times P_{12}$، و $P_5 \times P_{13}$، و $P_7 \times P_{11}$ بدون إختلافات معنويه فيما بينهم.
- أعطى الأبوان P_5، و P_7 أعلى محتوى للثمار من المواد الصلبة الذائبة الكلية، تلاهم الأبوان P_3، و P_6. تفوقت الهجن $P_3 \times P_{11}$، و $P_3 \times P_{12}$، و $P_5 \times P_{12}$، و $P_6 \times P_{12}$ – معنويا – على هجين المقارنة من حيث محتوى ثمارها من المواد الصلبة الذائبة الكلية الذى تراوح من ٥,٢ % إلى ٥,٣ %.
- كان الأب P_3 أعلى الطرز الوراثية المقيمة – معنويا - من حيث محتوى الثمار من صبغة البيتا كاروتين، و أقلهم – معنوياً - فى محتوى الثمار من صبغة الليكوبين، بينما كان الأبوان P_7، و P_6 أقل الآباء – معنوياً - من حيث المحتوى الثمرى من صبغة البيتا كاروتين، و الأبوان P_5، و P_6 كانا أعلى الآباء من حيث المحتوى الثمرى من صبغة الليكوبين. و بالنسبة للهجن فكان محتوى ثمارها من صبغة البيتا كاروتين قريباً من الأب الأقل فى هذه الصفة، بينما كان محتواها من صبغة الليكوبين و سطاً بين الأبوان.

ت- تحليل line × tester

- كانت Mean squares لكل من الطرز الوراثية، و الآباء، و الهجن عالية المعنوية لكل الصفات المدروسة، أما الآباء مقارنة بالهجن فكانت معنوية لصفات متوسط وزن الثمرة، و دليل شكل الثمرة، و المحتوى الثمرى من المواد الصلبة الذائبة الكلية و حامض الأسكوربيك، و غير معنوية للصفات الأخرى المقدرة.
- وجدت فروق عالية المعنوية بين lines، و كذلك بين testers فى كل الصفات المدروسة، أيضاً كان التفاعل بين lines و testers عالى المعنوية لصفات المحصول المبكر، و درجة حموضة الثمار، و المحتوى الثمرى من الحموضة المعايرة و حامض الأسكوربيك، و غير معنوى لباقى الصفات.
- تدل القيم العاليه لتباين القدرة العامة على التآلف بالمقارنة بتباين القدرة الخاصة على التآلف، و بالتالى زادت النسبة بينهم عن الواحد لكل الصفات المدروسة فيما عدا صفتى

المحصول المبكر للنبات، و درجة حموضة الثمار على أن الفعل الإضافى للجينات ذو تأثير أقوى على وراثة تلك الصفات. أما القيم العاليه لتباين القدرة الخاصة على التآلف بالمقارنة بتباين القدرة العامة على التآلف، و بالتالى قلت النسبة بينهم عن الواحد لصفتى المحصول المبكر للنبات، و درجة حموضة الثمار تدل على أن الفعل غير الإضافى للجينات ذو تأثير أقوى على وراثة الصفتين.

- بالنسبة لـ lines، كان الأب P_1 أفضل تآلفاً لصفات المحصول المبكر و الكلى للنبات، و متوسط وزن الثمرة. كان الأب P_2 أفضل تآلفاً لصفات التحمل للإصابة بالفيرس، و المحصول المبكر و الكلى للنبات، و درجة حموضة الثمار. كان الأب P_3 أفضل تآلفاً لصفات التحمل للإصابة بالفيرس، و محتوى الثمار من حامض الأسكوربيك و المواد الصلبة الذائبة الكلية. كان الأب P_4 أفضل تآلفاً لصفات المحصول المبكر و الكلى للنبات، و متوسط وزن الثمرة. كانت الآباء P_5، و P_6، و P_7 أفضل تآلفاً لصفات المحتوى الثمرى من حامض الأسكوربيك ، و الحموضة المعايرة، و المواد الصلبة الذائبة الكلية.
- بالنسبة لـ testers، كان الأب P_8 أفضل تآلفاً للمحصول الكلى للنبات، و متوسط وزن الثمرة، و رقم حموضة الثمار. و كان الأب P_9 أفضل تآلفاً لصفات التحمل للإصابة بالفيرس و محتوى الثمار من حامض الأسكوربيك، و الأب P_{10} أفضل تآلفاً لصفتى المحتوى الثمرى من الحموضة المعايرة و المواد الصلبة الذائبة الكلية، أيضا كان الأب P_{11} أفضل تآلفاً لهاتين الصفتين بالأضافة لصفة متوسط وزن الثمرة. كان الأب P_{12} أفضل تآلفاً لصفة التحمل للإصابة بالفيرس، بينما كان الأب P_{13} أفضل تآلفاً لصفات المحصول المبكر و الكلى للنبات، و متوسط وزن الثمار، و محتوى الثمار من حامض الأسكوربيك، و درجة حموضة الثمار.
- أثبت الهجينان $P_9 \times P_7$، و $P_{11} \times P_5$ أنهما أفضل الهجن لصفتى المحصول المبكر و الكلى للنبات.

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تاريخ منح الدرجة: ٢٤ / ١ / ٢٠١٠

المستخلص العربي

أجريت هذه الدراسة فى محطة التجارب الزراعية - كلية الزراعة - جامعة القاهرة خلال الفترة من ٢٠٠٥ حتى ٢٠٠٩ كخطوه أولية لبرنامج تربية طماطم محلى لمقاومة فيرس اصفرار و تجعد أوراق الطماطم .قيم إثنان و تسعون تركيباً وراثياً من الطماطم المنزرع و البري تحت ظروف الحقل المفتوح خلال المواسم الخريفية ٢٠٠٥، و ٢٠٠٦، و ٢٠٠٧، مع إجراء تجربة تقييم بالتطعيم لبعض السلالات التى لم تظهر علي نباتاتها أعراض إصابة فى موسم التقييم الحقلى الثالث لانتخاب أفضلهم مقاومة. اعتماداً على ردود فعل السلالات خلال مواسم التقييم الثلاثة، كانت كل السلالات المقيمة التابعة للأنواع *Solanum chessmaniae*، و *S. chilense*، و *S. chmielewskii*، و *S. habrochaites*، و *S. neorickii*، و *S. pennellii*، بالإضافة إلى معظم السلالات المقيمة من النوع *S. peruvianum* أظهرت مقاومة للفيرس. أما السلالات المقيمة التابعة للنوع *S. pimpinellifolium* فأظهرت مدى واسع من ردود الفعل للإصابة بالفيرس، و كان نحو ست عشرة سلالة منهم مقاومة للفيرس. لم تظهر المقاومة فى السلالات المقيمة التابعة للأنواع*S. lycopersicum* و *Solanum sp.*، إلا أن هناك سلالتان من كل نوع منهما كان من بين نباتاتهما نباتات لم تظهر عليها أعراض إصابة، انتخب نبات من كل سلالة فى موسم التقييم الأول و قيم نسل كل منهم فأثبت تحمله للإصابة فى مواسم التقييم التالية. تجربة التطعيم أظهرت أن السلالات LA 716 من *S. pennellii*، و LA 107، و LA 1474، و LA 1677، و LA 2157، و LA 2172، و PI 128652، و PI 270435 من *S. peruvianum* لم تكن حاملة للفيرس، لذا – اعتبرت هذه السلالات مقاومة للفيرس.

بناءً على نتائج التقييم تم انتخاب السلالات المقاومة LA 1317 من *S. chmielewskii*، و LA 1777 و PI 390662 من *S. habrochaites*، و منتخب من السلالة LYC 179/83 من *S. lycopersicum*، و LA 1326 من *S. neorickii*، و PI 211840 و PI 407543 من *S. pimpinellifolium*، و منتخب من PI 205017 من *Solanum sp.* لدراسة وراثة صفة المقاومة بهم. وجد أن المقاومة المستمدة من سلالة *S. chmielewskii* يتحكم فيها زوجان من العوامل الوراثية ذو سيادة جزئية للمقاومة على القابلية للإصابة، و قدرت درجة التوريث لها بنحو ٨٤,٩٪. وجد أن المقاومة المستمدة من LA 1777 و PI 390662 من *S. habrochaites*، و LA 1326 من *S. neorickii*، و PI 211840 و PI 407543 من *S. pimpinellifolium* يتحكم فى وراثتها ٣ أزواج من العوامل الوراثية ذو سيادة جزئية للمقاومة على القابلية للإصابة، و قدرت درجة التوريث على النطاق العريض لهم بنحو ٧١,٣، و ٧٤,٧، و ٧٥,٣، و ٧٠,٦، و ٦٨,٩٪، على التوالى. بينما وجد أن المقاومة المستمدة من المنتخبات من LYC 179/83 *S. lycpersicum* و من PI 205107 *Solanum sp.*يتحكم فى وراثتها ٨ و ٦ أزواج من العوامل الوراثية، على التوالى، مع سيادة جزئية للمقاومة على القابلية للإصابة، و قدرت درجة التوريث على النطاق العريض لهما بنحو ٦٠,٤، ٦٥,٥ ٪، على التوالى.

انتخبت السلالات التالية المتحملة للإصابة بالفيرس، و هى ذات صفات جودة مقبولة، و هى منتخبات من *S. lycopersicum* LA 3845 (P_1)، و LA 3846 (P_2)، و LYC 179/83 (P_3)، و LYC 83/83 (P_4)، و السلالة PI 211840 *S. pimpinellifolium* (P_5)، و منتخبات من *Solanum sp.* PI 126915 (P_6) و PI 205017 (P_7)، و تم التهجين بينهم من خلال برنامج تهجين Half-diallel cross لدراسة مدى إمكانية الاستفادة منها فى إنتاج هجن متحمل × متحمل. وجد أن التأثير الإضافى للجين يلعب دور كبير فى توارث الصفات المدروسة فيما عدا صفتى المحتوى الثمرى من حامض الأسكوربيك و رقم حموضة الثمار و التى كان التأثيراللاإضافى للجين يلعب دور كبير فى توريثهما. كان الآباء P_1، و P_2، و P_4 أفضل الآباء تآلفاً لصفات المحصول المبكر و الكلى للنبات، و متوسط وزن الثمرة. كان الهجين $P_1 \times P_2$ أفضل الهجن لصفات المحصول المبكر و الكلى للنبات، و متوسط وزن الثمرة، و محتوى الثمار من حامض الأسكوربيك و المواد الصلبة الذائبة الكلية، بينما كانت الهجن $P_1 \times P_4$، و $P_2 \times P_4$، و $P_5 \times P_6$ أفضل الهجن للمحصول المبكر و الكلى للنبات، و رقم حموضة الثمار، و محتوى الثمار من المواد الصلبة الذائبة الكلية.

الكلمات الدالة: الطماطم، فيرس اصفرار و تجعد الأوراق، المقاومة، التحمل، التقييم، الوراثة ، قدرة التآلف.

دراســـــات وراثيـــــة على الطمـــاطـــــم

رسالة دكتوراه الفلسفة
فى العلوم الزراعية
(خضر)

مقدمة من

أحمد محمد على محمود
بكالوريوس في العلوم الزراعية (بساتين)- كلية الزراعة - جامعة القاهرة، ١٩٩٩
ماجستير فى العلوم الزراعية (خضر) – كلية الزراعة – جامعة القاهرة، ٢٠٠٤

لجنة الإشراف

دكتور / أحمد عبد المنعم حسن
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دكتور / خالد السيد على عبد العاطى
أستاذ الخضر - كلية الزراعة – جامعة القاهرة

دراســـــات وراثيـــــة على الطمـــاطـــم

رسالة دكتوراه الفلسفة
فى العلوم الزراعية
(خضر)

مقدمة من

أحمد محمد على محمود
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لجنة الحكم

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دكتور/ أحمد عبد المنعم حسن.....
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التاريخ ٢٤/ ١/ ٢٠١٠

دراســـــات وراثيـــــة على الطمـــاطـــم

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ماجستير فى العلوم الزراعية (خضر) – كلية الزراعة – جامعة القاهرة، ٢٠٠٤

للحصول على درجة

دكتوراه الفلسفة

فـي

العلـوم الزراعية
(خضر)

قســـم الخضـــــر
كليـــة الزراعـــة
جامعة القاهرة
مصـــــر

٢٠١٠