Resistance to Cucurbit Yelling Stunting Disorder Virus (CYSDV) in Cucumis melo L.

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Additional index words. genetics, germplasm, inheritance, resistance gene, whitefly, Bemisia tabaci

Abstract. Forty-four accessions of Cucumis melo L. and related wild species were tested for reaction to a yelloving disease, incited by the recently identified cucurbit yelloving stunting disorder virus (CYSDV), under natural and controlled-inoculation conditions. The C. melo TGR-1551 accession and one Cucumis metuliferus Naud. accession were asymptomatic. The segregation ratios obtained following controlled inoculations of the family produced by crossing TGR-1551 with the susceptible Spanish cv. Piel de Sapo revealed that the resistance to CYSDV in TGR-1551 is conditioned by a dominant allele.

In southeast Spain, and in other Mediterranean countries, melon (Cucumis melo) crops grown in plastic greenhouses are severely affected by a yelloving disease; the causal agent was recently identified as the cucurbit yelloving stunting disorder virus (CYSDV), transmitted specifically by Bemisia tabaci Gennadius (Célix et al., 1996). Symptoms of this disease characteristically start with the appearance of interveinal chlorotic spots on the oldest leaves. These spots enlarge and eventually fuse together and the entire leaf, except the veins, becomes yellow (Gómez-Guillamón and Camero, 1993). Fruit number and weight are seriously reduced, and fruit quality is affected by this disease with a 30% to 40% reduction in yield.

The use of genetic resistance against pathogens is an effective strategy to limit the incidence of plant diseases (Browning, 1980); for viral diseases it is, in some cases, the only strategy (Fraser, 1990; Gray and Moyer, 1993). No resistance to CYSDV has been reported in crops. Therefore, control of the disease involves the use of insecticides against the vector do not eliminate the risk of spreading the virus, and chemical treatments against its vector do not eliminate the risk of spreading the virus. Resistance to CYSDV has been investigated for one Cucumis melo accession and one Cucumis metuliferus accession. The source of inoculum of Cucumis melo was ‘Piel de Sapo’ plants that showed characteristic yellowing symptoms. Resistance to the virus per se from resistance to the yellowing disease using controlled inoculation. This approach would distinguish resistance to the virus per se from resistance to transmission by B. tabaci. ‘Piel de Sapo’ plants that showed obvious yellowing symptoms were used as virus-infected stocks on which were grafted scions from putative-resistant C. melo TGR-1551 and C. metuliferus. Non-viruliferous whitefly colonies obtained from healthy tomato plants were maintained on melon plants in cages covered with whitefly-proof netting within a closed, air-conditioned glass greenhouse. For inoculation with CYSDV, groups of 60 whiteflies were inoculated into each cage using a 24-h acquisition feed before a 48-h inoculation period. Five plants of each accession were inoculated and, after inoculation, were placed in a whitefly-proof cage within an air-conditioned glass greenhouse. Fifteen days post-inoculation, the leaves on which the whiteflies had fed and their eggs were removed. Presence or absence of symptoms, and the date that symptoms first appeared, were recorded twice weekly for 4 weeks.

Materials and Methods

Evaluations of resistance against yellowing disease under controlled natural infection. Forty-two accessions of C. melo from Spain and other countries, one accession of Cucumis metuliferus Naud., and one accession of Cucumis anguria L. var. longipes (Table 1) were grown in a polyethylene greenhouse at the Experimental Station ‘La Mayora’. The melon cv. Piel de Sapo (C. melo ssp. melo Inodorus group) was used as a yellowing-susceptible control. Plants were grown in sandy soil typically used for greenhouse melon and vegetable production in southern Spain, with drip irrigation, and were trained for growth on a trellis. The side windows of the greenhouse remained open during the test in order to permit free entry and unrestricted access of whiteflies (Bemisia tabaci Gennadius) to the plants. The planting frame was 1 x 0.8 m² per plant. Two replications, both with a randomized layout of the 42 accessions, were used, and 10 plants of each accession were evaluated in each replication.

Yellowing incidence was recorded just before fruit harvest, when the disease was extensively established in the crop. Both presence or absence of yellowing and severity were recorded using a four-point scale: 0 = no symptoms; 1 = slight yellowing; 2 = moderate yellowing; 3 = severe yellowing. Whorl infestation per plant was recorded according to the following scale: 0 = no whiteflies, 1 = a few individuals on most of the leaves, 2 = whiteflies covering less than a half of the leaf on most of the leaves, 3 = a high number of whiteflies covering more than a half of the abaxial leaf surface on most leaves.

Evaluations of resistance against yellowing disease using controlled inoculation. Those accessions whose plants showed no yellowing symptoms in response to natural infection were then tested for resistance to yellowing under controlled inoculation. Seeds of each accession were planted in plastic pots inside a whitefly-proof glass greenhouse. Five seedlings of each accession were selected and inoculated when the first true leaves were fully expanded.

Inoculations were carried out with B. tabaci biotype B using leaf cages, following the method of López-Sesé (1997). The source of inoculum was ‘Piel de Sapo’ plants that showed characteristic yellowing symptoms. Inoculations were carried out with B. tabaci biotype B using leaf cages, following the method of López-Sesé (1997). The source of inoculum was ‘Piel de Sapo’ plants that showed characteristic yellowing symptoms. Non-viruliferous whitefly colonies obtained from healthy tomato plants were maintained on melon plants in cages covered with whitefly-proof netting within a closed, air-conditioned glass greenhouse. For inoculation with CYSDV, groups of 60 whiteflies were inoculated into each cage using a 24-h acquisition feed before a 48-h inoculation period. Five plants of each accession were inoculated and, after inoculation, were placed in a whitefly-proof cage within an air-conditioned glass greenhouse. Fifteen days post-inoculation, the leaves on which the whiteflies had fed and their eggs were removed. Presence or absence of symptoms, and the date that symptoms first appeared, were recorded twice weekly for 4 weeks.

Evaluation of resistance by grafting. Grafting is an efficient method of transmission of CYSDV (López-Sesé, 1997) and was performed with those accessions that showed no yellowing symptoms in the controlled-inoculation test. This approach would distinguish resistance to the virus per se from resistance to transmission by B. tabaci. ‘Piel de Sapo’ plants that showed obvious yellowing symptoms were used as virus-infected stocks on which were grafted scions from putative-resistant C. melo TGR-1551 and C. metuliferus. The healthy plants of ‘Piel de Sapo’ as the susceptible control. In addition, five plants of each of these accessions were grafted onto naturally infected melon plants that served as virus-free controls. All plants were kept in whitefly-proof cages within an air-conditioned glass greenhouse.

Determination of the genetics of resistance against CYSDV. To study the genetics of resistance, one of the accessions that demonstrated resistance to CYSDV was crossed with the susceptible ‘Piel de Sapo’ by manual pollinations to generate families and backcrosses (BC) and backcrosses (BC) to the resistant parent.

Twelve seedlings of each parent (P, and P₂) and F₁, 120 seedlings of the F₂ generation, and 40 plants of each of the backcrosses (BC) and backcrosses (BC) were inoculated with B. tabaci by using leaf cages, following the method of López-Sesé (1997). The source of inoculum of CYSDV was ‘Piel de Sapo’ plants that showed characteristic yellowing symptoms. Inoculations were done as described above. As controls, five non-inoculated plants of each of the parents, F₁, F₂, and backcrosses were kept under the same conditions during the inoculation period. Afterwards, they were transferred to a separate, protected, glass greenhouse to await the appearance of symptoms. After 3 weeks, the inoculated plants that showed no symptoms in response to natural infection were then tested for resistance to yellowing under controlled inoculation. Seeds of each accession were planted in plastic pots inside a whitefly-proof glass greenhouse. Five seedlings of each accession were selected and inoculated when the first true leaves were fully expanded.

Inoculations were carried out with B. tabaci biotype B using leaf cages, following the method of López-Sesé (1997). The source of inoculum of CYSDV was ‘Piel de Sapo’ plants that showed characteristic yellowing symptoms. Inoculations were done as described above. As controls, five non-inoculated plants of each of the parents, F₁, F₂, and backcrosses were kept under the same conditions during the inoculation period. Afterwards, they were transferred to a separate, protected, glass greenhouse to await the appearance of symptoms. After 3 weeks, the inoculated plants that showed no symptoms were selected and inoculated when the first true leaves were fully expanded.

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Received for publication 11 Dec. 1998. Accepted for publication 1 June 1999. This work was financed by the CICYT project AG92-0456-CO201. We also wish to thank Mr. David W. Schofield for translating the manuscript. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

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yellowing symptoms were subjected to a second round of inoculations to reduce the chances of escapes.

The data were analysed by the $\chi^2$ statistical test (Sokal and Rohlf, 1981) with Yates correction in those cases where the expected number in a class was less than five. The genetic models that conformed most closely to the results were subjected to tests of contrast.

**Results**

**Evaluation of resistance against yellowing disease under conditions of natural infection.** Under natural inoculation conditions, all the plants of the susceptible 'Piel de Sapo' showed clear symptoms of yellowing. None of the plants of *C. melo* accessions PI 414723, Kogane 9-G-0 Makawa, Kanro Makawa, TGR-1551, TGR-1920, TGR-1937, and TGR-554, or of the wild species *C. metuliferus* and *C. anguria* var. longipes, showed yellowing symptoms (Table 1). Population levels of *B. tabaci* were rated 1 on 26 accessions, 1–2 on 16 accessions, and 2 on one accession (Table 1).

**Evaluation of resistance against yellowing disease using controlled inoculation.** Under controlled-inoculation conditions, all 'Piel de Sapo' plants developed characteristic yellowing symptoms. No serological or nucleic acid techniques were used to confirm infection, but the symptoms in the inoculated plants were similar to symptoms shown by the plant sources of the inoculum identified as CYSDV (Célix et al., 1996). Some 80% or more of the plants of PI 414723, Kogane 9-G-0 Makawa, Ginsen Makawa, and *C. anguria* var. longipes developed yellowing symptoms, while 60% of the plants of TGR-554 and TGR-1920 exhibited yellowing symptoms (Table 2). Thirty-six percent of Kanro Makawa plants developed symptoms. Only 20% of the TGR-1937 accession showed yellowing symptoms (Table 2), and in this case, the symptoms were milder; only small areas of the leaf surfaces were affected. Symptoms appeared 30 d after inoculation with CYSDV in all the accessions except TGR-1920 and TGR-1937, when the yellowing symptoms appeared 40 and 45 d after inoculation, respectively (Table 2).

None of the inoculated Zimbabwean TGR-1551 or *C. metuliferus* accession plants showed yellowing symptoms (Table 2). Symptoms were not observed on susceptible melons when asymptomatic plants of TGR-1551 and *C. metuliferus* were used as sources of inoculum.

**Evaluation of resistance by grafting.** None of the TGR-1551 plants or *C. metuliferus* plants grafted onto infected plants of 'Piel de Sapo', showed yellowing symptoms. Healthy 'Piel de Sapo' plants grafted on infected plants, however, showed obvious symptoms of yellowing disease.

**Determination of the genetics of resistance against CYSDV.** None of the plants of the resistant TGR-1551 parental or of the F$_1$ inoculated with CYSDV showed yellowing symptoms. All plants of the susceptible 'Piel de Sapo' showed clear symptoms of yellowing that started to appear 24 d after inoculation.
About one-quarter of the inoculated plants of the F$_2$ generation, and half of the plants of the backcross to the susceptible parental (BC) showed the characteristic symptoms of disease (Table 3). The symptoms were uniform and consistent; the resistant and susceptible plants were clearly differentiated. The proportion of resistant to susceptible plants in the F$_2$ and the BC families was good fits to the expected 3:1 and 1:1 ratio, respectively (Table 3).

### Discussion

Some of the accessions tested responded differently to inoculations. Under natural inoculation conditions, all ‘Piel de Sapo’ plants showed symptoms of yellowing, while plants of Ginsen Makuwa and C. anguria var. longipes were asymptomatic. This indicates that Ginsen Makuwa and C. anguria var. longipes accessions escaped inoculation under natural-inoculation conditions. PI 414723 also appeared to be resistant under natural infection, with none of the plants showing symptoms of yellowing. However, nearly 82% of the plants inoculated under controlled conditions developed yellowing symptoms, indicating susceptibility to CYSDV. Under natural-inoculation conditions the numbers of whiteflies on the plants were very low, suggesting that plants of PI 414723 may have some degree of resistance to whitefly infestation, and that the resistance factors modify whitefly behavior (antixenosis), or affect their physiological processes, such as feeding or egg laying (antibiosis). This apparent resistance to the insect vector of the virus would explain the apparent resistance to the yellowing causal agent shown by accession PI 414723 following natural inoculation. Moreover, PI 414723 has been described as resistant to aphids and also to virus transmission by these insects (Pitrat and Lecq, 1982).

The results with Kanro Makuwa and TGR-1937 suggest that both accessions have a degree of resistance to either the virus or to the vector, because, under natural-inoculation conditions, plants of neither genotype developed symptoms, and under controlled-inoculation conditions, only a few plants showed symptoms of yellowing. Under natural-inoculation conditions, the whitefly densities on these accessions were very similar to those on the other accessions tested in this work, which indicates that both accessions seem to show resistance to the virus and could also have mechanisms of resistance to transmission of the virus by the insect vector, but not to the insect itself.

Under controlled-inoculation conditions, a high percentage (20%) of the plants of the TGR-1937 accession showed yellowing symptoms 40 d after inoculation (Table 2). Despite the high percentage (60%) of TGR-1920 plants that developed symptoms under controlled-inoculation conditions, symptoms appeared 45 d after inoculation (Table 2). The appearance of symptoms in plants of both TGR-1920 and TGR-1937 some 10 d after such symptoms appeared in plants of other accessions might be associated with the presence of mechanisms that inhibit either virus replication or movement or both. Soria and Gómez-Gullón (1994) reported a similar response in a C. melo ssp. agrestis when it was tested against beet pseudos yellow virus (BPYV), a closterovirus that causes a yellowing disease transmitted by Trialeurodes vaporariorum Westwood. These results suggest that TGR-1937 could have several mechanisms of resistance to CYSDV and BPYV, and probably also to virus transmission.

C. melo TGR-1551 and the C. meloaccession did not show yellowing symptoms under natural or controlled-inoculation conditions. Both accessions had whitely densities similar to those on the other accessions. The fact that none of the grafted TGR-1551 plants or C. melo plants showed yellowing symptoms suggests that these accessions are virus-resistant. They may also possess resistance to transmission of the virus by Bemisia tabaci biotype B. Although a search of the literature revealed no reference to resistance to the transmission of virus by whitefly in melons, resistance to transmission of virus by aphids. The Vat gene impede the colonization of the plant by Aphis gossypii Glover and the transmission by this aphid of some viruses, such as the cucumber mosaic virus (CMV) and zucchini yellow mosaic virus (ZYMV) (Pitrat and Lecq, 1982).

The resistance observed in C. melo TGR-1551 and the C. melo accessions could also be related to the existence of mechanisms that inhibit vascular transport of the pathogen, as indicated by resistance to infection following grafting to infected ‘Piel de Sapo’ plants. This type of resistance would affect long-distance movement of viral particles. Resistance could also involve cellular membrane changes that impede the diffusion or transport of infective virus particles from cell to cell, or an inhibition of virus particle replication in the tissues of the resistant host plant, as has been described for virus diseases in some cucurbit species (Gray et al., 1988), or even a combination of these two mechanisms. The resistant mechanisms acting in the C. melo TGR-1551 and C. melo accessions need to be further clarified.

Resistance to papaya ringspot virus in C. melo was reported (Provvidenti and Robinson, 1974) as well as to squash mosaic virus (Provvidenti, 1986), watermelon mosaic virus (Provvidenti and Robinson, 1977), and to a yellowing virus transmitted by T. vaporariorum (Soria, 1991). However, sexual incompatibility prevents exploitation of these resistances for melon by traditional plant breeding methods. TGR-1551 accession belongs to C. melo species, so there should be no impediment to using it as a donor of resistance against CYSDV to the other cultivated melon groups (Esquininas-Alcázar and Gulick, 1983). No reports are presently available that describe a C. melo genotype with resistance against CYSDV.

The results of the genetic analysis support the hypothesis that the resistance to CYSDV in TGR-1551 is controlled by a dominant allele at one locus (Table 3). In accordance with the rules of nomenclature proposed by Smouse et al. (1976) that are incorporated in the latest version of gene nomenclature for the Curcubitaceae (Curcubit Genetics Cooperative Gene List Committee, 1982), we propose the name Curticurb yellow stunting symbol Cys for the locus in C. melo TGR-1551 that conditions the resistance against CYSDV. This is the first gene described that conditions resistance to a whitefly-transmitted virus of melon (Lecq et al., 1998; Pitrat, 1998). It is the second gene for resistance to a virus yellows disease of melon; PI 124112 has two complementary, recessive genes for resistance to cucumber aphid-borne yellowing virus (Dogimont et al., 1997).

TGR-1551 carries antixenotic and antibotic resistance to B. tabaci, since the reproduction rate and the viability of the females of this insect on plants of TGR-1551 are significantly lower than on plants of commercial Spanish cultivars, e.g., Bola de Oro (Soria et al., 1999). This character could also contribute to reducing the populations of the sweetpotato whitefly in the crops. In southeastern Spain, cucumber (Cucumis sativus L.) and melon crops are grown in the same or adjacent areas and they overlap in their timing of cultivation. Both cucurbit species are hosts of CYSDV (Célix et al., 1996), and every year each species acts as an inoculum source or reservoir of this virus for the other species. Resistance in melons would decrease the incidence of CYSDV in cucumber crops, because there would be no infected melon plants to serve as sources of inoculum in the area. This resistance to CYSDV, in theory at least, would be easy to introduce into other melon genotypes to produce resistant commercial hybrids. Fruit of TGR-1551 are small-medium sized (700 g), of elongated shape, with yellow-orange, smooth and hard skin, white flesh, and low content of soluble solids (8 ‘Brix’). Certain undesirable hereditary characteristics of TGR-1551 observed in its hybrids with ‘Piel de Sapo’ and ‘Bola de Oro’ types, i.e., excessive

### Table 3

| Pedigree | Generation | Expected | Observed number of | Resistant | Susceptible |χ² | p |
|----------|------------|----------|--------------------|----------|-------------|---|---|
| TGR-1551 | F$_1$      | 1:1      | 12                 | 0        | 12          |   |   |
| TGR x PS | F$_2$     | 1:1      | 95                 | 25       | 70          | 1.11 | 0.29 |
| F$_1$ x PS | BC$^c$ | 3:1      | 18                 | 22       | 40          | 0.40 | 0.53 |
| F$_1$ x TGR | BC$^c$ | 1:1      | 40                 | 0        | 40          |   |   |

(C. melo)
length, hard skin, and low soluble-solids content (Sesé et al., 1997) should be easily eliminated in a backcrossing program to combine resistance with desired horticultural qualities.

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