

## Inheritance of *Podosphaera xanthii* resistance in melon line '90625'

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### Abstract

Several races of *Podosphaera xanthii* have been described on melon. The Indian melon line '90625' (PI 313970) which had already been described as resistant in the USA is a potential source of resistance for strains recently characterized in France. We have studied the inheritance of resistance in a Recombinant Inbred Line population between 'Védreantais' (susceptible) and '90625' using a leaf disk technique with 10 strains of *P. xanthii*. Potentially five genes could be present in '90625'. Two independent semi-dominant genes (*A* and *B*) are involved in resistance to strains 06Sm10 and S87-7 respectively. Resistance to the other strains seems to be under a digenic control, including *A* and *B* or not, with three other recessive genes. Some of these RILs could be used as additional differential lines for the characterization of the races.

### INTRODUCTION

Powdery mildew (PM) is one of the most common diseases of melon. Two species, *Podosphaera xanthii* (formerly *Sphaerotheca fuliginea*) and *Golovinomyces cichoracearum* (formerly *Erysiphe cichoracearum*), can induce worldwide typical and identical symptoms. Breeding PM resistant melon cultivars started in the 1930' in California with the release of 'PMR 45' (Jagger and Scott 1937). Since then, many resistant PM cultivars have been created in different cultigroups. The most commonly used sources of resistance were LJ 525 (source for PMR 45), PI 79376 (source for PMR 5, PMR 6...), PI 124112, PI 12411 (MR-1), all of them from India. The release of resistant cultivars has been more or less rapidly followed by the apparition of races able to overcome the resistance. For instance, race 2 has been identified almost immediately after the release of PMR 45 (Jagger et al. 1938) while race 3, able to overcome the resistance present in PMR 5, has been identified about 50 years after the release of this cultivar (Thomas 1978). Races are defined by the interaction of PM strains and melon differential lines (DL). There is not a general agreement on a set of DL ; however some DL have been commonly used (McCreight 2006). PM races other than 1, 2 and 3 have been described (Hosoya et al. 1999; Coffey et al. 2006).

The genetic control of PM resistance is not fully understood. Inheritance of several sources of resistance has been studied, but very few allelism tests have been conducted. Most of the publications are consistent with a monogenic dominant control (for a review see Jahn et al. 2002; Pitrat 2002; McCreight 2006).

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Melon line ‘90625’ (PI 313970) has been described as resistant to PM (McCreight 2001). The genetic control was one recessive gene for true leaf resistance to race 1, one or two recessive genes for cotyledon resistance to race 2US and one semi-dominant gene for true leaf resistance to race 2US (McCreight 2003). ‘90625’ is a promising source of resistance to PM strains which have been recently isolated in France and we have studied the inheritance of this resistance to 10 strains of PM.

## MATERIAL AND METHODS

### Plant material

A recombinant inbred line (RIL) population has been developed from the cross between the susceptible cultivar ‘Védrantais’ and ‘90625’ and I<sub>6</sub> progenies have been inoculated with 10 strains of PM. A maximum number of 70 lines (2 plants per RIL) has been studied with each strain.

### PM strains

Ten strains of *P. xanthii* have been used. They are maintained on in vitro cotyledons of *Lagenaria siceraria* (Nicot et al. 2002). The behavior of these strains on a set of melon DL is indicated in Table 1.

- Strains Sm3 and 06Sm10 can be considered as belonging to race 1 as ‘PMR 45’ is resistant;
- Strain S87-7 belongs to race 2 as only ‘Védrantais’ and ‘PMR 45’ are susceptible;
- Strain 00Sm39 belongs to race 3 as it attacks ‘PMR 5’ but not ‘WMR 29’;
- Strains 98Sm65, 00Sm74, and 06Sm7 as race 5 as they attack ‘WMR 29’ and ‘EDISTO 47’ but not ‘PMR 5’;
- Strains 04Sm2 and 06Sm14 belongs to race 3.5 as they attack ‘WMR 29’, ‘EDISTO 47’ and ‘PMR 5’;
- Strain 06Sm6 belongs to race 4.5 as it attacks ‘WMR 29’ and ‘PMR 5’ but not ‘EDISTO 47’.

Table 1. Interaction between strains of *P. xanthii* and some melon differential lines.

	Sm3	06Sm10	S87-7	00Sm39	06Sm6	98Sm65	00Sm74	06Sm7	04Sm2	06Sm14
Védrantais	S <sup>z</sup>	S	S	S	S	S	S	S	S	S
PMR 45	R	I	S	S	S	S	S	S	S	S
WMR 29	R	R	R	R	S	S	S	S	S	S
EDI 47	R	R	R	R	R	S	S	S	S	S
PMR 5	R	R	R	S	S	R	R	I	S	S
PI 414723	R	R	R	I	I	R	I	R	R	R
90625	R	R	R	R	R	R	R	R	I	I

<sup>z</sup> S = Susceptible, I = Intermediate, R = Resistant

### Inoculation technique and rating

Leaf disks (2 cm diameter) were cut out on young and old leaves of plants at 4 leaf stage of the controls (Tab. 1), the parents ('Védrantais' and '90625'), the F<sub>1</sub> and the RILs and placed on plastic boxes containing the following medium: mannitol (10 g.L<sup>-1</sup>), benzimidazol (30 mg.L<sup>-1</sup>) and agar (4 g.L<sup>-1</sup>) in 180 x 125 mm polystyrene boxes. Each plastic box was placed at the bottom of an inoculation tower (1 m high and 25 cm diameter) and conidia from a sporulating *L. siceraria* cotyledon were blown at the top of the tower with a Pasteur pipette. Leaf disks were incubated in a growth chamber (24°C and 16 hr day / 18°C and 8 hr night) and readings made under a binocular 10 days later on a 0 (no sporulation) to 9 (heavy sporulation) scale.

For each RIL and strain, two plants have been studied with two leaf disks from a young leaf and two leaf disks from an old leaf, resulting in 8 individual values. A mean value lower than 3 has been considered as resistant, from 3 to 5 as intermediate and greater than 5 as susceptible.

## RESULTS

### Resistance to strains 06Sm10 and S87-7

When pooling together the intermediate and susceptible behaviors versus the resistant one, one gene is involved in the genetic control of resistance to strain 06Sm10 and one gene is also involved for resistance to strain S87-7 (Tab. 2). The correlation between these two strains is quite low (R<sup>2</sup>=0.19, Tab. 3) and there are clearly RILs which are susceptible to 06Sm10 and resistant to S87-7 and conversely. The F<sub>1</sub> is intermediate with both strains. It can be concluded that two independent semi-dominant genes are involved in the genetic control of strain 06Sm10 (provisional symbol *A* in this paper) and of strain S87-7 (symbol *B*) (Tab. 4).

Table 2. Number of RILs 'Védrantais' x '90625' with the observed phenotype after inoculation with 10 strains of *P. xanthii*.

PM strains	Observed phenotype			Expected ratio	$\chi^2$	
	R	I	S		Value	Prob. (%)
Sm3	24	6	40	1 : 3	3.22	7.3
06Sm10	27	9	11	1 : 3	26.39	<0.001
				1 : 1	1.04	30.7
S87-7	35	16	18	1 : 3	24.35	<0.001
				1 : 1	0.01	90.4
00Sm39	21	9	39	1 : 3	1.09	29.7
06Sm6	10	10	27	1 : 3	0.35	55.6
98Sm65	24	2	43	1 : 3	3.52	6.1
				1 : 1	6.39	1.1
00Sm74	15	10	22	1 : 3	1.20	27.4
06Sm7	15	15	17	1 : 3	1.20	27.4
04Sm2	12	8	27	1 : 3	0.007	93.3
06Sm14	10	9	28	1 : 3	0.35	55.6

### Resistance to strains 06Sm6, 00Sm74, 06Sm7, 04Sm2, and 06Sm14

The F<sub>1</sub> ('Védraçais' x '90625') is susceptible and the observed segregations fit to a 1 resistant: 3 intermediate or susceptible ratio (Tab. 2). The correlations between 06Sm6, 00Sm74, 06Sm7, 04Sm2 and 06Sm14 are quite high (between 0.66 and 0.92, Tab. 3) and there is no RIL resistant to one strain and susceptible to another strain (Fig. 1) indicating that probably the resistance to these strains is controlled by the same genes. The R<sup>2</sup> between the strains of this group and 06Sm10 are between 0.56 and 0.85 (Tab. 3). The existence of RILs susceptible to strains of this group and resistant to 06Sm10 but not the opposite is an indication that one of the two genes involved in resistance could be gene *A* which controls resistance to 06Sm10. The R<sup>2</sup> between the strains of this group and S87-7 is much lower (between 0.05 and 0.30, Tab. 3) and there are RILs resistant to S87-7 and susceptible to one of the five others and conversely. The second gene involved in resistance to these five strains is unlikely to be *B*, and could be symbolized by *c*, and is recessive (Tab. 4).

Table 3. Pearson's coefficients of correlation between the RILs 'Védraçais' x '90625' for their behavior after inoculation with 10 strains of *P. xanthii*.

	06Sm10	S87-7	00Sm39	06Sm6	98Sm65	00Sm74	06Sm7	04Sm2	06Sm14
Sm3	0.33	0.51	0.54	0.25	0.66	0.35	0.47	0.17	0.16
06Sm10		0.19	0.34	0.71	0.08	0.74	0.85	0.63	0.56
S87-7			0.70	0.12	0.69	0.15	0.30	0.06	0.05
00Sm39				0.33	0.71	0.31	0.50	0.25	0.22
06Sm6					0.04	0.85	0.82	0.91	0.90
98Sm65						0.07	0.17	0.01	0.01
00Sm74							0.81	0.79	0.80
06Sm7								0.72	0.66
04Sm2									0.92

### Resistance to strain Sm3

The F<sub>1</sub> ('Védraçais' x '90625') is susceptible and the observed segregation fits to a 1 resistant: 3 intermediate or susceptible ratio (Tab. 2). Resistance to Sm3 is not well correlated with resistance to 06Sm10, S87-7 or the five previous strains (Tab. 3): there are RILs resistant to Sm3 and susceptible to the others and the opposite. It indicates that genes *A*, *B* or *c* are not involved in resistance to strain Sm3 and that two other genes, at least one of them recessive, control the resistance. The provisional symbols could be *d* and *e* (Tab. 4).

### Resistance to strains 00Sm39 and 98Sm65

The F<sub>1</sub> ('Védraçais' x '90625') is susceptible and the observed segregations fit to a 1 resistant: 3 intermediate or susceptible ratio (Tab. 2). The R<sup>2</sup> values between these two strains is high (R<sup>2</sup> = 0.71). The R<sup>2</sup> with strain S87-7 is also high (Tab. 3).

There are RILs which are susceptible to the two strains and resistant to S87-7 but not the opposite (Fig. 2). This could be an indication that gene *B* is involved in resistance to these two strains, but not the gene *A* because the  $R^2$  with 06Sm10 is much lower and there are RILs resistant to 06Sm10 and susceptible to the two strains and the opposite.

**Table 4.** Hypothesis on the genetic control for PM resistance in ‘90625’. The symbol ‘+’ indicates that the gene in this column is necessary for resistance to the strain of this row. Genes *A* and *B* are semi-dominant, genes *c*, *d*, and *e* are recessive.

PM strains	<i>A</i>	<i>B</i>	<i>c</i>	<i>d</i>	<i>e</i>
06Sm10	+				
S87-7		+			
06Sm6, 00Sm74, 06Sm7, 04Sm2, 06Sm14	+		+		
Sm3				+	+
00Sm39, 98Sm65		+		+ <sup>z</sup>	+ <sup>z</sup>

<sup>z</sup>Genes *d* or *e* could be implicated in the control of strains 00Sm39 and 98Sm65 in complement of gene *B*.

Correlations with Sm3 is quite good indicating that the other gene involved in resistance to strains 00Sm39 and 98Sm65 could be *d* or *e* (Tab. 4).

Correlations between 98Sm65 and, on the other hand, 06Sm6, 00Sm74, 06Sm7, 04Sm2 or 06Sm14 are very low (Fig. 3); and correlations between 00Sm39 and the five above mentioned strains are slightly higher but in both cases there are RILs resistant to one strain and susceptible to the other, indicating that neither gene *A* nor gene *c* are involved in the genetic control of strains 00Sm39 and 98Sm65.

## DISCUSSION AND CONCLUSION

These preliminary data must be confirmed on a higher number of RILs, on a higher number of plants per RIL and by inoculation on plants and not only on leaf disks, but some conclusions can already be inferred. The results from McCreight (2003) are confirmed. McCreight found one recessive gene for resistance to race 1; we found one semi-dominant gene (symbol *A*) for resistance to strain 06Sm10, a race 1 isolate. McCreight found that a semi-dominant gene confers resistance of true leaves to race 2. We also observed that a semi-dominant gene (symbol *B*) confers resistance on leaf-disks to S87-7, the only strain in our study belonging to race 2.

Resistance to strain Sm3, which is also a race 1 isolate, is controlled by two recessive genes different from *A*, showing the need of other DL for the characterization of the races and some of RILs of this study could be used; for instance RILs #62 or #84 which are resistant to 06Sm10 and susceptible to Sm3.

Resistance to the other strains is also under a digenic control, including one or two recessive genes. There are two main aspects we have to look at when using ‘90625’ in a breeding program: (i) at least three strains should be used to select the potential five genes, for instance strains Sm3, S87-7 and one of the strains in the group 06Sm6, 00Sm74, 06Sm7, 04Sm2 and 06Sm14; (ii) as these genes are recessive

or semi-dominant, resistance genes must be introduced in both parents when looking for a commercial F<sub>1</sub> hybrid.

The Indian accession '90625' belongs to the *acidulus* botanical group. The fruit is oval shaped and weights 200-400 g. The flesh is white, very firm, non sweet and has a typical acidic taste. '90625' has been described as resistant to several diseases including *Cucurbit aphid borne yellows virus* (CABYV) (Dogimont et al. 1996), *Lettuce infectious yellows virus* (LIYV) (McCreight 1992), *Diaphania hyalinata*, *Bemisia tabaci* and *Aphis gossypii* (Boissot et al. 2000). Mapping the genes and/or QTLs involved in the genetic control of these diseases would allow the development of a marker assisted selection program.

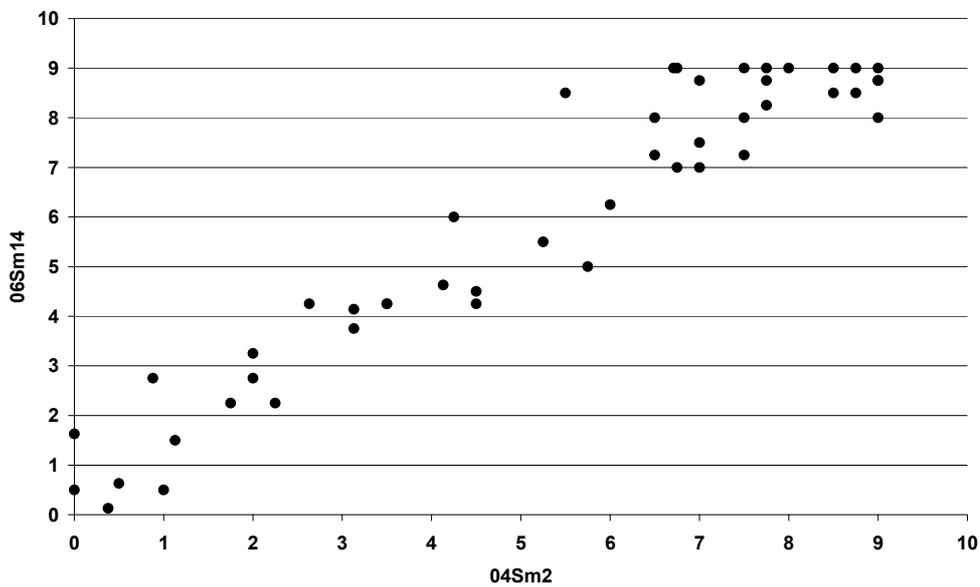


Figure 1. Example of behavior of the RILs 'Védrantais' x '90625' inoculated with PM strains 04Sm2 and 06Sm4 showing a very good correlation. Disease was rated on a 0 to 9 scale with 0=no symptoms and 9=heavy sporulation.

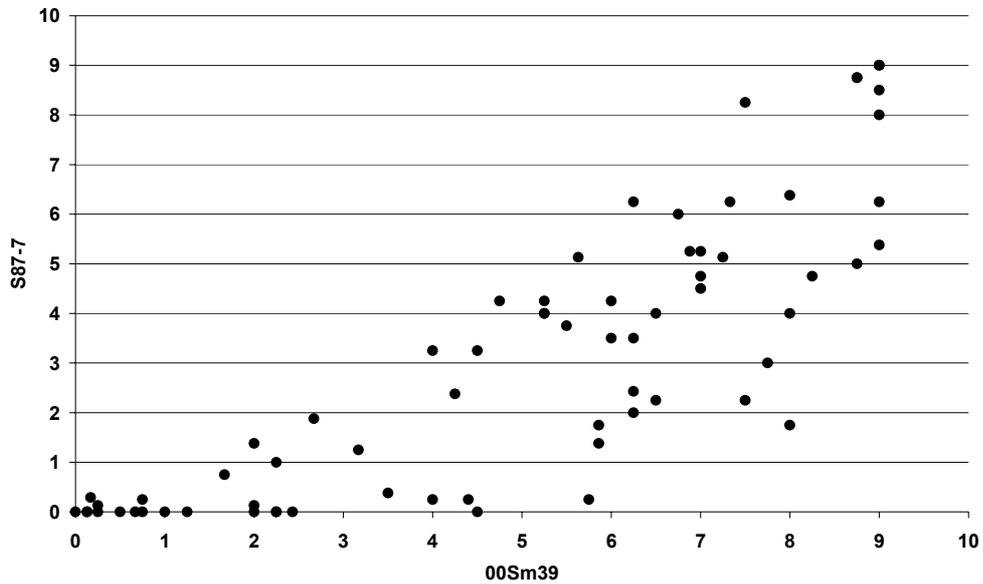


Figure 2. Example of behavior of the RILs ‘Védrantais’ x ‘90625’ inoculated with PM strains 00Sm39 and S87-7 showing RILs resistant to S87-7 and susceptible to 00Sm39 but not the opposite. Disease was rated on a 0 to 9 scale with 0=no symptoms and 9=heavy sporulation.

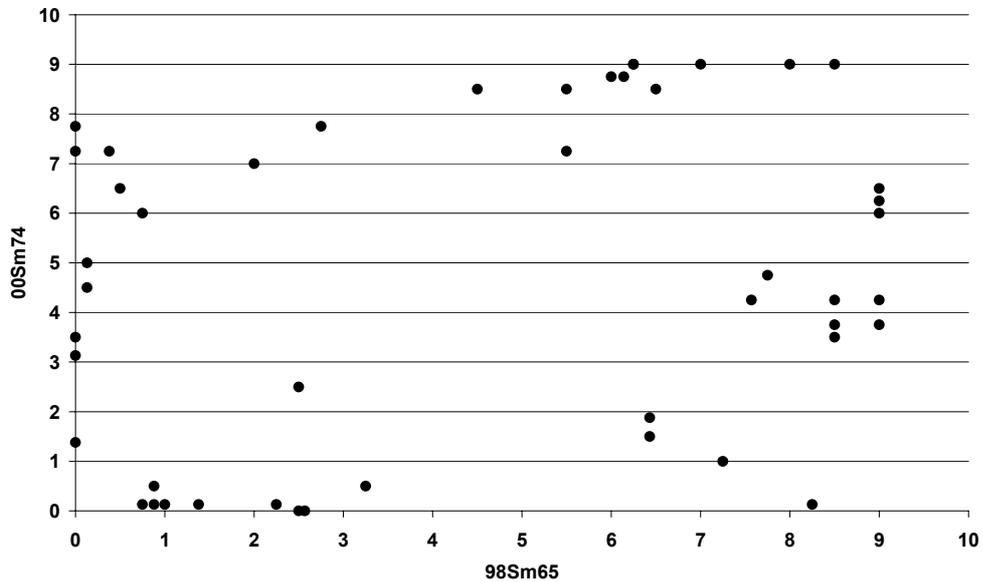


Figure 3. Example of behavior of the RILs ‘Védrantais’ x ‘90625’ inoculated with PM strains 98Sm65 and 00Sm74 showing RILs resistant to 98Sm65 and susceptible to 00Sm74 and conversely. Disease was rated on a 0 to 9 scale with 0=no symptoms and 9=heavy sporulation.

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