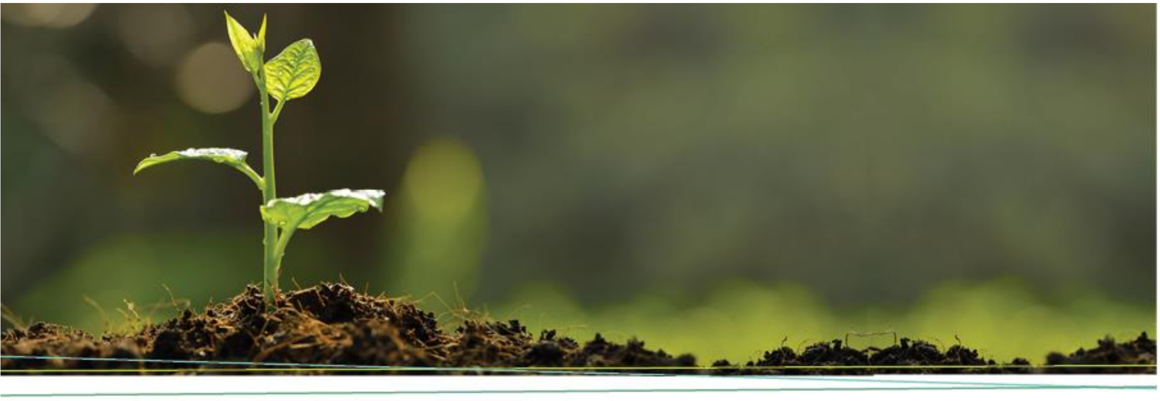

Focus Group SOIL-BORNE DISEASES

Mini-paper - *Success and failures of grafting against soil-borne pathogens*

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Introduction

Grafting horticultural crops on rootstocks is a quite old technique. A famous example is grafting the European grape vine on the rootstocks of American grape vine species to protect them from the threat of *Phylloxera* (Boley *et al.,* 1979). Grafting fruit trees is also a long established habit, in this case not to control soil-borne diseases or pest but mainly to modify their growth vigor, and since recently, to increase their resistance to fire blight. Grafting vegetable crops on rootstocks has its origin in Asia (Japan, Korea) and is now also widely used in Europe and North America (Lee *et al*., 2010). The use of disease- and nematode-resistant rootstocks has strongly increased in the last decades, mainly for crops such as tomato, bell pepper, and melon, to reduce susceptibility against pests, root rots and wilts causing pathogens, abiotic stresses and to increase yield (Louws *et al.,* 2010; Rouphael *et al.,* 2010). Pathogens generally considered minor can became major on the rootstocks in the absence of soil fumigation (Garibaldi and Gullino, 2010). Despite some disadvantages associated with grafting, including the additional cost and physiological disorders due to incompatibility between rootstocks and scions, grafting is considered one of the most important alternative to chemical fumigants for controlling soil-borne pathogens in vegetable crops adapted to grafting.

Facts

In Europe in 2009, Spain was the leading user with an estimated 129 million grafted plants, followed by Italy with 47 million and France with 28 million plants.

In Italy, 59 million vegetable plants are grafted at present. Less than 5% of pepper grown under protection are grafted plants with around 1.6 million of pepper grafted and an increase of about 30% in the period from 2008 to 2010 (Morra and Bilotto, 2010).

In Switzerland, no official data on the use of grafted plants are available. Most probably nearly all tomato plants are grafted, for traditional production in soil as well as for soilless production systems. Tomato seedlings grafted on rootstocks are even available for planting in the home garden.

In the Netherlands, grafting is mainly used in tomato and eggplant production with an estimate of 25 million rootstocks. In tomato more different rootstocks are used as they see a rise in the use of 'Fortamino' and 'Estamino' (Enza). In Sweet pepper 'Snooker' (Syngenta) is mainly used or 'Scarface' (Enza). As for cucumbers, rootstocks are only used in organic green houses and not in conventional production.

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Use of rootstocks on solanaceous crops

The resistance of grafted plants may break down under high disease pressure, with new races of pathogens evolving on rootstocks. Other limitations are related to evolution of new strains of pathogens, while pathogens, such as *Colletotrichum coccodes*, generally considered minor can become major pathogens on the rootstocks in the absence of soil fumigation (Garibaldi *et al.,* 2008). In Switzerland, the resistance of the tomato rootstock Maxifort to *Verticillium dahliae* (causal agent of Verticillium wilt), *Fusarium oxysporum* (causal agent for Fusarium wilt) and *Pyrenochaeta lycopersici* (causal agent of corky root) broke down after an infection of the roots by *C. coccodes* (Michel and Terrettaz, 2011). Verticillium wilt of eggplant incited by *V. dahliae* was consistently observed on eggplant grafted on *Solanum torvum* (Garibaldi *et al.,* 2005).

Compared to non-grafted tomato plants has grafting on resistant rootstocks a positive effect on the yield independently of the disease pressure by soil-borne pathogens (Michel, 2013). The much stronger growth vigor of the grafted plants can explain this effect, this stronger vigor is also the reason why tomato plants in soilless systems are normally grafted on rootstocks. In certain conditions, however, such as a cool summer season, grafting on resistant rootstocks will not result in a higher tomato yield (Michel and Lazzeri, 2010).

In the case of bell pepper and eggplant, grafting confers resistance to *Meloidogyne incognita* (Kokalis-Burelle et al., 2009), to *Phytophthora nicotianae* (Hamdi *et al.,* 2010), to *Phytophthora capsici*, *V. dahliae* and *Rhizoctonia solani* (Colla *et al.,* 2012).
Among rootstocks, 'Rocal' and 'Snooker' are resistant or a partially resistant to *R. solani* and no effect of the age of the plants was observed. 'Galaxy' and 'Robusto' have low resistance, and 'Tresor' and 'Atlante' are the most susceptible to *R. solani* (Gilardi *et al.,* 2014b). The susceptibility of pepper rootstocks against *R. solani* is age-dependent and older plants are more resistant against *R. solani* (Gilardi *et al.,* 2014b).
The same rootstocks are resistant to *V. dahliae* and susceptible to *C. coccodes* (Gilardi *et al.,* 2014).
Commercial tomato rootstocks showed resistance to *F. oxysporum* f. sp. *radicis-lycopersici*, *V. dahliae* and *F. oxysporum* f. sp. *lycopersici* (race 1) and partial resistance to *F. oxysporum* f. sp. lycopersici (race 2), *P. lycopersici, Ralstonia solanacearum* (causal agent of bacterial wilt), TMV, ToMV, PVY, Tm and nematodes, in particular for Maxifort and He-man (Table 1). Other rootstocks commonly used are Armstrong, Arnold, Beaufort, Big Power, Brigeor, Emperador, King Kong, Spirit and Superpro V295.
P. capsici, P. nicotianae and *C. coccodes* showed a broad host range among solanaceous and cucurbitaceous crops and the success of crop rotation is limited.
Susceptibility to *Phytophthora nicotianae* has been observed for rootstocks belonging to interspecific hybrids *of Solanum lycopersicum* x *S. hirsutum* (cvs. Beaufort, He-Man) and to *S. lycopersicum* (cv. Energy) (Gilardi *et al.,* 2011). Increased symptoms of basal rots caused by *R. solani* (anastomosys group AG4) were repeatedly observed on tomato grafted onto *S. lycopersicum* x *S. hirsutum* (Minuto *et al.,* 2007).
Colletotrichum coccodes attacks were observed on grafted bell pepper "Rocal" (Garibaldi *et al.,* 2012) and tomato plants (Minuto *et al*., 2008). New rootstocks like Arnold and Armstrong are resistant to *C. coccodes* (Gilardi *et al*., 2014a) and to *Phytophthora* crown and root rot (Gilarti *et al.,* 2013).
There is growing evidence that the continuous use of the same rootstock will lead to a breakdown of the resistance in a short period (Ros-Ibáñez *et al.,* 2014). This is worrying because a new resistance gene could be lost to soon. Careful planning of the crop rotation is advised.
According to the dutch experience, organic tomato growers lost a good rootstock with the phasing out of the root stock Big Power (Rijk Zwaan). There is some resistance and tolerance against *M. incognita* and *M. javanica* but not against *M. hapla*. Maxifort clearly has less resistance compared to other rootstocks (PG 76 and Brigeor). As in tomato, rootstocks of sweet pepper are sensitive to *M. hapla* and have shown some resistance to *M. incognita* and *M. javanica*. Most promising rootstocks are 'Capital', 'Snooker', '07zs102' and 'PR131'. The last two do give a lower production.

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Table 1 - Disease reaction of different tomato rootstocks screened for resistance to different soil-borne pathogens (from Gilardi *et al.,* 2011).

Rootstock	*F. oxysporum* f. sp. *lycopersici* (FOL) Race 2		FOL Race 1		*R. solani*		*F. oxysporum* f.sp. *radicis-lycopersici* (FORL)		*V. dahliae*	
	15[a]	30	15	30	15	30	15	30	15	30
He-Man	R[b]	R	PR	R	R	R	R	R	R	R
Maxfort	R	R	R	R	PR	R	R	R	R	R
Beaufort	HS	R	PR	R	PR	R	R	R	R	R
Unifort	S	R	R	R	PR	R	R	R	R	R
500267	S	R	R	R	PR	R	R	R	R	R
500292	HS	R	R	R	R	R	R	R	R	R
Natalya	PR	R	R	R	S	PR	R	R	R	R
Spirit	HS	R	PR	R	PR	R	R	R	R	R
-[c]	HS	HS	HS	HS	S	S	HS	S	S	PR

[a] Age of the plants artificially inoculated (days)
[b] Reaction: resistant (R, disease index from 0 to 10), partly resistant (PR, DI: 11–30), susceptible (S, DI: 31–60) and highly susceptible (HS, DI: 61–100)
[c] Susceptible control tomato cv. 'Cuore di bue' (Furia Sementi)

Use of rootstocks on cucurbitaceous crops

Among rootstocks available for cucurbitaceous crops, there are Macis, RS841, Shinztoza, Strongtosa, PS1313, Root Power, Forza, Nimbus for water melon, Dinero, RS841, Shintoza, Strongtosa, Camelforce, Elsi for melon, Kazako, Flexifort, Macic and Nimbus also for cucumber.
They are targeting resistance against *Fusarium oxysporum* f. sp. *melonis* (races 0, 1, 2, 1-2), *Fusarium oxysporum* f. sp. *niveum* (races 0, 1), *Fusarium oxysporum* f. sp. *cucumerinum* (races 0, 1), *Fusarium oxysporum* f. sp. *radicis-cucumerinum, Verticillim albo-atrum, Didymella bryoniae, Phomopsis sclerotioides, R. solani, M. incognita, Meloidogyne arenaria, Meloidogyne javanica*.

Vine decline of cantaloupe and other cucurbits, caused by *Monosporascus cannonballus* (Cohen *et al.,* 2000) is also emerging as a consequence of solarization and grafting may help. The pathogen has been reported in Italy on watermelon, melon and cucumber.

Jan Janse reported in 2010 that there are not much new breeding programmes against the root knot nematode. This is explained due to the very small organic market. Even worse, one of the more favourite rootstocks (Harry) for organic growers has been phased out by Syngenta in the last few years. Grafting of potential rootstocks (64-10 and 64-12) from Rijk Zwaan was difficult. These potential rootstocks were discontinued before they came commerial. This leaves (organic) growers with little choice. Research from Jan Janse *et al.,* (2010) has shown that *Meloiodogyne hapla* and *M. javanica* has difficulties reproducing on cucumber rootstocks. *M. incognita* has no problems reproducing.

Availability of resistant rootstocks and use under IPM

The availability of resistant rootstocks among the material currently available and adopted by growers looks particularly interesting and will permit an easy implementation of this strategy of disease control in practice. Information on the resistances of commercial rootstocks are published on the internet by the breeding companies. For example, the rootstocks for cucumber, eggplant, melon and tomato of DeRuiters are available under following address: www.deruiterseeds.com/Pages/default.aspx

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In some regions, growers cooperatives test new rootstocks and varieties of tomato and, most probably, of other grafted vegetable species, in their own research facilities. One such cooperative is "Flandria" in the Dutch speaking part of Belgium (http://en.professional.mijnflandria.be/board/research). In Switzerland, new tomato rootstocks were tested at Agroscope, a public research institute, until 2003. Based on growers request, such testing was stopped, as they prefer to test themselves newly released rootstocks. In France, Ctifl, the public research stations for applied research, works on different aspects of grafting and most probably other public research institutes in Europe do the same. In Italy, public research institutes like Agroinnova – University of Torino, since 2002 carries out trials to evaluate the resistance of rootstocks both in greenhouse and in open field conditions, providing farmers those information.
The use of resistant rootstocks is a key factor for an integrated plant protection strategy of high-value vegetable crops. Combination with other control methods such as the use of biofumigation (mainly with seed meal products), compost and organic amendments (Gilardi *et al.,* 2014a; Michel, 2010; Michel and Lazzeri, 2010) are possible. An integrated approach with other strategies is also recommended. Tomahawk' grafted onto Arnold', Armstrong' and Superpro V295' is significantly less affected by *C. coccodes*, while Arawak' is more resistant when Armstrong', Arnold', Emperador' and Beaufort' are used. Compost addition and biofumigation with Brassica pellets can slightly improve disease control, when combined with grafting in a soil naturally infested with *M. arenaria* but not on C. coccodes (Gilardi *et al.,* 2014a).
Regarding the control of *P. capsici* on bell pepper and tomato, the commercially available rootstocks, 'Tecnico 1', 'Terrano', 'Robusto', 'Snooker' and 'Capsifort', and the addition of compost improve disease control, while the combination of grafting with biofumigation is not able to improve C*. coccodes* control in comparison to grafting alone (Gilardi et al., 2014c).

Future developments

Grafting is a well-established method, at least in countries which banned methyl bromide before the official phasing-out starting in 2005, such as the Netherlands or Switzerland. In these countries, where all grafted vegetables species are grown in greenhouses or at least in heated tunnels, the importance of resistance to soil-borne diseases is decreasing. In contrast, other aspects influenced by grafting such as the quality will become more important (see COST-Action "Vegetable Grafting to Improve Yield and Fruit Quality under Biotic and Abiotic Stress Conditions" (http://www.cost.eu/COST_Actions/fa/Actions/FA1204).
In Southern European countries grafting has become an important method to control soil-borne pathogens, in particular for tomato and melon. Specialized grafting companies have been recently established and able to follow the increasing market request. Grafting has become popular also for hobby farmers, however it is relatively costly and therefore suitable only for certain crops. The higher cost is also due to the grafting process, that is labor intensive, it requires skilled technicians and it has not yet become fully automatic by machines or grafting equipments.
Consequently, among future developments and priorities for research, automatic grafting system must be considered and they may reduce grating costs. Another possibility to reduce the costs and need from practice is to transfer knowledge to farmers for producing grafted plants directly in their farms. Priority for farmers is also to receive more independent information about the resistance and vigor of rootstocks.

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