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The role of grafting technique to improve tomato growth and production under infestation by the branched broomrape

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Durinta and Petula broomrape-susceptible tomato varieties were grafted onto broomrape-tolerant rootstock (Eldorado) and broomrape-susceptible rootstocks (Maxifort and Integro) and grown under conditions of infestation by branched broomrape in greenhouses of Laboratory of Vegetable Biology and Pathology. Four months after the culture, vegetative and productive parameters were measured on each cultivated tomato plant. Thus, for tomato plants, the total number of leaves, floral bouquets, fruit bunches and fruits were determined. Moreover, the fresh and dry weight of the fruits and the vegetative parts were measured. For branched broomrape plants, the total number of attachments and emergences and the total fresh and dry weight per tomato plant were defined. The results show that the sensitivity of grafted plant to branched broomrape is conditioned by that of the rootstock. In addition, the grafting induced a deceleration of the development of the fixed broomrapes. Moreover, the Eldorado rootstock increases the production of fruits of the two varieties Durinta and Petula under infestation by the broomrape. Finally, the grafting improves the degree of tolerance of the variety to the broomrape. Grafting is therefore an important technique for tomato production under conditions of infestation by the broomrape when the rootstock is resistant or at least tolerant.

Key words: Grafted Tomato, Infestation, Tolerance, Sensitivity, Branched Broomrape.

INTRODUCTION

The infestation of tomato by the branched broomrape (Phelipanche ramosa L.) became a major problem particularly in the Mediterranean basin (Ait-abdallah et al., 1999; Joel et al., 2007), with considerable losses of output going until the total destruction of the culture. Phelipanche ssp. is a parasitic plant of root completely deprived of roots and chlorophyll. It depends thus completely on its host for his hydro-mineral and organic nutrition. *Via* the *haustorium,* the parasitic plant is connected thus to conducting tissues of the plant host and takes its water and nutriments necessary for its development. It enters thus in trophic competition with the proper well organs of the plant host.

The seed germination of broomrape begins in response to stimulants emitted by the roots of plant host. After its fixing on the roots of the plant host, the broomrape develops a tubercle then a stem which, after emergence, differences in a floral spike and produce a very high number of seeds. The danger of this parasite comes from the long viability of its tiny seeds (0.2-0.3 mm and 3 µg) in the ground, which exceeds at least the ten years, and of its very high rate of multiplication (100000 seeds plant^{-1}), (Cubero, 1983). Moreover, the majority of the damage on the host is caused during the underground growth of the parasite and no practical methods to control it effectively (Gressel et al., 2004). Several integrated methods based on cultural, physical, biological and chemical means are proposed to control broomrape in processing tomato (Montemurro et al., 2006). However, there is an increasing market for organically grown tomatoes, where the use of chemical pesticides is not an option (Lopez-Pérez et al., 2006).

The absence of resistant tomato cultivars makes the grafting onto resistant rootstocks, if exists, a possible solution to resist the broomrape. The grafting of vegetables made it possible to increase strength and output (Yetisir and Sari, 2003; Pogonyi et al., 2005), and absorption of macro-elements such as phosphorus, calcium, sulphate and nitrogen (Ruiz et al., 1996; Ruiz and Romero, 1999; Leonardi and Giuffrida, 2006), and micro-elements such as iron (Rivero et al., 2004) Photosynthetic rates (Matsuzoe et al., 1993a; Matsuzoe et al., 1993b), stomatic conductance (Fernandez-Garcia et al., 2002), as well as the synthesis of endogenous hormones (Proebsting et al., 1992) were increased by the grafting.

The grafting is very effective to surmount the abiotic stress such as salinity (Santa-Cruz et al., 2001; Santa-Cruz et al., 2002; Fernandez-Garcia et al., 2004b; Estan et al., 2005; Ruiz et al., 2005; Colla et al., 2006; Wang et al., 2017), soil excessive moisture (Black et al., 2003), high (Rivero et al., 2003; Rivero et al., 2003b; Abdelmageed et al., 2004) and low (Horváth et al., 1983; Bulder et al., 1991; Zijlstra et al., 1994) temperatures.

The first grafts were carried out at the beginning of the 20th century with an aim of reducing the attack by soil-borne pathogens. Currently, the grafting is effective against large pathogens panoply of soil including fungi, bacteria, viruses and nematodes (Gilardi et al., 2013; Yang et al., 2016). However, rootstocks allowed improving the output under infection by fusarium wilt caused by *Fusarium oxysporum f.sp.lycopersici* and root and stem rot caused by *F.oxysporum f. sp. Radicis-lycopersici* at tomato and watermelon (Scheffer, 1957; Pavlou et al., 2002; Rivero et al., 2003). Moreover, the grafting was used successfully to eliminate the verticillium wilt caused by *Verticillium dahliae* on melon, cucumber, tomato and potato (Tsror and Nachmias, 1995; Ioannou, 2001; Bletsos, 2005). In addition, studies made in soil infested by root rot caused by *Phytophthora cryptogea* showed that this technology is applicable to control the root rot at tomato in greenhouse (Upstone, 1968). The grafted tomatoes also made it possible to reduce the levels of the corky root rot caused by *Pyrenochaeta lycopersici* (Bradley, 1968; Ioannou, 2001; Stäubli, 2005). The graft is used also to control the root-knot nematodes caused by *Meloidogyne sp.* at tomato, melon, watermelon, cucumber and eggplant (Besri, 2001; Ioannou, 2001; Rahman et al., 2002; Giannakou and Karpouzas, 2003; Abdelhaq, 2004; Lopez-Péreza et al., 2006). Furthermore, the graft is fundamental in the reduction of the damage of bacterial wilt caused by *Ralstonia solanacearum* at *Solanaceae* (Tikoo et al., 1979; Peregrine and Binahmad, 1982; Grimault and Prior, 1994; Tresky and Walz, 1997; Oda, 1999). The grafting can be used as well as to control the disease of Tomato Yellow Leaf Curl Virus (Rivero et al., 2003).

Concerning *Phelipanche ramosa*, no information is available to date on the interest of the grafting and the rootstocks to control this parasite. This work thus is built to know if the tolerance of the rootstocks can be an asset to limit the parasitic incidence and the development of the broomrapes on the grafted plants. In addition, the impact of the grafting on the sensitivity of the rootstocks and the tolerance of the tomato varieties will be evaluated. The tomato grafted and parasitized by the broomrape is a biological model complex, for which it seemed to us interesting from a fundamental point of view to look further into the relations source-well between the scion, the rootstock and the broomrapes fixed at the rootstock.

MATERIALS AND METHODS

Vegetable materials

Three rootstocks (Eldorado from Enzazaden, Integro from Vilmorin and Maxifort from De Ruiter), selected for their different behaviors to the broomrape, were grafted with two varieties of tomato (Durinta and Petula) by the Brilland company (Saint Sébastien sur Loire), (Table 1). The seeds of branched broomrape were obtained starting from floral spikes of broomrapes collected in an infested field of colza (pathovar C, Saint-Martin-de-Fraigneau, Vendée, France, 2005).

Conditions of grafting

The sowing of rootstock is carried out one week before that of scion. The seeds are sown on rock wool in small pots 2 cm in diameter. The plants develop in greenhouse (temperature 25°C the day and 20°C the night, hygrometry 60%, lighting 800 watts m^{-2}). The sorting of the rootstocks and of the scions on their strength is made one week after sowing. The grafting is carried out 15 days after the sowing of the rootstock according to the technique of tube grafting (Rivard and Louws, 2006). The rootstock is cut under the first pair of leaves (cotyledons). The scion is cut above of cotyledons by leaving at least a well developed leaf. Once the cut of rootstock and scion, they are linked by a grafting clip of plastic, (Oda, 1995). The grafted plants are maintained with the darkness during 1 day then under lighting (100 watts m^{-2}) 3h per day during 6 days, under a high hygrometry (higher than 85%) and a temperature of 18-20° the night and 22-25° the day. From the eighth day, the success of the grafting is generally ensured 100%. The grafted plants are transferred in the greenhouse (temperature 20°C the night and 25°C the day, hygrometry 60%, lighting 800 watts m^{-2}). After one week from acclimatization, the plants are mended in the culture pots (pot of 3L), (show the following paragraph).

Interactions tomato-broomrape in pot

Seeds of *P. ramosa* (10 mg L^{-1} of soil; approximately 3700 seeds) are mixed with a mixture sand-soil-compost (1:1:1) in a pot of 3L. Ten infested pots are prepared for each tomato plant tested (n=10). The infestation of soil by seeds of *P. ramosa* then the homogenization of the mixture are carried out manually in each pot. The pots

Table 1. Principal characteristics and resistances of the tomato rootstocks; TMV: Tomato Mosaic Virus; For: *Fusarium oxysporum Radicis-lycopersici* (crown rot); Fol: *Fusarium oxysporum lycopersici* races 0 and 1 (1 and 2); CF: *Cladosporium fulvum*; CR: Corky Root (*Pyrenochaeta lycopersici*); V: *Verticillium sp.*; N: Nematodes: the most known species (*Meloidogyne ssp.*); St: *Stemphyllium*; Rs: Bacteria (*Ralstonia Solanacearum*); HR: High Resistance; IR: Intermediate resistance.

Rootstock	Society	Hybrid Identity	Resistance Codes
Integro	Vilmorin	*S. lycopersicum × S. hirsutum*	**HR** : TMV, V, Fol, N, CR, For
Maxifort	De Ruiter Seeds	*S. lycopersicum × S. habrochaites*	**HR** : TMV, V, Fol, For, CR, N
Eldorado	Enzazaden	*S. lycopersicum × Solanum sp.*	**HR** : TMV, CF, CR, V, Fol, For, N
Petula	Rijk Zwaan	*S. lycopersicum × S. lycopersicum*	**HR** : TMV, Fol, V (croissance moyenne)
Durinta	Western Seeds	*S. lycopersicum × S. lycopersicum*	**HR** : TMV, Fol, V (croissance vigoureuse)

are sprinkled and protected from the light by a black cover, then maintained in this state during one week with 25° C for the pre-conditioning of seeds of broomrape. Ten non-infested tomato pots (healthy soil) are carried out in parallel for each genotype tested.

Control and maintenance of the tomato cultures

The cultures are developed under conditions of greenhouse at 20-25°C in day and 15-18°C in night, 300 µmoles m^{-2} S^{-1} PAR and 16h of photoperiod. The grafted and non-grafted tomato plant are regularly fed by a nutritional solution composed of 50% of Coïc solution (Coïc and Lesaint, 1975). The tomato plants are addressed and propped with polypropylene string by a metal hook, which is used as support and makes it possible to optimize space. To avoid the rolling up of the plants on the string and their breakage, clips (in plastic) are posed under a leaf or a floral bouquet. The clips are well closed by wedging the wire in the brake of clips with a distance of 25 cm between the clips. The tomato plants are also disbudded progressively by eliminating the growths with the armpit from the leaves and the bouquets, this in order to guide their development on only one stem. Supports bouquets are posed as of flowering to reinforce the axis of the inflorescence and to avoid its folding under the weight of the fruits (advanced stage). The support bouquet is posed on the bunch of flowers, between the stages 2^d open flower and 4^{th} open flower. The faded leaves are eliminated progressively (Ferrère et al., 1997). The tomato plants are supervised during their development to avoid the attack by the harmful parasites.

Collect of experimental data

Four months after the culture and before harvest, vegetative and productive parameters were measured on each cultivated tomato plant. Thus, the total number of leaves, floral bouquets, borne fruit bunches and fruits were determined (Pavlou et al., 2002; Yetisir and Sari, 2003; Abdelmageed et al., 2004; Khah, 2005).

All the fruits of all the varieties tested and all the stages (green, orange, ripe) are collected. In order to determine the impact of the grafting and parasitism on the productivity of the studied varieties, the total number and the total mass (fresh and dry) of the fruits collected per tomato plant were measured (Edelstein et al., 1999; Pavlou et al., 2002; Kacjan-Marsic and Osvald, 2004; Oka et al., 2004; Sigüenza et al., 2005; Lopez-Pérez et al., 2006; Martinez-Rodriguez et al., 2008; Venema et al., 2008).

The tomato plants (grafted and non-grafted) are then carefully uprooted. The broomrapes (underground and emerged) are collected, washed carefully under water then classified. The degree of sensitivity to the broomrape of grafted and non-grafted tomatoes is evaluated by the total number of broomrapes fixed per plant (Sillero et al., 1996b), by the number of broomrapes emerged per plant (Gil et al., 1984; Gil et al., 1987; Cubero, 1991; Snelder et al., 1994; Qasem and Kasrawi, 1995; Sillero et al., 1996a), and by the total fresh and dry biomass of broomrapes per plant (El-Halmouch, 2004).

In parallel, the impact of grafting and parasitism on the development of tomato plants are estimated following the measurement of the fresh and dry biomass of the roots and the vegetative aerial parts of the infected and healthy plants (Solt and Dawson, 1958; Mapelli and Kinet, 1992; Holbrook et al., 2002; Santa-Cruz et al., 2002; Yetisir and Sari, 2003; Abdelmageed et al., 2004; Ozbay and Newman, 2004; Peres et al., 2005; Martinez-Rodriguez et al., 2008).

The dry biomass is measured after drying of the vegetative parts and the fruits of the different tomato plants at 80°C during 72 hours (El-Halmouch, 2004; Khah, 2005; Peres et al., 2005; Abbes, 2007).

Statistical treatments of results

The statistical analysis are carried out by using the software SigmaStat version 3.5. The comparisons of average are based on the test of Student Newman Keuls (ANOVA, SNK, $P \leq 0.05$, n=10). For the percentages of broomrapes emerged by plant, the results were

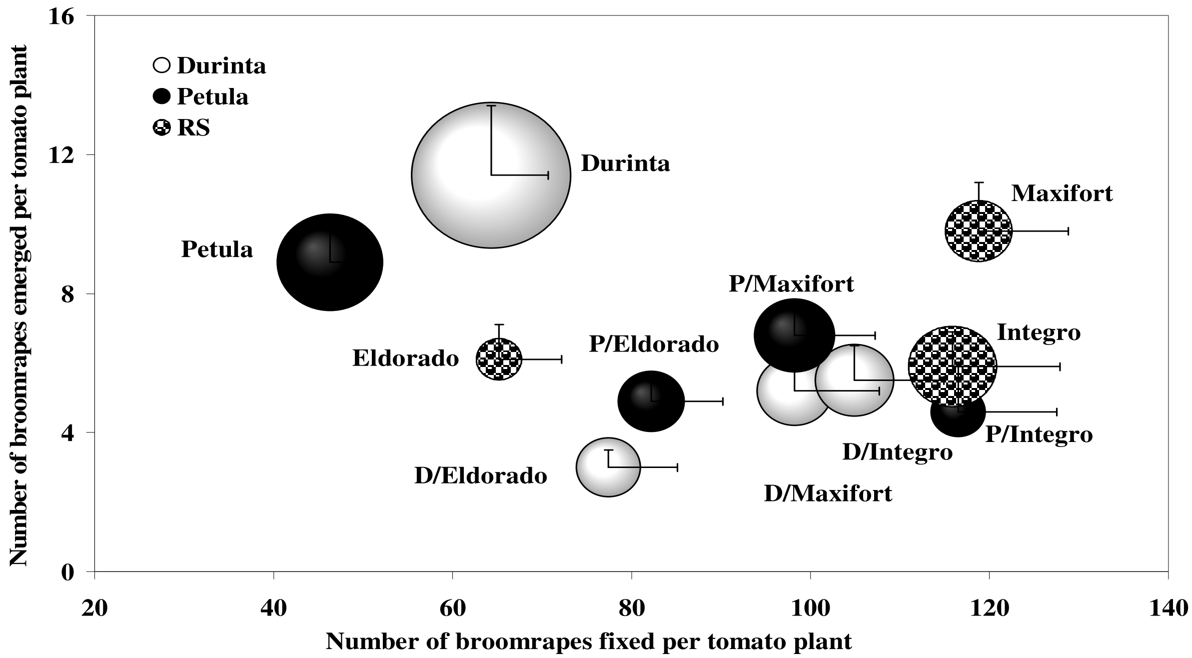

Fig. 1. Influence of the grafting on the sensitivity to the branched broomrape of different tomato genotypes. The values are the averages ± SE (n=10). The size of the circles corresponds to the total dry mass of the broomrapes fixed by tomato plant. In black: non-grafted Petula variety and grafted on the different rootstocks. In white: non-grafted Durinta variety and grafted on the different rootstocks. In sphere: rootstocks (RS: Eldorado, Maxifort and Integro).

transformed (arcsin^{-1} (square root of the ratio)) before being analyzed like previously.

RESULTS AND DISCUSSION

The work of DRAIE, (2009) showed that the development of the broomrape in post-fixing is limited for the rootstocks (Eldorado and Integro) compared to the other rootstock (Maxifort). The underground growth of the broomrapes leading to their emergence is thus under the dependence of a competition inter-well between the target organs specific to the rootstock (aerial vegetative parts and fruits in particular) and the fixed broomrapes, and between the broomrapes themselves. It is thus interesting to analyze the impact of the grafting on these relations inter-well, being able to lead to a limitation of the development of the fixed broomrapes, even to a reduction of the degree of sensitivity of the grafted plants, and thus to a profit of productivity under infestation.

The rootstocks Eldorado, Integro and Maxifort were selected for their discriminating characteristics in term of sensitivity to the broomrape (Eldorado/Integro and Maxifort) and of "capacity to support the emergence of the parasite" (Eldorado and Integro/Maxifort), (Draie, 2009). The grafting was carried out by the means of a service of the Brilland Company. The availability of batches of seeds certified was thus also a major argument in the choice of the rootstocks and the varieties to be grafted (Durinta and Petula).

Effect of grafting on the genotype sensitivity to the broomrape

After 4 months of culture under infestation, sensitivity to the branched broomrape of grafted (Durinta/Eldorado, Durinta/Maxifort, Durinta/Integro, Petula/Eldorado, Petula/Maxifort and Petula/Integro) and non-grafted (Durinta, Petula, Eldorado, Maxifort and Integro) tomato plants, was evaluated according to following indicators: number of fixed and emerged broomrapes per plant and total dry mass (DM) of the fixed broomrapes per plant (Fig. 1).

Analysis of variances (ANOVA, SNK, $P \leq 0.05$, n=10) place the Durinta and Petula varieties in the same group of sensitivity to the broomrape as the Eldorado rootstock, with an average of 63 broomrapes fixed per plant. Thus, this group is distinguished statistically from the group of the genotypes most sensitive to the broomrape and composed of the rootstocks Maxifort and Integro with an average of 109 broomrapes fixed per plant. On the other hand, in term of percentage of emerged broomrapes, the Petula and Durinta varieties define the group of the most favorable genotypes to the emergence of the parasite (in means 20% of emergences per plant). Conversely, the rootstocks Eldorado, Integro and Maxifort are characterized by a percentage of broomrapes emerged per plant definitely weaker (7% on average). Finally, the Durinta variety is distinguished from the Petula variety and the three rootstocks by a total mass of fixed broomrapes more significant. These results attest a good development of

Table 2. Comparison of the indicators of development and productivity of two non-grafted tomato varieties (Durinta and Petula) in condition of infestation by the branched broomrape. For each parameter, the values carrying the same letter are not significantly different (ANOVA, SNK, P≤0.05, n=10). FM-F: total fresh mass of the fruits (g); FM-AP: total fresh mass of the aerial parts (g); FM-R: fresh mass of the roots.

Variété	N° Feuilles	N° Bouquets floraux	N° Grappes	N° Fruits	FM-F	FM-AP	FM-R
Durinta	20.0^{a}	2.0^{a}	0.2^{a}	0.5^{a}	$\mathbf{19.0^{b}}$	50.5^{a}	16.3^{a}
Petula	18.0^{a}	2.0^{a}	0.5^{a}	0.7^{a}	$\mathbf{47.0^{a}}$	46.7^{a}	14.3^{a}

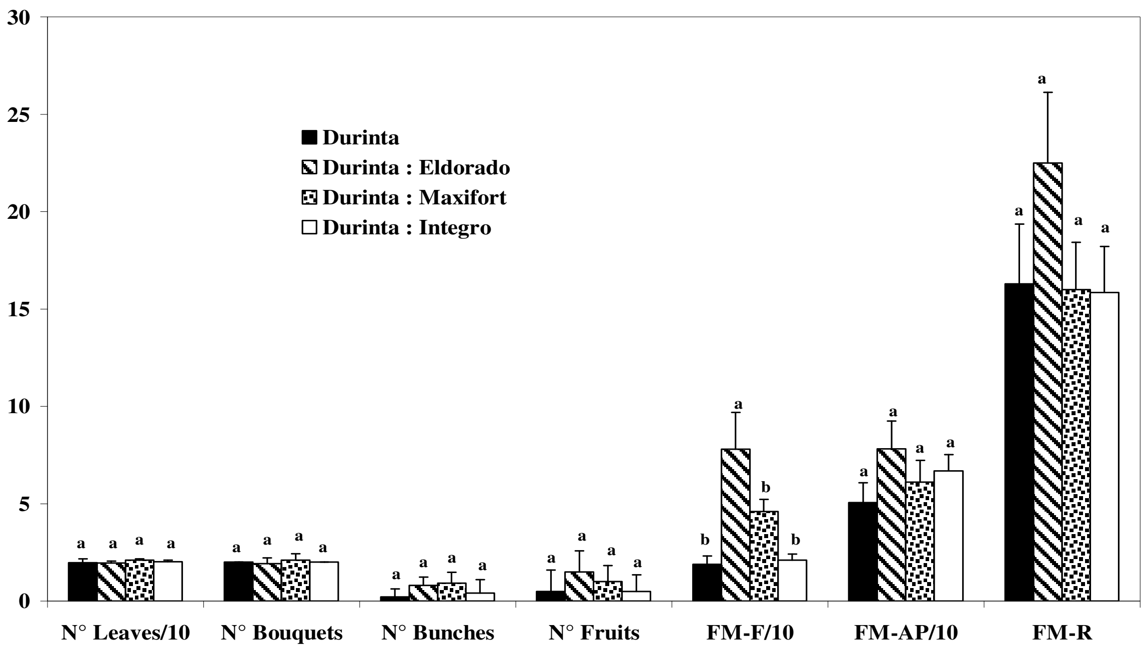

Fig. 2. Influence of the grafting of Durinta tomato variety on different indicators of development and productivity under infestation by the branched broomrape. The data are the averages ± SE (n=10). For each parameter, the values carrying the same letter are not significantly different (ANOVA, SNK, P≤0.05, n=10). N° Feuilles/10: the tenth of the total number of leaves; FM-F/10: the tenth of the total fresh mass of the fruits (g); FM-AP/10: the tenth of the total fresh mass of the aerial parts (g); FM-R: fresh mass of the roots.

the broomrapes on this variety.

According to the variance analysis on the whole of the non-grafted and grafted varieties and rootstocks, two groups not overlapping of sensitivity are constituted (ANOVA, SNK, P≤0.05, n=10 ; Fig. 1): the first group is composed of Petula, Durinta, Eldorado, Durinta/Eldorado and Petula/Eldorado, with an average of 63 broomrapes fixed per plant; Maxifort, Integro, Petula/Integro, Durinta/Integro, Durinta/Maxifort and Petula/Maxifort (109 fixings on average per plant) represent the second group.

In term of emergence, the variance analysis on the whole of the non-grafted and grafted varieties and the rootstocks compose two groups of plants (ANOVA, SNK, P≤0.05, n=10 ; Fig. 1): a first group composed of non-grafted Durinta and Petula (20% of emergences per plant) and a second group including the assembly of the rootstocks and the grafted varieties (<10% of emergences per plant).

Consequently:

- The grafting of the two varieties Durinta and Petula with Eldorado, the least sensitive rootstock, does not modify the degree of sensitivity of this rootstock (number of fixings per plant) but on the other hand induced a significant reduction of the percentage of emerged broomrapes and total dry mass of broomrapes fixed per plant.
- In the same way, the grafting of the two varieties Durinta and Petula on the most sensitive rootstocks, Integro and Maxifort, significantly does not modify the degree of sensitivity of these rootstocks (number of fixings per plant), but also induced a reduction of the percentage of emerged broomrapes. The total dry mass of the fixed broomrapes is reduced to a significant degree following the grafting of the Durinta variety on Integro and Maxifort. Such an influence of the rootstock is not observed for the Petula variety.

These results show that for the plants grafted in our

Table 3. Total dry Mass of different parts (vegetative and productive) of grafted and non-grafted tomato plants in conditions of infestation by the branched broomrape. For each organ, the values carrying the same letter are not significantly different (ANOVA, SNK, P≤0.05, n=10). DM: dry mass; V: Vegetative part; F: fruits.

Dry Mass	Durinta				Petula			
	Non-grafted	Eldorado	Maxifort	Integro	Non-grafted	Eldorado	Maxifort	Integro
Fruits	1.0^{a}	4.0^{a}	2.7^{a}	1.2^{a}	2.5^{a}	4.4^{a}	1.6^{a}	1.4^{a}
Aerial Parts	7.2^{a}	12.2^{a}	9.1^{a}	10.5^{a}	6.5^{a}	7.8^{a}	11.4^{a}	8.7^{a}
Roots	1.9^{a}	2.7^{a}	2.0^{a}	1.9^{a}	1.5^{a}	1.8^{a}	2.3^{a}	1.8^{a}
DM V / DM F	8.9^{a}	**3.8^{bc}**	**4.1^{b}**	10.5^{a}	3.2^{bc}	2.2^{c}	**8.4^{a}**	**7.7^{a}**

study:

- Their sensitivity is conditioned by that of the rootstock,
- The scion (variety) does not influence significantly the degree of sensitivity of the rootstock,
- Grafting, whatever the degree of sensitivity of the rootstock to the parasite, induced a deceleration of the development of the fixed broomrapes (percentage of emergences and total mass of broomrapes reduced).

In the case of a strong infestation of the grafted plant, because of a very sensitive rootstock (Integro or Maxifort), the trophic competition between the fixed broomrapes could partly explain the slowed down development of the broomrapes in post-fixing. Following the grafting, a modification of the relations source-well in favor of the scion (increased strength and/or productivity) contributes to it also certainly (show following chapter).

Concerning the influence of grafting on the sensitivity of the rootstock to the soil pathogens, it is interesting to discuss for example the work of Lopez-Pérez et al., (2006) on the resistance of grafted tomato to the nematodes. This work showed that the grafting of hypersensitive varieties to a resistant rootstock (Beaufort) led, under infestation, to a profit of fruits productivity (increased tolerance), with nevertheless the acquisition of a higher degree of sensitivity for the rootstock. The resistant rootstock thus allowed the production of tolerant grafted plants. Thus, these results differ as of ours in the sense that they attest of a significant influence of the graft on the degree of resistance (or sensitivity) of the rootstock to the nematodes. The work of Sigüenza et al., (2005) on the interest of the grafting of melon with an rootstock resistant to the nematodes led to the same observations.

Effect of grafting on the development and the productivity of tomato

Non-grafted and under infestation by the broomrape, the Petula and Durinta varieties present a similar number of leaves per plant as like as equivalent fresh masses of roots and aerial parts. On the other hand, they differ in term of productivity since the total fresh fruit mass per plant is twice higher for the Petula variety (Table 2). In addition, this variety presents a ratio of DM of vegetative parts / DM of fruits significantly weaker than that of Durinta (a factor of 3, Table 3). That represents at Petula an accentuated allowance of the DM in the fruits. This variety is thus more productive under infestation than Durinta, whereas Durinta is more productive than Petula in healthy conditions (Draie, 2009).

Under infestation by *P. ramosa* and whatever the rootstock, the grafting of the Durinta variety does not affect the total number of leaves and floral bouquets (20 leaves and 2 floral bouquets on average per plant) (Fig. 2). In the same way, the grafting with Integro does not influence the other indicators of the vegetative development and productivity.

In contrary, the grafted plants with the two other rootstocks (Maxifort and especially Eldorado) present an increase in all indices of productivity, and this of a factor 3 to 4 according to rootstocks (Fig. 3). In addition, the statistical analysis validates the profit of productivity (MF-F/10) for the plants Durinta/Eldorado (ANOVA, SNK, P≤0.05, n=10). The results also tend to show that the Durinta/Eldorado plants are more vigorous under infestation, following a profit of fresh weight of the roots and aerial parts. Nevertheless, the statistical analysis does not validate this benefit (ANOVA, SNK, P≤0.05, n=10).

Consequently, the grafted plants Durinta/Eldorado and Durinta/Maxifort are characterized by a ratio DM of vegetative parts/DM of fruits significantly smaller than that of non-grafted Durinta plants, which testifies to a modification by the grafting of the allowance of the DM in favor of the fruits.

The whole of the results shows that, only the grafting of Petula on the Eldorado rootstock impacts positively on the productivity under infestation by the branched broomrape, with a significant profit of the total mass fruits per plant (Fig. 4), (ANOVA, SNK, P≤0.05, n=10). The total number of bunches of fruits and fruits per plant also seems to be increased but these results are not validated statistically. In parallel, no combination of grafting seems to influence also clearly the fresh mass of the vegetative organs (roots and aerial parts).

The measurement of ratios DM of vegetative parts / DM of fruits underlines a better allowance of the DM in the fruits for the Petula/Eldorado plants in comparison with Petula/Maxifort and Petula/Integro (Table 3). On the other hand, the grafting of Petula on Maxifort and Integro significantly supports the allowance of the DM in the vegetative organs, as attests it the increase in a factor from 2 to 2.5 times of ratio DM vegetative parts / DM of

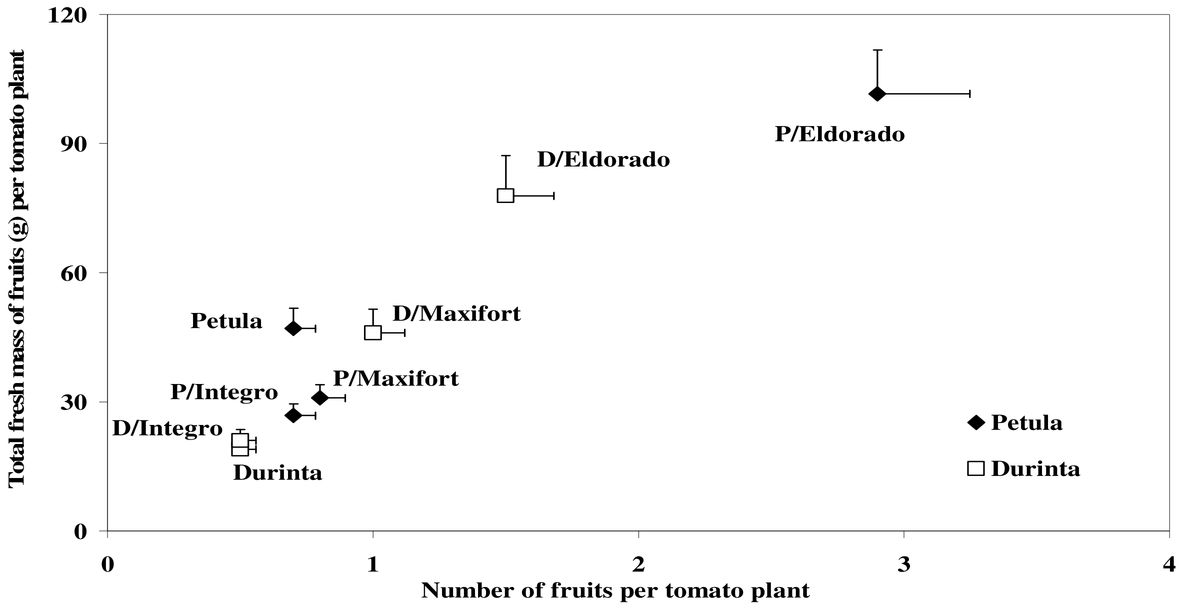

Fig. 3. Influence of the grafting on the fruit productivity of the varieties Durinta and Petula in condition of infestation by the branched broomrape. The data are the averages ± SE (n=10). D: Durinta; P: Petula. The rootstocks are Eldorado, Maxifort and Integro.

Table 4. Assessment of the effect of the grafting on the vegetative and productive development of the varieties grafted Durinta and Petula. The rootstocks are Eldorado, Maxifort and Integro. (-) effect tending to be negative; (.): no effect; (+): effect tending to be positive or significantly positive.

Combination	Vegetative Development	Productive Development
Durinta/Eldorado	+	+
Durinta/Maxifort	.	+
Durinta/Integro	.	.
Petula/Eldorado	.	+
Petula/Maxifort	+	-
Petula/Integro	+	-

fruits.

The Eldorado rootstock increases the production of fruits of the two varieties Durinta and Petula under infestation by the broomrape (Fig. 4, Table 4). Thus, for the Durinta variety, the Eldorado rootstock induces an increase in fruit yield (expressed in total fresh mass of fruit) of a factor of 4 compared to the non-grafted or grafted variety with Integro, and of 2 compared to the grafted variety with Maxifort ". The interest of the Maxifort rootstock is of this fact more moderated, and this more especially as it is without effect on the production of fruits of the Petula variety under infestation. Concerning the Integro rootstock, it led to no improvement of the productivity of the varieties Durinta and Petula under infestation. Knowing that Eldorado is initially less sensitive to the broomrape than the two other rootstocks (Draie, 2009), the interest under infestation of an rootstock tolerant to the broomrape is checked with Eldorado. This assertion is truer as the grafting does not modify the degree of sensitivity of the rootstock to the branched broomrape.

The interest of the grafting is generally observed under conditions of infestation by the pathogens, and not in healthy conditions (Kacjan-Marsic and Osvald, 2004; Khah et al., 2006). Some of our results are concordant with this assertion, others not. Thus, the Maxifort rootstock, without interest on the productivity of Durinta in conditions of non-infestation (Draie, 2009), brings a profit of productivity for this variety under infestation (Table 4). Conversely, the Maxifort rootstock is beneficial with the productivity of the Petula variety in conditions of non-infestation (Draie, 2009), but not under infestation by the broomrape (Table 4), and this without Petula impacting on the degree of sensitivity of the Maxifort rootstock to the branched broomrape. These results thus underline the influence of the scion on the interest of a rootstock in conditions of infestation. This influence is related most probably to the degree of tolerance of the

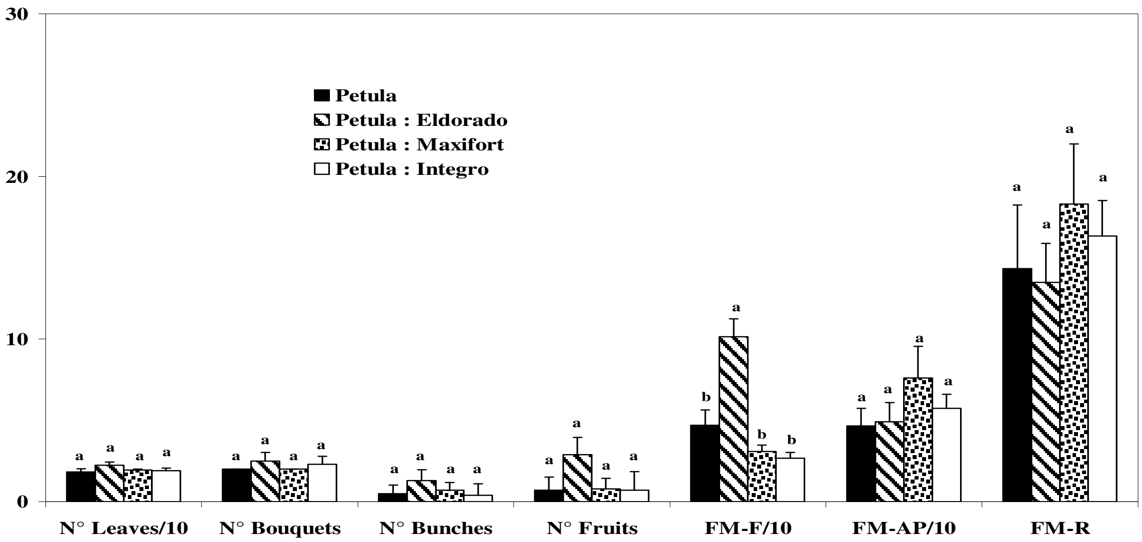

Fig. 4. Influence of the grafting of Petula tomato variety on different indicators of development and productivity under infestation by the branched broomrape. The data are the averages ± SE (n=10). For each parameter, the values carrying the same letter are not significantly different (ANOVA, SNK, P≤0.05, n=10). N° Feuilles/10: the tenth of the total number of leaves; FM-F/10: the tenth of the total fresh mass of the fruits (g); FM-AP/10: the tenth of the total fresh mass of the aerial parts (g); FM-R: fresh mass of the roots.

Table 5. Impact of the branched broomrape on the loss in DM of the varieties Durinta and Petula not grafted and grafted on various rootstocks (Eldorado, Maxifort and Integro). By line, the values carrying the same letter are not significantly different (ANOVA, SNK, P≤0.05, n=10). * Loss in DM of the fruits or the vegetative parts (g). ** Loss in DM of the fruits or the vegetative parts expressed in % of the loss in total DM.

		Durinta				Petula			
		Non-grafted	Eldorado	Maxifort	Integro	Non-grafted	Eldorado	Maxifort	Integro
Loss in dry mass (Tomato)	Total dry mass (g)	20.9^{a}	21.4^{a}	25.4^{a}	23.9^{a}	21.8^{a}	22.1^{a}	18.5^{a}	19.4^{a}
	Fruits (g) *	13.6^{a}	8.1^{b}	7.6^{b}	10.0^{ab}	7.3^{b}	8.7^{ab}	10.1^{ab}	8.0^{b}
	Fruits (%) **	65.3	37.9	30.1	41.7	33.4	39.2	54.7	41.2
	Vegetative parts (g) *	7.2^{b}	13.3^{ab}	17.7^{ab}	13.9^{ab}	14.6^{ab}	13.4^{ab}	8.4^{b}	11.4^{ab}
	Vegetative parts (%) **	34.7	62.1	69.9	58.3	66.6	60.8	45.3	58.8
Broomrape	Total dry mass (g)	5.3^{a}	2.1^{b}	2.5^{b}	2.6^{b}	3.5^{b}	2.2^{b}	2.7^{b}	1.8^{b}

scion to the broomrape which conditions its productivity under infestation (see following chapter). The possibility of an influence of the scion on the sensitivity of the rootstock to the broomrape (a number of broomrapes fixed per plant) must be also considered at this stage of the presentation of the results (see following chapter).

Effect of grafting on the tolerance degree of tomato to the branched broomrape

For the Durinta variety non-grafted, the parasitic attack very strongly affects the production of the fruits. Thus, the loss of DM of the fruits represents 65% of the total loss in DM of the plants (Table 5). The number and the total DM of the fruits are reduced of 96% and 93%, respectively (Table 6). Thus, Durinta is a variety sensitive and non-tolerant with the broomrape. The depressive effect of the parasite is less on the development of the vegetative organ of which the DM decreases by 44% under infestation (Table 5).

For the Petula variety non-grafted, the total loss of DM caused by the broomrape is equivalent to that observed on Durinta (Table 5). On the other hand, the distribution of the losses of DM between the vegetative organs and the fruits are reversed. Indeed, the parasitism mainly affects the development of the vegetative organs of the variety Petula, the loss of DM of these organs represents the 2/3 of the total loss of DM of the plants (Table 5). Nevertheless, the number and the total DM of the fruits are reduced of 86% and 74%, respectively (Table 6). Petula is thus a variety sensitive but more tolerant to the broomrape than Durinta. The productivity of Petula remains nevertheless very affected by the parasitism.

Whatever the rootstock, the impact of parasitism on the total loss of DM of the Durinta variety grafted is

Table 6. Percentage of reduction of the dry mass of the vegetative parts and the fruits of two tomato varieties (Durinta and Petula) non-grafted and grafted, in response to parasitism by the branched broomrape. The data correspond to the averages of 10 individuals per type of plant (n=10). The rootstocks are Eldorado, Maxifort and Petula.

% of reduction		Durinta				Petula			
		Non-grafted	Eldorado	Maxifort	Integro	Non-grafted	Eldorado	Maxifort	Integro
Vegetative parts	Total dry mass	44.2	47.1	61.4	52.7	64.4	58.3	37.9	52.1
Fruits	Number of fruits	96.4	83.0	91.3	95.1	86.0	77.0	88.9	89.2
	Total dry mass	93.0	67.1	73.8	89.4	74.2	66.4	86.1	85.4

equivalent to that observed on the non-grafted variety (Table 5). Nevertheless, the loss of DM mainly touches the vegetative organs of the grafted plants (60-70% of the total losses, Table 5). Thus, the grafting reduces the loss of DM of the fruits caused by the broomrape, which does not represent 30-40% of the total loss in DM. For the Durinta/Eldorado plants, that is accompanied even by a reduction of the loss in a number of fruits (Table 6). The whole of these results shows that the grafting accentuates the degree of tolerance of the Durinta variety to the broomrape, and this with the detriment of the development of the vegetative organs.

As for the Durinta variety, the grafting does not modify the total loss of DM caused by the broomrape on the Petula variety (Table 5). On the other hand, the effect of the graft on the degree of tolerance of the Petula variety is not clear as that observed for the Durinta variety. Indeed, this effect differs according to rootstock. It is as well as possible null for the graft on Eldorado and Integro, the distribution of the losses of DM due to parasitism between the vegetative organs (approximately 60%) and the fruits (approximately 40%) being similar to that observed for the non-grafted plants of Petula. It is negative for the graft on Maxifort since the losses of DM of the fruits caused by the broomrape on the Petula/Maxifort plants are higher than those recorded on the non-grafted variety (Table 5).

It is also interesting to note that under infestation, the total losses of DM observed for the two varieties are four to six times higher than the total DM of the fixed broomrapes. The loss in DM of the tomato plants is thus not explained primarily by a "loss to earn" for the plant host which causes the skirting of DM by the broomrape, but especially by the depressive effect of parasitism on the photosynthetic capacity of the tomato plants (Mauromicale et al., 2008).

CONCLUSION

The tomato grafted with a rootstock sensitive to the broomrape proved to be a complex physiological model to study in conditions of infestation. In this system, the broomrapes act like competitor wells with the proper wells of the tomato (vegetative organs in growth, fruits) and thus influence the regulation of the relations source-well of the grafted plant. For the rootstocks and the varieties tested, this study has nevertheless to show that:

- The grafting can modify the degree of tolerance of the variety to the broomrape. It can thus increase it (example/Durinta), and what the rootstock is sensitive (Eldorado) or definitely more sensitive (Maxifort) than non-grafted variety (sensitivity / number of attachments per plant). This beneficial effect can be explained by the fact why the grafting, whatever the rootstock used, limits the development of the fixed broomrapes. Those thus constitute a gravitational well for the photoassimilats of the grafted plant. Consequently, the grafting allowed for Durinta a modification of the relations source-well in favor of the production of fruits. Non-grafted, the Durinta variety is on the contrary very favorable to the development of the broomrapes (strong percentage of emergences and high fresh mass of the broomrapes). The broomrapes thus modified the relations source-well of Durinta non-grafted with their profit and with depend on the production of fruits. The tolerance with the broomrape of Durinta non-grafted is indeed quasi-null.
- The variety does not modify the degree of sensitivity of the rootstock. Thus, the sensitivity of the plant grafted to the branched broomrape is conditioned by that of the rootstock. For this reason, it is regrettable to have not identified a resistant rootstock in order to know if this resistance were maintained at the grafted tomato. Nevertheless, these results make possible the interest of rootstocks little sensitive, even resistant (if available) to the broomrape for the production of tomato in the infested areas.

To control the parasites of the soil, the grafting of tomato represents an obligatory overcost which is deadened by the profit of productivity (Vitre, 2002). The use of grafted plants represents a overcost of 1€ approximately per m². This overcost is to be compared with the cost of the disinfection of soil which can reach 0.8€ per m². Moreover, many producers benefit from the strength of the grafted plants to direct them on two stems. Thus, the density of plantation is reduced by half, while preserving at least the same yield (Vitre, 2002; Besri, 2003). Report of the two heads, the purchase of the grafted plants is less expensive approximately 0.3 € per m² (Vitre, 2002). Lastly, more vigorous, the grafted plants can be mended at a stage more advanced than non-grafted tomatoes, from where earlier cultures with one duration of longer production (Espuna, 2000; Besri, 2003).

Because of absence of rootstocks resistant to the branched broomrape, the producers and the selectors did not evaluate to date the profitability of the grafting of tomato in the crop protection against the broomrape. The urgency is above all to intensify the search for sources of resistance, in particular among the wild accessions.

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