

Global Advanced Research Journal of Agricultural Science (ISSN: 2315-5094) Vol. 6(6) pp. 160-169, June, 2017 Issue. Available online http://garj.org/garjas/home Copyright © 2017 Global Advanced Research Journals

Full Length Research Paper

Effect of grafting on tomato development and productivity in greenhouse conditions

Rida Draie^{ab}

^a Faculty of Agriculture, Idleb University, Syria ^b Research work carried out at Laboratoire de Biologie et PathologieVégétales(LBPV), Nantes, France. Email: ridadraie@hotmail.com

Accepted 24 June, 2017

The effect of grafting on tomato development and productivity was studied in greenhouse conditions in Laboratory of Vegetable Biology and Pathology. Durinta and Petula varieties used as scions and grafted, by tube grafting method, on Eldorado, Maxifort and Integro, which used as rootstocks. Controls non-grafted were used in parallel. Four months after the culture, vegetative and productive parameters were measured on each cultivated tomato plant. Thus, the total number of leaves, floral bouquets, fruit bunches and fruits were determined. Moreover, the fresh and dry biomass of the fruits and the vegetative parts (g plant⁻¹) were measured. A positive effect on vegetative development and a positive effect on productivity were observed when "Durinta" and "Petula" were grafted successively. The Eldorado rootstock gave the better results with the two scions. Grafting is therefore considered an important technique for tomato production when the choice of rootstock and scion is perfectly precise.

Keywords: Grafting, Tomato, Development, Productivity, Greenhouse

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is the third vegetable at the world level with a representation of 7% of the total vegetable production, behind potato and sweet potato (29% and 14%) respectively. It is cultivated on surface approximately 5 million hectares with an annual production of 170 million tons and an output of 34 tons ha⁻¹. China is the first tomato producer country; it produces 52 million tons on a surface of 1 million hectares. France occupies a minor place among the tomato producer countries, but with the highest output of production between the producer countries, about 199 tons ha⁻¹, (FAO, 2014). The tomato culture strongly intensified these last years, passing from 76,5 million tons produced on 2,9 million hectares of surface cultivated in 1990 to 170 million tons produced on 5 million hectares in 2014, which explains a factor of production increase about a 200%, with an output relatively stable, according to FAO (2014).

The tomatoes are at the head of vegetables list with regard to their content of vitamin C. The coloring of the tomato fruit is due to pigments in particular carotene (vitamin A precursor), lycopene and xanthophylls. It decreases hypertension gratitude to its potassium contents (Ringer and Bartlett, 2007; Anderson et al., 2008). Tomato is excellent for the liver (Launay, 2007), and to protect the skin against the sunstrokes and the acne and the insect bites (Di Mascio et al., 1989). Lycopene acts positively in the digestive system, the prostate, the lungs, the uterus and the ovaries (Giovannucci et al., 1995; Gann et al., 1999;

Bowen et al., 2002). This antioxidant is effective for the cardiovascular diseases (Omenn et al., 1996), the atherosclerosis and blindness (Bernier and Lavoie, 2001a, 2001b). Moreover, diuretic, the tomato helps to eliminate toxins produced by the thinners modes (Livernais-Saettel, 2000).

Currently, the vegetables culture is very intensive and continuous cropping is in common practice, vegetable grafting is an innovative technique with an increasing demand by farmers. Grafting consists of association between two fragments of plants: a rootstock and a scion. By its root system, the rootstock provides the necessary food to the growth and engenders an additional strength to the new plant. The scion corresponds to the aerial part of the new plant, it will bring the productive characters preferred (Zijlstra et al., 1994).

Vegetables grafting started for the first time in Japan and in Korea in the 1920s, when the water melon was grafted on a marrow rootstock (Rivero et al., 2003). The eggplant was grafted on scarlet eggplant in 1950s. Since, the culture of grafted plant increased considerably and the graft became an essential technique for the production of vegetables in Korea, Japan and some Asian and European countries, where the use of the ground is very intensive (Lee, 1994; Oda, 1995).

In 1998, 540 million and 750 millions plants grafted were produced in Korea and Japan respectively (either 81% and 54% of the total vegetable cultures) (Lee et al., 1998; Lee, 2003). This technique was adopted in the Mediterranean area when the grafting was proposed as like as an alternative to the applications of methyl bromide to control the soil-borne diseases and to increase the productivity of cultures (loannou, 2001; Rouphael et al. 2010). The number of grafted tomato plant in Spain increased from less than one million in 2000 to more than 45 millions in 2004 (Besri, 2005). The grafting of vegetables (especially the tomato) is also important in France and Italy. In Greece, the ratio of surface of production using the grafted plant on all the surface of production amounts to 90-100% for the early culture of water melon, 40-50% for melons under tunnels, 2-3% for tomato and eggplant, and 5-10% for cucumbers (Traka-Mavrona et al., 2000). In Morocco, the grafted tomato is cultivated on 25% of surface of production to control the soil-borne diseases and to prolong the duration of the harvest season (Besri, 2003; Besri, 2005). In United States, the grafting is a major base of agricultural practices because of the advantages which it brings, of which resistance to the root diseases, improvement of the productivity of the cultures and for its requirement for the biological and durable production of tomato (Rivard, 2006).

The first advantage of a rootstock is to present an excellent root system which brings a surplus of strength to the grafted plant, therefore a better output on a duration of longer production (Ruiz et al., 1997; Vitre, 2002; Stäubli, 2005). Thus, an increase of strength and output, expressed

by a number and a size of fruits higher compared to the not-grafted plant, were observed at water melon (Ruiz and Romero, 1999; Yetisir and Sari, 2003), cucumber (Pavlou et al., 2002), eggplant (Ibrahim et al., 2001; Rahman et al., 2002; Passam et al., 2005) and tomato (Upstone, 1968; Augustin et al., 2002; Pogonyi et al., 2005; Rivard, 2006). Moreover, at melon, the quality of the fruits, as indicated by the fruits firmness, can be improved considerably by the grafting (Roberts et al., 2005).

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; Borgognone et al., 2013, Ntatsi et al., 2014; Savvas 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.

Since the soil sterilization cannot ever be complete, grafting became an essential technique for the production of vegetables repeated cultures and the effective manage of a large specter of pathogens (Kyriacou et al., 2017). Thus, the grafting is an excellent solution to control verticillium wilt caused by Verticillium dahliae (Oda, 1999; Ioannou, 2001; Vitre, 2002; Bletsos, 2005; Rivard, 2006), wilt fusarium caused by Fusarium oxysporum f.sp.lycopersici and root and stem rot caused by F.oxysporum f. sp. Radicis-lycopersici (Pavlou et al., 2002; Rivard, 2006), root rot caused by Phytophthora cryptogea (Upstone, 1968), corky root rot caused by Pyrenochaeta lycopersici (Bradley, 1968; Ioannou, 2001; Stäubli, 2005), root-knot nematodes caused by Meloidogyne ssp. (Besri, 2001; Rahman et al., 2002; Giannakou and Karpouzas, 2003; Abdelhag, 2004; Lopez-Péreza et al., 2006), bacterial wilt caused by Ralstonia solanacearum (Tikoo et al., 1979; Peregrine and Binahmad, 1982; Matsuzoe et al., 1993; Grimault and Prior, 1994; Tresky and Walz, 1997) and Tomato Yellow Leaf Curl Virus (Rivero et al., 2003).

This work will lead to an analysis of the impact of the grafting on the strength and the productivity of tomato in greenhouse conditions.

MATERIALS AND METHODS

Vegetable material and grafting conditions

Three rootstocks (Eldorado, Integro and Maxifort) (Table 1) were grafted on two varieties of tomato (Durinta and Petula) by the Brilland company (Saint Sébastien sur Loire). 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 seedlings develop in greenhouse (temperature 25°C the day and 20°C the night, hygrometry 60%, lighting 800 watts m²). The sorting of the rootstocks and the scions on their strength is made one

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 (typical growth)
Durinta	Western Seeds	S. lycopersicum × S. lycopersicum	HR : TMV, Fol, V (vigorous growth)

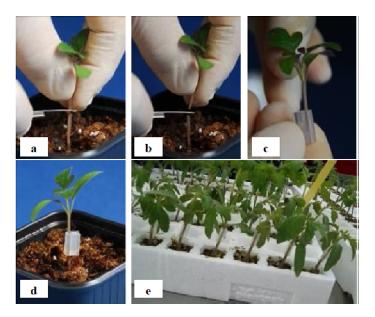


Figure 1. Different stages of grafting.

a- cut of the rootstock under the cotyledons, b- cut of scion above of the cotyledons by leaving at least a well development leaf; c- fixing of the scion in the clip of grafting; d- linking of scion and rootstock by the clip of grafting; e- seedlings of grafted tomato.

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 rootstocks is cut below the first pair of leaves (cotyledons) (Figure. 1-a). The scion is cut above the top of cotyledons by leaving at least a well-developed leaf, (Figure. 1-b&c). Once the cut rootstock and scion, they are linked by a plastic clip of grafting (Figure. 1-d) (Oda, 1995). The grafted seedlings are maintained in 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°C the night and 22-25°C the day. From the eighth day, the success of the grafting is generally ensured 100% (Figure. 1-e). The grafted seedlings are transferred in the greenhouse (temperature 20°C the night and 25°C the day, hygrometry 60%, lighting 800 watts m²). After one week from acclimatization, the seedlings are mended in larger containers (pot of 3L) containing a mixture sand-soilcompost (1:1:1). Ten pots are prepared for each association rootstock-scion tested (n=10).

Control and maintenance of the tomato cultures

The grafted tomato seedlings (Figure 2-a) are regularly fed by a nutritional solution composed of 50% of solution of Coïc (Coïc and Lesaint, 1975). The tomato seedlings are addressed and propped with polypropylene string by a metal hook (Figure 2-b1&2), 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 (Figure 2-c1). The clips are well closed by wedging the wire in the clip brake 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



Figure 2. Staking of the tomato plants.

a- sight general of propped tomato plant. b- metallic hook rolled progressively with polypropylene string (b1) hook fixed at the roof of greenhouse (b2) free edge of string attached on the basis of tomato stem. c- clip used for fixing of the stem of the tomato plant on the string (c1), reinforcement of bouquet stem of half moon (c2).

only one stem. Bouquets supports (Figure 2-c2) 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 bouquet support is posed on the bunch of flowers, between the stages 2^e open flower and 4^e 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, 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 stages (green, orange, ripe) are collected. To determine the impact of the grafting on the productivity of the studied varieties, the total number and mass (wet and dry) of the fruits collected by 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).

In parallel, the impact of the grafting on the development of the tomato seedlings is estimated following the measurement of the biomasses fresh and dry of the roots and the vegetative aerial parts of the grafted 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 biomasses are measured after drying of the vegetative parts and the fruits of the different tomato plants with 80°C during 72 hours (El-Halmouch, 2004; Khah, 2005; Peres et al., 2005; Abbes, 2007).

Statistical processing of results

The statistical analyses are carried out by using the software Sigma Stat version 3.5. The comparisons of average are based on the test of Student Newman Keuls (ANOVA, SNK, $P \le 0.05$, n=10).

RESULTS

The grafting was carried out by the means of a service near the Brilland Company. The availability of certified seeds and the known advantages of the selected genotypes (Table 1) were thus the major arguments in the choice of the rootstocks (Eldorado, Integro and Maxifort) and of the varieties to be grafted (Durinta and Petula). The biometric analysis of the grafted and not grafted plants was carried out after 4 months of culture and before harvest. The measured parameters are the total number of: leaves,

Variety	N° leaves	N° Bouquets floral	N° Bunches	N° Fruits	FM-F	FM-AP	FM-R
Durinta	24,0 ^a	5,9 ^a	3,9 ^a	13,9 ^ª	245,6 ^ª	78,3 ^a	17,6 ^a
Petula	23,0 ^a	5,7 ^a	2,4 ^a	5,0 ^b	163,4 ^b	105,3 ^a	24,3 ^a

Table 2. Comparison of development and productivity index of two non-grafted tomato varieties "Durinta et Petula" in healthy conditions.

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 fruits (g); FM-AP: total fresh mass of aerial parts (g); FM-R: total fresh mass of roots.

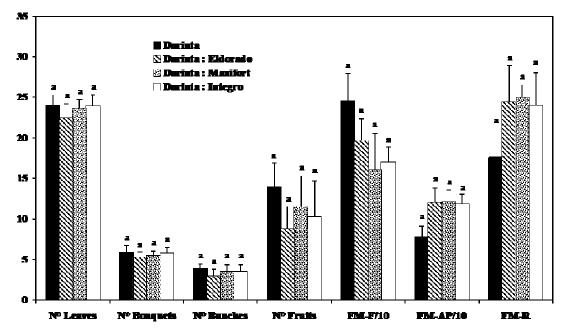


Figure 3. Influence of grafting of the tomato variety "Durinta" on different index of development and productivity in healthy conditions. The data are the averages \pm SE (n=10). For each parameter, the values carrying the same letter are not significantly different (ANOVA, SNK, P≤0.05, n=10). FM-F/10: the tenth of the total fresh mass of the fruits (g); FM-AP/10: the tenth of the total fresh mass of the vegetative aerial parts (g); FM-R: fresh mass of the roots.

floral bouquets, fruit-bearing bunches and fruits per plant. All fruits (at all stages: green, orange and ripe) were collected and their total mass (wet and dry) was measured per plant. It is the same for the wet and dry masses for the roots and the vegetative aerial parts.

Characterization of Durinta and Petula varieties (not grafted)

Not grafted, the tomato varieties Petula and Durinta show different characteristics of vegetative growth and productivity (Table 2). Indeed, the Durinta variety has at the same time a total number and a total wet mass of fruit per plant significantly higher than the Petula variety. On the other hand, the results tend to show that the vegetative organs (roots and aerial parts) of the Petula variety are more developed than those of Durinta, no significant differences nevertheless, (ANOVA, SNK, P≤0.05, n=10).

Effect of grafting on the Durinta variety

Whatever the rootstock, the grafting of the Durinta variety does not induce any modification of leaves number, floral bouquets and bunches of fruits (Figure. 3). It even tends to reduce the productivity in term not only of a number of fruits per plant (14 fruits for not grafted Durinta; 9 fruits for Durinta/Eldorado; 12 fruits for Durinta/Maxifort and 10 fruits for Durinta/Integro), but also of total wet mass of fruits (246g for not grafted Durinta; 196g for Durinta/Eldorado; 161g for Durinta/Maxifort and 170g for Durinta/Integro) (Figure. 3). In parallel, the grafting tends to support the development of the vegetative organs, with in particular an increase in the wet mass of the aerial parts (78g for not grafted Durinta and 121g for grafted Durinta). It must be specified that these differences are not significant with the test of variances (ANOVA, SNK, P≤0.05, n=10). Nevertheless, it arises from the whole of these results that

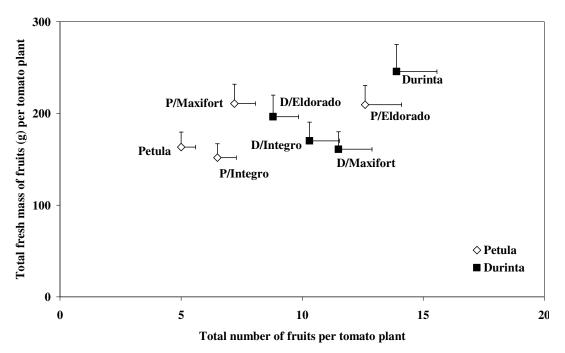


Figure 4. Influence of grafting on the fruit productivity of Durinta and Petula varieties in healthy conditions. The data are the averages ± SE (n=10). D: Durinta; P: Petula. The rootstocks are Eldorado, Integro and Maxifort.

			1 1 I.I. I.I.
Table 3. Impact of grafting or	n the development and the pr	oductivity of Durinta and Petul	a varieties in healthy conditions.

Des Maaa	Durinta				Petula			
Dry Mass	Non grafted	Eldorado	Maxifort	Integro	Non grafted	Eldorado	Maxifort	Integro
Fruits	14,7 ^a	12,1 ^a	10,3 ^a	11,1 ^a	9,8 ^a	13,1 ^a	11,7 ^a	9,3 ^a
Aerial Parts	14,5 ^a	24,1 ^a	25,2 ^a	23,3 ^a	19,8 ^a	19,9 ^a	18,3 ^a	18,7 ^a
Roots	1,9 ^a	4,1 ^a	3,7 ^a	3,1 ^a	2,8 ^a	3,1 ^a	3,8 ^a	3,2 ^a
DM V / DM F	1,1 ^b	2,3 ^a	2,8 ^a	2,4 ^a	2,3 ^a	1,8 ^{ab}	1,9 ^{ab}	2,4 ^a

The data are the averages of 10 repetitions per plant (n=10). V: vegetative organs (roots and aerial parts); F: Fruits; DM: dry mass. The rootstocks are Eldorado, Maxifort and Integro. For each organ, the values carrying the same letter are not significantly different (ANOVA, SNK, P \leq 0.05, n=10).

the grafting of the Durinta variety does not bring a benefit in productivity in healthy conditions (Figure 4). On the other hand, the grafting of Durinta induces a significant increase in a factor two of ratio DM of vegetative parts / DM of fruits (Table 3), and thus tends to increase the strength of the tomato plants.

Effect of grafting on the Petula variety

Contrary to the Durinta variety, the grafting of the Petula variety does not influence the development of the vegetative organs, the number of leaves and the mass of the aerial parts being similar for the grafted and not grafted plants (Figure 5). On the other hand, the grafting with the Eldorado rootstocks and Maxifort seems to have a

beneficial effect on the production of fruits. Thus, for the Petula/Eldorado plants, the grafting tends to increase at the same time the number of fruits (13 fruits instead of 5 for not grafted Petula) and the total mass of the fruits (221g DM instead of 160g DM) (Figure 5). Only the total mass of the fruits seems to be increased for the Petula/Maxifort plants. On the other hand, the grafted plants Petula/Integro are as productive as the not grafted plants of Petula. Although the observed differences are not validated statistically by the test used (ANOVA, SNK, P≤0,05, n=10), the results tend to show that the grafting of the Petula variety on the rootstocks Eldorado and Maxifort improves the productivity of Petula in healthy conditions. Thus, the grafting of the Petula variety with the Eldorado rootstock raises the productivity of Petula on a level close to that of

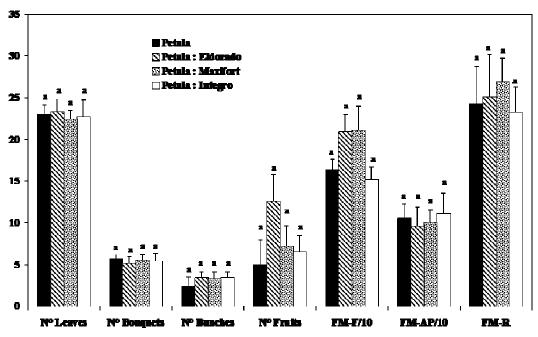


Figure 5. Influence of grafting of the variety of tomato "Petula" on different index of development and productivity in healthy conditions. The data are the averages \pm SE (n=10). For each parameter, the values carrying the same letter are not significantly different (ANOVA, SNK, P≤0.05, n=10). FM-F/10: 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 4. Evaluation of the effect of grafting on the vegetative and productive development of the grafted varieties "Durinta and Petula".

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

The rootstocks are Eldorado, Maxifort and Integro. (-) effect tending to be negative; (.): no effect; (+): effect tending to be positive or significantly positive

Durinta not grafted (Figure. 5). In the same way, the grafting of Petula with the Eldorado and Maxifort rootstocks thus tend to reduce the ratio DM of vegetative parts / DM of fruits, and this with a similar value of that of Durinta (Table 3). For this reason, our results for Petula/Eldorado and Petula/Maxifort join those of Lee (1994) and Oda (1995) which also showed a profit of productivity for these grafted plants.

DISCUSSION AND CONCLUSIONS

In healthy condition, six combinations scion/rootstock of twelve tested are beneficial on strength (3 Durinta) or the productivity (2 Petula), (Table 4). The Eldorado rootstock increases the vegetative development of the Durinta variety and the production of fruits of the Petula variety. In the same way, the Maxifort rootstock increases the vegetative development of the two varieties and the production of fruits of the Petula variety only. Whereas the Integro rootstock influences positively only the vegetative development of the Durinta variety and do not influence on the Petula variety. Thus, the grafting of the Durinta variety had a positive effect on the vegetative development and a negative effect on the production of fruits some is the rootstock used. Whereas, the grafting of the Petula variety offered a positive effect with the two rootstocks (Eldorado and Maxifort) and do not give any change with the Integro rootstock.

The grafting of tomatoes on vigorous rootstocks made it possible to improve considerably the yield (Augustin et al., 2002; Pogonyi et al., 2005). The profit of productivity is

very frequently explained by the advantage brought by the rootstock on the absorption and the mineral nutrition of the grafted plants. Thus, the absorption of phosphorus, calcium and sulphate is increased at grafted melon (Ruiz et al., 1996) and eggplant and tomato grafted plant (Leonardi and Giuffrida, 2006). The absorption of iron as well as the translocation of this element towards the aerial parts of grafted tomato (Rivero et al., 2004) and nitrogen assimilation of grafted melon (Ruiz and Romero, 1999) are also supported. Photosynthetic rates (Matsuzoe et al., 1993a; Matsuzoe et al., 1993b), stomata conductance (Fernandez-Garcia et al., 2002), and endogenous hormones synthesis (Proebsting et al., 1992) higher were proven at the grafted plants. Research showed that the increase in yield is probably due to the strength brought by the rootstock which significantly improves the vegetative growth of the grafted plant and reinforces consequently the rate of water and nutritive elements absorption at the vigorous rootstocks having a very developed root system (Romero et al., 1997; Cohen and Naor, 2002).

It should be known that the interest of grafting is generally observed under infestation conditions by telluric pathogens such as verticillium wilt (Rivard, 2006), fusarium wilt and root and stem rot (Pavlou et al., 2002), Root rot (Upstone, 1968), corky root rot (Stäubli, 2005), root-knot nematodes (Lopez-Pérez et al., 2006), bacterial wilt (Tresky and Walz, 1997), Tomato Yellow Leaf Curl Virus (Rivero et al., 2003), or by abiotic stress such as salinity (Colla et al., 2006), soil excessive moisture (Black et al., 2003), high (Abdelmageed et al., 2004) and low (Zijlstra et al., 1994) temperatures.

Whereas in healthy conditions, the grafting did not give promising results (Kacjan-Marsic and Osvald, 2004; Khah et al., 2006). Some of our results are concordant with this assertion (case of Petula variety), others not (case of Durinta variety). In consequence, the effect of grafting in healthy conditions depends of rootstock and grafted variety.

ACKNOWLEDGEMENTS

The author thanks Prof. Philippe SIMIER and Dr. SéverineTHOIRON for guiding the research and allowing it to be conducted in the LBPV laboratory; the Rootstocks Furnishers Societies (De Ruiter seeds, Enzazaden Gautier, and Vilmorin); Brilland Company for the grafting realization; MrLequileuc for his advices and Dominique Bozec and Johanes Schmidt for technical assistance.

REFERENCES

Abbes Z (2007). Estimation de la sensibilité et de la tolérance de différents génotypes de féverole (Vicia faba L.) à la plante parasite Orobanche foetida Poiret. Impact du génotype hôte sur les particularités physiologiques et métaboliques du parasite. Thèse de Doctorat Université de Nantes: 155p

- Abdelhaq H (2004). Integrated production and protection in greenhouse crops. Institut Agronomique et Vétérinaire Hassan II: 95-106
- Abdelmageed AHA, Gruda N, Geyer B (2004). Effects of Temperature and Grafting on the Growth and Development of Tomato Plants under Controlled Conditions. Rural Poverty Reduction through Research for Development and Transformation. Deutscher Tropentag 2004: 3p
- Anderson J, Young L, Long E (2008). Potassium and Health. Food and Nutrition Series. Colorado State University 9355: 1-4
- Augustin B, Graf V, Laun N (2002). Temperature influencing efficiency of grafted tomato cultivars against root-knot nematode (Meloidogyne arenaria) and corky root (Pyrenochaeta lycopersici). Zeitschrift Fur Pflanzenkrankheiten Und Pflanzenschutz. Journal of Plant Diseases and Protection 109: 371-383
- Bernier V, Lavoie D (2001a). Le Lycopène : Un Antioxydant Très Puissant, Première Partie. Le Clinicien, Consultations en Nutrition 15 (11): 49-56
- Bernier V, Lavoie D (2001b). Le Lycopène : Un Antioxydant Très Puissant, Deuxième Partie. Le Clinicien, Consultations en Nutrition 16 (12): 53-60
- Besri M (2001). New developments of alternatives to methyl bromide for the control of tomato soilborne pathogens in covered cultivation in a developing country, Morocco. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. San Diego, California: 9.1-9.3
- Besri M (2003). Tomato grafting as an alternative to Methyl Bromide in Morocco. Proceedings of the international research conference on methyl bromide alternatives and emissions reductions. San Diego California: 12
- Besri M (2005). Current situation of tomato grafting as alternative to methyl bromide for tomato production in the Mediterranean region. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions at San Diego, California USA
- Black LL, Wu DL, Wang JF, Kalb T, Abbass D, Chen JH (2003). Grafting tomatoes for production in the hot-wet season. Asian Vegetable Research & Development Center
- Bletsos FA (2005). Use of grafting and calcium cyanamide as alternatives to methyl bromide soil fumigation and their effects on growth, yield, quality and fusarium wilt control in melon. Journal of Phytopathology 153: 155-161
- Borgognone, D., Colla, G., Rouphael, Y., Cardarelli, M., Rea, E., Schwarz, D. (2013). Effect of nitrogen form and nutrient solution pH on growth and mineral composition of self-grafted and grafted tomatoes. Sci. Hortic. 149: 61–69.
- Bowen P, Chen L, Stacewicz-Sapuntzakis M, Duncan C, Sharifi R, Ghosh L, Kim H, Christov-Tzelkov K, Van Breemen R (2002). Tomato Sauce Supplementation and Prostate Cancer: Lycopene Accumulation and Modulation of Biomarkers of Carcinogenesis. Society for Experimental Biology and Medicine 227(10): 886-893
- Bradley JA (1968). Tomato grafting to control root diseases. New Zealand Journal of Agriculture: 116:126
- Bulder HAM, Den Nijs APM, Speek EJ, Van Hasselt PR, Kuiper PJC (1991). The effect of low root temperature on growth and lipidcomposition of lowtemperature tolerant rootstock genotypes for cucumber. Journal of Plant Physiology 138: 661-666
- Cohen S, Naor A (2002). The effect of three rootstocks on water use, canopy conductance and hydraulic parameters of apple trees and predicting canopy from hydraulic conductance. Plant, Cell and Environment 25: 17-28
- Coïc Y, Lesaint C (1975). La nutrition minérale et en eau des plantes en horticulture avancée. Le Document Technique de la SCPA 23: 1-22
- Colla G, Rouphael Y, Cardarelli M, Rea E (2006). Effect of salinity on yield, fruit quality, leaf gas exchange, and mineral composition of grafted watermelon plants. HortScience 41: 622–627
- Di Mascio P, Kaiser S, Sies H (1989). Lycopene as the most efficient biological carotenoid singlet oxygen quencher. Arch Biochem Biophys 274: 532–538
- Edelstein M, Cohen R, Burger Y, Shriber SR, Pivonia S, Shtienberg D (1999) Integrated management of sudden wilt in melons, caused by Monosporascus cannonballus, using grafting and reduced rates of methyl bromide. Plant Disease 83: 1142-1145

- El-Halmouch YH (2004). Recherche de mécanismes de résistance à l'*Orobanche* chez des génotypes de tomate ; Aspects histologiques, physiologiques, moléculaires et génétiques Thèse de Doctorat Université de Nantes: 328
- Estan MT, Martinez-Rodriguez MM, Perez-Alfocea F, Flowers TJ, Bolarin MC (2005). Grafting raises the salt tolerance of tomato through limiting the transport of sodium and chloride to the shoot. Journal of Experimental Botany 56: 703-712
- FAO (2014). Food and Agriculture Organisation of the United Nations. http://faostat.fao.org/ FAOSTAT: 2014
- Fernandez-Garcia N, Martinez V, Cerda A, Carvajal M (2002). Water and nutrient uptake of grafted tomato plants grown under saline conditions. Journal of Plant Physiology 159: 899-905
- Fernandez-Garcia N, Martínez V, Cerda A, Carvajal M (2004b). Fruit quality of grafted tomato plants grown under saline conditions. Journal of Horticultural Science & Biotechnology 79: 995-1001
- Ferrère P, Daraux J, Lherbier P, Terrien JP (1997). Tomate de serre, entretien des culture et récolte. Formation des chefs d'équipe et des saisonniers. OFFSET, Fafsea, fnpl, Fasti Ctifl: 28p
- Gann PH, Ma J, Giovannucci E, Willet W, Sacks FM, Hennekens CH, Stampfer MJ (1999). Lower prostate cancer risk in men with elevated plasma lycopene levels: results of a prospective analysis. J Cancer Res 59: 1225–1230
- Giannakou I, Karpouzas D (2003). Evaluation of chemical and integrated strategies as alternatives to methyl bromide for the control of root-knot nematodes in Greece. Pest Management Science 59: 883-892
- Giovannucci E, Ascherio A, Rimm EB, Stampher MJ, Colditz GA, Willett WC (1995). Intake of carotenoids and retinol in the relation to risk of prostate cancer. J Natl Cancer Inst 87: 1767–1776
- Grimault V, Prior P (1994) Grafting tomato cultivars resistant of and susceptible to bacterial wilt–Analysis of resistance mechanisms. Journal of Phytopathology-Phytopathologische Zeitschrift 141: 330-334
- Holbrook NM, Shashidhar VR, James RA, Munns R (2002). Stomatal control in tomato with ABA-deficient roots: response of grafted plants to soil drying. J Exp Bot 53: 1503-1514
- Horváth Í, Vigh L, Van Hasselt PR, Woltjes J, Kuiper PJC (1983). Lipid composition in leaves of cucumber genotypes as affected by different temperature regimes and grafting. Physiologia Plantarum 57: 532-536
- Ibrahim M, Munira MK, Kabir MS, Islam AKMS, Miah MMU (2001). Seed Germination and Graft Compatibility of Wild Solanum as Rootstock of Tomato. Journal of Biological Sciences 1: 701-703
- loannou N (2001). Integrating soil solarization with grafting on resistant rootstocks for management of soil-borne pathogens of eggplant. Journal of Horticultural Science & Biotechnology 76: 396-401
- Kacjan-Marsic N, Osvald J (2004). The influence of grafting on yield of two tomato cultivars (Lycopersicon esculentum Mill.) grown in a plastic house. Acta Agriculturae Slovenica 83(2): 243-249
- Khah EM (2005). Effect of grafting on growth, performance and yield of aubergine (*Solanum melongena* L) in the field and greenhouse. Journal of Food, Agriculture & Environment 3(3&4): 92-94
- Khah EM, Kakava E, Mavromatis A, Chachalis D, Goulas C (2006). Effect of grafting on growth and yield of tomato (*Lycopersicon esculentum* Mill.) in greenhouse and open-field. Journal of Applied Horticulture 8(1): 3-7
- Kyriacou MC, Rouphael Y, Colla G, Zrenner R, Schwarz D, (2017). Vegetable Grafting: The Implications of a Growing Agronomic Imperative for Vegetable Fruit Quality and Nutritive Value. Frontiers in Plant Science 8(741): 1-23.
- Launay M (2007). La Tomate dans Tout ses Etats. Bulletin de Caramel 34 Lee JM (1994) Cultivation of grafted vegetables. 1. Current status,
- grafting methods, and benefits. HortScience 29: 235-239 Lee JM (2003). Advances in vegetable grafting. Chronica Horticulturae 43: 13-19
- Lee JM, Bang HJ, Ham HS (1998). Grafting of vegetables. Journal of the Japanese Society for Horticultural Science 67: 1098-1104
- Leonardi C, Giuffrida F (2006). Variation of plant growth and macronutrient uptake in grafted tomatoes and eggplants on three different rootstocks. European Journal of Horticultural Science 71: 97-101

- Livernais-Saettel L (2000). Tomates, Lycopersicon esculentum. http://www.dietobio.com/aliments/fr/tomate.html
- Lopez-Pérez JA, Le Strange M, Kaloshian I, Ploeg AT (2006). Differential response of Mi gene-resistant tomato rootstocksto root-knot nematodes (*Meloidogyne incognita*). Crop Protection 25: 382–388
- Lopez-Péreza JA, Le Strangeb M, Kaloshiana I, Ploeg AT (2006) Differential response of Mi gene-resistant tomato rootstocksto root-knot nematodes (*Meloidogyne incognita*). Crop Protection 25: 382–388
- Mapelli S, Kinet JM (1992). Plant growth regulator and graft control of axillary bud formation and development in the TO-2 mutant tomato. Plant Growth Regulation 11: 385-390
- Martinez-Rodriguez MM, Estan MT, Moyano E, Garcia-Abellan JO, Flores FB, Camposa JF, Al-Azzawi MJ, Flowers TJ, Bolarin MC (2008). The effectiveness of grafting to improve salt tolerance in tomato when an 'excluder' genotype is used as scion. Environmental and Experimental Botany 63: 392-401
- Matsuzoe N, Okubo H, Fujieda K (1993). Resistance of tomato plants grafted on Solanum rootstocks to bacterial wilt and root-knot nematode. Journal of the Japanese Society for Horticultural Science 61: 865-872
- Ntatsi G, Savvas D, Huntenburg K, Druege U, Schwarz D (2014). A study on ABA involvement in the response of tomato to suboptimal root temperature using reciprocal grafts with notabilis, a null mutant in the ABA-biosynthesis gene LeNCED1. Environ. Exp. Bot. 97: 11–21.
- Oda M (1995). New grafting method for fruit-bearing vegetables in Japan. Japan Agricultural Research Quarterly 29: 187-194
- Oda M (1999). Grafting of vegetables to improve greenhouse production. Extension Bulletin (December). College of Agriculture, Osaka Prefecture University, Osaka Japan: 12p
- Oka Y, Offenbach R, Pivonia S (2004). Pepper Rootstock Graft Compatibility and Response to *Meloidogyne javanica* and *M. incognita*. Journal of Nematology 36(2): 137-141
- Omenn GS, Goodman GE, Thornquist MD, Balmes J, Cullen MR, Glass A, Keogh JP, Meyskens FL, Valanis B, Williams JH, Barnhart S, Hammar S (1996). Effects of a combination of beta carotene and vitamin A on lung cancer and cardiovascular disease. N Engl J Med 334: 1150–1155
- Ozbay N, Newman SE (2004). Fusarium Crown and Root Rot of Tomato and Control Methods. Plant Pathology Journal 3(1): 9-18
- Passam HC, Stylianou M, Kotsiras A (2005). Performance of eggplant grafted on tomato and eggplant rootstocks. European Journal of Horticultural Science 70: 130-134
- Pavlou GC, Vakalounakis DJ, Ligoxigakis EK (2002). Control of root and stem rot of cucumber, caused by Fusarium oxysporum f. sp radiciscucumerinum, by grafting onto resistant rootstocks. Plant Disease 86: 379-382
- Peregrine WTH, Binahmad K (1982). Grafting a simple technique for overcoming bacterial wilt in tomato. Tropical Pest Management 28: 71-76
- Peres LEP, Carvalho RF, Zsögön A, Bermudez-Zambrano OD, Robles WGR, Tavares S (2005) Grafting of tomato mutants onto potato rootstocks: An approach to study leaf-derived signaling on tuberization. Plant Science 169: 680-688
- Pogonyi A, Pék Z, Helyes L, Lugasi A (2005). Effect of grafting on the tomato's yield, quality and main fruit components in spring forcing. Acta Alimentaria 34: 453-462
- Proebsting WMP, Hedden MJ, Lewis SJ, Croker-Proebsting LN (1992). Gibberellin concentration and transport in genetic lines of pea. Plant Physiology 100: 1354-1360
- Rahman MA, Rashid MA, Salam MA, Masud MAT, Masum ASMH, Hossain MM (2002). Performance of some grafted eggplant genotypes on wild solanum root stocks against root-knot nematode. Journal of Biological Sciences 2: 446-448
- Ringer JO, Bartlett Y (2007). The Significance of Potassium. The Pharmaceutical Journal 278: 497-501
- Rivard CL (2006). Grafting tomato to manage soilborne diseases and improve yield in organic production systems. A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Master of Science. Plant Pathology. Raleigh, North Carolina USA: 112

- Rivard CL, Louws FJ (2006). Grafting for disease resistance in heirloom tomatoes. North Carolina Cooperative Extension Service Ag-675: 8p
- Rivero RM, Ruiz JM, Romero L (2003). Role of grafting in horticultural plants under stress conditions. Food, Agriculture & Environment 1(1): 70-74
- Rivero RM, Ruiz JM, Romero L (2003b). Can grafting in tomato plants strengthen resistance to thermal stress? . Journal of the Science of Food and Agriculture 83: 1315-1319
- Rivero RM, Ruiz JM, Romero L (2004). Iron metabolism in tomato and watermelon plants: Influence of grafting. Journal of Plant Nutrition 27: 2221-2234
- Roberts BW, Fish WW, Bruton BD, Popham TW, Taylor MJ (2005). Effects of watermelon grafting on fruit yield and quality. Hortscience 40(3): 871
- Romero L, Belakbir A, Ragala L, Ruiz JM (1997). Response of plant yield and leaf pigments to saline conditions: effectiveness of different rootstocks in melon plants (Cucumis melo L.). Soil Science of Plant Nutrition 43: 855–862
- Rouphael Y, Schwarz D, Krumbein A, Colla G (2010). Impact of grafting on product quality of fruit vegetables. Scientia Horticulturae, 127(2): 172-179.
- Ruiz JM, Belakbir A, Romero L (1996). Foliar level of phosphorus and its bioindicators in Cucumis melo grafted plants. A possible effect of rootstocks. Journal of Plant Physiology 149: 400-404
- Ruiz JM, Blasco B, Rivero RM, Romero L (2005). Nicotine-free and salttolerant tobacco plants obtained by grafting to salinity-resistant rootstocks of tomato. Physiologia Plantarum 124: 465-475
- Ruiz JM, Romero L (1999). Nitrogen efficiency and metabolism in grafted melon plants. Scientia Horticulturae 81: 113-123
- Santa-Cruz A, Martínez-Rodríguez MM, Cuartero J, Bolarin MC (2001). Response of plant yield and ion contents to salinity in grafted tomato plants. Acta Horticulturae 559: 413–417
- Santa-Cruz A, Martínez-Rodríguez MM, Perez-Alfocea F, Romero-Aranda R, Bolarin MC (2002). The rootstock effect on the tomato salinity response depends on the shoot genotype. Plant Science 162: 825–831
- Savvas D. Öztekin GB, Tepecik M, Ropokis A, Tüzel Y, Ntatsi G, (2017). Impact of grafting and rootstock on nutrient-to-water uptake ratios during the first month after planting of hydroponically grown tomato. J. Hortic. Sci. Biotechnol. 92: 294–302.

- Sigüenza C, Schochow M, Turini T, Ploeg A (2005). Use of *Cucumis metuliferus* as a Rootstock for Melon to Manage *Meloidogyne incognita*. Journal of Nematology 37(3): 276-280
- Solt ML, Dawson RF (1958). Production, Translocation and Accumulation of Alkaloids in Tobacco Scions Grafted to Tomato Rootstocks. Plant Physiol 33: 375-381
- Stäubli A (2005). Porte-greffe résistants au corky root de la tomate. http://www.racchangins.ch/doc/fr/producteurs/faits/ Agroscope
- Tikoo SK, Mathai PJ, Kishan R (1979). Successful graft culture of tomato in bacterial wilt sick soils. Current Science 48: 259-260
- Traka-Mavrona, Koutsika-Sotiriou EM, Pritsa T (2000). Response of squash (Cucurbita spp.) as rootstock for melon (Cucumis melo L.). Scientia Hortic. 83: 353-362
- Tresky S, Walz E (1997). Testing solutions for control of bacterial wilt in tomatoes. Organic Farming Research Foundation Bulletin 4: 8-9
- Upstone ME (1968). Effects of methyl bromide fumigation and grafting on yield and root diseases of tomatoes. Plant Pathology 17: 103
- Venema JH, Dijk BE, Bax JM, Van Hasselt PR, Elzenga JTM (2008). Grafting tomato (*Solanum lycopersicum*) onto the rootstock of a highaltitude accession of *Solanum habrochaites* improves suboptimaltemperature tolerance. Environmental and Experimental Botany 63: 359-367
- Vitre A (2002). Le greffage des tomates. Rapport technique: 4p
- Yetisir H, Sari N (2003). Effect of different rootstock on plant growth, yield, and quality of watermelon. Australian Journal of Experimental Agriculture 43: 1269-1274
- Zijlstra S, Groot SPC, J JJ (1994). Genotypic variation of rootstocks for growth and production in cucumber; possibilities for improving the root system by plant breeding. Sci. Hortic 56: 185-186