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**Control of *Colletotrichum coccodes* on tomato by grafting and soil amendments**

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**Keywords:**Colletotrichum root rot, grafting, compost, biofumigation, integrated disease management, *Solanum lycopersicum.*

**Abstract**

Eight trials were carried out in 2011 and 2012 in northern Italy to evaluate the efficacy of grafting, compost and biofumigation with *Brassica carinata* against *Colletotrichum coccodes* on tomato. Four trials were carried out in commercial farms and four trials were carried out in plastic tunnels at an experimental centre. The rootstocks ‘Armstrong’, ‘Arnold’, ‘Beaufort’, ‘Big Power’, ‘Brigeor’, ‘Emperador’, ‘King Kong’, ‘Spirit’ and ‘Superpro V295’ were tested. Host plants included several tomato F1 hybrids: ‘Amantino’, ‘Arawak’, ‘CLX 37438’, ‘Cauralina’, ‘CU 8301’, ‘CU 8506’, ‘DRK 7021’, ‘E 34431’, ‘E 50070’, ‘EXP’, ‘Gotico’, ‘Ingrid’, ‘ISI 61401’, ‘ISI 61402’, ‘Profitto’, ‘Punente’, ‘Rugantino’ and ‘Tomahawk’. Tomato roots from the control plots were 34 to 87 % diseased in both naturally and artificially infested soil.

Among the nineteen commercial tomato hybrids tested, in the presence of a very high disease pressure in a naturally infested soil, ‘Rugantino’ was the least affected by *C. coccodes,* showing 32% infected roots. ‘Tomahawk’ grafted onto ‘Arnold’, ‘Armstrong’ and ‘Superpro V295’ was significantly less affected by *C. coccodes*, while ‘Arawak’ grafted onto ‘Armstrong’, ‘Arnold’, ‘Emperador’ and ‘Beaufort’ provided very good control of root rot in the different trials. Compost addition and biofumigation with *Brassica* pellets were also tested with and without grafting. Soil amendment with compost, in the case of the ‘Arawak’ and ‘Tomahawk’, resulted in a slightly improved disease control only on non-grafted plants. When grafting and biofumigation were combined in a soil naturally infested with *C. coccodes* and *Meloidogyne arenaria*, biofumigation did not improve *C. coccodes* control in comparison to grafting alone. In a naturally infested soil, compost alone and combined with biofumigation improved disease control only on non-grafted ‘Tomahawk’ plants. In general, grafting by itself provided very good results in terms of disease control, which were not significantly improved by combination with compost and/or biofumigation.

**Introduction**

Tomato (*Solanum lycopersicum* L.) is widely grown in Italy in highly specialized and intensive cultivation systems which involve the repeated planting of the same crop in the same soil. This type of intensive production system favours the development of soil-borne diseases (Katan 1984; Garibaldi and Gullino 1995; Katan and Vanachter 2010) that, in industrialized countries since 2005, cannot be controlled by soil disinfestation with methyl bromide (Gullino et al. 2003; 2005; Di Tullio et al. 2006). As consequence of loss of effective fumigants, pathogens generally considered minor can became major on tomato grafted onto interspecific hybrids (Garibaldi and Gullino 2010). Increased attacks by *Rhizoctonia solani* (Kuhn), 1858 (anastomosis group AG-4), *Phytophthora nicotianae* (Breda de Haan), 1896, and *P. capsici* (Leonian), 1922, were repeatedly observed on tomato grafted onto *S. lycopersicum* x *S. hirsutum* (Garibaldi and Gullino 2010; Garibaldi et al. 2012a). On the other hand, grafting confers resistance to several pest and diseases, such as Fusarium wilt, bacterial wilt caused by *Ralstonia solanacearum* (Smith), 1896, and root-knot nematodes (King et al. 2008; Louws et al. 2010; Yamazaki et al. 2000). Other research showed that the adoption of ‘Energy’ as a rootstock seemed the best solution for grafted tomatoes grown in sandy soils heavily infested withroot knot nematodes (*Meloidogyne* spp.), while the adoption of rootstocks such as ‘Beaufort’ and ‘He-Man’ made it possible to grow grafted tomatoes in soils heavily infected with *Fusarium oxysporum* f.sp *radicis-lycopersici* (Garibaldi and Minuto 2003).

In the early 2000’s, a root rot caused by *Colletotrichum coccodes* (Wallr.) S. Hughes, 1958, was observed during surveys carried out in Piedmont, Liguria, Campania, Lazio and Sicily on grafted and non-grafted tomatoes, where methyl bromide was being replaced by other fumigants or alternative control methods (Garibaldi and Gullino 2010). This re-emerging pathogen affects the root system with considerable necrosis deteriorating both the old and young roots. Upon visual examination the root tissues can be seen to become blackish and to show cracks (Garibaldi et al. 2008). Previous research showed that among the most popular rootstocks used in Italy, ‘Beaufort’ seemed more sensitive to *C. coccodes* infection than ‘Energy’ and ‘He Man’ (Minuto et al. 2008).

The host range of *C. coccodes* includes cultivated species such as tomato, pepper, potato, eggplant, lettuce, chrysanthemum, some species of Cucurbitaceae and Brassicaceae (Dillard 1992), and several weeds including Amarantaceae, Chenopodiaceae, Compositae, Convulvolaceae, Cruciferae, Graminaceae, Malvaceae, Oxalidaceae, Polygonaceae and Solanaceae (Raid and Pennypacker 1987). Indeed, during a survey carried out in July 2011 in Piedmont (northern Italy), root rots were also observed on grafted and non-grafted sweet pepper plants and *C. coccodes* was isolated from infected tissues (Garibaldi et al. 2012b).

Grafting has been used to confer tolerance to high and low temperatures, to increase the absorption of nutrients and water, to improve plant vigour and fruit yield, to extend the harvest period, and to increase resistance to soil-borne pests and diseases (King et al. 2008; Lee et al. 2010; Rouphael et al*.* 2010; Leal-Fernández et al. 2012). In particular, with the loss of methyl bromide, the use of grafting has expanded to manage a broad range of pathogens including fungi, oomycetes, bacteria, nematodes and viruses (Louws et al. 2010), even though the degree of tolerance varies considerably with the rootstocks (Lee et al. 2010). In spite of the disadvantages associated, including additional costs, the use of resistant rootstocks has significantly increased for vegetable crops such as tomato, bell pepper and melon, with more than 59 million plants grafted in Italy (Morra and Bilotto 2010).

Watermelon and tomato are the two major grafted vegetables throughout the world (Lee et al. 2010). In Piedmont (northern Italy) grafted plants are mostly used in tomato cropping systems, and are also becoming popular for bell pepper (Gilardi et al. 2013).

However, over-reliance on specific rootstocks has led to the emergence of new pathogens, shifts in the host specificity of the pathogens (Louws et al. 2010), and resurgent problems such as tomato brown root rot caused *by C. coccodes* (Garibaldi et al. 2008).

The use of grafting to control soil-borne pests and diseases might be more successful when complemented with other tactics (King et al. 2008; Louws et al. 2010), including the use of organic soil amendments (Ros et al. 2005; Garibaldi et al. 2010).

The use of *Brassica* species as green manure is a type of biofumigation involving the release of isothiocyanates, thiocyanates, nitriles or oxazolidinethiones that control multiple soil-borne problems (Larkin and Griffin 2007; Handiseni et al. 2012). Biofumigation can be achieved by incorporating fresh plant material (green manure), seed meals, dried plant material or by using brassica intercrops. However, some studies indicate that the effectiveness of organic amendments including brassica residues is variable and, in some cases, can enhance severity of some diseases (Mazzola et al. 2007; Lu et al. 2010).

Some composts have been found to suppress soil-borne pathogens (Noble and Coventry 2005), however, due to variability in quality and reproducibility of disease suppressiveness (Termorshuizen et al. 2006), growers are still reluctant to rely on compost for controlling soil-borne diseases (Hadar 2011; Pugliese et al. 2011; Hadar and Papadopoulos 2012).

The aim of this work was to test the ability of grafting tomato onto resistant rootstocks, combined or not with the use of compost and biofumigation with *Brassica carinata* (A. Braun), to control *C. coccodes*.

**Materials and Methods**

Eight trials were carried out in 2011 and 2012 in northern Italy (Piedmont) against *C. coccodes* on tomato: four in plastic tunnels at the CReSO Experimental Center in Boves (Cuneo), two in plastic tunnels at a specialized commercial farm in Villafaletto (Cuneo), and two in a commercial glasshouse at a farm in Boves (Cuneo), as summarized in Table 1.

**Plant material and soil characteristics**

Different rootstocks of tomato (‘Armstrong’, ‘Arnold’, ‘Beaufort’, ‘Big Power’, ‘Brigeor’, ‘Emperador’, ‘King Kong’, ‘Spirit’ and ‘Superpro V295’) commercially available and grafted from a local nursery (Ricca Sebastiano, Carignano, Turin, Italy ), were tested for their susceptibility to *C.* *coccodes* under local growing conditions.

Host plants used in the trials included several tomato F1 hybrids (‘Amantino’, ‘Arawak’, ‘CLX 37438’, ‘Cauralina’, ‘CU 8301’, ‘CU 8506’, ‘DRK 7021’, ‘E 34431’, ‘E 50070’, ‘EXP’, ‘Gotico’, ‘Ingrid’, ‘ISI 61401’, ‘ISI 61402’, ‘Profitto’, ‘Punente’, ‘Rugantino’ and ‘Tomahawk’).

Four trials (1-4) were carried out at CReSO experimental station on tomato grown in plastic tunnels with loam soil texture (68% sand, 21.8% clay and 10% silt), pH 5.8, medium availability of organic carbon (1.39%), high organic matter content (2.4%) and medium content of total nitrogen (2.1 g/kg).

Trials 5 and 6 were carried out on tomato under greenhouse conditions at a commercial farm with silt loam soil texture (60.1 % sand, 21.8 % clay and 18 % silt), pH 7.5, medium content of total organic carbon (1.99%), high organic matter content (3.43%) and high content of total nitrogen (3.9 g/kg).

Two other trials (7 and 8) were carried out under greenhouse conditions at a commercial farm with sandy clay loam soil texture (58% sand, 15% silt, 27% clay), pH 7.5 , medium content of total organic carbon (1.79%), high organic matter content (3.09%) and high content of total nitrogen (3.6 g/kg). The soil in trials 7 and 8 was naturally infested with root knot nematode *Meloidogyne arenaria* (Chitwood), 1949.

**Pathogen inoculum and soil infestation**

Five-mm-diameter disks of Potato Dextrose Agar colonized by the strain of *C. coccodes* isolated from infected tomato grafted on Beaufort was inoculated in flasks filled with sterilized wheat kernels and maintained for 30 days at 23°C. In order to achieve a uniform soil infestation and high disease incidence in the trials carried out under experimental conditions (trials 2 and 4), the inoculum of *C. coccodes* at the dosage of 100 g/m2 of infected wheat kernels was incorporated into the soil by rototilling at a depth of 15–25 cm before transplantation (Table 1).

In the case of *M. arenaria,* soil samples were taken at the end of the trial within the feeder-root zone excluding the top 2.5 to 5 cm of soil. Each plot was sampled independently; 1,000 to 1,500 g of soil was collected for each treatment made up of 10 to 20 subsamples taken from across the area. The number of eggs of *M. arenaria* was 12,366 per 500 ml of soil in the not treated soil, and 7,520 per 500 ml of soil in the biofumigated soil.

**Treatments with organic amendments**

In three out of eight trials, grafted tomato was combined with compost amendment (Trial 6), *Brassica* dried pellets (Trial 7), and the combination of both these amendments (Trial 8). Compost prepared from the organic fraction of municipal solid and biodegradable wastes (ACEA Pinerolese, Pinerolo, Italy) was mixed into the soil at 5 kg/m2, at soil depth of 25 cm (Table 1, Trial 6) or localized in the row (1 m wide) at 5 kg/m2 (Table 1, Trial 8).

*Brassica carinata* dried pellets (Biofence, Triumph, Italy) were mixed into the soil at 250 g/m2 (Trial 7). The liquid formulation of *B. carinata* (Biofence FL, Triumph, Italy) at 2 ml/l was used alone or in combination with compost (Trial 8).

**Disease evaluation, yield parameters and statistical analysis**

At the end of the trials, 120-150 days after transplantation, assessment was carried out by removing tomato plants and evaluating the symptoms of the disease expressed as a percentage of roots infected by *C. coccodes*. The symptoms consisted of root stunting, discoloration and decomposition. The root cortex became loose, showing the presence of abundant blackish areas with a diameter smaller than 1 mm and often coalescent in larger brown areas. Root rot was measured by evaluating the discoloration of total root system caused by *C.coccodes*, which was rated from 0 to 100. The symptomatic roots, were removed for confirmation by isolation of the pathogen onto potato dextrose agar (PDA, Merck, Germany), and identification by microscopic assessment of the morphological characteristics.

All data, reported as a mean value of three or four replicates, were analysed by SPSS 18.0 windows software for the statistical analysis of variance (ANOVA). Data were analyzed to check for normal distribution with Shapiro-Wilk Test. Tukey’s test was used to compare the means with *P*=0.05. The general linear model was used to investigate the effect of each factor (rootstocks, scion, compost and biofumigation) and their interactions on *C.coccodes* symptoms in trials 3, 5, 6, 7 and 8.

**Results**

Disease severity ranged from 34 to 87 % affected tomato roots in the different trials in the control plots, both in naturally and artificially infested soil (Tables 3-9). The level of disease in the control plots permitted a good evaluation of the different control strategies tested. According to the general linear model, grafting was a significant factor influencing disease incidence in trials 3, 5 and 6. The percentage of diseased roots were significantly influenced by the use of compost (Trial 6) and biofumigation (Trial 7). No interaction was found between grafting and compost, biofumigation and grafting, and compost and cultivar.

Among the nineteen commercial tomato hybrids tested, in the presence of a very high disease pressure in a naturally infested soil, ‘Rugantino’ was the least affected by *C. coccodes* with 32% infected roots, followed by ‘CLX 37438’ with 38.7% infected roots. Most of the hybrids tested were severely affected, with more than 50% infected roots. The hybrid ‘Profitto’ was the most susceptible, with 74.7% infected roots (Table 2).

In trial 2, carried out under artificial soil infestation, in the presence of a very high disease pressure (86.5 % diseased roots on ‘Tomahawk’ non-grafted tomato plants), plants of ‘Tomahawk’ grafted onto ‘Arnold’, ‘Armstrong’ and ‘Superpro V295’ were significantly less affected by *C. coccodes* (Table 3).

In trial 3, carried out in a naturally infested soil, in the presence of a lower disease pressure compared to trial 2 (59.3% diseased roots in the control plots), ‘Armstrong’, ‘Big Power’, and ‘Arnold’ confirmed their low susceptibility to the disease when used to graft ‘Tomahawk’. ‘Arawak’ grafted onto ‘Armstrong’, ‘Arnold’ and ‘Emperador’ provided the best results for control of the pathogen (Table 4).

In trial 4, ‘Arawak’ grafted on ‘Beaufort’ and ‘Arnold’ provided a very high disease control at the first evaluation, but ‘Arnold’ showed statistically better results at the last evaluation, in the presence of 72.5% diseased roots on non-grafted ‘Arawak’.

In trial 5, in the presence of a high disease severity in the non-grafted control plants ‘Arawak’, ‘Tomahawk’, and ‘EXP’ (71.3 to 79.2% diseased roots), the three rootstocks (‘Arnold’, ‘Armstrong’, and ‘Beaufort’) strongly reduced disease severity to values of 5 to 19% diseased roots (Table 6).

The combination of soil amendment with compost in the case of the grafted and non-grafted ‘Arawak’ resulted in a slightly improved, but not significant, disease control on non-grafted plants (with a reduction from 73.2% to 51.8% diseased roots) and on plants grafted onto ‘Beaufort’ in trial 6 (Table 7). ‘Arawak’ grafted onto ‘Arnold’ showed very low infection by the pathogen; the use of compost did not improve the disease control (Table 7).

When grafting and biofumigation were combined in a soil naturally infested with *C. coccodes* and *M. arenaria*, in the presence of a medium disease severity (36% diseased roots in the non-grafted cultivar ‘Arawak’), biofumigation did not improve *C. coccodes* control in comparison to grafting alone. ‘Arnold’ confirmed its effectiveness as a control of *C. coccodes* when used as rootstock (Table 8).

When tested in trial 8 on the cultivar ‘Tomahawk’ in a naturally infested soil, compost alone and combined with biofumigation improved disease control on non-grafted ‘Tomahawk’ tomato plants (Table 9). The combination of compost and biofumigation significantly reduced the percentage of diseased roots on non-grafted plants from 33.7% to 10%. Grafting by itself provided very good results in terms of disease control, which could not be significantly improved by combination with compost and/or biofumigation (Table 9).

**Discussion**

Grafting is a technique increasingly adopted in solaneaceous crops for several purposes, including to confer resistance to soil-borne pests and diseases (King et al. 2008; Lee et al. 2010; Louws et al. 2010; Rouphael et al*.* 2010; Leal-Fernández et al. 2012). In Italy, despite the higher cost of grafted plants, this technique is becoming more widely adopted.

However, growers have to make decisions on selection of rootstocks most suitable for their specific requirements, taking into account that grafting provides a site-specific management tool relying on proper disease diagnosis (Lee et al. 2010; Louws et al 2010). In addition, selection pressure caused by widespread use of rootstocks may lead to the emergence of new races or pathotypes, or resurgent problems. These issues can be mitigated by rotating the rootstocks, continued breeding for resistance, and extensive monitoring for new pest outbreaks in grafted plants (King et al. 2010).

The Piedmont tomato growing system is conducive to *C. coccodes* infection, a re-emerging pathogen. Our results show that some of the commercially available rootstocks, such as ‘Arnold’, ‘Armstrong’, ‘Big Power’ and ‘Beaufort’ confer high levels of resistance to *Colletotrichum coccodes* root rot.

Grafting can represent a solution on its own or it can be combined with other treatments within Integrated Pest Management (IPM) protocols for improving its efficacy (King et al. 2010).

In the case of this study, grafting was very effective by itself, providing high level of *Colletotrichum* root rot control. For grafted plants, neither compost nor biofumigation with *Brassica* pellets could increase disease control. However, in the case of non-grafted plants, compost and biofumigation did show a slight, but not significant, increase in disease control.

In conclusion, the use of grafted tomato plants represents a very effective option for the control of *C. coccodes* in specialized farms and in the presence of high disease incidence.

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**Tables**

Table 1. Factors and design of tomato trials.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Trial No. | Site and Year | Scion cultivar | Rootstock  cultivar | Soil infestation with *C.* *coccodesa* | Treatment | Number of plants/plot (replicates) |
| 1 | Experimental station CReSO (Boves, CN) (2011) | Several F1 hybrids | non grafted | Natural | - | 10 (3) |
| 2 | Experimental station CReSO (Boves, CN)  (2011) | Arawak and Tomahawk | Armstrong, Arnold, Beaufort, Big Power, Emperador, King Kong, Spirit, Superpro V295 | Artificial, 100 g/m2 of *C. coccodes* biomass | - | 10 (3) |
| 3 | Experimental station CReSO (Boves, CN)  (2011) | Arawak and Tomahawk | Armstrong, Arnold, Beaufort, Big Power, Brigeor, Emperador, | Natural | - | 10 (3) |
| 4 | Experimental station CReSO (Boves, CN)  (2012) | Arawak | Arnold, Beaufort | Artificial, 100 g/m2 of *C. coccodes* biomass | - | 6 (4) |
| 5 | Farm NaturAmica (Villafaletto, CN) (2011) | Arawak, Tomahawk and EXP | Armstrong, Arnold, Beaufort | Natural | - | 10 (3) |
| 6 | Farm NaturAmica (Villafaletto, CN) (2012) | Arawak | Arnold, Beaufort | Natural | Compost 5kg/m2 | 10 (3) |
| 7 | Farm Dutto e Giordanengo (Boves, CN) (2011) | Arawak | Arnold, Beaufort | Naturala | Biofumigation with Brassica pellet (BIOFENCE) | 10 (3) |
| 8 | Farm Dutto e Giordanengo (Boves, CN) (2012) | Tomahawk | Beaufort | Naturala | Biofumigation  with Brassica (BIOFENCE FL)  and compost at 5 kg/m | 10 (3) |

a *Meloidogyne arenaria* was also present.

Table 2. Susceptibility of tomato hybrids to *Colletotrichum coccodes* in naturally infested soil (Trial 1).

|  |  |  |  |
| --- | --- | --- | --- |
| Hybrid | Seed company | % Diseased roots a | |
| Amantino | Horta Center | 62.7 ± 0.6 | abcb |
| Arawak | Syngenta | 52.0 ± 0.5 | abc |
| CLX 37438 | Clause | 38.7 ± 1.4 | ab |
| Cauralina | Gautier | 69.3 ± 1.2 | bc |
| CU 8301 | Syngenta | 58.7 ± 0.5 | abc |
| CU 8506 | Syngenta | 46.7 ± 0.1 | abc |
| DRK 7021 | De Ruiter Monsanto | 57.3 ± 1.4 | abc |
| E 34431 | Enza Zaden | 58.7 ± 1.0 | abc |
| E 50070 | Enza Zaden | 55.7 ± 1.2 | abc |
| Gotico | Isi sementi | 66.7 ± 0.9 | bc |
| Ingrid | De Ruiter Monsanto | 66.0 ± 1.0 | abc |
| ISI 61401 | Isi sementi | 64.7 ± 0.9 | abc |
| ISI 61402 | Isi sementi | 63.3 ± 1.7 | abc |
| Profitto | De Ruiter Monsanto | 74.7 ± 1.1 | c |
| Punente | De Ruiter Monsanto | 57.3 ± 1.2 | abc |
| Rugantino | Rijk Zwaan | 32.0 ± 1.8 | a |
| Tomahawk | Syngenta | 60.7 ± 1.0 | abc |

a Three replicates, with ten plants per replicate.

b Means of the same column, followed by the same letter, do not significantly differ following Tukey's test (*P* < 0.05).

Table 3. Susceptibility to *Colletotrichum coccodes* of tomato cultivar ‘Tomahawk’, grafted or non-grafted on different commercial rootstocks*,* under artificial soil infestation (Trial 2).

|  |  |  |
| --- | --- | --- |
| Rootstocks | % Diseased rootsa | |
| Arnold | 5.9 ± 0.5 | ab |
| Armstrong | 8.2 ± 1.7 | ab |
| Beaufort | 19.3 ± 0.5 | abc |
| King Kong | 22.6 ± 2.8 | bc |
| Spirit | 36.5 ± 2.6 | c |
| Superpro V295 | 14.6 ± 2.3 | ab |
| Non-grafted | 86.5 ± 1.8 | d |

a Three replicates, with ten plants per replicate.

bMeans of the same column, followed by the same letter, do not significantly differ following Tukey's test (*P* < 0.05).

Table 4. Susceptibility to *Colletotrichum coccodes* of tomato cultivars ‘Arawak’ and ‘Tomahawk’, grafted or non-grafted onto different commercial rootstocks in a naturally infested soil (Trial 3).

|  |  |  |  |
| --- | --- | --- | --- |
| Cultivar | Rootstocks | % Diseased rootsa | |
| Arawak | Armstrong | 2.0 ± 0.3 | ab |
| Arawak | Arnold | 8.7 ± 2.4 | a |
| Arawak | Beaufort | 30.7 ± 3.4 | ab |
| Arawak | Big Power | 26.7 ± 6.5 | a |
| Arawak | Brigeor | 19.0 ± 3.7 | a |
| Arawak | Emperador | 12.7 ± 3.4 | a |
| Arawak | Non-grafted | 66.3 ± 3.3 | c |
| Tomahawk | Amstrong | 5.3 ± 1.0 | a |
| Tomahawk | Arnold | 10.0 ± 1.3 | a |
| Tomahawk | Beaufort | 28.7 ± 2.4 | ab |
| Tomahawk | Big Power | 8.0 ± 1.1 | a |
| Tomahawk | Brigeor | 22.3 ± 3.9 | a |
| Tomahawk | Emperador | 30.0 ± 1.6 | ab |
| Tomahawk | Non-grafted | 59.3 ± 3.0 | bc |

a Three replicates, with ten plants per replicate.

b Means of the same column, followed by the same letter, do not significantly differ following Tukey's test (*P*<0.05).

According to the general linear model, scion was not a significant factor influencing the percentage of diseased roots (*P* = 0.939), while grafting was significant (*P* = 0.04). The interaction between grafting and cultivar was not significant (*P* = 0.112).

Table 5. Susceptibility to *Colletotrichum coccodes* of tomato cultivar ‘Arawak’, grafted or non-grafted onto ‘Beaufort’ and ‘Arnold’ rootstocks in soil artificially infested with the pathogen (Trial 4).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rootstocks | % Diseased rootsa on | | | | | | | |
| 08/08/2012 | | 20/08/2012 | | 18/09/2012 | | 31/10/2012 | |
| Beaufort | 21.3 ± 3.5 | bb | 20.0 ± 3.3 | b | 28.8 ± 2.6 | b | 30.0 ± 7.5 | b |
| Arnold | 0.0 ± 0.0 | a | 3.8 ± 2.0 | a | 1.3 ± 1.0 | a | 2.5 ± 1.2 | a |
| Non-grafted | 35.0 ± 1.7 | c | 40.0 ± 1.7 | c | 60.0 ± 3.3 | c | 72.5 ± 3.9 | c |

a Four replicates, with six plants per replicate.

bMeans of the same column, followed by the same letter, do not significantly differ following Tukey's test (*P* < 0.05).

Table 6. Susceptibility to *Colletotrichum coccodes* of tomato cultivar ‘Arawak’, ‘Tomahawk’ and ‘EXP’, grafted or non-grafted on different commercial rootstocks, in a naturally infested soil (Trial 5).

|  |  |  |  |
| --- | --- | --- | --- |
| Cultivar | Rootstocks | % Diseased rootsa | |
| Arawak | Non-grafted | 71.3 ± 0.8 | bb |
| Tomahawk | Non-grafted | 71.2 ± 1.3 | b |
| EXP | Non-grafted | 79.2 ± 0.1 | b |
| Arawak | Arnold | 6.3 ± 0.1 | a |
| Arawak | Armstrong | 5.0 ± 0.1 | a |
| Arawak | Beaufort | 10.3 ± 0.3 | a |
| Tomahawk | Arnold | 9.0 ± 0.5 | a |
| Tomahawk | Armstrong | 7.7 ± 0.3 | a |
| Tomahawk | Beaufort | 16.0 ± 0.6 | a |
| EXP | Arnold | 18.0 ± 0.1 | a |
| EXP | Armstrong | 8.7 ± 0.3 | a |
| EXP | Beaufort | 9.7 ± 0.6 | a |

a Three replicates, with ten plants per replicate.

bMeans of the same column, followed by the same letter, do not significantly differ following Tukey's test (*P* < 0.05).

According to the general linear model, scion was not a significant factor influencing the percentage of diseased roots (*P* = 0.057), while grafting was significant (*P* < 0.0001). The interaction between grafting and scion was not significant (*P* = 0.244).

Table 7. Susceptibility to *Colletotrichum coccodes* of tomato cultivar ‘Arawak’, grafted or non-grafted onto ‘Arnold’ and ‘Beaufort’ rootstocks, with or without the addition of compost, in a naturally infested soil (Trial 6).

|  |  |  |  |
| --- | --- | --- | --- |
| Rootstocks | Compost | % Diseased rootsa | |
| Non-grafted | No | 73.2 ± 6.2 | cb |
| Beaufort | No | 26.5 ± 2.1 | ab |
| Arnold | No | 1.9 ± 0.6 | a |
| Non-grafted | Yes | 51.8 ± 4.2 | bc |
| Beaufort | Yes | 8.1 ± 1.4 | a |
| Arnold | Yes | 3.5 ± 1.1 | a |

a Three replicates, with ten plants per replicate.

b Means of the same column, followed by the same letter, do not significantly differ following Tukey's test (*P<0.05*).

According to the general linear model, rootstocks (*P* < 0.0001) and compost (*P* = 0.021), were significant factors influencing the percentage of diseased roots while their interaction was not significant (*P* = 0.167).

Table 8. Incidence of *C.* *coccodes* expressed as percentage of infected roots on tomato cultivar ‘Arawak’, grafted or non-grafted, in a naturally infested soil, with or without the addition of *Brassica* pellets (Trial 7).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Rootstocks | Biofumigation | Training system | % of roots affected by *C. coccodes*a | |
| Non-grafted | No | 1 branch | 35.9 ± 2.9 | cb |
| Beaufort | Yes | 1 branch | 21.3 ± 1.5 | ab |
| Beaufort | Yes | 2 branches | 23.4 ± 2.8 | abc |
| Arnold | Yes | 1 branch | 14.1 ± 1.3 | a |
| Arnold | Yes | 2 branches | 14.1 ± 1.0 | a |
| Non-grafted | Yes | 1 branch | 24.4 ± 1.9 | abc |
| Beaufort | No | 1 branch | 31.6 ± 2.1 | bc |
| Beaufort | No | 2 branches | 25.0 ± 1.6 | abc |
| Arnold | No | 1 branch | 16.9 ± 1.3 | a |
| Arnold | No | 2 branches | 15.6 ± 1.2 | a |

a Three replicates, with ten plants per replicate.

bMeans of the same column, followed by the same letter, do not significantly differ following Tukey's test (*P < 0.05*).

According to the general linear model, rootstocks and biofumigation were significant factors influencing the percentage of diseased roots (*P* < 0.0001), while their interaction was not significant (P = 0.151).

Table 9. Effect of compost and biofumigation with *Brassica* pellets against *C. coccodes* on tomato cultivar ‘Tomahawk’, grafted and non-grafted onto ‘Beaufort’ rootstock, in a naturally infested soil (Trial 8).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Rootstocks | Soil amendment | % Diseased rootsa | |  |  |
| Non-grafted | - | 33.7 ± 1.3 | cb |  |  |
| Non-grafted | Compost | 24.0 ± 1.4 | bc |  |  |
| Non-grafted | Compost + Brassica | 10.0 ± 3.9 | ab |  |  |
| Non-grafted | Brassica | 19.7 ± 2.7 | abc |  |  |
| Beaufort | - | 3.7 ± 1.1 | a |  |  |
| Beaufort | Compost | 5.7 ± 2.3 | a |  |  |
| Beaufort | Compost + Brassica | 4.8 ± 2.0 | a |  |  |
| Beaufort | Brassica | 3.3 ± 0.9 | a |  |  |

a Three replicates, with ten plants per replicate.

bMeans of the same column, followed by the same letter, do not significantly differ following Tukey's test (*P<0.05*).

According to the general linear model, rootstocks, biofumigation and compost were significant factors influencing the percentage of diseased roots (*P* < 0.0001), while their integration was not significant (P = 0.451).