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Resistance in melon to *Monosporascus cannonballus* and *M. eutypoides*; fungal pathogens associated with Monosporascus root rot and vine decline

Short running page heading title: Resistance to *M. cannonballus* and *M. eutypoides*

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SUMMARY

The fungal species *Monosporascus cannonballus* and *M. eutypoides* have been described as the causal agents of Monosporascus root rot and vine decline disease (MRRVD), which mainly affects melon and watermelon crops. Resistance to *M. cannonballus* has been reported in some melon cultivars (ssp. *melo*). Moreover, melon ssp. *agrestis* accessions have proven to be better resistance sources. This is the case of the Korean accession 'Pat 81', highly resistant under field and artificial inoculation. The objective of the work here presented was the evaluation of the resistance to MRRVD of different accessions representing the variability of *Cucumis melo* ssp. *agrestis*, against both, *M. cannonballus* and *M. eutypoides*, in a multiyear assay under different infection conditions. In general, *M. eutypoides* was less aggressive than *M. cannonballus* in the different environmental conditions. There was a strong influence of temperature on MRRVD, with more severe symptoms with higher temperatures and with variable effect of infection on plant development depending on the fungal species considered. Resistance to MRRVD has been confirmed in 'Pat 81' and in its derived F1 with a susceptible Piel de Sapo melon. Among the new germplasm explored, African accessions (both wild *agrestis* and exotic cultivated acidulus) showed good performance in artificial inoculation assays and in field conditions. These sources do not present compatibility problems with commercial melons, so they can be introduced in backcrossing programs. The accession assayed of the wild relative *Cucumis metuliferus*, also resistant to Fusarium wilt and to root-knot

nematode, was highly resistant to MRRVD. The interest of this accession mainly relies in its advantages as a rootstock for melon.

Keywords: MRRVD, *Cucumis melo* spp. *agrestis*, temperature, breeding

INTRODUCTION

Melon vine decline is a syndrome characterized by the wilting of the vines followed by plant collapse late in the season (Martyn & Miller, 1996). Different causal agents have been reported for many melon vine declines (Bruton, Russo, García-Jiménez, & Miller, 1998). However, among them, Monosporascus root rot and vine decline (MRRVD) caused by *Monosporascus* spp. is well characterized (Cohen, Pivonia, Crosby, & Martyn, 2012). This soil-borne disease mainly affects melon (*Cucumis melo* L.) and watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) crops in hot arid and semiarid cucurbit-growing areas worldwide (Al-Mawaali, Al-Sadi, Al-Said, & Deadman, 2013; Chew-Madinaveitia, Gaytán-Mascorro, & Herrera-Pérez, 2012; Hamza, Belkadhi, Triki & Zouba, 2007; Iglesias, Picó, & Nuez, 2000a; Markakis et al., 2018; Martyn, Batten, Park, & Miller, 1996; Sales Júnior et al., 2012; Yan, Zang, Huang, & Wang, 2016). The disease causes important economic loses in certain areas, such as the southwestern region of the United States, and the main cucurbits producing areas of Central and South America (Brazil, Guatemala, Honduras and Mexico), the Mediterranean basin (Greece, Israel, Italy, Spain and Tunisia), and Middle to Far East (China, India, Iran, Japan, Oman, Pakistan, Saudi Arabia and Taiwan) (Martyn et al., 1996; Cohen et al., 2012; Negreiros, Júnior, Rodrigues, León, & Armengol, 2019).

Symptoms of MRRVD often appear at time of fruit maturity. The vines show an initial yellowing and decay of leaves. These symptoms are followed by progressive defoliation and partial or complete vine decline. As a consequence, fruit sunburn occurs and production is lost at harvest. Root lesions develop as rots or necrosis at the joints between secondary and tertiary roots or at the rot tips. Loss of feeder roots also occurs (Cluck et al., 2009; Martyn & Miller, 1996; Pico, Roig, Fita, & Nuez, 2008). Perithecia of *Monosporascus* spp. develop on affected roots, which release ascospores at the end of the cropping season (Martyn & Miller, 1996), being the primary survival structure and the primary inoculum. Root infections may occur from the germination of ascospores or active mycelium in infested soils (Cohen et al., 2000; Stanghellini, Alcantara, & Ferrin, 2010).

The ascomycete genus *Monosporascus* has been traditionally reported to include five species: *M. adenantherae* (S. D. & C. Ramesh) A. Pande (Patil & Ramesh, 1987), *M. cannonballus* Pollack & Uecker (Pollack & Uecker, 1974), *M. eutypoides* (Petrak) von Arx (Ben Salem et al., 2013; Petrak & Ahmad, 1954), *M. ibericus* Collado, Ant. González, Stchigel, Guarro, & Peláez (Collado et al., 2002) and *M. monosporus* (Malloch & Cain) D. Hawksw. & Ciccar (Malloch & Cain, 1971). Recently, five new *Monosporascus* species have been described, isolated from native weed species in Northeastern Brazil (Negreiros Sales Júnior, Rodrigues, León, & Armengol, 2019). These species are: *M. brasiliensis*, *M. caatinguensis*, *M. mossoroensis*, *M. nordestinus* and *M. semiaridus* (the authority of all of them is A. Negreiros, M. León, J. Armengol & R. Sales Júnior). But, up to date only the species *M. cannonballus* and *M. eutypoides* have been reported as causal agents of MRRVD disease in cucurbits (Ben Salem et al., 2013; Cohen et al., 2002; Martyn & Miller, 1996; Negreiros et al., 2019). Both species were suggested to be conspecific, until recent results demonstrated that they are distinct, being *M. cannonballus* the most well-known species of the genus and the most wide-spread (Ben Salem et al., 2013). *Monosporascus eutypoides* has been reported associated to MRRVD in different cucurbit growing areas such as Israel (Reuveni, Krikun, & Shani, 1983) and Tunisia (Ben Salem et al., 2013).

Monosporascus spp. are adapted to hot semiarid climates, where they are pathogenic, while persist saprophytically in cooler areas (Aegerter, Gordon, & Davis, 2000). Several researches have investigated the relationship of air and soil temperatures with disease development. Vine decline has been associated with high ambient temperatures late in the growing season (Bruton, García-Jiménez, & Armengol, 1999; Wolff, 1996; Wolff, Leskovar, Black, & Miller, 1997). Besides that, a high correlation has been found between soil temperatures above 20ºC during the first 30 days after planting and collapse at the end of the season (Pivonia, Cohen, Kigel, & Katan, 2002). Root colonization by the pathogen is higher with higher temperatures, given that ascospore germination and hyphal penetration are enhanced by increasing temperatures (Pivonia, Cohen, Kigel, & Katan, 2002).

The influence of environmental factors in the expression of symptoms associated with MRRVD makes difficult the identification of resistance to this disease and the comparison of resistance sources evaluated in different conditions. Resistance to collapse caused by *M. cannonballus* in United States was reported in some melon cultivars, such as ‘Doublon’ (*C. melo* L. ssp. *melo* cantalupensis group) and ‘Deltex’ (*C. melo* ssp. *melo*

ananas group) (Crosby, 2000a; Crosby, Wolff, & Millerc, 2000; Wolff, 1995; Wolff & Miller, 1998). Further field assays described variable responses in 'Deltex' (Cohen et al., 2000; Fita, Picó, Dias, & Nuez, 2008; Sinclair, 2003), while resistance in 'Doublon' was later confirmed in different conditions (Fita, Picó, Dias, & Nuez, 2008). Only moderate resistance has been identified within the ssp. *melo* in screenings under different conditions (Esteva & Nuez, 1994; Sales Junior, Senhor, Michereff, Negreiros2019). The spp. *agrestis* of *C. melo* has been more useful in providing pathogen resistance for melon breeding (Pitrat et al., 2017). Although, screenings against *M. cannonballus* are scarce, a few papers report resistance to *M. cannonballus* derived from melon ssp. *agrestis* accessions, being their resistance superior than that of the best ssp. *melo* resistant lines (Crosby 2001; Dias, Picó, Espinos & Nuez, 2004; Iglesias, Picó & Nuez, 1999). For example, the Korean ssp. *agrestis* accession 'Pat 81' (*C. melo* L. ssp. *agrestis* chinensis group) has been reported as highly resistant to *M. cannonballus* under field and artificial inoculation (Iglesias, Picó, & Nuez, 2000 a,b). Resistance in 'Pat 81' is expressed as a low level of collapse in field assays. Root lesions are less widespread and less severe than those observed in the susceptible genotypes. A second factor, a better root structure in 'Pat 81', is also critical to overcome the disease. The development of a long and branched root system allows a deeper rooting ability and increases the soil volume explored (Dias, Picó, Espinos, & Nuez, 2004; Iglesias, Picó, & Nuez, 2000b). This second mechanism has not been described in resistance sources belonging to the ssp. *melo*. The resistance derived from this source has been introgressed into the genetic background of the Piel de Sapo market class, by crossing it to the Piñonet Piel de Sapo cultivar (*Cucumis melo* spp. *agrestis* ibericus group) (Fita, Esteras, Picó, & Nuez, 2009a). 'Pat 81' has also proven useful as rootstock for melon, given that it retains its favourable root architecture, while having reduced effect on fruit quality (Fita, Picó, Roig, & Nuez, 2007). The molecular basis of the resistance in 'Pat 81' has also been investigated by comparing root transcriptional responses in both, the susceptible Piel de Sapo cultivar Piñonet and the resistant 'Pat 81'. Differences between both genotypes suggest that the jasmonic acid-mediate response might be associated to the resistance in 'Pat 81'(Roig et al., 2012).

To date, resistance to *M. eutypoides* in melon cultivars (ssp. *melo*) has not been investigated and it should be confirmed in previously reported sources of resistance to *M. cannonballus*. Also, the variability in the response against MRRVD of the subspecies *agrestis* of *C. melo* has been underexploited to date and the identification of new resistance sources to this disease would increase the range of variation available in

breeding programs for its use either as donors of resistance genes or as rootstocks. The objective of the work here presented was the evaluation of the response of different genotypes selected to represent intraspecific variation of *C. melo* spp. *agrestis* to both species, *M. cannonballus* and *M. eutypoides*, in a multiyear assay under different infection conditions.

MATERIAL AND METHODS

Isolates of *Monosporascus*

The isolates of *Monosporascus cannonballus* and *M. eutypoides* used in the assays were MC0504 (collected from melon in Spain) and MT47 (collected from watermelon in Tunisia), respectively, obtained from the Culture Collection of the Instituto Agroforestal Mediterráneo (Valencia, Spain). Both isolates were hyphal-tipped and stored at -80ºC in cryovials. To obtain fresh cultures, agar plugs from each isolate were transferred to potato dextrose agar (PDA) plates and incubated at 25ºC for 10 days in the dark.

Plant material

The Korean accession 'Pat 81' (Chin-Pat81Ko, *C. melo* spp. *agrestis*, chinensis group) previously reported as highly resistant to *M. cannonballus*, as well as its F1 hybrid to Piñonet Piel de Sapo (F1 Pat81xPs), previously used as resistant rootstock for melon (Fita et al. 2007), were included as resistant controls. The Piñonet Piel de Sapo cultivar (Ib-PsPiñSp, *C. melo* spp. *melo*, ibericus group) was used as the susceptible control. A Brazilian ssp. *melo* landrace (La-PE4Bra), that showed previously tolerance in Brazilian infested fields (Dantas, Holanda, Esteras, Nunes, & Picó, 2015) was also included as reference. Other accessions belonging to different groups of the ssp. *agrestis* were assayed: two wild *agrestis* types (*C. melo* ssp. *agrestis* wild type group), one African, from Ghana (Ag-15591Gha, a selection by selfing of the USDA accession PI 185111), and the second from India (Ag-TriInd, Ames 24297), representing the two molecular groups of wild African and Asian *agrestis* (Gonzalo et al., 2019; Leida et al., 2015), and an African acidulus (*C. melo* ssp. *agrestis* acidulus group) from Zimbabwe (Ac-TGR139Zimb, a selection by selfing of the USDA accession PI 482394). Apart from the melon accessions, an accession belonging to the close African *Cucumis* species *C. metuliferus* (Met-BGV11135Afr), previously used as nematode resistant rootstock for melons, was also evaluated (Exposito et al., 2018).

These eight genotypes were tested in all the artificial inoculation assays and in the natural field assay, where two Piel de Sapo commercial hybrids were also included: 'Don

Quixote' (Sakata) and 'Iberico' (Syngenta), both resistant to *Fusarium oxysporum* f. sp. *melonis*, races 0, 1 and races 0, 1, 2, respectively.

Artificial inoculation assays

The artificial inoculation tests were carried out in a greenhouse at the UPV for three consecutive years (summer of 2015, 2016 and 2017) and with both fungal species, *M. cannonballus* and *M. eutypoides*, in approximately a 40 days period from mid-June to the beginning of August. Through the paper these assays are referred to as the year followed by the initials of the fungal species (i.e., 2015MC, 2015ME, 2016MC, etc.).

Monosporascus spp. inoculum (isolates MC0504 and MT47) was prepared as described by Ben Salem et al. (2015). Wheat seeds were hydrated for 24 hours in water and then the water was removed. About half kilo of wet seeds were distributed to each 1 L glass bottle, which were autoclaved on three successive days at 120ºC for 1 hour and 1 atmosphere pressure. Each bottle was inoculated by introducing 4 disks of the 1 week-old *Monosporascus* spp. PDA cultures. Bottles were incubated at 25ºC for 4 weeks until colonization ended. Bottles were shaken manually when a third part of wheat was colonized to avoid clustering of inoculum.

The wheat seeds inoculum was mixed with the substrate (peat). Firstly, all the bottles inoculated with each isolate (MC0504 and MT47) were poured into a 10 L bowl and mixed manually to homogenize the inoculum. Secondly, all the inoculum and the peat were mixed in the suitable proportions. Once prepared, the mixture of the peat and the wheat seed inoculum was distributed in 0.52 L pots at which the germinated seedlings were transplanted ten days after germinating in Petri dishes. The experimental protocol was a completely randomized design with 8 plants per genotype and per assay (2015MC, 2015ME, 2016MC, 2016ME, 2017MC, 2017ME). A treatment consisting in 4 plants per genotype growing in peat substrate was included as a non-inoculated control.

Plants were grown in a greenhouse at the UPV facilities. Temperature was measured in the greenhouse at 10 minutes intervals to register ambient conditions. The inoculated substrate was sterilized in autoclave after plants evaluation, at 120°C for 90 min and 1 atmosphere pressure.

Disease evaluation

Fifteen and thirty days after transplanting (dat) the vigour of the developing plants was scored using a vigour index (VI) (0 to 4), where 0 = dead plant; 1 = vigour less than 25% of the control plant; 2 = vigour less than 50 % of the control plant; 3 = vigour less than 75% of the plant control; and 4 = more than 75% of the plant control.

At the end of the experiment, the roots were carefully washed to remove the substrate, and evaluated for hypocotyl and root damage using different indices: hypocotyl disease index (HDI), visually scored from 0 to 4, where 0 = healthy with no lesions or discoloration, 1 = slight discoloration, 2 = moderate discoloration and/or with lesions, 3 = moderate maceration, and 4 = severe maceration (Biernacki & Bruton 2000; Dias et al., 2004), and root disease index (RDI), visually scored from 0 to 4, where 0 = no symptoms; 1 = lesions covering less than 10% of the root system/hypocotyl, 2 = rot of secondary roots or lesions covering approximately 25% of the root system/hypocotyl, 3 = lesions covering more than 50% of the root system and dead secondary roots; and 4 = more than 50% of the root is rotted (Ben Salem, Armengol, Berbegal, & Boughalleb-M'Hamdi, 2015). According to previous studies, those plants with average severity indices < 2.5 are considered resistant whereas those > 2.5 are considered susceptible (Dias, Picó, Espinos, & Nuez, 2004).

In addition, vine fresh weight (VFW, g), vine dry weight (VDW, g), vine length (VL, cm), root fresh weight (RFW, g) and root dry weight (RDW, g) were also measured for each plant. The vine and root dry weights were measured after drying plants at 70°C for 2 days.

Digital analysis of root systems.

After scoring, vines were cut and roots extended over a transparent sheet, scanned at high resolution and digitally analyzed using the specific software WinRhizo Pro 2.3 (Regent Instruments Inc., Quebec, Canada). The following parameters were measured using WinRhizo Pro 2.3: total root length (TRL, cm), total projected root area (TPRA, cm^2), average root diameter (ARD, mm), number of tips, forks and crossings.

Natural field inoculation assay

The natural field inoculation test was carried out in Valencia (summer 2016). The selected field was naturally infested with *M. cannonballus* and had a history of MRRVD incidence on melon crops in previous years. The 11 genotypes assayed were placed in 3 blocks, a total of 9 plants per genotype, 3 per block. During the cultivation, VI was evaluated at 15 and 30 days after transplanting (dat), using the scale previously described. At the end of the assay roots were carefully washed to remove the soil, and evaluated for hypocotyl and root damage as described for artificial inoculation analysis.

Re-isolation of *M. cannonballus* and *M. eutypoides* from infected plants

Both species were re-isolated from one plant of each genotype and assay after artificial inoculation, and *M. cannonballus* was re-isolated from field assays. For this purpose,

roots were washed and small root pieces were transferred to Petri dishes containing PDA amended with 0.5 g/L of streptomycin sulfate, which were incubated during 1 week at 25ºC in darkness. All colonies were transferred to PDA plates and incubated at 25ºC in darkness for growth and sporulation.

Data analyses

Statistical analyses were performed using Statgraphics Centurion XVI. The Student's t-test ($p < 0.05$) were carried out to compare root disease index and hypocotyl disease index between each genotype compared to the susceptible control Ib-PsPiñSp, for inoculation with each fungal species and year. Besides that, this same analysis was used to analyze differences between *M. cannonballus* inoculated plants and the non-inoculated control and significant differences between *M. eutypoides* inoculated plants and the non-inoculated control, for each genotype and year, for root and vine weight and length parameters and parameters measured with WinRhizo, for the six artificial inoculation assays.

RESULTS

Artificial inoculation

Mortality and plant development

Clear differences were found among years, regarding temperature during the assay period (Figure 1). Average, average maximum and average minimum temperature were much higher in 2015 between June and August. Thermal regime was similar in 2016 and 2017, except for June, in the initial stages of plant development, when temperatures were higher in 2017.

Mortality at 30 dat caused by both *Monosporascus* species was higher in 2015 for most of the accessions tested (Figure 2). All the plants of the susceptible control, Ib-PsPiñSp, died as a consequence of the inoculation with *M. cannonballus* in this year (2015MC), with percentages of mortality between 50 and 83% in the rest of the genotypes assayed. This year percentages of mortality associated with inoculation with *M. eutypoides* (2015ME) were lower. All plants of Ib-PsPiñSp and Chin-Pat81Ko survived in 2015ME, with mortality for the rest of the genotypes between 16 and 50%. In 2016 and 2017 mortality affected a lower number of genotypes with lower percentages. In fact, mortality in Ib-PsPiñSp was 0 and 40%, respectively in 2016MC and 2017MC, and 0 and 20% in 2016ME and 2017ME, while none of the plants of the resistant control, Chin-Pat81Ko,

died in these assays. Wild African and Asian accessions, showed a behaviour similar to Chin-Pat81Ko after MC inoculation, whereas the remaining genotypes were intermediated between Chin-Pat81Ko and the susceptible control, Ib-PsPiñSp.

Evolution of plant vigour between 15 dat and 30 dat differed when comparing the year and the fungal species used for inoculation (Figure 3). In 2015, when temperatures and plant mortality were higher, vigour index for most of the accessions and with both species, either was similar or decreased between 15 dat and 30 dat. The tendency for most of the accessions in 2016, with milder temperatures and lower mortality percentages, was an increase in vigour index with time for both, *M. cannonballus* and *M. eutypoides*. In the 2017 assay, in which the temperatures in the initial stages of plant development were intermediate between 2015 and 2016, the response depended on the fungal species: in plants inoculated with *M. cannonballus* vigour index was similar between 15 dat and 30 dat for most of the accessions, while for plants inoculated with *M. eutypoides* there was an increase in vigour at 30 dat.

Plants of most genotypes inoculated with *M. eutypoides* showed higher vigour index than those inoculated with *M. cannonballus*, with few exceptions (Figure 3). The most severe assay conditions were in 2015MC, i.e. high temperature with the most aggressive species, *M. cannonballus*. In these conditions, the susceptible control, Ib-PsPiñSp, exhibited lower vigour index than the rest of the accessions, while the highest vigour was shown by F1Pat81xPs. The vigour index in wild accessions was intermediate between Ib-PsPiñSp and F1Pat81xPs at 30 dat in these conditions. The response was similar in 2017MC, although with higher vigour for all the genotypes. Chin-Pat81Ko developed the most vigorous plants along with their F1 Pat 81xPs. Differences between the genotypes were less accused with milder conditions, i.e., the moderate temperatures of 2016 and/or inoculation with *M. eutypoides.* With these conditions, plant vigour did not seem to discriminate between susceptible and resistant accessions.

The plant vigour index was positively correlated to vine fresh and dry weight and to vine length at 30 dat (Supplementary table 1). Correlations were higher in the three *M. cannonballus* assays (r^2 = 0.49 to 0.61, 0.29 to 0.37 and 0.51 to 0.63 with $p < 0.01$, respectively for 2015, 2016 and 2017) than in *M. eutypoides* assay (ns for 2015 and 2017 and r^2 = 0.38 to 0.46 $p < 0.01$ for 2016), where less differences in vigour among genotypes were observed. Fungal infection resulted in a significant decrease in vine weight and length, observed when comparing inoculated plants with respect to the non-inoculated

controls (Supplementary table 2). These losses were, in average, higher at each year in plants inoculated with *M. cannonballus* with respect to plants inoculated with *M. eutypoides* this same year. Moreover, differences were observed among years, being more pronounced in 2015, accordingly to the warmer temperatures. The susceptible control, Ib-PsPiñSp, showed the highest losses, particularly in the case of inoculations with *M. cannonballus*.

Root damage

Differences in plant development were associated to differences in root damage. In figure S3 photograph of a root system per genotype, treatment and assay is included, showing root development and fungal damage on roots.

Higher root disease indices (RDI) were observed in roots from assays of 2015 (2015MC and 2015ME), when compared with assays in 2016 and 2017, for most of the accessions assayed (Figure 4a). As previously stated, MC2015 represented the most unfavourable conditions. In the susceptible control, Ib-PsPiñSp, it was not possible to score RDI that year, given that mortality was 100%. Average RDI in the resistant control, Pat81, in 2015MC was higher than 3. In fact, the only accession with lower RDI (< 2.5) in MC2015 was *C. metuliferus*. Root damage caused by *M. eutypoides* in 2015ME, was significantly lower for most of the accessions, with respect to 2015MC, which indicated the lower aggressiveness of *M. eutypoides*, even in unfavourable conditions The genotypes with the more damaged roots (RDI > 2.5) were the susceptible control, Ib-PsPiñSp, and the Indian *agrestis* wild type Agr-TriInd. The resistant control, Chin-Pat81Ko, and the wild African *agrestis* Agr-15991Gha, showed the best response (RDI < 1.5).

In 2016 and 2017 the assays took place in milder conditions. In 2016MC and 2017MC, RDI was significantly higher in the susceptible control, Ib-PsPiñSp, when compared with the rest of the accessions assayed (Figure 4a). In 2016MC the response in the rest of the accessions, all with low RDI index, was similar (RDI from 0.4 to 1.5). In 2017MC, the remaining accessions were still resistant, but differences were identified between some of them (Figure 4a). Chin-Pat81Ko showed the lowest RDI (0.25), followed by F1 Pat81xPs and Agr-15991Gha (both with RDI < 1). The results in 2016 and 2017 confirmed the lower aggressiveness of *M. eutypoides*. Despite the lower root damage in Ib-PsPiñSp, RDI in this susceptible control was higher than that of most of the remaining

genotypes in both assays (RDI 2 *versus* 0 to 1.89 and RDI 1.3 *versus* 0.3 to 1 in Ib-PsPiñSp and the remaining genotypes in ME2016 and ME 2017, respectively).

Similar results were found for Hypocotyl disease index (HDI) (Figure 4b). Correlation between HDI and RDI was significant for all the assays, but was higher in the inoculations with *M. cannonballus* (values ranging from 0.84-0.97 in MC *versus* 0.48-0.85 in ME, in all cases $p < 0{,}0002$) (Supplementary Table 1). The highest correlation values corresponded to the assay with the more severe conditions in inoculations with *M. cannonballus* (2015MC) (those plants with severely affected roots showed also severe lesions in hypocotyls), and the lowest in 2015ME. In fact, the high-pressure conditions in 2015 were enough for *M. eutypoides* to cause root damage higher than that of 2016 and 2017, but not enough to cause important hypocotyls lesions. Lesions in hypocotyls caused by the two pathogens were similar under low-pressure conditions in 2016 and 2017 assays (Figure 4b).

Significant negative correlations were found between RDI, and in some cases HDI, and Root fresh weight (supplementary Table 1), higher in the most severe assays of 2015 (r^2 = -0.63 and -0.47 $p < 0.001$ for MC and ME respectively), but also significant in 2016 (r^2= -0.33 and -0.45). In 2017, they were not significant, but RDI negatively correlated to plant vigour at 15 dat in both species (r^2 = -0.62 and -0.50 for MC and ME, respectively). Therefore, under severe infection, root damage results in severely root losses, and under less severe conditions, the observation of root lesions is associated to a decrease in plant development, even when root losses are not yet apparent. Supplementary Table 2 shows Root fresh and dry weight decrease in inoculated plants with respect to the non-inoculated plants. Reduction was higher in assays inoculated with *M. cannonballus* and with higher temperatures, and higher reductions on average in the susceptible control Ib-PsPiñSp.

Root image analysis allowed a more detailed characterization of root systems. All the parameters measuring root size (TRL, TPRA, TRSA, and TRV) were highly correlated ($r^2 > 0.9059$, $p < 0.00001$), as well as all related to the level of root branching (tips, crossings and forks) (0.7293, $p < 0.00001$). Interestingly there was a high positive correlation between root weight and all WhinRhizo´s parameters related to root size and branching, suggesting that root lesions lead to root pruning, affecting root structure. This effect was observed with both pathogens.

It was possible to re-isolate the corresponding fungal species (*M. cannonballus* or *M. eutypoides*) from one plant of each genotype in each of the assays (an example is provided in Supplementary Figure S3).

Field response

The same accessions artificially inoculated in the three assays, were tested in field conditions in 2016. Two F1 hybrids of the Piel de sapo market class were also included. For most of the accessions, plant vigour increased between 15 and 30 dat (Figure 5). Only in the most susceptible ones, Ib-PsPiñSp and 'Don Quixote', there was a slight decrease in vigour with time. The highest vigour indices corresponded to F1 Pat81xPs, whereas the lowest values corresponded to the commercial Piel de Sapo hybrids 'Don Quixote' and 'Iberico'. Plant vigour was consistent with root damage, being the susceptible control Ib-PsPiñSp and 'Iberico' scored with the highest RDI, thus showing the susceptibility of this F1 hybrid. Among the wild accessions, the Indian agrestis wild type Agr-TriInd was the only one with significantly higher RDI than the resistant control, Chin-Pat81Ko. The African wild *agrestis* and acidulus accessions, Ag-15591Gha and AcTGR139Zimb, as well as the African wild relative *C. metuliferus* behaved similarly to the resistant control. Also the F1 Pat 81xPs hybrid had a very good resistant response under field conditions.

M. cannonballus was re-isolated from one plant of each genotype.

DISCUSSION

Monosporascus root rot and vine decline can be caused by *M. cannonballus* and *M. eutypoides*, but most of the previous studies dealing with this disease focused only on *M. cannonballus,* which has a wider geographical distribution (Ben Salem et al., 2013; Reuveni, Krikun, & Shani, 1983). In fact, this is the first research evaluating the response of different genotypes of *C. melo* spp. *agrestis* to inoculation with *M. eutypoides*. Symptoms produced by MRRVD, root lesions and the occurrence of vine collapse, are highly dependent on several factors, such as temperature, method of inoculation or cultural practices, among others (Fita, Picó, Roig, & Nuez, 2007;Martyn, 2007). These factors difficult the selection of the best resistant sources in breeding programs.

In the work here presented, evaluations with artificial inoculation were carried out in three different years, representing different environmental conditions, and testing the

aggressiveness of both species, *M cannonballus* and *M. eutypoides*, on a selection of genotypes with different levels of resistance.

In all the conditions assayed, aggressiveness shown by *M. eutypoides* was lower than that exhibited by *M. cannonballus*. Despite the low aggressiveness, this pathogen was able to cause moderate root lesions. These mild root damage was similar in MRRVD susceptible and resistant genotypes under moderate temperature conditions (even the susceptible control Ib-PsPiñSp behaved as tolerant), and only under high temperature stressful conditions, root lesions were more severe in susceptible genotypes. Even, under these stressful conditions, the moderate root damage had a low impact on plant development and did not result in plant death. In a previous study, Ben Salem et al. (2013), in a pathogenicity test with different isolates of *M. cannonballus* and *M. eutypoides* did not found significant differences between the pathogenic isolates of both species. The different conditions used in these assays could explain these discrepancies. In fact, in our assay differences between both species were not so important in the 2016 assay, with the low temperatures.

Apart from the species effect, the results obtained support the strong influence of temperature conditions on this disease. Previous studies have reported that high ambient temperatures late in the growing season (Bruton, García-Jiménez, & Armengol,1999; Wolff, 1996; Wolff, Leskovar, Black, & Miller, 1997), as well as temperatures above 20ºC during the first 30 days after planting (Pivonia, Cohen, Kigel, & Katan, 2002), are associated with a more severe canopy collapse caused by *M. cannonballus*. Our results also confirmed the effect of high temperatures (for both fungal species) on root and vine symptoms. The effect of the more aggressive species (*M. cannonballus*) on roots varied with temperature, with highly severe to moderate and milder symptoms in assays conducted at high (2015), moderate (2017) or lower (2016) temperatures, respectively. *M. cannonballus* root lesions affected plant development at both high and moderate temperature assay conditions, whereas *M. eutypoides* only interfered with plant growth at high temperatures.

Our assays also confirmed the utility of the root disease indices, especially RDI that correlated better to plant and root development, as well as several parameters measured with WhinRhizo Pro in disease assessment. High and significant correlations were identified between parameters related to root development and between parameters related to root structure. Similar results were reported previously (Fita, Picó, Roig, &

Nuez, 2007). Thus, it would be possible to reduce the number of parameters considered in the analysis. Moreover, correlation between both, RDI and HDI, with root development and root structure parameters measured with WhinRhizo Pro were significant for both fungal species with the thermal regimes in 2015 and 2016. These results imply that with certain environmental conditions in artificial inoculation assays, it would be possible to use objective parameters in disease evaluation, instead of the score systems. As previously stated, visual score systems are time consuming, require skilled expertise and are subjective measurements that depend on the observer (Fita, Picó, & Nuez, 2007b). The use of image system evaluation can complement the score evaluation with more objective measurements, highly correlated with disease indexes.

Screening assays aimed at the identification of tolerance or resistance to collapse caused by *M. cannonballus* have been carried out in different conditions (Crosby, 2000a; Crosby, Wolff, & Miller, 2000; Esteva & Nuez, 1994; Sales Júnior, Senhor, Michereff, & Negreiros, 2019; Wolff, 1995; Wolff & Miller, 1998). However, very few resistance sources have been identified so far. A recent screening of commercial melon cultivars under natural *M. cannonballus*-infested soils in Brazil has attributed the difficulty in identifying resistant sources to the aggressiveness of the pathogen (Sales Júnior, Senhor, Michereff, & Negreiros, 2019). The influence of the environmental factors in the expression of symptoms has also been reported as hindering the identification of resistance sources (Cohen et al., 2000; Fita, Picó, Monforte, & Nuez, 2008). In the artificial inoculation assays presented here, RDI was high for all the accession in 2015MC, while with milder conditions, most of them were considered resistant. Extremely high disease pressure in artificial inoculation assays has been described as restricting performance of genotypes that grow well in the field. On the contrary, good performance under greenhouse conditions does not always imply good response in field (Crosby, 2000b). The resistance of all the accessions found resistant in our inoculation assays was confirmed in field conditions, with the only exception of Ag-TriInd, which was not resistant under field conditions. However, consistently, this Indian wild *agrestis* was the only agrestis type that showed RDI > 3 (considered susceptible) in the high pressure assay of 2015 with *M. cannonballus.*

Resistance under field and artificial inoculation conditions has been confirmed in the 'Pat 81' source and in their derived F1 with Piel de Sapo ((Dias, Picó, Espinos, & Nuez, 2004; Iglesias, Picó, & Nuez, 2000a; Roig, Fita, Ríos, Hammond, Nuez, & Picó, 2012)), but

also in new germplasm, originated from Africa. Among the most interesting sources are Ag-15591Gha that represented the group of wild African *agrestis*, molecularly different from that of Indian wild types (Endl et al., 2018; Gonzalo et al., 2019), and the African acidulus accession Ac-TGR139Zimb. These accessions showed a similar behavior to 'Pat 81' in all artificial inoculation assays, although with higher RDI in MC inoculations, but showed a very good performance under field conditions. The spp. *agrestis* has been reported as an interesting source for pathogen resistance in melon breeding (Pitrat, 2017). Both wild accessions and acidulus accessions have been proven useful, such as the multiresistant TGR-1551, resistant to powdery mildew caused by *Podosphaera xanthii* (Yuste-Lisbona, López-Sesé, Gómez-Guillamón, & 2009), to the yellowing caused by *Cucurbit yellow stunting disorder virus* (López-Sesé & Gómez-Guillamón, 2000) and to *Watermelon mosaic virus* (Díaz-Pendón et al., 2003). These accessions can be easily used in breeding programs as they belong to the *C. melo* species and there are no compatibility problems with commercial melons.

Also interesting is the behaviour of the close relative *C. metuliferus*. The accession Met-BGV11135Afr behaved as resistant in both, artificial inoculation and field assays presented here, even with RDI lower than Pat 81 under high-pressure conditions, although with high HDI in fields. *C. metuliferus* cannot be crossed to *C. melo* so its interest mainly relies in its advantages as a rootstock for melon, without effects on plant growing and melon fruit quality. Moreover, this accession shows resistance to Fusarium wilt (Gisbert et al., 2014) as well as to different root-knot nematode isolates (Expósito et al., 2018). Confirmation of resistance to MRRVD increases the interest for the potential use of this accession as melon rootstock.

The Brazilian Landrace La-PE4Bra has previously been reported as promising source of resistance to different pathogens (Dantas, Holanda, Esteras, Nunes, & Picó, 2005). and showed tolerance to MRRVD in Brazilian infested soils (Dr. Nunes, personal communication). Our field results also confirm god behavior in Spanish fields, but under artificial inoculation, root damage was more severe than in the *agrestis* sources.

The accessions selected here can be useful for breeding new melon cultivars and rootstocks resistant to the two main pathogens involved in MRRVD, *M. cannonballus* and *M. eutypoides*.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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SUPPORTING INFORMATION

TABLE S1 Correlations between vigour, root and vine weight and length parameters, disease indices and parameters measured with WinRhizo, for the six artificial inoculation assays

TABLE S2 Root and vine weight and length parameters, disease indices and parameters measured with WinRhizo, for the six artificial inoculation assays

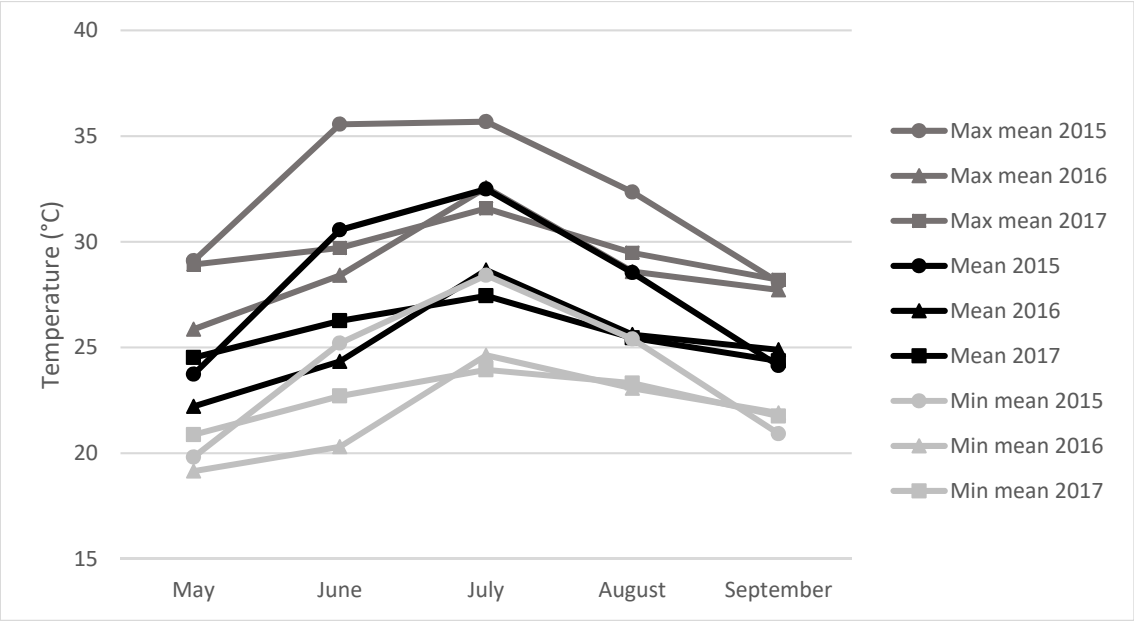


FIGURE 1 Greenhouse temperatures in the artificial inoculation assays: mean temperature, mean of the daily maximum temperatures and mean of the daily minimum temperatures

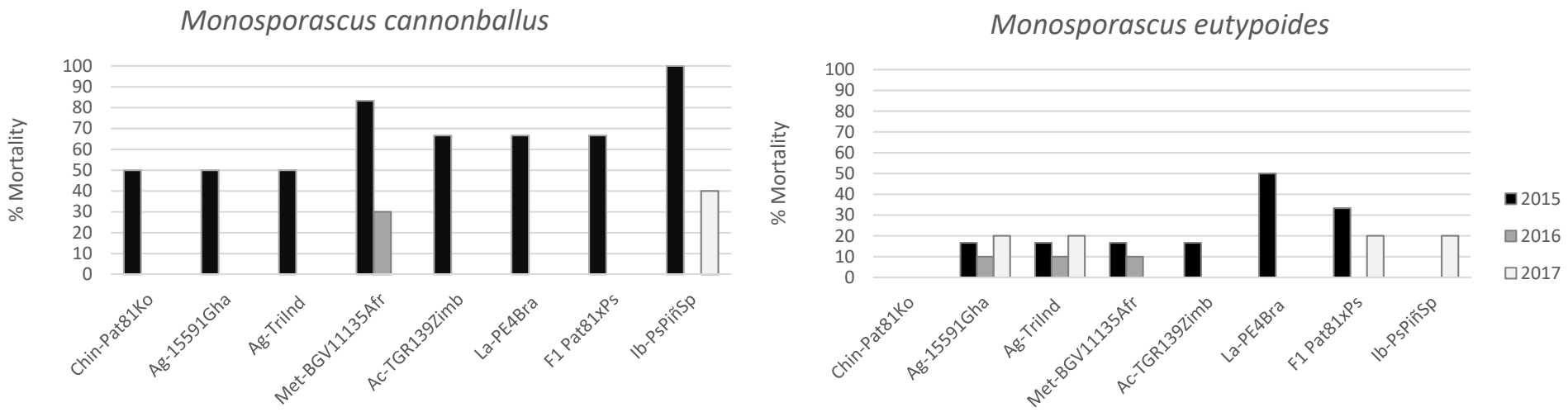


FIGURE 2 Percentage of dead plants in the three artificial inoculation assays at 30 days after transplanting

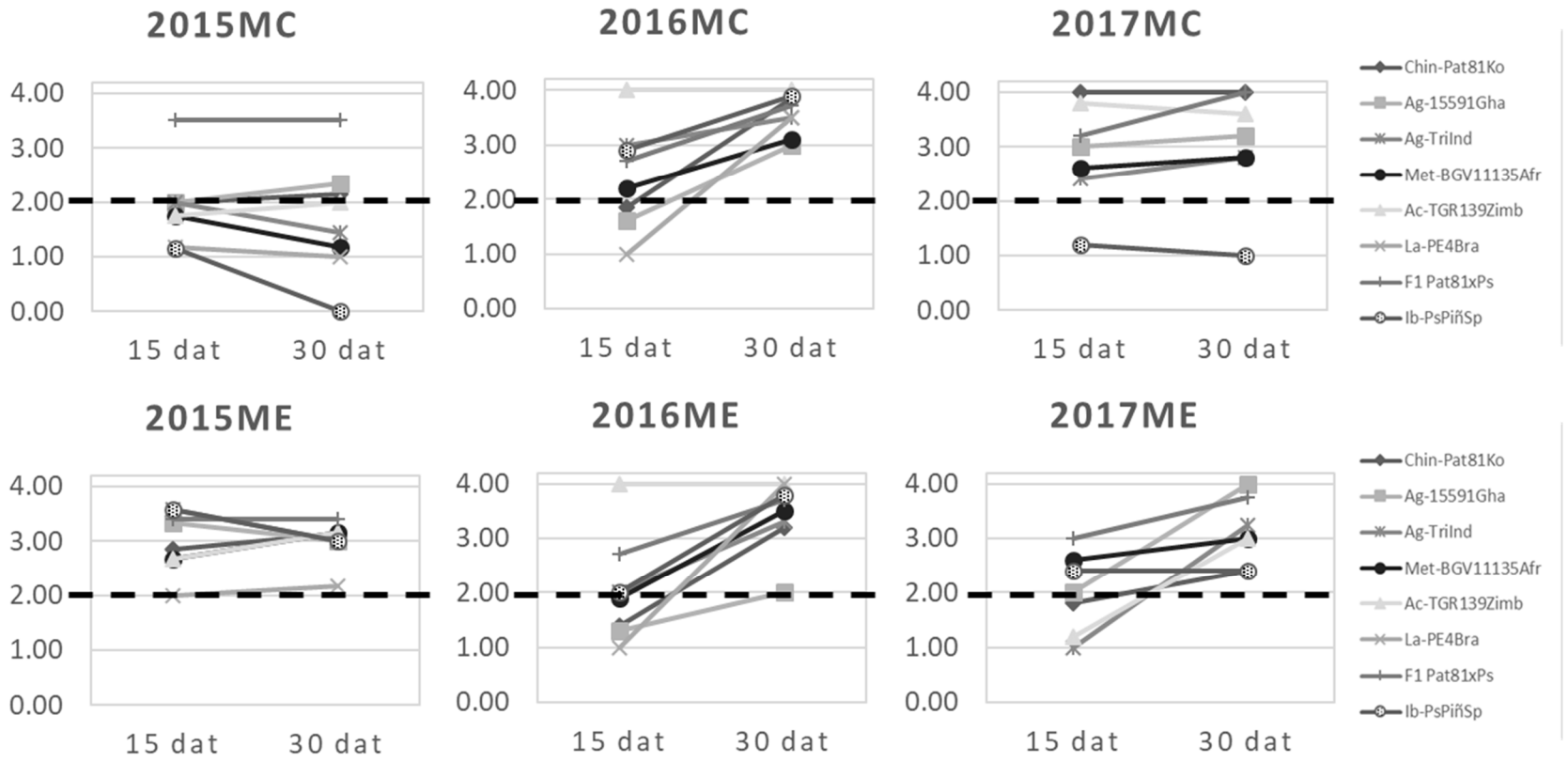
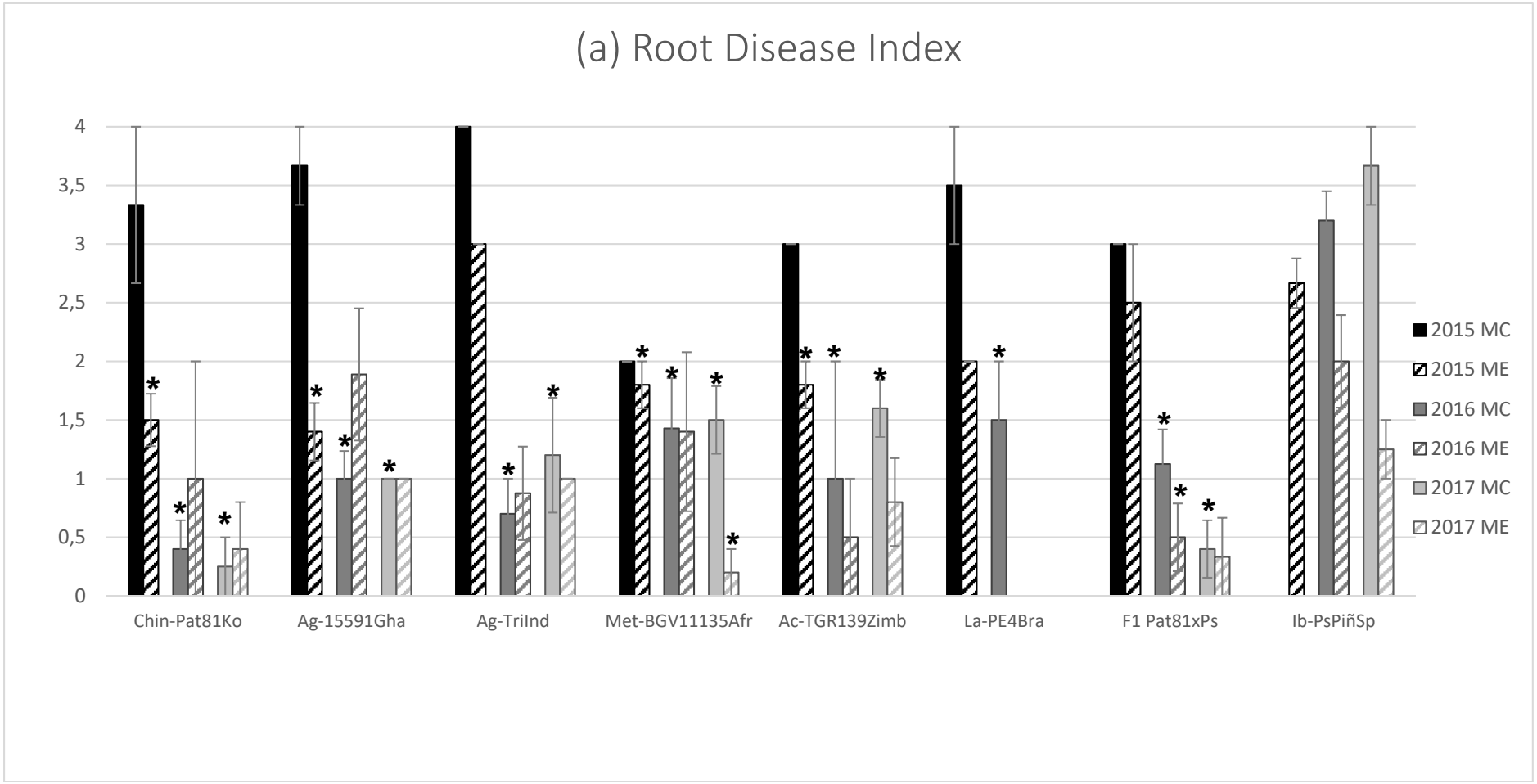


FIGURE 3 Evolution of plant vigour (0-4, see text for description) in the three artificial inoculation assays at 15 and 30 days after transplanting (dat)


(a) Root Disease Index
4
3,5
3
2,5
2
1,5
1
0,5
0
Chin-Pat81Ko
Ag-15591Gha
Ag-TriInd
Met-BGV11135Afr
Ac-TGR139Zimb
La-PE4Bra
F1 Pat81xPs
Ib-PsPiñSp
2015 MC
2015 ME
2016 MC
2016 ME
2017 MC
2017 ME

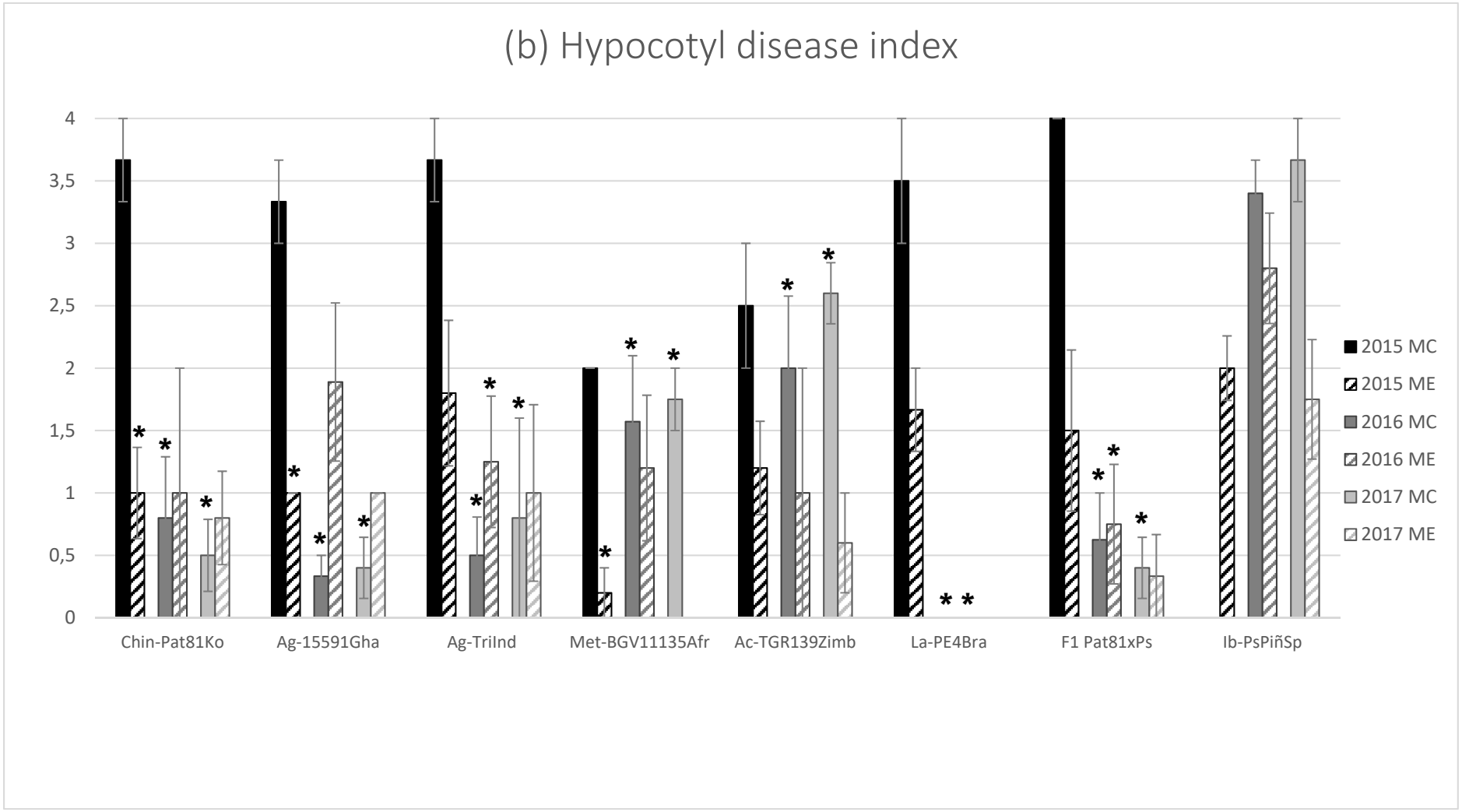
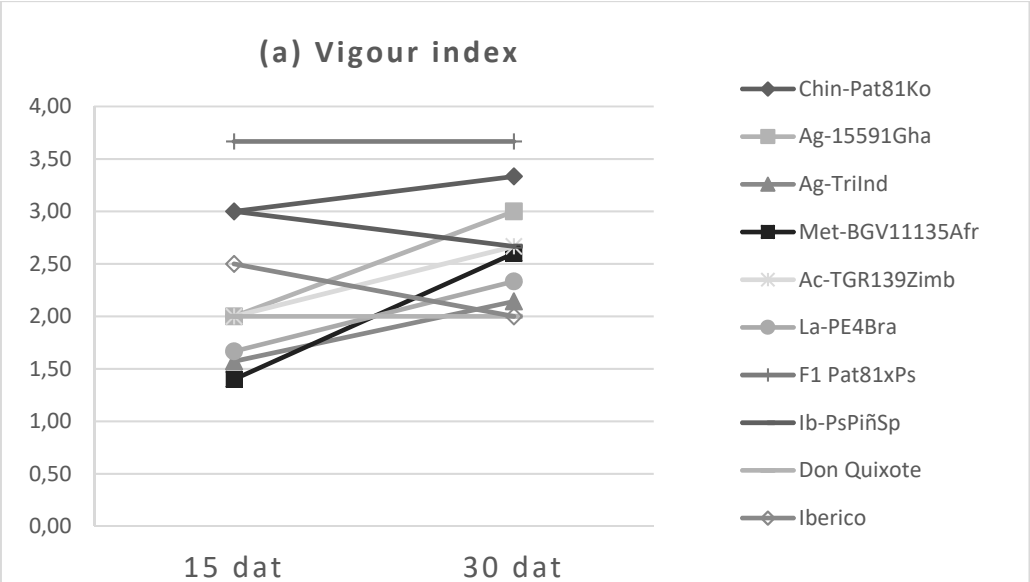
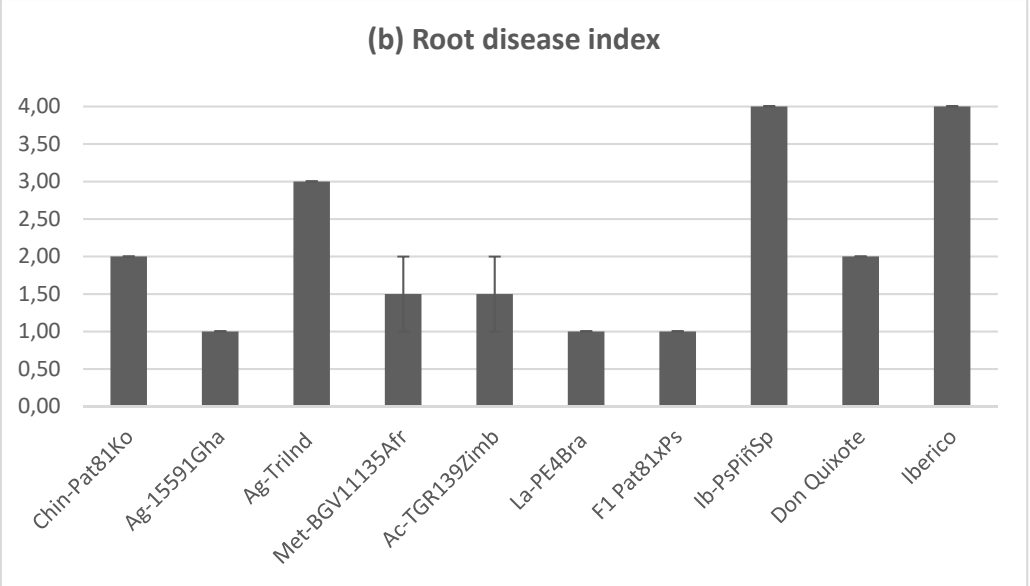

(b) Hypocotyl disease index
4
3,5
3
2,5
2
1,5
1
0,5
0
Chin-Pat81Ko
Ag-15591Gha
Ag-TriInd
Met-BGV11135Afr
Ac-TGR139Zimb
La-PE4Bra
F1 Pat81xPs
Ib-PsPiñSp
2015 MC
2015 ME
2016 MC
2016 ME
2017 MC
2017 ME

FIGURE 4 (a) Root disease index (0-4, see text for description); (b) Hypocotyl disease index (0 to 4, see text for description). Asterisk denotes significant differences between each genotype compared to the susceptible control Ib-PsPiñSp, for inoculation with each fungal species and year ($p < 0.05$, Student's t test). Error bars represent standard error. MC = *Monosporascus cannonballus*, ME = *Monosporascus eutypoides*


(a) Vigour index
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
15 dat
30 dat
Chin-Pat81Ko
Ag-15591Gha
Ag-TriInd
Met-BGV11135Afr
Ac-TGR139Zimb
La-PE4Bra
F1 Pat81xPs
Ib-PsPiñSp
Don Quixote
Iberico


(b) Root disease index
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Chin-Pat81Ko
Ag-15591Gha
Ag-TriInd
Met-BGV11135Afr
Ac-TGR139Zimb
La-PE4Bra
F1 Pat81xPs
Ib-PsPiñSp
Don Quixote
Iberico

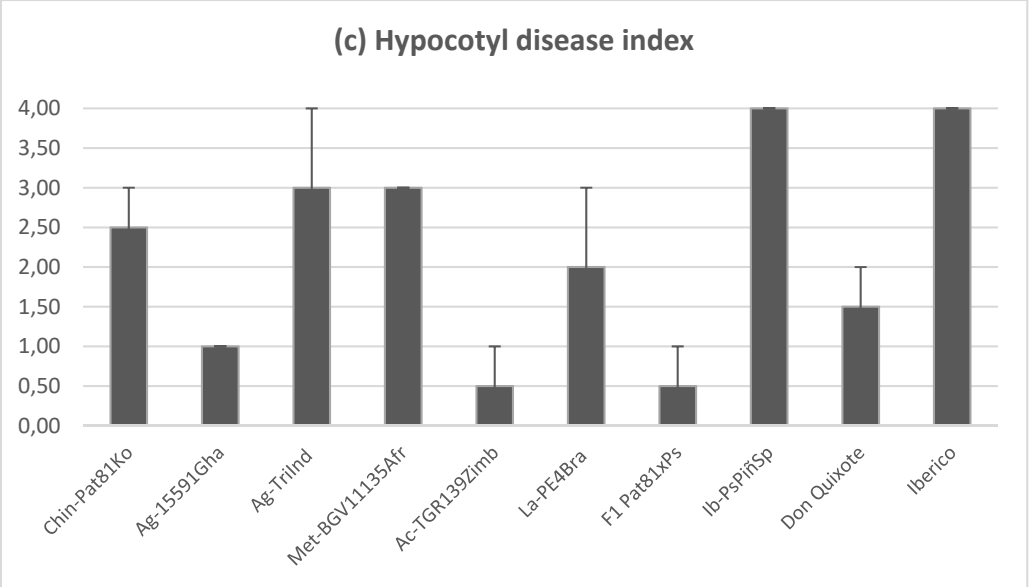

(c) Hypocotyl disease index
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Chin-Pat81Ko
Ag-15591Gha
Ag-TriInd
Met-BGV11135Afr
Ac-TGR139Zimb
La-PE4Bra
F1 Pat81xPs
Ib-PsPiñSp
Don Quixote
Iberico

FIGURE 5 Field assay: (a) Evolution of plant vigour at 15 and 30 days after transplanting (dat). (b) Root disease index. (c) Hypocotyl disease index; the three indices were evaluated from 0 to 4 (see text for description). Error bars represent standard error

Table S1. Correlations (and significance values, below; p<0.05 highlighted in grey) between vigour, root and vine weight and length parameters, disease indeces and parameters measured with WinRhizo, for the six artificial inoculation assays (each assay in the correspondign sheet).

2015MC

	Vigour 15 dat	Vigour 30 dat	VFW	VDW	VL	HDI	RDI	RFW	RDW	TRL	TPRA	ARD	Tips	Forks	Crossings
Vigour 15 dat		0,9569	0,4527	0,5793	0,5338	-0,6474	-0,7291	0,2258	0,3166	0,4088	0,3609	-0,4518	0,3866	0,391	0,4047
		<0,0001	0,0082	0,0004	0,0014	<0,0001	<0,0001	0,214	0,0726	0,0182	0,0391	0,0083	0,0263	0,0245	0,0195
Vigour 30 dat	0,9569		0,4888	0,605	0,5663	-0,6833	-0,7692	0,297	0,3727	0,4468	0,4105	-0,3618	0,4165	0,425	0,4287
	<0,0001		0,0039	0,0002	0,0006	<0,0001	<0,0001	0,0988	0,0327	0,0091	0,0177	0,0385	0,0159	0,0137	0,0128
VFW	0,4527	0,4888		0,8321	0,6739	-0,7452	-0,7357	0,7288	0,7053	0,4938	0,55	-0,0779	0,3829	0,4573	0,4092
	0,0082	0,0039		<0,0001	<0,0001	<0,0001	<0,0001	<0,0001	<0,0001	0,0035	0,0009	0,6667	0,0279	0,0075	0,018
VDW	0,5793	0,605	0,8321		0,7023	-0,7697	-0,7626	0,4763	0,762	0,4005	0,4591	-0,1744	0,2856	0,373	0,3194
	0,0004	0,0002	<0,0001		<0,0001	<0,0001	<0,0001	0,0059	<0,0001	0,0209	0,0072	0,3316	0,1072	0,0325	0,07
VL	0,5338	0,5663	0,6739	0,7023		-0,8159	-0,8011	0,6229	0,6856	0,6369	0,6201	-0,3257	0,6065	0,6264	0,6226
	0,0014	0,0006	<0,0001	<0,0001		<0,0001	<0,0001	0,0001	<0,0001	0,0001	0,0001	0,0644	0,0002	0,0001	0,0001
HDI	-0,6474	-0,6833	-0,7452	-0,7697	-0,8159		0,9697	-0,6626	-0,6221	-0,6162	-0,6277	0,3311	-0,5411	-0,5784	-0,551
	<0,0001	<0,0001	<0,0001	<0,0001	<0,0001		<0,0001	<0,0001	0,0001	0,0001	0,0001	0,0598	0,0011	0,0004	0,0009
RDI	-0,7291	-0,7692	-0,7357	-0,7626	-0,8011	0,9697		-0,6259	-0,6221	-0,6132	-0,6207	0,3494	-0,5423	-0,5771	-0,5517
	<0,0001	<0,0001	<0,0001	<0,0001	<0,0001	<0,0001		0,0001	0,0001	0,0001	0,0001	0,0462	0,0011	0,0004	0,0009
RFW	0,2258	0,297	0,7288	0,4763	0,6229	-0,6626	-0,6259		0,5029	0,6033	0,6171	-0,084	0,6193	0,6188	0,5801
	0,214	0,0988	<0,0001	0,0059	0,0001	<0,0001	0,0001		0,0034	0,0003	0,0002	0,6477	0,0002	0,0002	0,0005
RDW	0,3166	0,3727	0,7053	0,762	0,6856	-0,6221	-0,6221	0,5029		0,4006	0,4706	-0,1164	0,3118	0,3677	0,3071
	0,0726	0,0327	<0,0001	<0,0001	<0,0001	0,0001	0,0001	0,0034		0,0209	0,0057	0,5189	0,0773	0,0353	0,0822
TRL	0,4088	0,4468	0,4938	0,4005	0,6369	-0,6162	-0,6132	0,6033	0,4006		0,9839	-0,3047	0,9717	0,99	0,9786
	0,0182	0,0091	0,0035	0,0209	0,0001	0,0001	0,0001	0,0003	0,0209		<0,0001	0,0847	<0,0001	<0,0001	<0,0001
TPRA	0,3609	0,4105	0,55	0,4591	0,6201	-0,6277	-0,6207	0,6171	0,4706	0,9839		-0,2329	0,9263	0,965	0,9334
	0,0391	0,0177	0,0009	0,0072	0,0001	0,0001	0,0001	0,0002	0,0057	<0,0001		0,1921	<0,0001	<0,0001	<0,0001
ARD	-0,4518	-0,3618	-0,0779	-0,1744	-0,3257	0,3311	0,3494	-0,084	-0,1164	-0,3047	-0,2329		-0,3292	-0,2861	-0,3123
	0,0083	0,0385	0,6667	0,3316	0,0644	0,0598	0,0462	0,6477	0,5189	0,0847	0,1921		0,0614	0,1066	0,0769
Tips	0,3866	0,4165	0,3829	0,2856	0,6065	-0,5411	-0,5423	0,6193	0,3118	0,9717	0,9263	-0,3292		0,987	0,9916
	0,0263	0,0159	0,0279	0,1072	0,0002	0,0011	0,0011	0,0002	0,0773	<0,0001	<0,0001	0,0614		<0,0001	<0,0001
Forks	0,391	0,425	0,4573	0,373	0,6264	-0,5784	-0,5771	0,6188	0,3677	0,99	0,965	-0,2861	0,987		0,9916
	0,0245	0,0137	0,0075	0,0325	0,0001	0,0004	0,0004	0,0002	0,0353	<0,0001	<0,0001	0,1066	<0,0001		<0,0001
Crossings	0,4047	0,4287	0,4092	0,3194	0,6226	-0,551	-0,5517	0,5801	0,3071	0,9786	0,9334	-0,3123	0,9916	0,9916	
	0,0195	0,0128	0,018	0,07	0,0001	0,0009	0,0009	0,0005	0,0822	<0,0001	<0,0001	0,0769	<0,0001	<0,0001	

ABBREVIATIONS

dat	days after transplanting
VFW	vine fresh weight (g)
VDW	vine dry weight (g)
VL	vine length (cm)
HDI	hypocotyl disease index (0-4)
RDI	root disease index (0-4)
RFW	root fresh weight (RFW, g)
RDW	root dry weight (RDW, g)
TRL	total root length (TRL, cm),
TPRA	total projected root area (TPRA, cm^2),
ARD	average root diameter (ARD, mm),
Tips	number of tips
Forks	number of forks
Crossings	number of crossings

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2016MC

	Vigour 15 dat	Vigour 30 dat	VFW	VDW	VL	HDI	RDI	RFW	RDW	TRL	TPRA	ARD	Tips	Forks	Crossings
Vigour 15 dat		0,4303	0,3116	0,3934	0,3352	-0,0151	-0,198	0,2786	0,2299	0,3516	0,3496	0,0566	0,2611	0,3007	0,3001
		0,0001	0,0077	0,0006	0,004	0,8981	0,0908	0,0162	0,0487	0,0023	0,0024	0,6342	0,0257	0,0097	0,0099
Vigour 30 dat	0,4303		0,2854	0,348	0,3695	-0,2086	-0,3271	0,3056	0,113	0,2874	0,2881	0,1228	0,2434	0,2566	0,2522
	0,0001		0,0151	0,0027	0,0014	0,0745	0,0045	0,0081	0,3379	0,0137	0,0134	0,3007	0,038	0,0285	0,0314
VFW	0,3116	0,2854		0,6079	0,4098	-0,2793	-0,3343	0,568	0,2497	0,4267	0,472	0,2737	0,3279	0,339	0,2941
	0,0077	0,0151		<0,0001	0,0004	0,0175	0,0041	<0,0001	0,0344	0,0002	<0,0001	0,0209	0,0052	0,0038	0,0128
VDW	0,3934	0,348	0,6079		0,3551	-0,1269	-0,2271	0,5114	0,2344	0,4218	0,4526	0,2844	0,3913	0,4062	0,3819
	0,0006	0,0027	<0,0001		0,0022	0,2882	0,055	<0,0001	0,0475	0,0002	0,0001	0,0162	0,0007	0,0004	0,001
VL	0,3352	0,3695	0,4098	0,3551		-0,2597	-0,3183	0,2046	0,0908	0,3736	0,3851	0,1653	0,2911	0,2911	0,2643
	0,004	0,0014	0,0004	0,0022		0,0276	0,0064	0,0848	0,4481	0,0013	0,0009	0,1684	0,0138	0,0138	0,0259
HDI	-0,0151	-0,2086	-0,2793	-0,1269	-0,2597		0,8375	-0,2588	-0,1464	-0,3162	-0,3395	-0,0876	-0,2377	-0,2316	-0,1881
	0,8981	0,0745	0,0175	0,2882	0,0276		<0,0001	0,026	0,2131	0,0064	0,0033	0,4611	0,0429	0,0486	0,111
RDI	-0,198	-0,3271	-0,3343	-0,2271	-0,3183	0,8375		-0,3274	-0,1897	-0,4057	-0,4073	0,0167	-0,345	-0,2981	-0,267
	0,0908	0,0045	0,0041	0,055	0,0064	<0,0001		0,0044	0,1054	0,0004	0,0003	0,8884	0,0028	0,0104	0,0224
RFW	0,2786	0,3056	0,568	0,5114	0,2046	-0,2588	-0,3274		0,1865	0,7351	0,797	0,336	0,7153	0,7644	0,7003
	0,0162	0,0081	<0,0001	<0,0001	0,0848	0,026	0,0044		0,1117	<0,0001	<0,0001	0,0037	<0,0001	<0,0001	<0,0001
RDW	0,2299	0,113	0,2497	0,2344	0,0908	-0,1464	-0,1897	0,1865		0,2822	0,2742	0,0293	0,272	0,2647	0,2935
	0,0487	0,3379	0,0344	0,0475	0,4481	0,2131	0,1054	0,1117		0,0156	0,0189	0,8058	0,0199	0,0236	0,0117
TRL	0,3516	0,2874	0,4267	0,4218	0,3736	-0,3162	-0,4057	0,7351	0,2822		0,9784	0,015	0,9682	0,9617	0,9392
	0,0023	0,0137	0,0002	0,0002	0,0013	0,0064	0,0004	<0,0001	0,0156		<0,0001	0,8998	<0,0001	<0,0001	<0,0001
TPRA	0,3496	0,2881	0,472	0,4526	0,3851	-0,3395	-0,4073	0,797	0,2742	0,9784		0,1943	0,9254	0,9623	0,9133
	0,0024	0,0134	<0,0001	0,0001	0,0009	0,0033	0,0003	<0,0001	0,0189	<0,0001		0,0995	<0,0001	<0,0001	<0,0001
ARD	0,0566	0,1228	0,2737	0,2844	0,1653	-0,0876	0,0167	0,336	0,0293	0,015	0,1943		-0,0618	0,1126	0,0001
	0,6342	0,3007	0,0209	0,0162	0,1684	0,4611	0,8884	0,0037	0,8058	0,8998	0,0995		0,6032	0,3429	0,9993
Tips	0,2611	0,2434	0,3279	0,3913	0,2911	-0,2377	-0,345	0,7153	0,272	0,9682	0,9254	-0,0618		0,9501	0,9451
	0,0257	0,038	0,0052	0,0007	0,0138	0,0429	0,0028	<0,0001	0,0199	<0,0001	<0,0001	0,6032		<0,0001	<0,0001
Forks	0,3007	0,2566	0,339	0,4062	0,2911	-0,2316	-0,2981	0,7644	0,2647	0,9617	0,9623	0,1126	0,9501		0,9805
	0,0097	0,0285	0,0038	0,0004	0,0138	0,0486	0,0104	<0,0001	0,0236	<0,0001	<0,0001	0,3429	<0,0001		<0,0001
Crossings	0,3001	0,2522	0,2941	0,3819	0,2643	-0,1881	-0,267	0,7003	0,2935	0,9392	0,9133	0,0001	0,9451	0,9805	
	0,0099	0,0314	0,0128	0,001	0,0259	0,111	0,0224	<0,0001	0,0117	<0,0001	<0,0001	0,9993	<0,0001	<0,0001	

ABBREVIATIONS

dat	days after transplanting
VFW	vine fresh weight (g)
VDW	vine dry weight (g)
VL	vine length (cm)
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2017MC

	Vigour 15 dat	Vigour 30 dat	VFW	VDW	VL	HDI	RDI	RFW	RDW	TRL	TPRA	ARD	Tips	Forks	Crossings
Vigour 15 dat		0,7896	0,5679	0,5843	0,4035	-0,5322	-0,6212	0,5069	0,2418	0,4125	0,2391	-0,2612	0,5375	0,2814	0,3473
		<0,0001	0,0001	<0,0001	0,0066	0,0002	<0,0001	0,0004	0,1137	0,006	0,1225	0,0906	0,0002	0,0676	0,0225
Vigour 30 dat	0,7896		0,6329	0,5145	0,5241	-0,6459	-0,7783	0,3754	0,1906	0,3416	0,1754	-0,2106	0,431	0,1804	0,2936
	<0,0001		<0,0001	0,0004	0,0003	<0,0001	<0,0001	0,012	0,2152	0,025	0,2606	0,1752	0,0039	0,2469	0,056
VFW	0,5679	0,6329		0,643	0,3986	-0,3176	-0,5058	0,7326	0,3177	0,6378	0,4242	-0,1192	0,6234	0,4365	0,5304
	0,0001	<0,0001		<0,0001	0,0074	0,0356	0,0005	<0,0001	0,0356	<0,0001	0,0046	0,4463	<0,0001	0,0034	0,0003
VDW	0,5843	0,5145	0,643		0,573	-0,4178	-0,5027	0,4773	0,1088	0,2374	-0,0616	-0,5087	0,7828	-0,0025	0,1479
	<0,0001	0,0004	<0,0001		<0,0001	0,0048	0,0005	0,0011	0,482	0,1254	0,6948	0,0005	<0,0001	0,9874	0,344
VL	0,4035	0,5241	0,3986	0,573		-0,3997	-0,477	0,1162	0,0595	0,0103	-0,2199	-0,5495	0,5668	-0,1816	-0,0668
	0,0066	0,0003	0,0074	<0,0001		0,0072	0,0011	0,4526	0,7013	0,9479	0,1564	0,0001	0,0001	0,2438	0,6705
HDI	-0,5322	-0,6459	-0,3176	-0,4178	-0,3997		0,8526	-0,0746	-0,1389	-0,0428	0,1442	0,3467	-0,3801	0,1287	-0,0896
	0,0002	<0,0001	0,0356	0,0048	0,0072		<0,0001	0,6305	0,3686	0,7853	0,3561	0,0228	0,0119	0,4108	0,5676
RDI	-0,6212	-0,7783	-0,5058	-0,5027	-0,477	0,8526		-0,2573	-0,1906	-0,2069	0,0153	0,3849	-0,4819	-0,0084	-0,2218
	<0,0001	<0,0001	0,0005	0,0005	0,0011	<0,0001		0,0918	0,2153	0,1831	0,9226	0,0108	0,0011	0,9573	0,1528
RFW	0,5069	0,3754	0,7326	0,4773	0,1162	-0,0746	-0,2573		0,2131	0,7914	0,6464	0,0251	0,6112	0,6929	0,6183
	0,0004	0,012	<0,0001	0,0011	0,4526	0,6305	0,0918		0,1649	<0,0001	<0,0001	0,8732	<0,0001	<0,0001	<0,0001
RDW	0,2418	0,1906	0,3177	0,1088	0,0595	-0,1389	-0,1906	0,2131		0,0793	0,003	-0,2411	0,2357	-0,0057	-0,0691
	0,1137	0,2152	0,0356	0,482	0,7013	0,3686	0,2153	0,1649		0,6134	0,9848	0,1194	0,128	0,9713	0,6598
TRL	0,4125	0,3416	0,6378	0,2374	0,0103	-0,0428	-0,2069	0,7914	0,0793		0,914	0,3943	0,347	0,9075	0,8734
	0,006	0,025	<0,0001	0,1254	0,9479	0,7853	0,1831	<0,0001	0,6134		<0,0001	0,0089	0,0226	<0,0001	<0,0001
TPRA	0,2391	0,1754	0,4242	-0,0616	-0,2199	0,1442	0,0153	0,6464	0,003	0,914		0,6772	-0,0226	0,9509	0,7954
	0,1225	0,2606	0,0046	0,6948	0,1564	0,3561	0,9226	<0,0001	0,9848	<0,0001		<0,0001	0,8857	<0,0001	<0,0001
ARD	-0,2612	-0,2106	-0,1192	-0,5087	-0,5495	0,3467	0,3849	0,0251	-0,2411	0,3943	0,6772		-0,6014	0,5571	0,3773
	0,0906	0,1752	0,4463	0,0005	0,0001	0,0228	0,0108	0,8732	0,1194	0,0089	<0,0001		<0,0001	0,0001	0,0126
Tips	0,5375	0,431	0,6234	0,7828	0,5668	-0,3801	-0,4819	0,6112	0,2357	0,347	-0,0226	-0,6014		0,1006	0,2434
	0,0002	0,0039	<0,0001	<0,0001	0,0001	0,0119	0,0011	<0,0001	0,128	0,0226	0,8857	<0,0001		0,5211	0,1158
Forks	0,2814	0,1804	0,4365	-0,0025	-0,1816	0,1287	-0,0084	0,6929	-0,0057	0,9075	0,9509	0,5571	0,1006		0,8698
	0,0676	0,2469	0,0034	0,9874	0,2438	0,4108	0,9573	<0,0001	0,9713	<0,0001	<0,0001	0,0001	0,5211		<0,0001
Crossings	0,3473	0,2936	0,5304	0,1479	-0,0668	-0,0896	-0,2218	0,6183	-0,0691	0,8734	0,7954	0,3773	0,2434	0,8698	
	0,0225	0,056	0,0003	0,344	0,6705	0,5676	0,1528	<0,0001	0,6598	<0,0001	<0,0001	0,0126	0,1158	<0,0001	

ABBREVIATIONS

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2015ME

	Vigour 15 dat	Vigour 30 dat	VFW	VDW	VL	HDI	RDI	RFW	RDW	TRL	TPRA	ARD	Tips	Forks	Crossings
Vigour 15 dat		0,6988	-0,284	-0,0806	0,0486	-0,0021	-0,289	0,0749	-0,0611	0,0598	-0,0301	-0,3709	0,1412	0,0485	0,1124
		<0,0001	0,0356	0,5901	0,7269	0,988	0,0324	0,5941	0,6831	0,6648	0,8272	0,0053	0,3038	0,7249	0,4137
Vigour 30 dat	0,6988		-0,2073	-0,1057	-0,046	-0,1773	-0,3813	0,1586	-0,1263	0,172	0,1206	-0,3372	0,21	0,1888	0,2242
	<0,0001		0,1288	0,4794	0,7414	0,1954	0,0041	0,2567	0,3976	0,2094	0,3803	0,0118	0,1238	0,1675	0,0999
VFW	-0,284	-0,2073		0,7477	0,1542	-0,0642	-0,2324	0,4572	0,3687	0,2994	0,3806	0,3013	0,2175	0,309	0,244
	0,0356	0,1288		<0,0001	0,2657	0,6415	0,0877	0,0006	0,0108	0,0264	0,0041	0,0254	0,1107	0,0217	0,0726
VDW	-0,0806	-0,1057	0,7477		0,2954	-0,1403	-0,1299	0,4001	0,5678	0,2717	0,3747	0,2133	0,1445	0,2875	0,2082
	0,5901	0,4794	<0,0001		0,0462	0,3468	0,3842	0,0065	<0,0001	0,0647	0,0095	0,1501	0,3324	0,0501	0,1602
VL	0,0486	-0,046	0,1542	0,2954		0,0558	0,0074	0,1247	0,2667	0,2008	0,1925	-0,1436	0,199	0,1849	0,1939
	0,7269	0,7414	0,2657	0,0462		0,6887	0,9577	0,3786	0,0732	0,1454	0,1632	0,3003	0,1492	0,1807	0,1601
HDI	-0,0021	-0,1773	-0,0642	-0,1403	0,0558		0,4829	-0,3466	-0,2744	-0,3909	-0,3813	0,4539	-0,3718	-0,3732	-0,3704
	0,988	0,1954	0,6415	0,3468	0,6887		0,0002	0,011	0,062	0,0032	0,0041	0,0005	0,0052	0,005	0,0054
RDI	-0,289	-0,3813	-0,2324	-0,1299	0,0074	0,4829		-0,4649	0,0319	-0,4541	-0,4306	0,2689	-0,4868	-0,4619	-0,4722
	0,0324	0,0041	0,0877	0,3842	0,9577	0,0002		0,0005	0,8317	0,0005	0,001	0,0471	0,0002	0,0004	0,0003
RFW	0,0749	0,1586	0,4572	0,4001	0,1247	-0,3466	-0,4649		0,3795	0,7133	0,722	-0,1445	0,7275	0,7458	0,7178
	0,5941	0,2567	0,0006	0,0065	0,3786	0,011	0,0005		0,0101	<0,0001	<0,0001	0,3018	<0,0001	<0,0001	<0,0001
RDW	-0,0611	-0,1263	0,3687	0,5678	0,2667	-0,2744	0,0319	0,3795		0,3078	0,3598	-0,1392	0,1772	0,255	0,2036
	0,6831	0,3976	0,0108	<0,0001	0,0732	0,062	0,8317	0,0101		0,0353	0,013	0,3506	0,2335	0,0837	0,1699
TRL	0,0598	0,172	0,2994	0,2717	0,2008	-0,3909	-0,4541	0,7133	0,3078		0,9836	-0,3755	0,9561	0,987	0,9763
	0,6648	0,2094	0,0264	0,0647	0,1454	0,0032	0,0005	<0,0001	0,0353		<0,0001	0,0047	<0,0001	<0,0001	<0,0001
TPRA	-0,0301	0,1206	0,3806	0,3747	0,1925	-0,3813	-0,4306	0,722	0,3598	0,9836		-0,2796	0,9021	0,9711	0,9351
	0,8272	0,3803	0,0041	0,0095	0,1632	0,0041	0,001	<0,0001	0,013	<0,0001		0,0387	<0,0001	<0,0001	<0,0001
ARD	-0,3709	-0,3372	0,3013	0,2133	-0,1436	0,4539	0,2689	-0,1445	-0,1392	-0,3755	-0,2796		-0,4158	-0,3436	-0,3972
	0,0053	0,0118	0,0254	0,1501	0,3003	0,0005	0,0471	0,3018	0,3506	0,0047	0,0387		0,0016	0,0102	0,0027
Tips	0,1412	0,21	0,2175	0,1445	0,199	-0,3718	-0,4868	0,7275	0,1772	0,9561	0,9021	-0,4158		0,965	0,9848
	0,3038	0,1238	0,1107	0,3324	0,1492	0,0052	0,0002	<0,0001	0,2335	<0,0001	<0,0001	0,0016		<0,0001	<0,0001
Forks	0,0485	0,1888	0,309	0,2875	0,1849	-0,3732	-0,4619	0,7458	0,255	0,987	0,9711	-0,3436	0,965		0,9883
	0,7249	0,1675	0,0217	0,0501	0,1807	0,005	0,0004	<0,0001	0,0837	<0,0001	<0,0001	0,0102	<0,0001		<0,0001
Crossings	0,1124	0,2242	0,244	0,2082	0,1939	-0,3704	-0,4722	0,7178	0,2036	0,9763	0,9351	-0,3972	0,9848	0,9883	
	0,4137	0,0999	0,0726	0,1602	0,1601	0,0054	0,0003	<0,0001	0,1699	<0,0001	<0,0001	0,0027	<0,0001	<0,0001	

ABBREVIATIONS

dat	days after transplanting
VFW	vine fresh weight (g)
VDW	vine dry weight (g)
VL	vine length (cm)
HDI	hypocotyl disease index (0-4)
RDI	root disease index (0-4)
RFW	root fresh weight (RFW, g)
RDW	root dry weight (RDW, g)
TRL	total root length (TRL, cm),
TPRA	total projected root area (TPRA, cm^2),
ARD	average root diameter (ARD, mm),
Tips	number of tips
Forks	number of forks
Crossings	number of crossings

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Table S1. Correlations (and significance values, below; p<0.05 highlighted in grey) between vigour, root and vine weight and length parameters, disease indeces and parameters measured with WinRhizo, for the six artificial inoculation assays (each assay in the correspondign sheet).

2016ME

	Vigour 15 dat	Vigour 30 dat	VFW	VDW	VL	HDI	RDI	RFW	RDW	TRL	TPRA	ARD	Tips	Forks	Crossings
Vigour 15 dat		0,4664	0,5007	0,6281	0,351	-0,4712	-0,5487	0,417	0,2681	0,5463	0,522	0,1746	0,4677	0,4349	0,4246
		0,0001	<0,0001	<0,0001	0,0041	0,0001	<0,0001	0,0005	0,0309	<0,0001	<0,0001	0,1711	0,0001	0,0004	0,0005
Vigour 30 dat	0,4664		0,3824	0,3901	0,4617	-0,333	-0,3989	0,3418	0,1324	0,3462	0,3211	0,2814	0,3466	0,3169	0,3234
	0,0001		0,0017	0,0013	0,0001	0,0067	0,001	0,0053	0,2932	0,0054	0,0103	0,0255	0,0054	0,0114	0,0097
VFW	0,5007	0,3824		0,8291	0,4786	-0,2891	-0,3701	0,6676	0,2347	0,5415	0,5766	0,455	0,4468	0,5035	0,4533
	<0,0001	0,0017		<0,0001	0,0001	0,0195	0,0024	<0,0001	0,0599	<0,0001	<0,0001	0,0002	0,0002	<0,0001	0,0002
VDW	0,6281	0,3901	0,8291		0,5406	-0,454	-0,4709	0,682	0,3277	0,6619	0,6613	0,3195	0,5837	0,6111	0,6036
	<0,0001	0,0013	<0,0001		<0,0001	0,0001	0,0001	<0,0001	0,0077	<0,0001	<0,0001	0,0107	<0,0001	<0,0001	<0,0001
VL	0,351	0,4617	0,4786	0,5406		-0,3393	-0,3185	0,4073	0,086	0,5105	0,4887	0,1872	0,4682	0,4613	0,461
	0,0041	0,0001	0,0001	<0,0001		0,0057	0,0097	0,0008	0,4957	<0,0001	<0,0001	0,1418	0,0001	0,0001	0,0001
HDI	-0,4712	-0,333	-0,2891	-0,454	-0,3393		0,8479	-0,4085	-0,1703	-0,4814	-0,4539	-0,2113	-0,4322	-0,4006	-0,4261
	0,0001	0,0067	0,0195	0,0001	0,0057		<0,0001	0,0007	0,1751	0,0001	0,0002	0,0965	0,0004	0,0011	0,0005
RDI	-0,5487	-0,3989	-0,3701	-0,4709	-0,3185	0,8479		-0,453	-0,1718	-0,5285	-0,4981	-0,2308	-0,4534	-0,4305	-0,4517
	<0,0001	0,001	0,0024	0,0001	0,0097	<0,0001		0,0002	0,1712	<0,0001	<0,0001	0,0688	0,0002	0,0004	0,0002
RFW	0,417	0,3418	0,6676	0,682	0,4073	-0,4085	-0,453		0,2062	0,8371	0,8714	0,4847	0,8132	0,855	0,8116
	0,0005	0,0053	<0,0001	<0,0001	0,0008	0,0007	0,0002		0,0994	<0,0001	<0,0001	0,0001	<0,0001	<0,0001	<0,0001
RDW	0,2681	0,1324	0,2347	0,3277	0,086	-0,1703	-0,1718	0,2062		0,2937	0,269	0,0548	0,3165	0,2698	0,3153
	0,0309	0,2932	0,0599	0,0077	0,4957	0,1751	0,1712	0,0994		0,0195	0,033	0,6698	0,0115	0,0325	0,0118
TRL	0,5463	0,3462	0,5415	0,6619	0,5105	-0,4814	-0,5285	0,8371	0,2937		0,9864	0,282	0,9775	0,9657	0,9461
	<0,0001	0,0054	<0,0001	<0,0001	<0,0001	0,0001	<0,0001	<0,0001	0,0195		<0,0001	0,0251	<0,0001	<0,0001	<0,0001
TPRA	0,522	0,3211	0,5766	0,6613	0,4887	-0,4539	-0,4981	0,8714	0,269	0,9864		0,3935	0,9562	0,9648	0,9262
	<0,0001	0,0103	<0,0001	<0,0001	<0,0001	0,0002	<0,0001	<0,0001	0,033	<0,0001		0,0014	<0,0001	<0,0001	<0,0001
ARD	0,1746	0,2814	0,455	0,3195	0,1872	-0,2113	-0,2308	0,4847	0,0548	0,282	0,3935		0,2425	0,3283	0,2447
	0,1711	0,0255	0,0002	0,0107	0,1418	0,0965	0,0688	0,0001	0,6698	0,0251	0,0014		0,0555	0,0086	0,0532
Tips	0,4677	0,3466	0,4468	0,5837	0,4682	-0,4322	-0,4534	0,8132	0,3165	0,9775	0,9562	0,2425		0,9757	0,9658
	0,0001	0,0054	0,0002	<0,0001	0,0001	0,0004	0,0002	<0,0001	0,0115	<0,0001	<0,0001	0,0555		<0,0001	<0,0001
Forks	0,4349	0,3169	0,5035	0,6111	0,4613	-0,4006	-0,4305	0,855	0,2698	0,9657	0,9648	0,3283	0,9757		0,9839
	0,0004	0,0114	<0,0001	<0,0001	0,0001	0,0011	0,0004	<0,0001	0,0325	<0,0001	<0,0001	0,0086	<0,0001		<0,0001
Crossings	0,4246	0,3234	0,4533	0,6036	0,461	-0,4261	-0,4517	0,8116	0,3153	0,9461	0,9262	0,2447	0,9658	0,9839	
	0,0005	0,0097	0,0002	<0,0001	0,0001	0,0005	0,0002	<0,0001	0,0118	<0,0001	<0,0001	0,0532	<0,0001	<0,0001	

ABBREVIATIONS

dat	days after transplanting
VFW	vine fresh weight (g)
VDW	vine dry weight (g)
VL	vine length (cm)
HDI	hypocotyl disease index (0-4)
RDI	root disease index (0-4)
RFW	root fresh weight (RFW, g)
RDW	root dry weight (RDW, g)
TRL	total root length (TRL, cm),
TPRA	total projected root area (TPRA, cm^2),
ARD	average root diameter (ARD, mm),
Tips	number of tips
Forks	number of forks
Crossings	number of crossings

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2017ME

	Vigour 15 dat	Vigour 30 dat	VFW	VDW	VL	HDI	RDI	RFW	RDW	TRL	TPRA	ARD	Tips	Forks	Crossings
Vigour 15 dat		0,5186	0,4901	0,4265	0,7246	-0,387	-0,5009	0,4568	0,3071	0,5548	0,4893	-0,0818	0,5486	0,4436	0,4084
		0,0004	0,001	0,0049	<0,0001	0,0124	0,0009	0,0024	0,0479	0,0002	0,0012	0,611	0,0002	0,0037	0,008
Vigour 30 dat	0,5186		0,0809	0,1775	0,2307	-0,2668	-0,0693	0,1941	0,1943	0,4421	0,3271	-0,2903	0,4733	0,3268	0,3214
	0,0004		0,6105	0,2607	0,1416	0,0918	0,667	0,2182	0,2175	0,0038	0,0368	0,0656	0,0018	0,037	0,0405
VFW	0,4901	0,0809		0,5429	0,3335	0,0724	-0,0935	0,5775	0,1747	0,5748	0,6409	0,5415	0,4979	0,5937	0,4704
	0,001	0,6105		0,0002	0,0309	0,653	0,5608	0,0001	0,2685	0,0001	<0,0001	0,0003	0,0009	<0,0001	0,0019
VDW	0,4265	0,1775	0,5429		0,3725	-0,3348	-0,3386	0,7603	0,1193	0,6213	0,6298	0,3165	0,6568	0,5813	0,4409
	0,0049	0,2607	0,0002		0,0151	0,0324	0,0304	<0,0001	0,4517	<0,0001	<0,0001	0,0438	<0,0001	0,0001	0,0039
VL	0,7246	0,2307	0,3335	0,3725		-0,3569	-0,4573	0,3204	0,1084	0,3742	0,2921	-0,1462	0,4285	0,2485	0,2452
	<0,0001	0,1416	0,0309	0,0151		0,022	0,0027	0,0386	0,4945	0,0159	0,0639	0,3617	0,0052	0,1173	0,1223
HDI	-0,387	-0,2668	0,0724	-0,3348	-0,3569		0,5736	-0,2423	-0,2042	-0,1941	-0,1254	0,1251	-0,2165	-0,1151	-0,1634
	0,0124	0,0918	0,653	0,0324	0,022		0,0001	0,1269	0,2004	0,23	0,4407	0,442	0,1797	0,4794	0,3137
RDI	-0,5009	-0,0693	-0,0935	-0,3386	-0,4573	0,5736		-0,1913	-0,2106	-0,1231	-0,0621	0,1605	-0,1748	-0,0539	0,0711
	0,0009	0,667	0,5608	0,0304	0,0027	0,0001		0,2309	0,1862	0,4493	0,7034	0,3224	0,2807	0,7411	0,6627
RFW	0,4568	0,1941	0,5775	0,7603	0,3204	-0,2423	-0,1913		0,2358	0,7458	0,7703	0,4243	0,7698	0,6898	0,6255
	0,0024	0,2182	0,0001	<0,0001	0,0386	0,1269	0,2309		0,1328	<0,0001	<0,0001	0,0057	<0,0001	<0,0001	<0,0001
RDW	0,3071	0,1943	0,1747	0,1193	0,1084	-0,2042	-0,2106	0,2358		0,1376	0,0886	-0,1107	0,1832	0,0339	0,0122
	0,0479	0,2175	0,2685	0,4517	0,4945	0,2004	0,1862	0,1328		0,3911	0,5816	0,4908	0,2516	0,8334	0,9399
TRL	0,5548	0,4421	0,5748	0,6213	0,3742	-0,1941	-0,1231	0,7458	0,1376		0,9698	0,3034	0,9455	0,9554	0,8789
	0,0002	0,0038	0,0001	<0,0001	0,0159	0,23	0,4493	<0,0001	0,3911		<0,0001	0,0538	<0,0001	<0,0001	<0,0001
TPRA	0,4893	0,3271	0,6409	0,6298	0,2921	-0,1254	-0,0621	0,7703	0,0886	0,9698		0,5113	0,868	0,9819	0,9031
	0,0012	0,0368	<0,0001	<0,0001	0,0639	0,4407	0,7034	<0,0001	0,5816	<0,0001		0,0006	<0,0001	<0,0001	<0,0001
ARD	-0,0818	-0,2903	0,5415	0,3165	-0,1462	0,1251	0,1605	0,4243	-0,1107	0,3034	0,5113		0,14	0,4818	0,4147
	0,611	0,0656	0,0003	0,0438	0,3617	0,442	0,3224	0,0057	0,4908	0,0538	0,0006		0,3827	0,0014	0,007
Tips	0,5486	0,4733	0,4979	0,6568	0,4285	-0,2165	-0,1748	0,7698	0,1832	0,9455	0,868	0,14		0,8464	0,7524
	0,0002	0,0018	0,0009	<0,0001	0,0052	0,1797	0,2807	<0,0001	0,2516	<0,0001	<0,0001	0,3827		<0,0001	<0,0001
Forks	0,4436	0,3268	0,5937	0,5813	0,2485	-0,1151	-0,0539	0,6898	0,0339	0,9554	0,9819	0,4818	0,8464		0,9123
	0,0037	0,037	<0,0001	0,0001	0,1173	0,4794	0,7411	<0,0001	0,8334	<0,0001	<0,0001	0,0014	<0,0001		<0,0001
Crossings	0,4084	0,3214	0,4704	0,4409	0,2452	-0,1634	0,0711	0,6255	0,0122	0,8789	0,9031	0,4147	0,7524	0,9123	
	0,008	0,0405	0,0019	0,0039	0,1223	0,3137	0,6627	<0,0001	0,9399	<0,0001	<0,0001	0,007	<0,0001	<0,0001	

ABBREVIATIONS

dat	days after transplanting
VFW	vine fresh weight (g)
VDW	vine dry weight (g)
VL	vine length (cm)
HDI	hypocotyl disease index (0-4)
RDI	root disease index (0-4)
RFW	root fresh weight (RFW, g)
RDW	root dry weight (RDW, g)
TRL	total root length (TRL, cm),
TPRA	total projected root area (TPRA, cm^2),
ARD	average root diameter (ARD, mm),
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Forks	number of forks
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Table S2. Root and vine weight and length parameters and parameters measured with WinRhizo, for the six artificial inoculation assays. Asterisk denotes significant differences between *Monosporascus cannonballus* inoculated plants and the non-inoculated control and significant differences between *M. eutypoides* inoculated plants and the non-inoculated control, for each genotype and year (p<0.05, Student's t test).

	2015			2016			2017		
	Control	*M. cannonballus*	*M. eutypoides*	Control	*M. cannonballus*	*M. eutypoides*	Control	*M. cannonballus*	*M. eutypoides*
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
Vine Fresh Weight (g)									
Chin-Pat81Ko	**11,77**	0.96*	11,99	**18,87**	19,07	10,52	**14,08**	10,80	16,20
Ag-15591Gha	**7,27**	1.44*	10,79	**17,87**	6.22*	2.04*	**12,54**	10,72	15,45
Ag-TriInd	**11,60**	0.64*	5.22*	**11,25**	6.75*	8,04	**9,49**	9,93	4,90
Met-BGV11135Afr	**17,82**	9.04*	12,86	**12,81**	3.83*	6,38	**18,25**	9,22	7.43*
Ac-TGR139Zimb	**10,63**	2.51*	10,65	**12,88**	18,04	11,78	**20,12**	19,32	13,39
La-PE4Bra	**19,46**	3.53*	20,80	**26,11**	17.78*	10,04	-	-	-
F1 Pat81xPs	**13,82**	0.76*	4.82*	**25,39**	7.69*	12,54	**24,18**	13.70*	18,91
Ib-PsPiñSp	**15,30**	-	12,51	**31,62**	6.25*	15.86*	**19,10**	3.99*	28.15*
Vine Dry Weight (g)									
Chin-Pat81Ko	**1,70**	0.16*	1,46	**4,64**	3,90	1,91	**1,89**	0.99*	1,33
Ag-15591Gha	**1,61**	0.31*	1,95	**3,43**	0.96*	0.66*	**1,82**	0,80	1,41
Ag-TriInd	**1,46**	0.09*	1,26	**2,25**	2,06	1,58	**1,10**	0,97	1,00
Met-BGV11135Afr	**3,45**	0.7*	2,42	**2,68**	2,58	1,55	**2,07**	0.74*	0.63*
Ac-TGR139Zimb	**1,56**	0,37	1,55	**2,02**	2,97	2,00	**2,68**	1.04*	1,62
La-PE4Bra	**1,41**	0,34	2,47	**4,00**	1.54*	1.72*	-	-	-
F1 Pat81xPs	**1,98**	0.21*	1,45	**4,34**	3,00	1.89*	**2,73**	0.62*	1,79
Ib-PsPiñSp	**2,27**	-	1,78	**3,48**	2,45	1,97	**1,17**	0.34*	1,18
Vine Lenght (cm)									
Chin-Pat81Ko	**105,00**	10.47*	106,83	**146,45**	135,68	123,75	**85,50**	78,75	66,40
Ag-15591Gha	**89,50**	38,00	122,20	**167,70**	126,84	71.58*	**165,50**	70,40	27.45*
Ag-TriInd	**163,50**	19.33*	117,40	**208,65**	113.28*	140,69	**101,00**	62,40	37.50*
Met-BGV11135Afr	**153,50**	98.00*	126,80	**154,80**	108,25	122,10	**129,00**	43.39*	65.50*
Ac-TGR139Zimb	**60,50**	19,75	81,20	**98,00**	108,67	105,50	**71,50**	56,60	47.60*
La-PE4Bra	**77,25**	14.00*	97,00	**99,35**	85,75	108,15	-	-	-
F1 Pat81xPs	**104,00**	21.00*	83,75	**134,35**	125,38	99,88	**127,50**	52.80*	53.88*
Ib-PsPiñSp	**100,00**	-	123,75	**170,28**	106.52*	111,37	**78,00**	45,50	75,75
Root Fresh Weight (g)									
Chin-Pat81Ko	**1,53**	0.25*	0.30*	**1,60**	1,42	1,11	**1,08**	0.61*	0,88
Ag-15591Gha	**1,12**	0.32*	1,23	**1,13**	0,69	0.36*	**0,83**	0,43	0,95
Ag-TriInd	**1,25**	0.17*	0.31*	**0,80**	1,17	0,95	**0,75**	0,61	0.26*
Met-BGV11135Afr	**1,04**	1,11	0,79	**2,53**	0.70*	0.70*	**2,07**	0.79*	0.55*
Ac-TGR139Zimb	**1,35**	0,87	0,99	**1,52**	1,97	1,52	**2,08**	2,14	1,37
La-PE4Bra	**0,98**	0,44	0,66	**2,00**	1,17	1,25	-	-	-
F1 Pat81xPs	**1,08**	0.22*	0.26*	**1,57**	1,24	1,02	**1,74**	0.91*	1,35
Ib-PsPiñSp	**1,28**	-	0.43*	**1,22**	0,65	1,02	**1,08**	0.22*	0,98
Root Dry Weight (g)									
Chin-Pat81Ko	**0,04**	0,02	0,04	**0,16**	0,08	0,11	**0,19**	0,09	0,07
Ag-15591Gha	**0,06**	0.02*	0,09	**0,19**	0.05*	0.03*	**0,07**	0,08	0.04*
Ag-TriInd	**0,05**	0.02*	0,05	**0,18**	0.10*	0.08*	**0,07**	0,10	0.04*
Met-BGV11135Afr	**0,07**	0,05	0,06	**0,23**	0.04*	0.06*	**0,26**	0.10*	0.04*
Ac-TGR139Zimb	**0,04**	0,04	0,08	**0,07**	0,23	0,17	**0,17**	0,17	0,12
La-PE4Bra	**0,04**	0,02	0,06	**0,17**	0,09	0,06	-	-	-
F1 Pat81xPs	**0,04**	0,03	0,05	**0,18**	0.06*	0.10*	**0,09**	0,06	0,13
Ib-PsPiñSp	**0,05**	-	0,03	**0,14**	0.04*	0,10	**0,14**	0,05	0.06*
Total root length (cm)									
Chin-Pat81Ko	**580,21**	63,83	99,90	**535,41**	353,90	312,24	**63,36**	151.42*	62,49
Ag-15591Gha	**536,99**	92.33*	503,80	**420,18**	227,67	103.23*	**129,50**	117,80	-
Ag-TriInd	**587,56**	48,97	135.71*	**356,53**	315,27	290,03	**62,29**	134,37	26,44
Met-BGV11135Afr	**606,39**	211.47*	345,11	**783,94**	215.65*	223.34*	**160,06**	131,18	71,84
Ac-TGR139Zimb	**434,31**	330,27	477,85	**236,25**	303,59	323,37	**159,87**	287,50	72,85
La-PE4Bra	**196,36**	182,30	352,02	**378,12**	222,75	256,18	-	-	-
F1 Pat81xPs	**298,54**	156,25	75,75	**565,87**	281,22	196.53*	**218,70**	131.99*	156,40
Ib-PsPiñSp	**550,01**	-	120,70	**388,02**	230,22	233,11	**110,65**	17.37*	97,03
Total Projected Root Area (cm2)									
Chin-Pat81Ko	**16,37**	2,34	3,96	**22,89**	14,57	13,10	**2,74**	12.85*	3,30
Ag-15591Gha	**17,71**	3.38*	17,40	**19,55**	8.96*	3.95*	**4,76**	7,73	-
Ag-TriInd	**18,29**	1,88	4.74*	**13,95**	12,48	12,54	**2,24**	10,79	1,11
Met-BGV11135Afr	**21,63**	8,71	13,67	**37,09**	9.08*	9.83*	**6,42**	9,93	2,95
Ac-TGR139Zimb	**17,00**	13,50	18,23	**5,77**	11,11	12.66*	**7,58**	25,98	3,57
La-PE4Bra	**7,65**	7,85	14,71	**17,97**	9,89	11,85	-	-	-
F1 Pat81xPs	**10,00**	4,65	2,68	**24,60**	13,30	9.73*	**9,65**	10,40	7,88
Ib-PsPiñSp	**18,95**	-	5,30	**17,18**	9,20	10,99	**3,99**	1,27	4,92
Average Diameter (mm)									
Chin-Pat81Ko	**0,27**	0,37	0.41*	**0,43**	0,41	0,36	**0,42**	0.85*	0,48
Ag-15591Gha	**0,33**	0,45	0,35	**0,45**	0,40	0,37	**0,36**	0.64*	-
Ag-TriInd	**0,33**	0,42	0,35	**0,39**	0,39	0,42	**0,35**	0.78*	0,41
Met-BGV11135Afr	**0,36**	0.41*	0.40*	**0,48**	0.42*	0,45	**0,38**	0.76*	0,41
Ac-TGR139Zimb	**0,39**	0,40	0,38	**0,24**	0,36	0.39*	**0,46**	0.88*	0,48
La-PE4Bra	**0,39**	0,39	0,43	**0,48**	0,44	0,44	-	-	-
F1 Pat81xPs	**0,33**	0,30	0,36	**0,44**	0,49	0.49*	**0,44**	0.78*	0.51*
Ib-PsPiñSp	**0,36**	-	0,46	**0,44**	0,43	0,47	**0,36**	0.72*	0,49
Tips									
Chin-Pat81Ko	**2559,00**	248,67	306,00	**1397,00**	1127,00	893,50	**664,50**	291.50*	603,50
Ag-15591Gha	**2132,50**	314.00*	1588,80	**917,00**	594,22	236.38*	**1318,00**	217.20*	-
Ag-TriInd	**2301,50**	200,00	316,20	**817,00**	936,00	744,00	**728,50**	242.20*	250.00*
Met-BGV11135Afr	**2142,00**	758,00	908.80*	**2071,33**	601.57*	663.40*	**1518,50**	350,33	601.20*
Ac-TGR139Zimb	**1442,50**	1064,50	1228,20	**649,00**	1026,50	949.50*	**1363,00**	529.80*	824,00
La-PE4Bra	**545,00**	507,00	964,00	**843,00**	580,50	643,00	-	-	-
F1 Pat81xPs	**961,50**	712,50	219,50	**1495,50**	771,63	514.75*	**1952,00**	303.60*	1186,00
Ib-PsPiñSp	**1500,00**	-	295.33*	**793,00**	657,22	617,89	**1094,00**	85.67*	740.75*
Forks									
Chin-Pat81Ko	**6555,50**	746,67	860,17	**5497,00**	3413,00	3749,00	**78,50**	391.50*	100,75
Ag-15591Gha	**6152,50**	873.33*	5089,60	**3833,00**	1935.33*	770.375*	**173,50**	203,40	-
Ag-TriInd	**5994,00**	536,67	767,00	**2910,50**	3204,10	3117,50	**68,00**	273,60	29,25
Met-BGV11135Afr	**6827,50**	2162.00*	3383,20	**8566,33**	2414.14*	2624.80*	**207,50**	324,33	92,80
Ac-TGR139Zimb	**4579,50**	3159,50	4841,00	**1728,00**	2648,00	3249.50*	**267,00**	854,40	112,00
La-PE4Bra	**1522,00**	1689,50	3551,00	**3882,00**	2023,50	2210,50	-	-	-
F1 Pat81xPs	**3011,00**	1441,00	557,25	**5642,50**	3523,63	2234.50*	**410,00**	324,00	330.00*
Ib-PsPiñSp	**4889,50**	-	1032,00	**3244,25**	2583,78	2697,22	**117,00**	32.33*	170,50
Crossings									
Chin-Pat81Ko	**1314,50**	96,00	105,33	**767,00**	473,20	568,50	**5,00**	21,50	8,25
Ag-15591Gha	**1028,00**	120.33*	841,00	**515,50**	249.33*	115.13*	**12,00**	19,80	-
Ag-TriInd	**1140,50**	76,67	116,20	**413,00**	456,50	420,50	**10,50**	17,20	3,50
Met-BGV11135Afr	**1126,00**	280.00*	488,00	**1062,00**	324.43*	358.40*	**22,00**	19,33	11,40
Ac-TGR139Zimb	**660,00**	432,00	717,40	**338,00**	352,00	482,50	**18,00**	37,40	10,00
La-PE4Bra	**217,00**	227,50	482,00	**479,00**	261,50	303,50	-	-	-
F1 Pat81xPs	**513,00**	233,00	71,75	**806,50**	481,88	253.25*	**32,50**	23,40	30,50
Ib-PsPiñSp	**876,50**	-	109,83	**414,25**	372,67	319,11	**8,00**	1.00*	14,25

Castro G, Perpiñá G, Esteras C, Armengol J, Picó B,Pérez-de-Castro A. 2020. Resistance in melon to Monosporascus cannonballus and M. eutypoides; fungal pathogens associated with Monosporascus root rot and vine decline. Annals of Applied Biology

Figure S3.

a) WinRhizo images of roots corresponding to each of the genotypes, for each of the assays. Each slide includes a representative of the non-inoculated control, a plant inoculated with *Monosporascus cannonballus* and a plant inoculated with *M*. *eutypoides*.

b) Pictures of roots from the field assay.

c) Re-isolation of *Monosporascus cannonballus.*

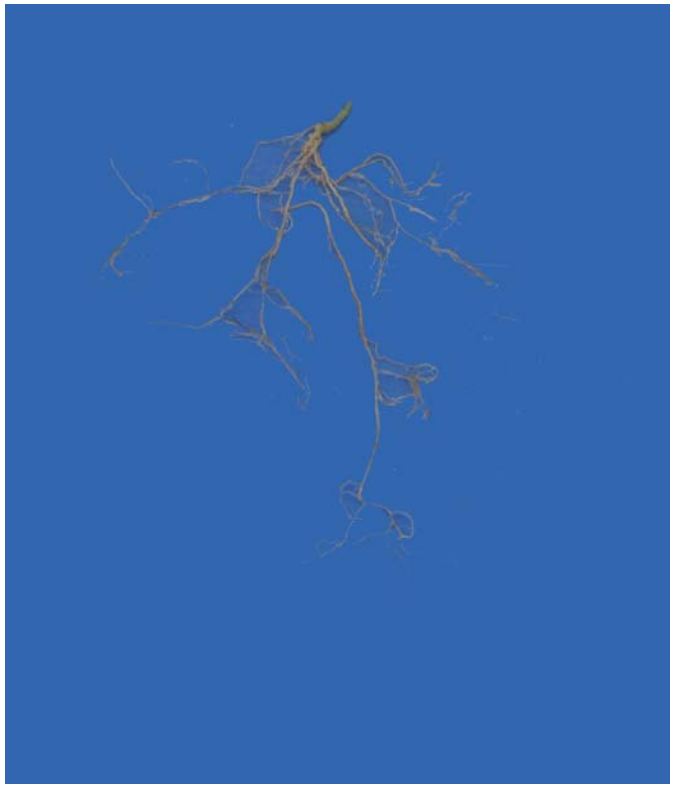
Castro G, Perpiñá G, Esteras C, Armengol J, Picó B,Pérez-de-Castro A. 2019. Resistance in melon to Monosporascus cannonballus and M. eutypoides; fungal pathogens associated with Monosporascus root rot and vine decline. Annals of Applied Biology.

a)

2015

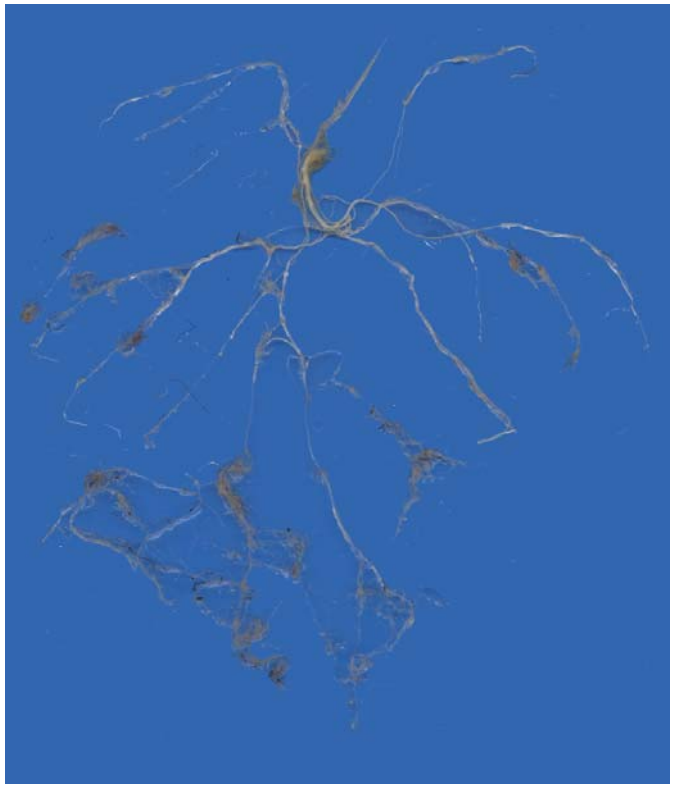
Chin-Pat81Ko
Control

Chin-Pat81Ko
M. cannonballus



Chin-Pat81Ko
M. eutypoides

2015



Ag-15591Gha
Control

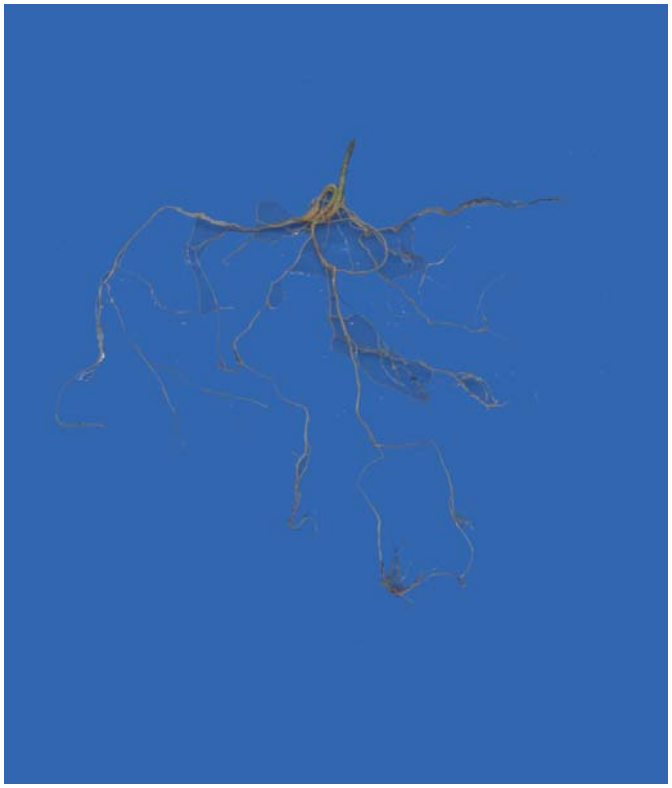
Ag-15591Gha
M. cannonballus

Ag-15591Gha
M. eutypoides

2015

Ag-TriInd
Control

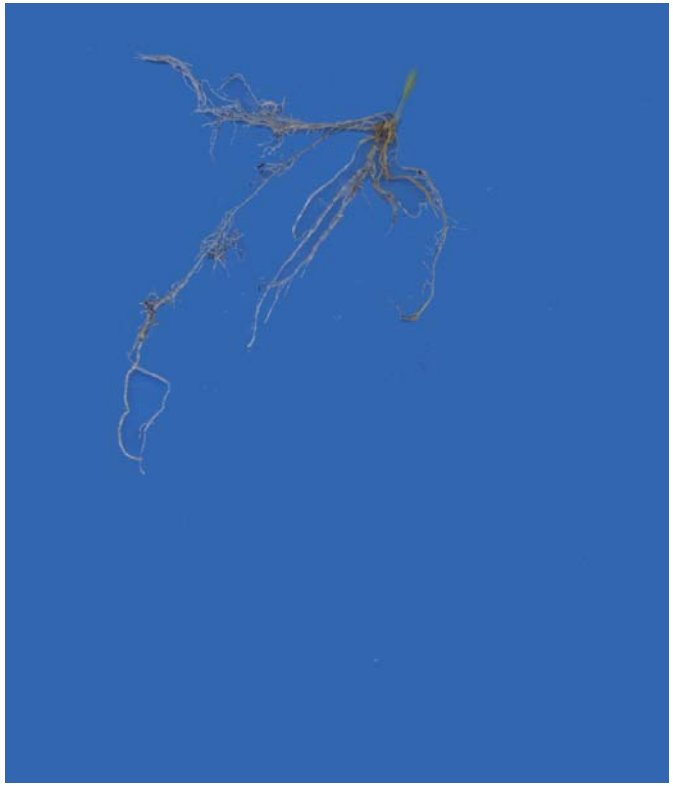
Ag-TriInd
M. cannonballus



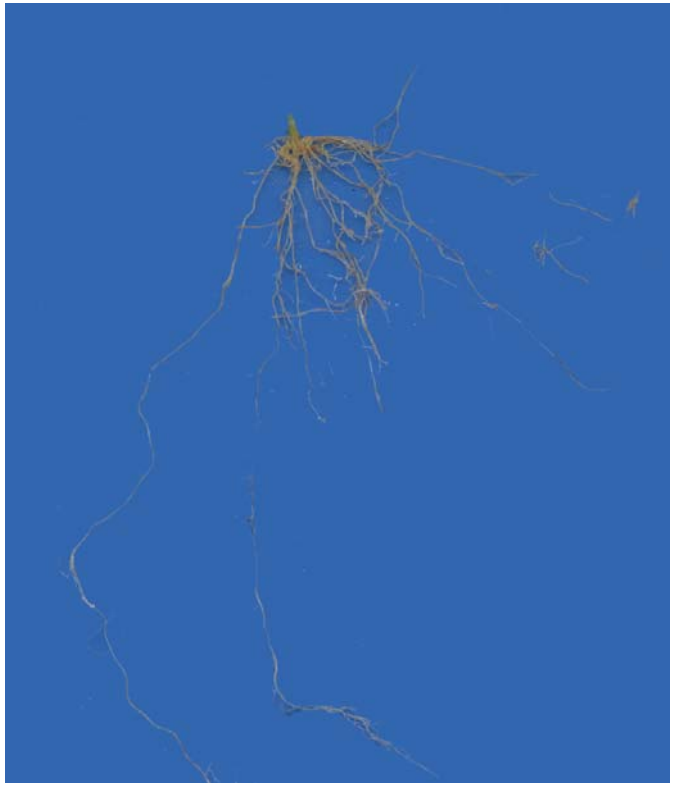
Ag-TriInd
M. eutypoides

2015

Met-BGV11135Afr
Control



Met-BGV11135Afr
M. cannonballus



Met-BGV11135Afr
M. eutypoides

2015

Ac-TGR139Zimb
Control

Ac-TGR139Zimb
M. cannonballus

Ac-TGR139Zimb
M. eutypoides

2015

La-PE4Bra
Control

La-PE4Bra
M. cannonballus

La-PE4Bra
M. eutypoides

2015

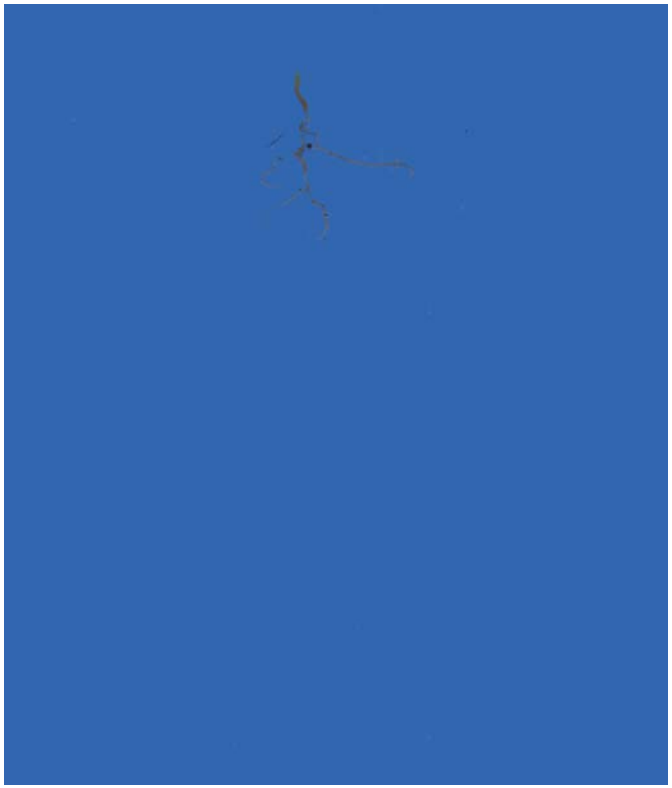
F1 Pat81xPs
Control

F1 Pat81xPs
M. cannonballus

F1 Pat81xPs
M. eutypoides

2015

Ib-PsPiñSp
Control



Ib-PsPiñSp
M. cannonballus

Ib-PsPiñSp
M. eutypoides

2016

Chin-Pat81Ko
Control

Chin-Pat81Ko
M. cannonballus

Chin-Pat81Ko
M. eutypoides

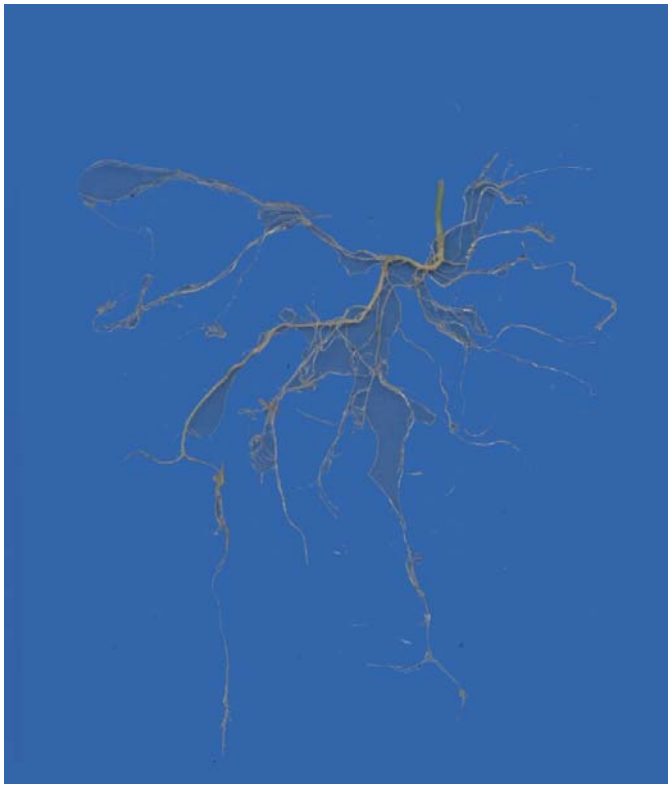
2016

Ag-15591Gha
Control

Ag-15591Gha
M. cannonballus

Ag-15591Gha
M. eutypoides

2016



Ag-TriInd
Control

Ag-TriInd
M. cannonballus

Ag-TriInd
M. eutypoides

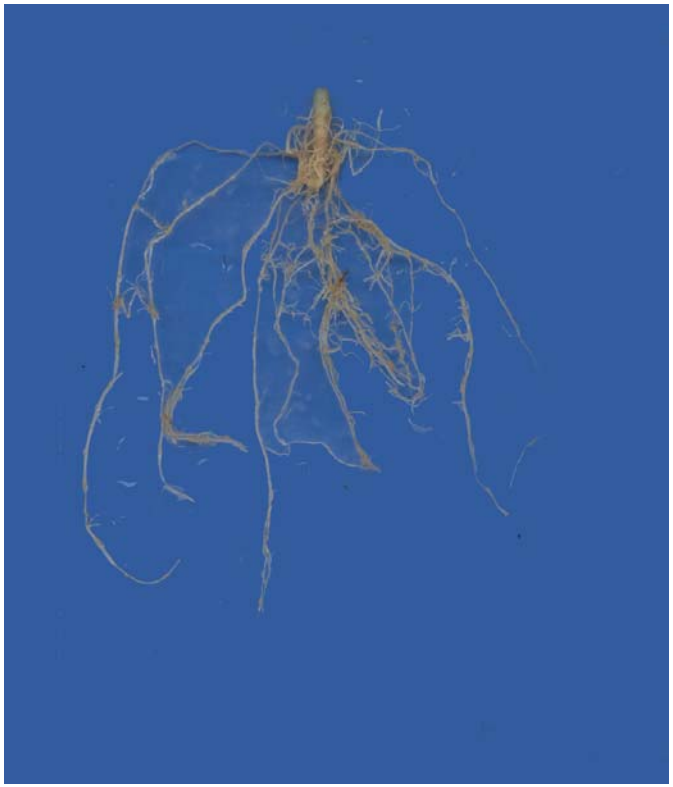
2016

Met-BGV11135Afr
Control

Met-BGV11135Afr
M. cannonballus

Met-BGV11135Afr
M. eutypoides

2016



Ac-TGR139Zimb
Control

Ac-TGR139Zimb
M. cannonballus

Ac-TGR139Zimb
M. eutypoides

2016

La-PE4Bra
Control

La-PE4Bra
M. cannonballus

La-PE4Bra
M. eutypoides

2016

F1 Pat81xPs
Control

F1 Pat81xPs
M. cannonballus

F1 Pat81xPs
M. eutypoides

2016

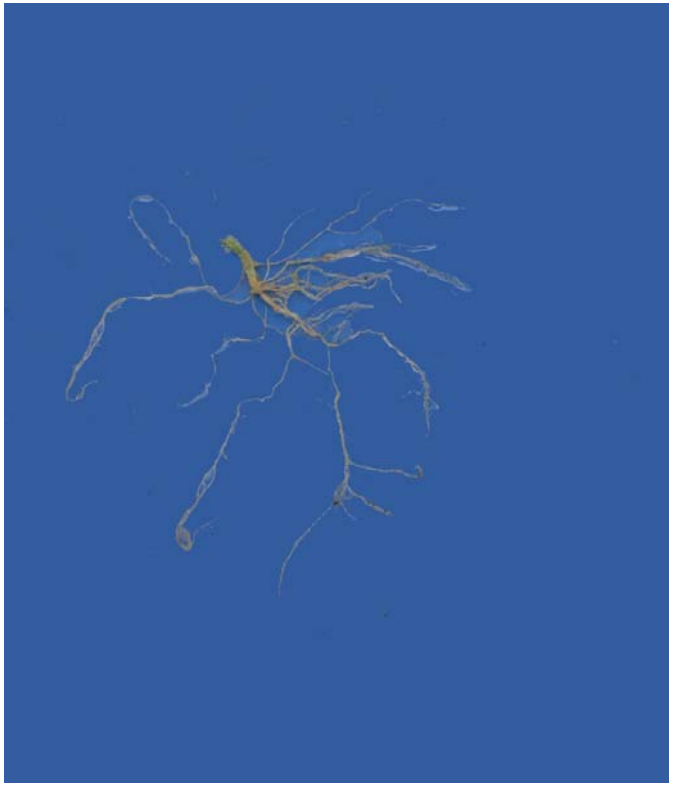
Ib-PsPiñSp
Control

Ib-PsPiñSp
M. cannonballus

Ib-PsPiñSp
M. eutypoides

2017

Chin-Pat81Ko
Control



Chin-Pat81Ko
M. cannonballus

Chin-Pat81Ko
M. eutypoides

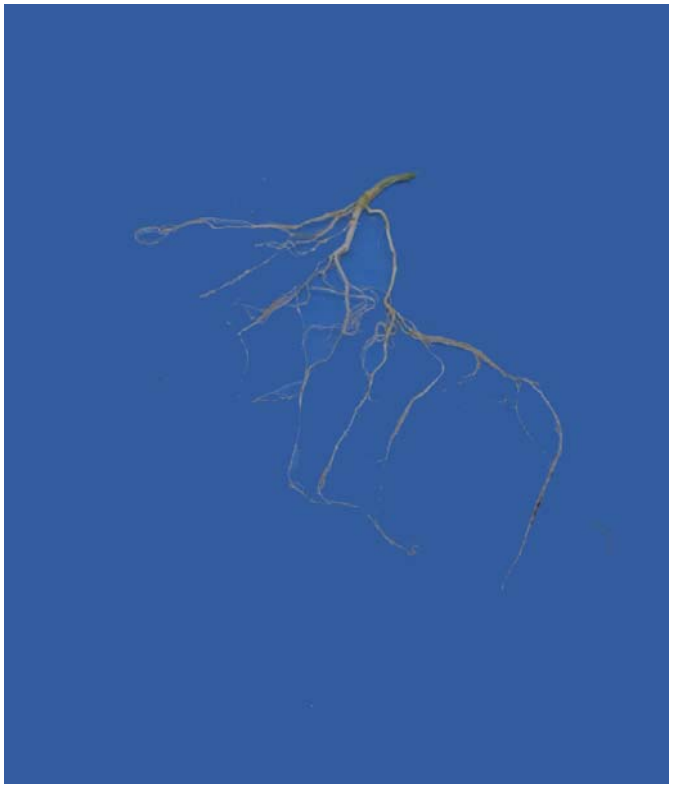
2017

Ag-15591Gha
Control

Ag-15591Gha
M. cannonballus

2017

Ag-TriInd
Control

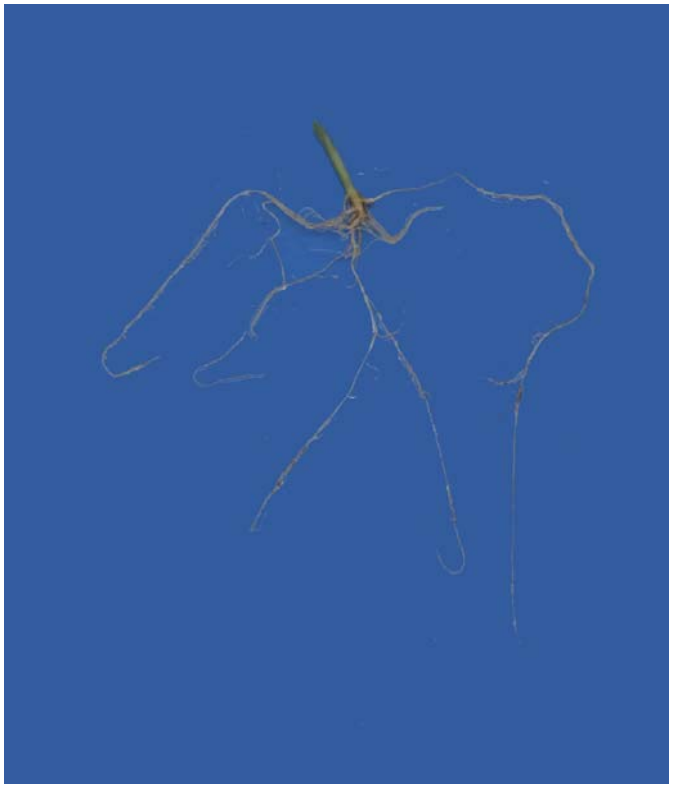


Ag-TriInd
M. cannonballus

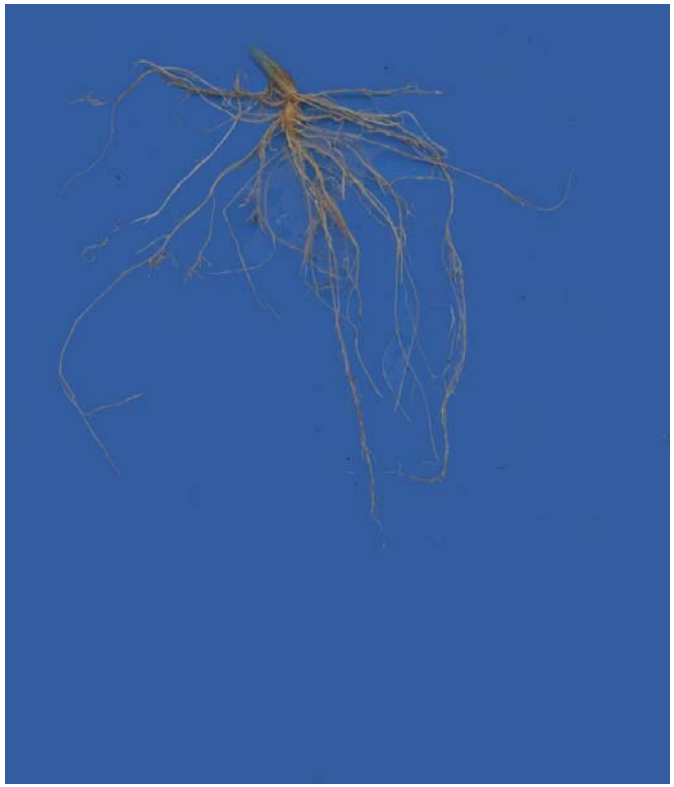
Ag-TriInd
M. eutypoides

2017

Met-BGV11135Afr
Control



Met-BGV11135Afr
M. cannonballus



Met-BGV11135Afr
M. eutypoides

2017

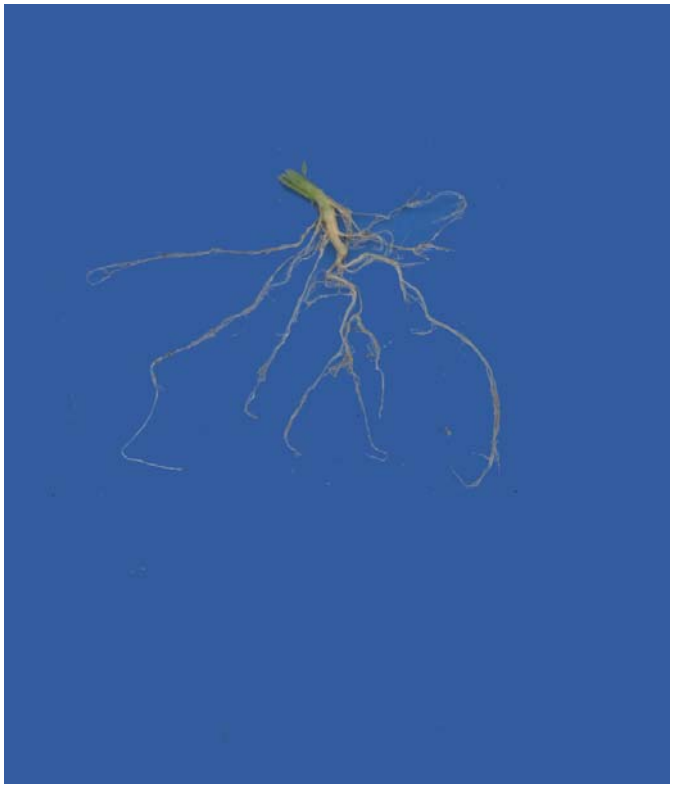
Ac-TGR139Zimb
Control

Ac-TGR139Zimb
M. cannonballus

Ac-TGR139Zimb
M. eutypoides

2017

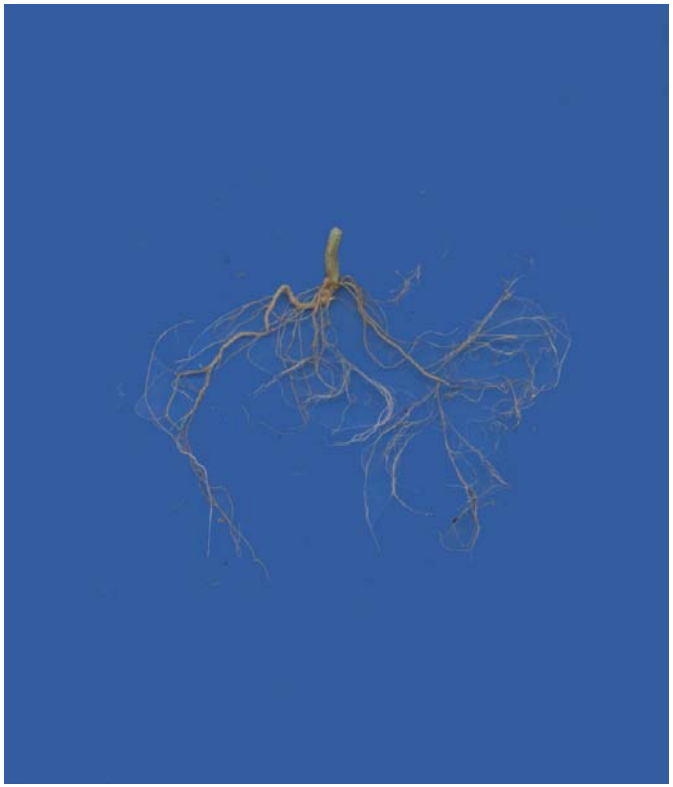
F1 Pat81xPs
Control



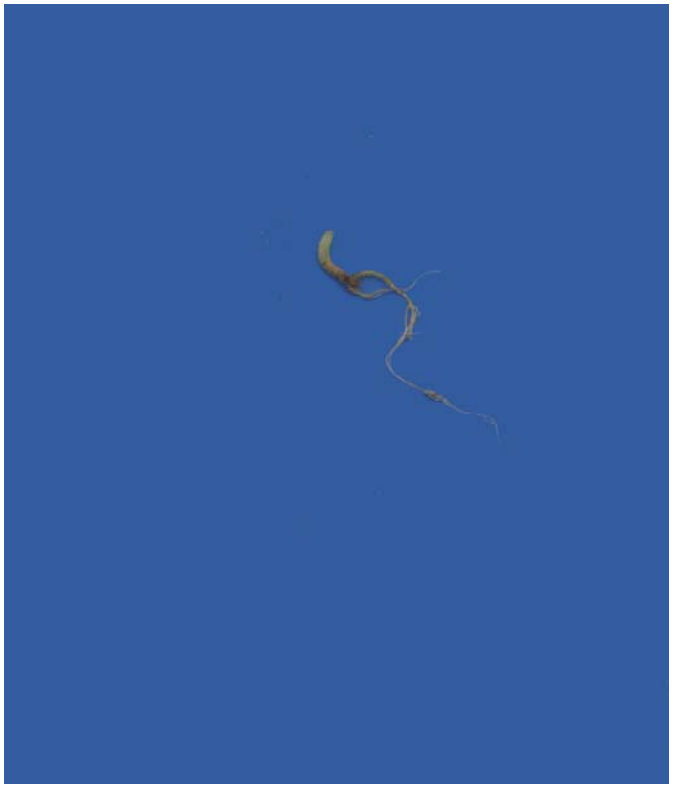
F1 Pat81xPs
M. cannonballus

F1 Pat81xPs
M. eutypoides

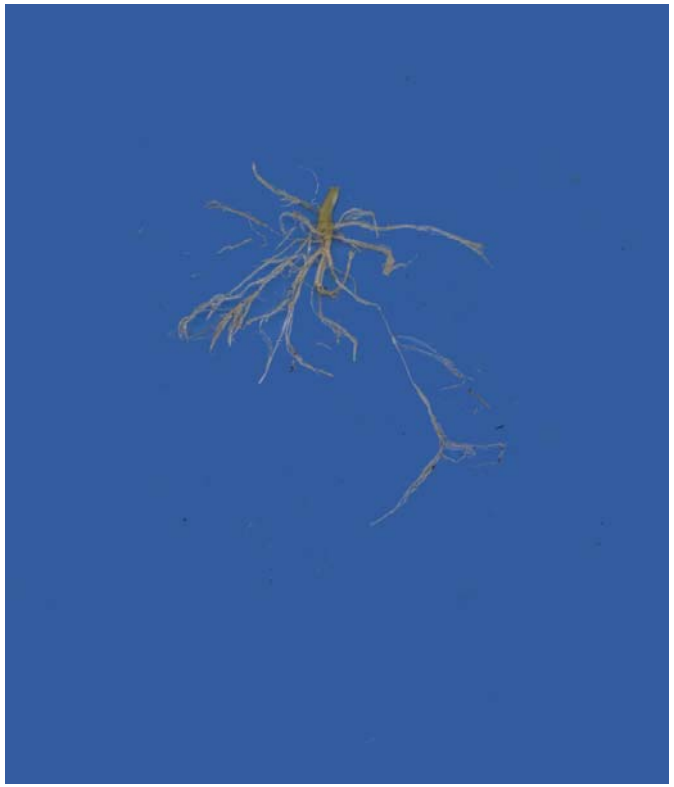
2017



Ib-PsPiñSp
Control



Ib-PsPiñSp
M. cannonballus

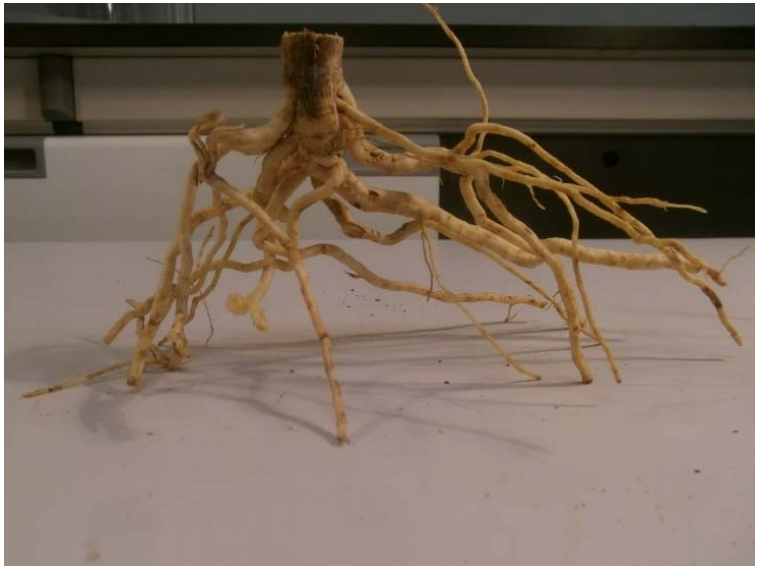


Ib-PsPiñSp
M. eutypoides

b) Field assay

Ib-PsPiñSp

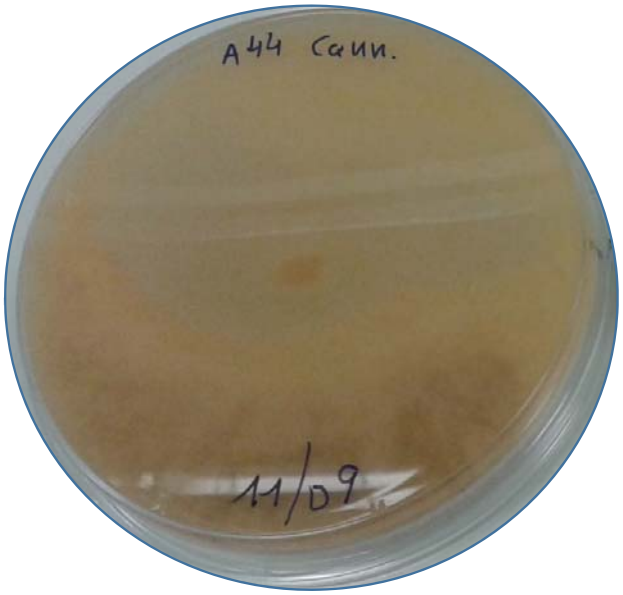
F1 Pat81xPs



Met-BGV11135Afr

c) Re-isolation

Re-isolation of *Monosoporascus cannonbalus* from infected roots in a PDA plate



Growth from agar plug transferred to fresh PDA plate