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Original article

Green compost influences yield and quality of carrots (*Daucus carota* L.) by enhancing root rot suppression to *Sclerotinia sclerotiorum* (Lib. De Bary)

G. Cucci[1], G. Lacolla[1], M.A. Mastro[1], D. Caranfa[1], A. Monteforte[2] and U. De Corato[3]

[1] University of Bari 'Aldo Moro', Department of Agricultural and Environmental Science (DiSAAT), Bari, Italy
[2] Tersan Puglia S.p.A., Modugno (Bari), Italy
[3] Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Department of Bioenergy, Biorefinery and Green Chemistry, Territorial Office of Bari, Bari, Italy

Summary

The aim of this research, carried out in Bari and Policoro (Southern Italy) from March to June 2018, was to evaluate the effects of two different green composts on yield, quality, and root rot suppression of carrot (*Daucus carota* L.) cv. Rubrovitamin when compared to a mineral fertilizer and a plant growing media of peat-pumice. Green composts obtained from the municipal solid waste (Biovegetal) and olive pomace by olive mill were used in outdoor crop as fertilizer to enhance root yield and quality and in glasshouse to evaluate root rot suppression against *Sclerotinia sclerotiorum*. A randomized complete block design with six replicates was used. A total of eight treatments was compared in outdoor (mineral fertilization, three levels of each compost and unfertilized control). A total of five treatments was used in glasshouse: carrot was cropped in a growing media made of peat and pumice and fertilized with the two composts at two different levels, compared to an un-sterile potting mix of 60% peat with 40% pumice used as control.

In the carrot grown outdoors the different composts did not influence either the length of the phenological phases or the entire crop cycle, but the highest dose of olive pomace (30 Mg ha^{-1}) favored the greatest root production with an increase of 19.9% if compared to the mineral fertilizer. Biovegetal at the highest dose (30 Mg ha^{-1}) provided non-statistically differences in root production from that obtained with the mineral fertilization, as well as the lowest rate (15 Mg ha^{-1}) of composted olive pomace supplemented with 50 kg N ha^{-1}. The highest carotenoids content, total soluble solids and specific weight were recorded by the amendment with the highest composted olive pomace rate. Concerning the root rot suppression effect, Biovegetal showed to be more effective than composted olive pomace. Thus, the use of green compost could represent a useful alternative to mineral fertilization and soil-borne disease control by synthetic fungicides through an adding-value due to by-products reusing and waste recycling.

Keywords
composted municipal solid waste, composted olive pomace, soil-borne plant disease, sustainable agriculture

Significance of this study

What is already known on this subject?

- The effects of green composts sourced from a wide range of feedstocks made of agro-waste, municipal solid waste, and agro-industrial residues on many horticultural cropping systems have recently been studied under greenhouse condition in order to control soil-borne plant pathogens without use of synthetic fungicides.

What are the new findings?

- The effects of two new green composts on yield, quality, and root rot suppression on carrot crops, in comparison to a mineral fertilizer and plant growing media of peat-pumice, were studied through a multidisciplinary approach.

What is the expected impact on horticulture?

- We expect that the increasing need to recycle great amount of agro-waste through the production of compost within a circular economy and biorefinery system, can be usefully combined with the increasing demand from the horticultural market for a better quality of vegetables cultivated with low inputs of mineral fertilizer and synthetic fungicide.

Introduction

Italy is one of the most important European vegetable-producing countries with over one hundred thousand hectares of land destined for open field vegetable crops only in Apulia (South Italy) (ISTAT, 2017). The demand for carrot root (*Daucus carota* L.) produced under organic agriculture conditions is increasing over time, both in the Italian and international trade markets. Carrot cultivation is strongly requested, particularly for producing minimally-processed baby carrots and carrot juice due to their high nutritional value and anti-oxidant properties (De Corato, 2020). Unfortunately, to reach this goal, the content of soil organic matter in some Apulian areas is too low since it can be even below 1% (Costantini and Lorenzetti, 2013). This severe reduction has been especially found in clay soils, where alarming levels of organic matter can compromise soil structure, apparent density, and optimal condition for carrot root growth (Anon., 2007).

The introduction and diffusion of door-to-door collection system of the municipal solid waste (MSW) has increased the quantity and quality of the organic fraction of waste produced by municipalities (Brunetti et al., 2019). The increasing use of soil organic amendments by tailored composts obtained from green manure and wider range of green sources (De Corato et al., 2016, 2018b) are nowadays considered as an effective means for the reintegration of organic matter into the soil and restoration of its fertility (Cucci et al., 2013). At the same time, the use of green compost for increasing suppression to soil-borne plant diseases was frequently adopted in many horticultural systems practised under greenhouse conditions where the suppressive capacity of compost is mainly determined by taxonomic composition of its microbiota (De Corato et al., 2018c). Composting is considered as a powerful technology that converts organic wastes to eco-friendly soil amendments, thus attenuating the pressure of landfill and incineration of industrial waste and bio-waste (Kumar, 2011; Amore et al., 2013). Consequently, if on the one hand the development of new composting techniques has rapidly proceeded over time by a circular economy approach (De Corato et al., 2018a), on the other hand the banned substances for soil fumigation with methyl bromide, 1,3-dichloropropene and chloropicrin against root rot of carrot by *Sclerotinia sclerotiorum* (Lib.) de Bary should be replaced with eco-friendly organic fertilizers. The current national legislation on organic fertilizers (Italian Legislative Decree No. 217/06; Italian Legislative Decree No. 75/10) identifies three types of composted biomasses based on their origin and quality: (i) green compost used as soil conditioner; (ii) mixed compost employed as soil amendment; and (iii) compound peat soil conditioner. The adding of ‘green compost’ derived from agro-waste, agro-industrial co/by-products and bioenergy residues into the soil, whenever the content of organic matter is often below 1% and severe outbreaks of carrot root rot by *S. sclerotiorum* occurred, can be advantageous for growers. Compost should be added to plant growing media within a specific application range for avoiding either phytotoxic effects (De Corato et al., 2016) or significant increases of the salts and heavy metals content (Hargreaves et al., 2008).

In this work, we suggested a reliable solution to stimulate carrot production toward a perspective of sustainable agriculture and residual biomass recycling by composted municipal solid wastes (MSW mixed with food, garden wastes and residual biomass deriving from farms and agrofood industries, and possibly residential and no harmful sewage sludge). To this aim, the productive performances and root rot suppression to *S. sclerotiorum* were studied. The goal of this work was thus reached to study the effects of two different green composts on the yield, quality and root rot suppression of carrot crops when compared to a mineral fertilizer and peat-pumice mix, respectively, which are input materials usually used in the Italian cropping systems.

Materials and methods

Green composts

The two composted feedstocks considered included a compost made of olive pomace produced by the University of Bari and a patented green compost (Biovegetal) provided by the Biovegetal Srl, Modugno, Bari. Composted olive pomace was obtained from bio-oxidation and maturation of olive mill pomace (74%) mixed with shredded green wastes coming from the pruning of ornamental and fruit trees (21%), ‘Pedian LRM’ (2.5%) used as composting starter, and urea (2.5%) as nitrogen source. Pedian is a natural inoculum for compost consisting of a mixture of polysaccharides and raw organic material in order to stimulate the activity of microorganisms into composting piles such accelerating the decomposition process of the organic wastes. Biovegetal was a green compost obtained from a careful selection of organic matrices, principally made of wet organic waste coming from the separate collection of municipal solid waste (MSW) mixed with a heterogeneous feedstock of lignocellulosic sources (green waste) deriving from the pruning of parks and gardens far from the busy areas.

The main physicochemical characteristics of composts were determined according to the official methods given by the current Italian legislation on organic fertilizers (ANPA, 2001).

The microbial composition of composts was quantified according to the procedures described by De Corato et al. (2016). Briefly, the abundances of culturable total filamentous fungi and total bacteria including the most important biocontrol agents (BCAs) of compost microbiota (De Corato et al., 2018c), were enumerated in order to determine compost microbiological load. Fungi, bacteria and BCAs groups were counted in triplicate from three independent replicates of each compost by plate count method on an aliquot of 25 g fresh weight which do not change the real field status for microbial analysis. Aliquot was transferred into a Stomacher-bag filled with 225 mL of maximum recovery diluent (Oxoid, United Kingdom) to obtain ten-fold dilutions. After a 2-min homogenization into a Stomacher homogenizer (Stomacher 400 Circulator; Seward, UK) at 25°C for 20 min with 90 mL sterile 0.02 M potassium-phosphate buffer (PPB) pH 7.0, ten-fold dilutions into PPB were done, and aliquots placed on agar in Petri plates (100 µL per plate) by an automated spiral plater (Eddy Jet; IUL Instruments, Barcelona, Spain). Abundance of fungi and bacteria was determined according to the methods described by Larkin and Honeycutt (2006) by general, semi-selective and selective growing media (De Corato et al., 2016) into Petri plates. Sets of analyses were performed on the same batch of compost used throughout all the experiments. Data were recorded as colony forming unit per gram of compost (CFU g^{-1}) and expressed as log CFU g^{-1}. The triplicate data from each sample were pooled before statistical analyses.

Study sites, plant cultivation and experimental trials

In order to assess yield and quality of carrot root, the trials were carried in outdoor out during one cropping season, from 15th March to 25th June 2018, at the experimental field of the Faculty of Agriculture of the University of Bari (Italy) (40°11’08”N, 16°88’05”E). Carrot plants cv. Rubrovitamin were sowed in plastic containers made of a truncated cone shape having a height of 40 cm, major and minor diameter corresponding to 40 and 35 cm, respectively, each filled with 75 kg potting mixes made of medium-grain clay soil. The characterization of the main physicochemical properties of the medium-grain clay soil used for evaluating yield and quality of carrot (Table 1) was performed according to official methods (Violante, 2000). A total of eight treatments were compared (Table 2): (i) mineral fertilization (M) which provided 100 kg ha^{-1} nitrogen in the form of ammonium nitrate, 80 kg ha^{-1} phosphorus as mineral superphosphate, and 200 kg ha^{-1} potassium as potassium sulphate; (ii) three levels of composted olive pomace (O1, O2 and O3, corresponding to 15, 20 and 30 Mg ha^{-1}, respectively); and (iii) three levels of Biovegetal (B1, B2 and B3 corresponding to 15, 20 and 30

Table 1. Main physicochemical properties of the medium-grain clay soil used for evaluating yield and quality of carrot crop.

Parameter		Measure unity	Value
Particle-size analysis:			
Total sand	2>Ø>0.02 mm	g 100 g^{-1}	21.24
Silt	0.02>Ø>0.002 mm	g 100 g^{-1}	44.76
Clay	Ø<0.002 mm	g 100 g^{-1}	34.00
Chemical properties:			
Total nitrogen (Kjeldahl method)		g kg^{-1}	1.32
Available phosphorus (Olsen method)		mg kg^{-1}	31.50
Exchangeable potassium ($BaCl_2$ method)		mg kg^{-1}	352.00
Organic matter (Walkley Black method)		g 100 g^{-1}	2.15
Total limestone (Dietrich-Frühling method)		g 100 g^{-1}	4.68
Active limestone		g 100 g^{-1}	3.40
ECe[a]		dS m^{-1}	0.68
ESP[b]		%	0.80
pH (in water)			7.24
CEC[c] ($BaCl_2$ method)		meq 100 g^{-1}	28.00
Hydrologic properties:			
Field capacity (field determination)		g 100 g^{-1} d.m.	32.50
Wilting point (-1.5 MPa)		g 100 g^{-1} d.m.	18.10
Bulk density		kg dm^{-3}	1.22

[a] ECe: saturation extract electrical conductivity. [b] ESP: exchangeable sodium percentage. [c] CEC: cation exchange capacity. $BaCl_2$: barium chloride. d.m.: dry matter.

Table 2. Fertilization types applied to carrot crop.

Treatment	Composted olive pomace (Mg ha^{-1})	Biovegetal (Mg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
Co	–	–	0	0	0
M	–	–	100	80	200
O1	15	–	50	0	0
O2	20	–	0	0	0
O3	30	–	0	0	0
B1	–	15	50	0	0
B2	–	20	0	0	0
B3	–	30	0	0	0

Co: unfertilized control. M: treatment with mineral fertilizer. O: treatments with composted olive mill pomace at three doses (O1, O2 and O3). B: treatments with Biovegetal at three doses (B1, B2 and B3).

Mg ha^{-1}, respectively). An unfertilized control (Co) was included. The treatments O1 and B1 were supplemented with 50 kg N ha^{-1} in the form of ammonium nitrate. After sowing, the containers were located outdoors and carrot plants were maintained under open field conditions for three months before being harvested. The composts were immediately buried after distribution and, after more than one month, seed bed was prepared for carrot cultivation. Sowing took place on 15th March 2018 making a planting density of 40 plants m^{-2} distributed over two rows per container. Irrigation management consisted in returning to the entire soil mass the field water capacity at the depletion of 30% of the available water determined by evaporation-transpiration method. Besides that, all the cultivation techniques were carried out according to the common techniques practiced in the area under consideration. A completely randomized block design with eight treatments (Co, M, O1, O2, O3, B1, B2 and B3) × six replicates was used; four plants were present in each pot.

In order to evaluate root rot suppression of carrot plants, supplementary trials were performed, from March to June 2018, in a glasshouse located at the ENEA of Policoro (Italy) (41°27’37”N, 15°30’05”E). Carrot plants cv. Rubrovitamin were sowed into paper pots (90 holes, 5 cm diameter per hole) containing sterilized vermiculite-peat and transplanted at the one to two true-leaf stage in rows (20 × 1.5 × 0.35 m, length × width × depth) filled with the growing media made of peat and pumice amended with the two composts at the different dosages. Before transplanting, all media were artificially infested with a phytopathogenic strain of *S. sclerotiorum* isolated from lettuce cv. Iceberg (strain Ss-Uniba-009876-2018) provided by the University of Bari. Inoculum of pathogen was prepared grinding wheat seeds which were placed in a 500-mL flask, saturated with potato dextrose broth (Oxoid) at 1:10 (w/w) and autoclaved at 121°C for 30 min. Flasks were inoculated with agar discs taken from colonies grown on potato dextrose agar (Oxoid) in glass

Petri dishes (Ø = 200 mm) at 23°C under light condition until sclerotia were abundantly produced, and incubated at 25°C for 21 days. The millet inoculum was air-dried for 3 days and added to the growing media at a 2% (volume/volume, v/v). A mix of *Sphagnum* peat (50% light peat + 50% dark peat: fraction 0–15 mm, air content 15–25%, volume porosity more than 85% and pH adjusted to 5.75 with 4 g L^{-1} $CaCO_3$) and pumice was used in comparative treatments for evaluating compost suppressiveness. A total of five treatments were compared: (i) 45% sterile peat + 15% unsterile Biovegetal + 40% sterile pumice; (ii) 45% sterile peat + 15% unsterile composted olive pomace + 40% sterile pumice; (iii) 30% sterile peat + 30% unsterile Biovegetal + 40% sterile pumice; (iv) 30% sterile peat + 30% unsterile composted olive pomace + 40% sterile pumice; and (v) an un-sterile potting mix of 60% peat with 40% pumice used as control. Sterilization was carried out in autoclave twice at 121°C for 1 h before being tested. Media were fertilised with 4 g L^{-1} Osmocote 10-11-18 NPK (Scotts, Italy) before being tested. After transplanting, rows were covered with a hydrolysed protein-based mulching coating for avoiding solarization effect (Sartore et al., 2018). Plants were daily watered with an equal amount of irrigation water and maintained at 25 ± 2°C and 90 ± 5% RH under a 12h/12h light/dark cycle for 40 days. A completely randomized block scheme comprising 5 treatments × 6 replicates × 20 plants was designed. Four replications were inoculated with the pathogen, while the remaining two were not inoculated. Each trial was repeated twice in April and September.

Morphometric-physiological parameters, yield and root quality

1. Morphometric parameters. The following morphometric parameters were determined: (i) shoot fresh weight and dry matter; (ii) root fresh weight and dry matter; (iii) root length and diameter. Dry matter was determined in an oven at 70°C for 48 hours. Root length was measured from the collar to the end of the tip, while the root diameter was measured with a caliber at 2 cm from the collar. Each sample was composed by 4 carrots.

2. Chlorophyll content. The shoot chlorophyll content was determined by means of SPAD index using a chlorophyll meter (SPAD-502; Spectrum Technologies Inc., Aurora, IL, USA) 80 days after sowing.

3. Specific gravity. Each root carrot was individually weighed in air and subsequently immersed in a graduated cylinder to measure the displaced water volume. The specific weight was calculated by applying the following index (Mackey et al., 1973):

$$\text{Specific gravity} = \frac{\text{Mass (weight carrot in g)}}{\text{Volume (mL water displaced)}} \qquad (1)$$

4. Total soluble solids. The soluble solids content was determined by taking a sample from the central part of fresh carrots, then cut into small pieces, mixed, and blended with a blender until a homogenate was obtained (Gills et al., 1999). Homogenate was filtered with Whatman No. 1 filter paper to obtain a carrot juice extract. The soluble solids were measured using a portable digital refractometer (HI 96811; Hanna Instruments, Italy Srl). From three to four drops of extract were placed on the refractometer cell to measure soluble solids expressed as °Bx.

5. Total carotenoids. The total carotenoids content was measured according to the method described by Alasalvar et al. (2005). The carrot extract as previously prepared was brought to 100 mL with the extraction solvent to afford the extract, and absorbance at the wavelength of 471 and 477 nm was measured against a blank (acetone) using a spectrophotometer (T60UV-Visble; PG Instruments Ltd., UK). The total carotenoids content, expressed as mg 100 g^{-1} fresh carrots, was calculated by applying the following index:

$$\text{Total carotenoids} = \frac{\text{Absmax}}{250} * \frac{25\text{ mL acetone} \times \text{dilution}}{\text{Sample weight}} * 100 \qquad (2)$$

6. Root rot suppression. Symptoms of root rot (Figure 1) were recorded on carrots by counting the number of diseased roots at the end of bioassay. In order to assess the suppressive effect of each treatment in comparison to the respective sterilized media, the suppression degree amongst growth media was measured applying the following disease suppression index (De Corato et al., 2016):

$$\text{DSI \%} = [(N_{PA} - N_{CA})/N_{PA}] * 100 \qquad (3)$$

where N_{CA} is the number of diseased roots in the different media and N_{PA} in the respective sterilized media.

FIGURE 1. Symptom of root rot on carrots caused by *Sclerotinia sclerotiorum* after an artificial inoculation with a pathogenic strain of the fungus.

Data analysis

Experimental data were tested against the normal distribution using the Shapiro-Wilk's test and against the homogeneity of variance by the Bartlett's test, and then analyzed using the GLM procedure of the statistical analysis system (SAS, 2009). Normally distributed data means regarding to the morphometric-physiological, yield and root quality parameters showing homogeneity of variance were subjected to one-way analysis of variance (one-way ANOVA), and the differences judged as significant were separated with the Student-Newman-Keuls (SNK) test at $P \leq 0.01$ level. Means regarding to the abundances of fungi, bacteria and specific taxonomic groups related to disease suppression, and root rot suppression index showing homogeneity of variance, were analysed by one-way ANOVA and separated by the Duncan's multiple range test (DMRT) when differences were judged as significant at $P \leq 0.05$ level.

Results

Compost properties

The main physicochemical characteristics of composts were reported in Table 3. Different values in pH, saturation extract electric conductivity (ECe) and carbon/nitrogen ratio (C/N) amongst the composts were found. Particularly, composted olive pomace shows higher pH (7.9) and lower ECe (1.27 dS m^{-1}) and C/N (7.5) than Biovegetal that instead shows lower pH (7.5) and higher ECe (1.57 dS m^{-1}) and C/N (15).

Abundance of culturable fungi and bacteria, as well as specific taxonomic groups related to biocontrol of soil-borne plant diseases, were both shown in Figure 2. Biovegetal shows a high colonization of both total filamentous fungi and bacteria more than composted olive pomace. Moreover, all the most important fungal BCAs belonging to the *Trichoder-*

TABLE 3. Physicochemical properties of composts measured on dry matter.

Parameter	Measure unity	Composted olive pomace	Biovegetal
Moisture	%	30	20
pH	–	7.9	7.5
ECe[a]	dS m^{-1}	1.27	1.57
Total carbon (C)	g kg^{-1}	23.6	30
Total nitrogen (N)	g kg^{-1}	3.16	2
C/N	–	7.5	15
Total phosphorus (P)	g kg^{-1}	0.72	8.6
Total potassium (K)	g kg^{-1}	8.5	14
Calcium (Ca)	g kg^{-1}	2.9	3.5
Magnesium (Mg)	g kg^{-1}	1.4	1.2
Zinc (Zn)	mg kg^{-1}	41.4	164
Copper (Cu)	mg kg^{-1}	24.6	97

[a] ECe: saturation extract electrical conductivity.

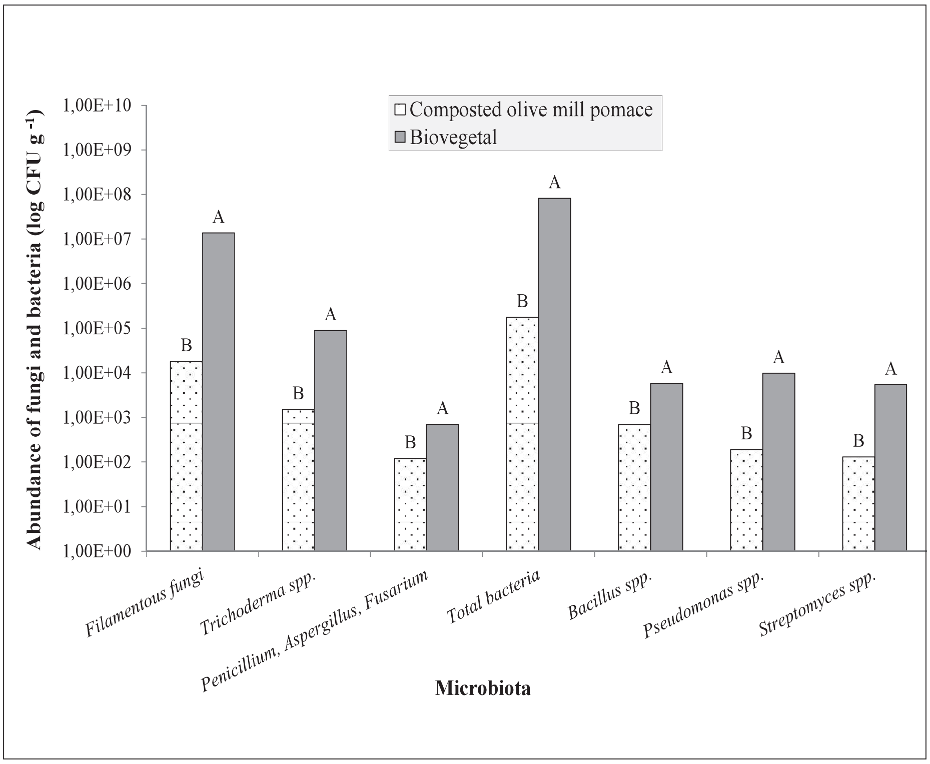

FIGURE 2. Cultivable microbial groups enumerated in two different composts. Abundances of filamentous fungi and total bacteria, and specific biocontrol agents to soil-borne plant pathogens (*Trichoderma*, *Penicillium*, *Aspergillus*, *Fusarium*, *Bacillus*, *Pseudomonas* and *Streptomyces*), are determined by ten-fold dilutions in Petri plates (Ø = 90 mm) on different media after incubation at various temperatures and times. Values of colony forming unity per fresh gram of compost (CFU g^{-1}), expressed as log CFU g^{-1}, are the pooled mean of three replications of 25 g each. Different uppercase letters for each microbial group indicate significant differences according to one-way analysis of variance (one-way ANOVA) and the Duncan's multiple range test (DMRT) ($P \leq 0.05$).

ma, *Penicillium*, *Aspergillus* and *Fusarium* genera, as well as bacterial BCAs belonging to the *Bacillus*, *Pseudomonas* and *Streptomyces* genera, resulted more abundant in Biovegetal than composted olive pomace, ranging from 1 to 3 log units among the composts.

Morphometric-physiological parameters, yield and root quality

1. Morphometric parameters and chlorophyll content. Tables 4 and 5 show the effects of different doses of composted olive pomace and Biovegetal, and the mineral fertilizer, on the morphometric parameters and the chlorophyll content in carrot crops. SPAD index shows (Table 4) that there are no significant differences among the treatments (on average equal to 30), while the lowest value (15.93) was recorded in the unfertilized control.

The highest shoot fresh weights (Table 4) were obtained with the application of the highest dose of Biovegetal (52.71 g) and composed olive pomace (56.38 g) which were not significantly different from the treatment with mineral fertilizer that gave 54.15 g fresh biomass. Amendments with 15 Mg ha^{-1} composted olive pomace, after supplementation with 50 kg ha^{-1} N, has produced to reach 53.28 g fresh biomass, while a lower effect was obtained amending with 15 Mg ha^{-1} Biovegetal supplemented with 50 kg ha^{-1} N (34.59 g). The percentage of shoot dry matter (Table 4) was significantly higher in the unfertilized control (22.68%). Regarding to the averaged root fresh weight (Table 5), it resulted significantly variable. The highest root fresh weight value was recorded with the supplementation of 30 Mg ha^{-1} with composted olive pomace (109.51 g), accounting for an increase of about 489.9% if compared to the unfertilized control (18.5 g). No difference was detected between the root fresh weight obtained after amendment with the mineral fertilizer (91.36 g) compared with those obtained by 30 Mg ha^{-1} Biovegetal (90.09 g), and with the lowest dose of composted olive pomace supplemented with 50 kg ha^{-1} N (92.19 g). Nonetheless, lower root fresh weight was found after amendment with 20 Mg ha^{-1} composted olive pomace (75.61 g), 15 Mg ha^{-1} Biovegetal supplemented with 50 kg ha^{-1} N (53.73 g), and 20 Mg ha^{-1} Biovegetal (69.87 g). The highest root dry matter (Table 5) was found in the unfertilized control (16.84%), while a beneficial effect was found by amendment with the lowest dose of Biovegetal supplemented with 50 kg ha^{-1} N (15.15%). Finally, regarding to length and diameter of root (Table 5), they were significantly influenced by mineral and organic fertilization. The longest and thickest sizes were recorded when the crop was supplemented with mineral fertilizer (19.77 and 3.63 cm, respectively) and organic amendments (on average, 20.15 and 3.41 cm, respectively) at the different doses. The shortest and thinnest sizes were found amending the potting mix with 15 Mg ha^{-1} Biovegetal supple-

Table 4. Effect of different doses of composted wet olive pomace and Biovegetal, and the mineral fertilization, on Spad index, fresh weight and dry matter of carrot shoot.

Treatment	Spad index (–)	Fresh weight (g plant^{-1})	Dry matter (g 100 g^{-1})
Co	15.93 ± 3.3B	11.04 ± 0.6C	22.68 ± 1.2A
M	34.70 ± 2.3A	54.15 ± 3.5A	19.51 ± 0.3C
O1	28.33 ± 4.7A	53.28 ± 0.5A	20.33 ± 0.5C
O2	33.50 ± 5.7A	40.64 ± 4.7B	21.25 ± 0.6B
O3	34.43 ± 2.6A	56.38 ± 3.5A	20.84 ± 0.4BC
B1	29.27 ± 1.2A	34.59 ± 2.6B	20.00 ± 0.2C
B2	33.40 ± 1.6A	36.46 ± 5.6B	19.65 ± 0.4C
B3	33.87 ± 1.7A	52.71 ± 2.9A	19.80 ± 0.3C

Co: unfertilized control. M: mineral fertilization. O1: 15 Mg ha^{-1} composted olive pomace + 50 kg ha^{-1} N. O2 and O3: 20 and 30 Mg ha^{-1} composted olive pomace, respectively. B1: 15 Mg ha^{-1} Biovegetal + 50 kg ha^{-1} N. B2 and B3: 20 and 30 Mg ha^{-1} Biovegetal, respectively. Mean ± standard deviation. Values followed with different uppercase letters in each column indicate significant differences according to the SNK test at $P \leq 0.01$.

Table 5. Effect of different doses of composted olive pomace and Biovegetal, and the mineral fertilization, on the morphometric-physiological and qualitative parameters of carrot root.

Treatment	Fresh weight (g plant^{-1})	Dry matter (g 100 g^{-1})	Length (cm)	Diameter (cm)	Specific gravity (g mL^{-1})	Total soluble solids (°Bx)
Co	18.5 ± 3.2D	16.84 ± 0.9A	11.97 ± 0.3C	1.87 ± 0.3C	1.27 ± 0.1A	12.97 ± 0.8A
M	91.36 ± 3.7B	12.74 ± 0.3C	19.77 ± 0.2A	3.63 ± 0.3A	1.16 ± 0.2C	11.43 ± 0.4AB
O1	92.19 ± 4.8B	12.34 ± 0.3C	19.10 ± 0.1A	3.47 ± 0.4AB	1.17 ± 0.1C	10.57 ± 0.6B
O2	75.61 ± 5.2BC	12.86 ± 0.6C	21.13 ± 0.2A	3.13 ± 0.6AB	1.21 ± 0.1BC	11.30 ± 0.8AB
O3	109.51 ± 4.3A	11.80 ± 0.8C	21.33 ± 0.3A	3.80 ± 0.6A	1.20 ± 0.2BC	10.77 ± 0.9B
B1	53.73 ± 5.2C	15.15 ± 0.4B	16.67 ± 0.3B	2.57 ± 0.4B	1.22 ± 0.1B	12.30 ± 0.4AB
B2	69.87 ± 3.8BC	12.60 ± 0.3C	19.30 ± 0.2A	3.20 ± 0.3AB	1.20 ± 0.1BC	11.63 ± 0.2AB
B3	90.09 ± 4.7B	12.69 ± 0.5C	19.87 ± 0.2A	3.43 ± 0.4AB	1.18 ± 0.2BC	11.37 ± 0.3AB

Co: unfertilized control. M: mineral fertilization. O1: 15 Mg ha^{-1} composted olive pomace + 50 kg ha^{-1} N. O2 and O3: 20 and 30 Mg ha^{-1} composted olive pomace, respectively. B1: 15 Mg ha^{-1} Biovegetal + 50 kg ha^{-1} N. B2 and B3: 20 and 30 Mg ha^{-1} Biovegetal, respectively. Mean ± standard deviation. Values followed with different uppercase letters in each column indicate significant differences according to the SNK test at $P \leq 0.01$.

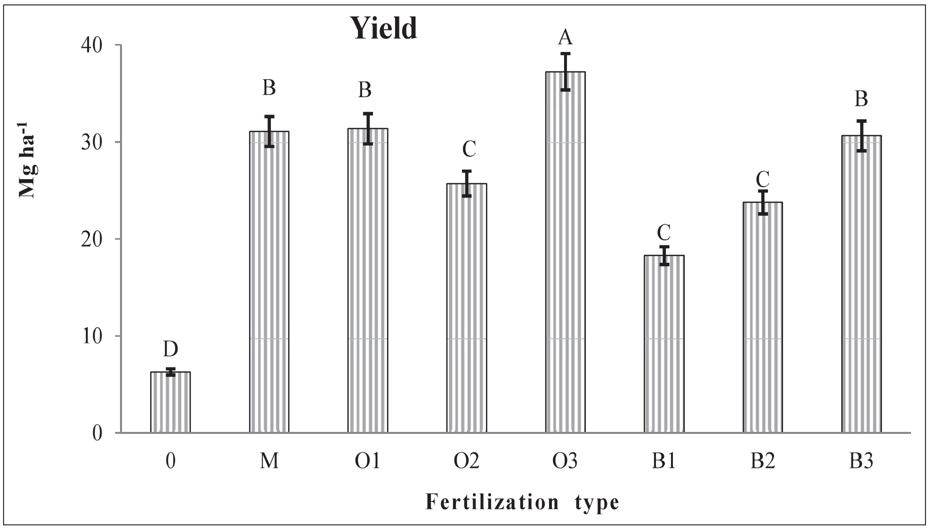

FIGURE 3. Root fresh yield of carrots tested at three different doses of composted olive pomace (O1, O2 and O3) and Biovegetal (B1, B2 and B3) compared to the mineral fertilizer (M) and unfertilized control (Co). Values are means of six replicates of 4 carrots for each. Values with different uppercase letters in each treatment indicate significant differences according to one-way ANOVA and the Student-Newman-Keuls (SNK) test ($P \leq 0.01$). Bar indicates standard error (SE) of the mean.

mented with 50 kg ha^{-1} N (16.67 and 2.57 cm, respectively) and in the unfertilized control (11.97 and 1.87 cm, respectively). Finally, no malformed or bifurcated roots were found.

Figure 3 shows root fresh yield tested against different doses of composts and the mineral fertilizer. The highest production (37.23 Mg ha^{-1}) was obtained by adding 30 Mg ha^{-1} composted olive pomace; then, it decreased on average by 30.2% using the mineral fertilization, 15 Mg ha^{-1} composted olive pomace supplemented with 50 kg ha^{-1} N, and 30 Mg ha^{-1} Biovegetal; finally, it decreased on average from 25 to 18% after amendment with 20 Mg ha^{-1} composted olive pomace and 15 Mg ha^{-1} Biovegetal supplemented with 50 kg ha^{-1} N, respectively.

2. Specific gravity. Table 5 shows the effects of different doses of composted olive pomace, Biovegetal and the mineral fertilizer on specific gravity, a parameter that generally result to be positively correlated with the root dry matter content. The highest value occurred in the unfertilized control (1.27 g mL^{-1}). Instead, the lowest value was found in the potting mix supplemented with the mineral fertilizer (1.16 g mL^{-1}). Amongst composts, the highest value was recorded amending with 15 Mg ha^{-1} Biovegetal supplemented with 50 kg ha^{-1} N (1.22 g mL^{-1}), while the lowest specific gravity value was found for composted olive pomace supplemented with 50 kg ha^{-1} N (1.17 g mL^{-1}).

3. Total soluble solids. Table 5 shows the effects of different doses of composted olive pomace, Biovegetal, and the mineral fertilizer on total soluble solids. This parameter resulted in lower values in treatments with the composted olive pomace supplemented with 50 kg ha^{-1} N (10.57 °Bx) and 30 Mg ha^{-1} composted olive pomace (10.77 °Bx). While, higher soluble solids contents were found in the unfertilized control (12.97 °Bx), followed by the treatment with 15 Mg ha^{-1} Biovegetal supplemented with 50 kg ha^{-1} N (12.30 °Bx). Finally, the treatment with mineral fertilizer, reaching the value of 11.43 °Bx, resulted quite intermediate amongst the composts.

4. Total carotenoids. Figure 4 shows the total carotenoids content of carrots tested against different doses of composts and mineral fertilizer. The addition of the highest dose of composted olive pomace produced carrots with the highest total carotenoid content (29.85 mg 100 g^{-1}); while intermediate values without significant difference among them were detected in carrots fertilized with 30 Mg ha^{-1} Biovegetal, 20 Mg ha^{-1} composted olive pomace, and the mineral fertilizer. Instead, the lowest content of total carotenoids (on average 20.02 mg 100 g^{-1}) was found in the unfertilized control and in crops amended with the lowest doses of both composts supplemented with 50 kg ha^{-1} N and 20 Mg ha^{-1} Biovegetal.

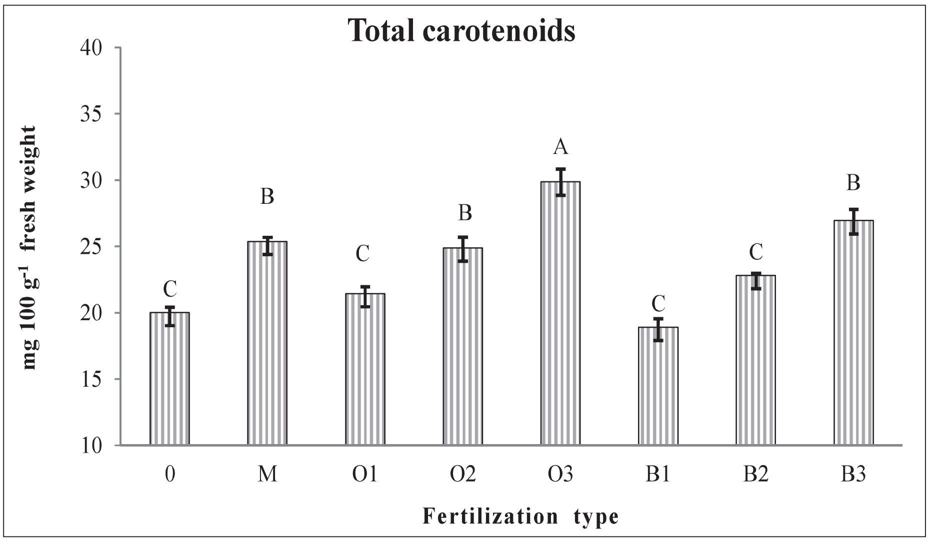

FIGURE 4. Total carotenoids content of carrots tested at three different doses of composted olive pomace (O1, O2 and O3) and Biovegetal (B1, B2 and B3) compared to the mineral fertilizer (M) and unfertilized control (Co). Values are means of three replicates of 0.5 g fresh weight for each. Values with different uppercase letters in each treatment indicate significant differences according to one-way ANOVA and the SNK test ($P \leq 0.01$). Bar indicates SE.

Root rot suppression

Figure 5 shows the root rot suppression index of inoculated carrot plants with *S. sclerotiorum*. The best result in terms of healthy roots was obtained by 70% suppression through a treatment carried out with 30% peat + 30% Biovegetal + 40% pumice, followed by a treatment performed with 30% peat + 30% composted olive pomace + 40% pumice that has allowed to obtain 48% suppression. While, the treatment carried out with unsterile 60% peat + 40% pumice has obtained only 18% suppression.

Discussion

From the physicochemical perspective, both composts were observed to be of good quality for suitable uses in horticulture according with the European directive (Regulation EC No. 2003/2003) and Italian law (Legislative Decree No. 75/10). From the microbiological point of view, Biovegetal was colonized by the different microbial groups under consideration more than composted olive pomace. Our findings agree with the findings of De Corato et al. (2018c) that concluded that compost microbiota primarily depend on the feedstock from which each compost was derived, and with those of Hoitink et al. (1997) that demonstrated that composts with C/N > 10 were well colonized by a wider range of microbiota belonging to different genera. Thus, we can suppose that Biovegetal could have provided an optimal substrate to support the microbial biomass growth capable to suppress *S. sclerotiorum* more than composted olive pomace Nevertheless, it is due to underline that the interaction between living microbiota of compost and *S. sclerotiorum* suppression has not been yet fully elucidated since the variables that drive suppression against *Sclerotinia* root rot are not completely clear.

Concerning yield and quality parameters related to the high standards required from the minimally-processed fresh carrot market, such as root fresh weight and total carotenoids content (De Corato, 2020), they have generally shown a positive response following the employment of both composts. Most likely, in literature it is reported that compost can improve plant growth through various mechanisms which overall include reduction of nutritional constraints by improving soil moisture retention and reducing the incidence or impacts caused by pests or diseases (Brainard and Corey, 2012). Nevertheless, some growth parameters investigated in this work have shown contrasting productive responses by both composts in place of the mineral fertilizer. In general, our findings were confirmed by many authors that have reported similar positive productive responses after amendment with organic fertilizers on carrot yield (Mog, 2007; Sunandarani and Mallareddy, 2007; Hailu et al., 2008). On the other hand, authors have observed negative effects on morphometric and quality parameters of carrots. For instance, Mufwanzala and Dikinya (2010) found a decrease in the length of shoots of carrot when the doses of chicken manure (pollen) added to the soil increased; Zakir et al. (2010) found no differences between carrot crops raised on sandy soil fertilized with a commercial organic fertilizer (Biomeal) compared to unfertilized soil, while Rubatzky et al. (1999) concluded that a larger leaf size and a greater production of foliar biomass do not always correspond to a larger root size. In addition to this, Mbatha et al. (2014) also found lower values of dry matter in the crop fertilized with organic material. Although Zakir et al. (2010) documented no significant differences in the length of carrot roots, cv. New Kuroda, in soils amended with organic fertilizers (11.1 cm) if compared to the roots developed in soils that had not received any fertilizer (10.7 cm), nevertheless the same authors measured longer roots (13.6 cm) when the carrot crop was fertilized with an inorganic fertilizer combined with Biomeal. However, the same authors have found longer roots (16.6 cm) when the carrot crop was fertilized with organic fertilizer combined with the mineral one, while no difference was found in their diameter. Although Kristensen and Thorup-Kristensen (2002) documented that soils with a high clay content may allow carrot roots to penetrate to a greater depth because the bulk density of the soil decreases, nevertheless this finding has not been detected in this work. The same authors found that supplying organic fertilizers in clay soils can reduce soil

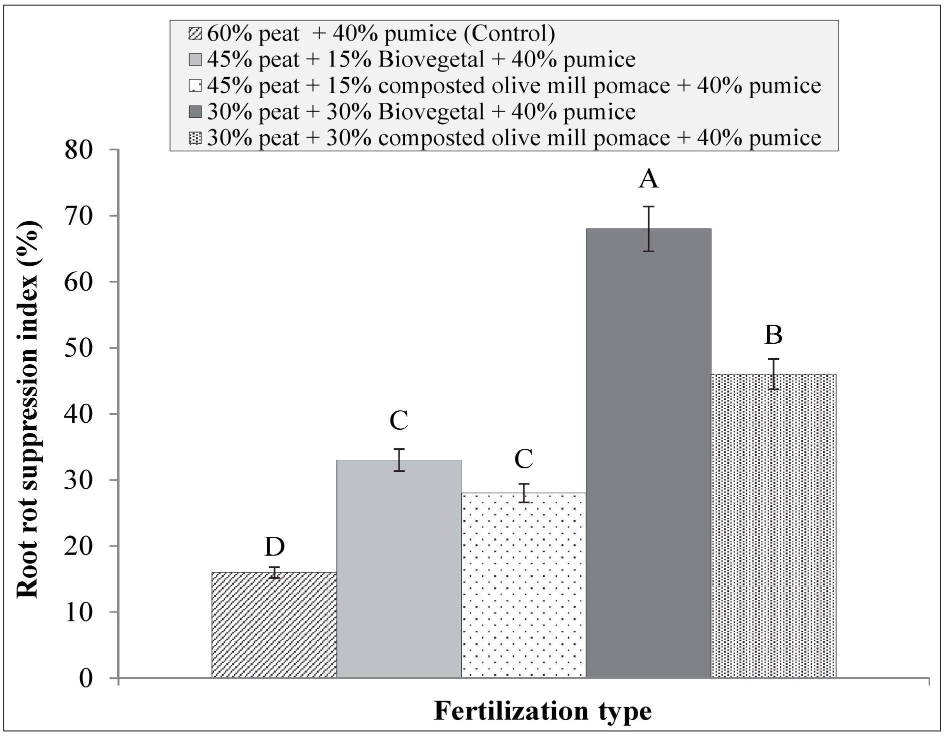

Figure 5. Root rot suppression index of inoculated carrot plants with a phytopathogenic strain of *S. sclerotiorum*. Plants are tested in five potting mixes including two different doses of Biovegetal and composted olive pomace (15 and 30%) and a peat/pumice-based control. Values are the pooled means of two experiments. Values with different uppercase letters in each treatment indicate significant differences according to one-way ANOVA and the DMRT test ($P \leq 0.05$). Bar indicates SE.

bulk density enabling carrot roots penetration into the soil at a higher depth. Furthermore, it is very important to use a well-ripened compost after curing time before the carrot is sown for soil structure modification, as well as immature compost could favor the formation of bifurcated roots, besides the well-known phytotoxic effects on lettuce and cress (De Corato et al., 2016). Moreover, a different feedstock of organic fertilizers and diverse application dosages can significantly influence the number and length of carrot leaves and roots (Kumar et al., 2014; Mbatha et al., 2014; Gatsinzi et al., 2016). The application of high doses of organic fertilizer can promote excessive growth of the foliar apparatus with the production of coarse and forged roots (Gutezeit, 2001). Regarding total soluble solids, our findings are in disagreement with those of Zakir et al. (2010) and Mbatha et al. (2014) that detected values of 4.92 and 8.30 °Bx in fertilized and unfertilized crops, respectively. In general, the reduced value of total soluble solids in carrots grown in the soil fertilized with the mineral fertilizer and in the same soil amended with the two composts may depend on the increase in nitrogen, phosphorus and potassium into root tissue, which has a negative effect on the accumulation of sucrose (Hochmuth et al., 1998; Gatsinzi et al., 2016). On the other side, Kumar et al. (2014) found no difference in total soluble solids when soil fertilizer treatments varied; while Mbatha et al. (2014) concluded that the total solids content and root dry matter may significantly decrease with the addition of high doses (more than 50%) of compost in potting mixes. The carotenoid content in minimally-processed 'baby carrots' is another important indicator for evaluating the benefits of fresh carrots for human health (De Corato, 2020). Authors found no significant differences between the productive and qualitative parameters of the carrot fertilized with mineral and organic fertilizer, except for the more intense orange color of the carrots grown with compost (Yasuda et al., 2017). This finding is very interesting by considering that a more intense orange color is linked to greater content of β-carotene, a very useful pigment that is converted in the liver. If this data will be confirmed in further researches, the organic carrot would be an added value product from the nutraceutical point of view. Finally, as regards to the different responses of carrot root fresh weight and length after amendment with composted olive pomace and Biovegetal, we can suppose that these two parameters could be influenced by compost salinity. Authors concluded that carrot crop is considered strongly sensible (Gibberd et al., 2002) or moderately sensible (Mangal et al., 1989) to soil salinity. Other authors quantified that a very significant production loss of carrots, ranging from 35 to 50%, was detected whenever soil ECe ranged between 1.5 and 2.5 dS m^{-1}, respectively (Unlukara et al., 2011).

Regarding to *Sclerotinia* root rot suppression, our findings showed that the best result was reached adding 30% Biovegetal mixed with 30% peat and 40% pumice, either in place of composted olive pomace at the same dose or in place of unsterile 60% peat mixed with 40% pumice. The contribution to suppression by the peat-pumice mix was irrelevant since it was sterilized before being tested. Very little information is available in literature for clarifying the suppression mechanisms of *S. sclerotiorum* root rot on carrot by compost. Authors documented positive and highly significant Pearson correlations between root rot suppression by *Sclerotinia* species and abundance of filamentous fungi, total bacteria and *Trichoderma* populations by using on-farm composted agro-bioenergy wastes and residues in a lettuce soilless system under glasshouse condition (De Corato et al., 2018b). The same authors concluded that compost microbiota is primarily involved for effectively suppressing *Sclerotinia* root rot in many horticultural cropping systems due to antibiosis mechanisms elicited by antifungal substances produced by certain *Penicillium*, *Aspergillus*, *Fusarium* and *Trichoderma* species or of *Bacillus*, *Pseudomonas* and *Streptomyces* in presence of the susceptible host plant (De Corato et al., 2016). On the other hand, it is due to underline that, although authors have positively correlated the suppressive effect of *S. sclerotiorum* on lavender to sub-alkaline pH of compost (ranging from 6.8 to 7.6) and its high C/N rate (more than 10) (Chilosi et al., 2017), the known models driving *S. sclerotiorum* suppression are not still cleared. In fact, authors have negatively correlated *Sclerotinia* suppression on cress and lettuce to compost salinity (Pane et al., 2011), but this finding is contrasting with our results where Biovegetal resulted to be more saline than composted olive pomace. However, the physicochemical parameters and microbiota variables of compost that drive *S. sclerotiorum* suppression were not still in-depth cleared, because too many variables of compost and unpredictable factors of suppression were involved that should be analysed by a multivariate approach in further researches.

FIGURE 6. Carrot crops cultivated under greenhouse conditions in rows filled with two different growing media (on the left, 30% sterile peat + 30% composted olive pomace + 40% sterile pumice; on the right, 30% sterile peat + 30% Biovegetal + 40% sterile pumice) for assessing root rot suppression index on seedlings artificially inoculated with a phytopathogenic strain of *S. sclerotiorum*.

Conclusion

In conclusion, the following statements can be drawn. First, the different types of fertilization did not influence either the length of the phenological phases of carrot or the entire crop cycle. Fertilization with composted olive pomace at the highest dose favored the highest root production with an increase of 19.9% compared to the mineral fertilizer. Second, the supply of Biovegetal at the highest dose gave a non-statistically different root production from that obtained by the mineral fertilization and by the lowest dose of composted olive pomace supplemented with 50 kg ha^{-1} N. Third, the total solids content and dry matter of carrots decreased with the highest dose of both composts. Carrots with the greatest content of carotenoids were produced from the soil amended with composted olive pomace at the highest dose, while no significant difference was found between the crop fertilized with the mineral fertilizer and the highest dose of Biovegetal. Therefore, the best combination resulting in the high content of carotenoids, total soluble solids and specific weight occurred when the crop was fertilized with 30 Mg ha^{-1} of composted olive pomace. Fourth, no difference was found between the mineral fertilization and the highest dose of Biovegetal for morphometric parameters. Finally, Biovegetal effectively suppressed root rot of carrots by *S. sclerotiorum* more than composted olive pomace (Figure 6) because it resulted to be more effectively colonized by a beneficial microbiota composed by the high abundance of potential BCAs.

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Addresses of authors:
G. Cucci[1,*], G. Lacolla[1], M.A. Mastro[1], D. Caranfa[1], A. Monteforte[2] and U. De Corato[3]
[1] University of Bari 'Aldo Moro', Department of Agricultural and Environmental Science (DiSAAT), Via Amendola 165/A, Bari 70126, Italy
[2] Tersan Puglia S.p.A., S.P. 231, km. 1,600, Modugno (Bari) 70026, Italy
[3] Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Department of Bioenergy, Biorefinery and Green Chemistry, Territorial Office of Bari, Via Giulio Petroni 15/F, Bari 70124, Italy
* Corresponding author;
E-mail: giovanna.cucci@uniba.it