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Research Article
Physical, Chemical and Biological Properties of some Alternative Growing Substrates

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Abstract

Background: Peat represented the predominant constituent of growing media for soilless production in the last decades. However, due to the high cost of extraction and future availability and sustainability, a worldwide search for alternative substrates has been developed, focusing on secondary processing compounds or recycling wastes. In order to evaluate the suitability of new materials, organic by-products, namely hemp fiber (2 particle sizes) and grape marc were studied and compared with peat and some rising substitutes: Coir (3% fiber) and green compost. **Methodology:** Some of the main physical (particle size distribution, bulk density, water holding capacity and air capacity), chemical (pH, electrical conductivity, ash, carbon, hydrogen, nitrogen and heavy metals content) and biological properties (phytotoxicity) were analyzed. **Results:** All materials showed water holding capacity $\geq$40% (threshold considered sufficient on the base of peat-related classification), except for coir and hemp with large particle size and marc that registered a poor water-holding capacity (<40% retained water). The pH of the base materials was different with values ranging between 6.21 and 9.05. Compost and marc showed high values of electrical conductivity and copper content (and heavy metals for green compost) and a possible negative influence on germination of cress as resulting from the bioassay. **Conclusion:** Physical, chemical and biological properties of the materials suggested that coir has the potential to partially or totally replace peat, whereas marc and compost require to be mixed with other materials or properly select the source-of-origin materials before processing.

Key words: Coir, hemp fiber, green compost, grape marc, organic by-products

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The production of pot plants is characterized by the use of growing media, materials other than soil, usually composed of different constituents. Peat is the main constituent used in Europe, gaining a good reputation among growing media producers and growers for the combination of unique properties useful for plant cultivation[1]. Nevertheless, the high price of good quality horticultural peat, especially in countries without peat moss resources and the questionable availability of peat in the near future due to environmental constraints are driving the research to investigate new alternative media[2,3]. Recycled and reclaimed solid wastes and various organic residues generated by agriculture, industries and city are alternative source of materials for substrate production[4-10] with the advantage of circular economy. Some alternative materials for soilless cultivation are already represented by residues of coconuts processing (coir)[11-13] and composted waste from different sources[14-18]. Other sources of materials may originate from grape pressing (marc) and hemp harvest (stem and fiber). Grape marc has already been used as growing media after composting[19-23] but little information is available about the suitability of non-composted marc and melted hemp residues. In Italy, marc is a common residual of wine production, hemp plants are used for human and animal nutrition and industrial purposes and their re-use as growing media may provide an interesting alternative application of their residues.

The aim of this study was to evaluate the suitability of grape marc residues and used hemp fibers as materials for alternative growing media or media components, in comparative studies with peat and some rising substitute substrates (i.e., coir and compost). Some basic analyses of media were undertaken to characterize the physical properties of the single fractions. Germination tests were also executed to study their biological properties (phytotoxicity).

MATERIALS AND METHODS

Four organic materials were collected from different sources (hemp, coir, grape marc and compost). Residues of the hemp plant (*Cannabis sativa* L.) were used: Dry stalks and fiber covering the stalks. The by-product was divided into two fractions: Fine material (Hf) chopped with a 6 mm mesh size mill and gross material (Hg), with coarse parts bigger than 6 mm. Dry coconut from Mozambique (*Cocos nucifera* L.) fruit mesocarps containing fine particle (coir pith) and medium-long fiber (coir fiber) were recovered during the coconut oil production. Coir was used to prepare 3 mixes: 100% coco pith (Cp), 70% coco pith with 30% coco fiber (Cm) and 40% coco pith with 60% coco fiber (Cg). Grape marc (Gm) from the grape (*Vitis vinifera* L.) wine press was composed of grape skin, seed and stalk, dried in the oven at 105°C for 48 h and chopped with a 6 mm sieve size mill. Green compost (Gc) was produced with organic waste materials such as tree branches, leaves, grass clippings and plant residues, recovered from private and public green urban areas. Materials were crumbled and placed in heaps to be composted for 24 weeks at a temperature between 55 and 73°C, humidity of 45-55%, periodically reversing the mass to not reduce the O_2 concentration below 6%.

The materials were stored in a well-ventilated room to obtain an humidity around 10%, then the Bulk Density (BD) was measured using a cylinder container 5 L volume (V), filled with materials without compression (UNI EN 15103:2010)[24]. The full cylinders were Weighted (W) and the bulk density (ρ) was calculated as follow:

$$\rho = W/V \qquad (1)$$

For the water holding capacity, the procedure suggested by Cattivello *et al.*[25] was followed: Water was poured on 0.3 L of material at humidity of 55% to calculate the retained water, measuring the drained water. The samples were put into pots (100 mm larger diameter) placed upon 1 L beaker, to collect the leachate. About 0.05 L of water were poured on samples, after 30 min of drainage and the operation was repeated 4 times using a total 0.20 L of water. The volume of drained water (Dw) was measured and the water holding capacity (WHC) was calculated:

$$\text{WHC} = 100-\frac{\text{Dw}}{200}\times 100 \qquad (2)$$

After the measurement, the samples were dried in the oven at 105°C for 48 h, weighed and used for the analysis of particle size class. The samples were put on a set of sieves with decreasing mesh size (15, 10, 5, 2, 1, 0.5 and 0.2 mm), sieved for 6 min and the particles collected from each sieve were weighed. The class fractions were expressed as (% w/w).

The Air Filled Porosity (AFP) was measured using the Wolverhampton method[26]. This method presumes that in a completely saturated media, the air space is filled by water and after drainage water is lost from the macro-pores and replaced with air, the volume of drained water is equal to the air within macro-pores in the media. For the measurements, pots (diameter of 130 mm, height of 110 mm and volume of 1.1 L) were filled with media up to 20 mm over the top of the pots, after applying a 60 mm collar on the top. The pots were placed in a container filled with water up to the level of the media, to allow the complete saturation by capillarity, the water was added slowly to avoid floating effect. After the saturation, the pots were drained for 10 min and this operation repeated twice again, to obtain material stabilization. The collar was removed with the excess material and media was leveled to obtain a volume equal to the pot volume (V). Prepared materials were completely saturated and placed on a beaker for 30 min to drain. The volume of drained water was measured and the Air Filled Porosity (AFP) calculated according to the following formula:

$$AFP = Dw \times \frac{100}{V} \quad (3)$$

Two other parameters, pH and Electric Conductivity (EC), were analyzed on water extract (1:5 v/v) prepared by filtering a suspension of material (0.06 L) and demineralized water (0.3 L) mixed for 1 h using a probe pH meter (Criso, pH meter GLP 21, Barcelona, Spain) and a probe portable conductivity meter (Cond 70, XS Instruments, Giorgio-Bormac srl, Carpi, Italy). The same solution was used to perform a bioassay. To evaluate a possible inhibition effect on the plants growth, the germination index[27] (GI) of cress (*Lepidium sativum* L.) seeds was calculated. Cress seeds were placed in petri dishes (5 seeds per dish) on filtering paper wetted with water extracts (0.0015 L) and incubated for 48 h at 27°C in the dark, to permit the germination. Ten replicates were arranged for each material and compared with demineralized water (control). After the incubation, the number of germinated seeds (G) and the root length (R) in the tested materials and in the control (Gt and Rt) were recorded to calculate the Germination Index (GI):

$$GI = \frac{G \times R}{G_t \times R_t} \times 100 \quad (4)$$

Moreover, a series of chemical analysis were performed to complete the characterization of the studied materials. Using 1 g of material, according to the method UNI EN 14775[28], the ash content was determined. According to the method UNI EN 15290[29], the total content of C, H and N were determined with an Analyzer Perkins Elmer 2400. Consequently, the heavy metal (As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn) content was determinated using an emission spectrophotometer Perkin Elmer, according to UNI EN 15290.

Data analysis: About 8-10 replicates per each studied organic material were used for every single tested parameter and results were expressed as average±standard error (where possible). An ANOVA statistical analysis was not performed because the objective of this study was the description of the main characteristics of the studied materials and not the comparison between them.

RESULTS AND DISCUSSION

The particle size distribution (Fig. 1) was expressed as percentage of material weight in the different particle classes referred to the total weight of the sample. The results underlined differences between materials, connected to the shape and size of particles. Materials containing 60% fiber (Cg) or coarse fraction of hemp stalk (Hg) showed a high percentage of particle >15 mm, composed of mesocarp long fiber or woody stalk chips. Conversely, 100% coir pith (Cp), green compost (Gc) and grape marc (Gm) contained no particles within a range of 10-15 mm. In particular, green compost and 100% coir pith showed the highest distribution of particles in a range of 0.2 and 2 mm, while grape marc was characterized by the highest percentage of particle less than to 2 mm in diameter.

The tested materials showed a different bulk density (Table 1), higher in green compost and grape marc compared to coir and hemp that contained lower percentage of fibrous particles and consequently were less dense and lighter.

According to the specific characteristics of the materials, the water drained after four irrigation events varied and consequently the water holding capacity, expressed as percentage of retained water, changed (Fig. 2). Hundred percent coir pith showed the highest water holding capacity (91.9%), draining only 0.0163 L of the total amount of poured water (0.20 L). The values of retained water decreased in the most fibrous and coarse materials, like coir with 60% of fiber (25.3%) and hemp >6 mm (14%). Grape marc retained water poorly (29.8%). A water holding capacity of the growing media higher than 60% is classified as good[25], whereas values lower than 40% are insufficient (30% coir pith+60% fiber, hemp >6 mm and grape marc).

Table 1: Bulk Density (BD) of the tested materials

Material	Acronym	BD (kg m^{-3})
Hemp >6 mm	Hg	38
Hemp = 6 mm	Hf	136
100% coir pith	Cp	132
70% coir pith+30% coir fiber	Cm	123
40% coir pith+60% coir fiber	Cg	48
Grape marc	Gm	472
Green compost	Gc	329

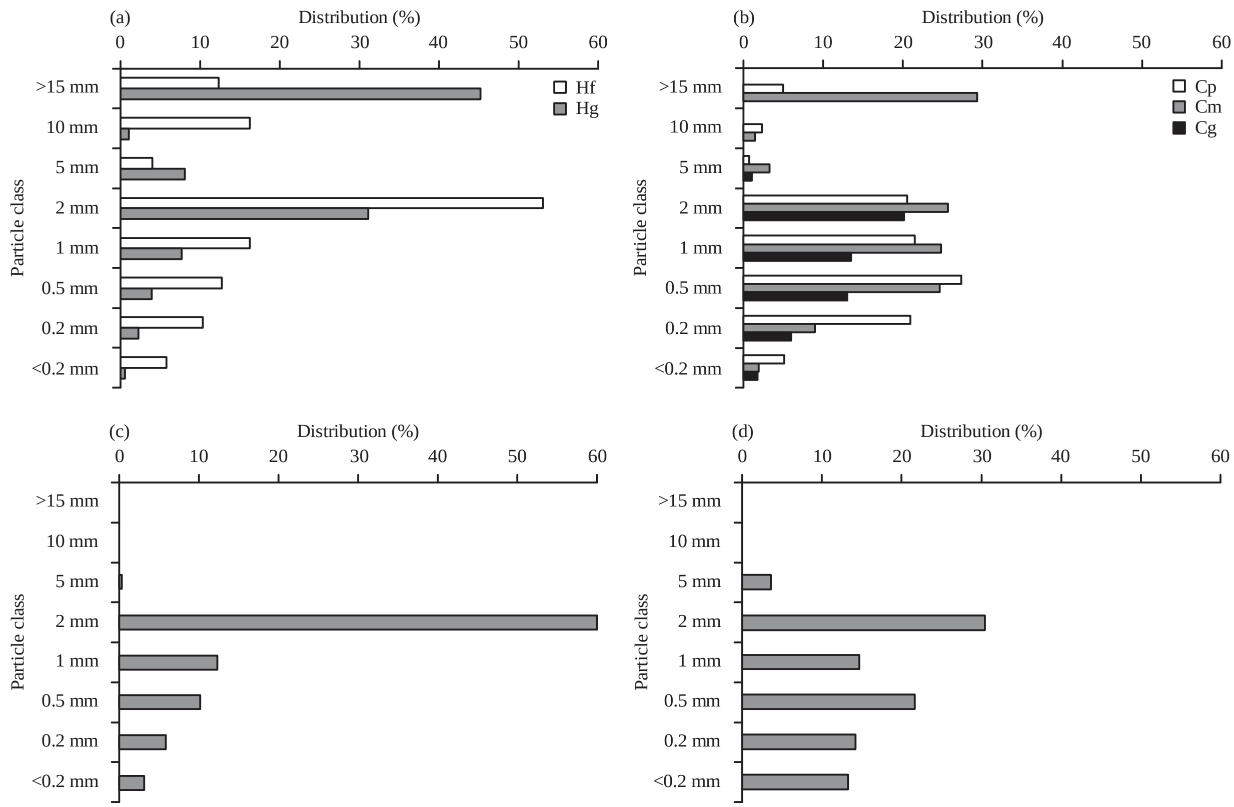

Fig. 1(a-d): Particle size distribution of the tested materials expressed as percentage of weight class on total sample weight (w/w). (a) Hg: Hemp >6 mm, Hf: Hemp = 6 mm, (b) Cp: 100% pith, Cm: 70% pith+30% fiber, Cg: 40% pith+60% fiber, (c) Grape marc (Gm) and (d) Green compost (Gc)

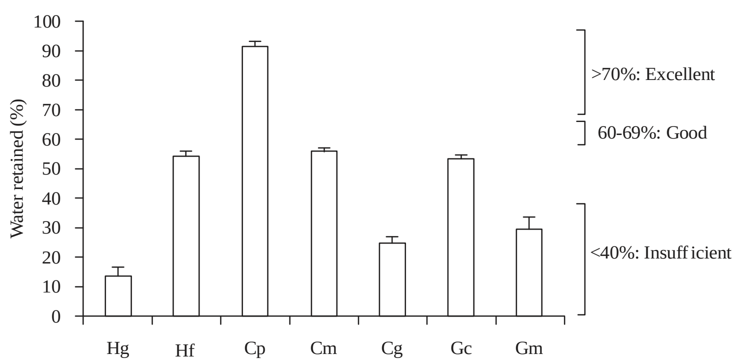

Fig. 2: Water Holding Capacity (WHC) of tested materials, expressed as percentage of retained water. Hg: Hemp >6 mm, Hf: Hemp = 6 mm, Cp: 100% pith, Cm: 70% pith+30% fiber, Cg: 40% pith+60% fiber, Gc: Green compost, Gm: Grape marc. Bars indicatethe standard error. For a peat-based substrate, WHC >70%: Excellent, between 60-69: Good, 50-59: Discrete, 40-49: Sufficient, <40%: Insufficient[25]

Differences between the materials were detected for the air filled porosity (Fig. 3). The presence of fiber and coarse parts created excess of macro porosity in the materials, limiting water retention, because pores were occupied by air. Hemp >6 mm showed the highest AFP compared to the other materials. Also mix containing 60% of coir fiber showed high AFP compared to the other coir mixes, where the values of AFP decreased by increasing the percentage of coir pith and 100% coir pith (Cp) had the lowest values. Green compost also showed low values of AFP, similar to 100% coir pith. The

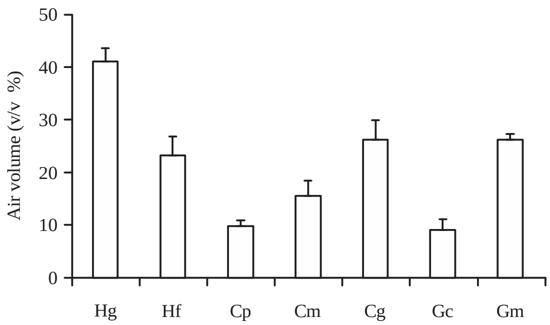

Fig. 3: Air Filled Porosity (AFP) of tested materials expressed as percentage of air volume. Hg: Hemp >6 mm, Hf: hemp = 6 mm, Cp: 100% coir pith, Cm: 70% coir pith+30% coir fiber, Cg: 40% coir pith+60% coir fiber, Gc: Green compost, Gm: Grape marc. Bars indicate the standard error

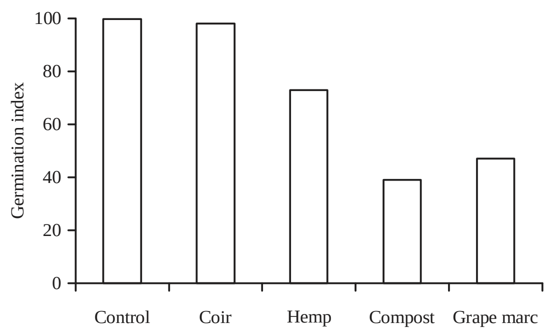

Fig. 4: Bioassay results expressed as Germination Index (GI) of cress after 48 h of contact with a water extract of the tested materials, grouped according to their origin. Demineralized water was used as control

hemp = 6 mm (Hf) and the grape marc showed similar AFP values, in a range between 20 and 30%.

Considering the range between 5.5 and 6.5 as a suitable pH for a growing media, only coir and grape marc showed a sub-acid pH around 6 (Table 2), pH of the hemp and green compost was neutral and basic, respectively. The EC was low for all the tested materials, except for compost (1.52 mS cm^{-1}) and grape marc with an extremely high value (3.43 mS cm^{-1}). The potential inhibition of plant growth, evaluated through the bioassay (Fig. 4) showed a low reduction of GI in hemp (73%) and a high reduction in green compost (37%) and grape marc (47%) with a reduction to about 50% compared to demineralized water (control). Only coir did not show potential toxic property (Fig. 4). The reduction of GI was may be due to the EC values higher for compost and marc compared to the other materials, as well as to a possible toxic effect, or to improper nutrient content.

Table 2: pH and Electric Conductivity (EC) of tested materials

Materials	Acronym	pH	EC (mS cm^{-1})
Hemp >6 mm	Hg	7.28	0.18
Hemp = 6 mm	Hf	7.69	0.06
100% coir pith	Cp	6.30	0.52
70% coir pith+30% coir fiber	Cm	6.21	0.77
40% coir pith+60% coir fiber	Cg	6.41	0.26
Grape marc	Gm	6.56	3.43
Green compost	Gc	9.05	1.52

Table 3: Content of ash, total carbon, hydrogen, nitrogen and heavy metals in the tested materials (UNI EC 15290 and 14775)

Parameters	Hemp	Coir	Grape marc	Green compost
Ash (%)	7.5	9.6	9.9	41.9
Carbon (C) (%)	47.4	48.3	53.3	34.1
Hydrogen (H) (%)	4.7	4.4	6.0	3.2
Nitrogen (N) (%)	0.5	0.5	2.1	2.3
Arsenic (As) (mg kg^{-1})	<1.0	<0.1	<0.1	<0.1
Cadmium (Cd) (mg kg^{-1})	<0.5	0.3	<0.5	1.1
Chrome (Cr) (mg kg^{-1})	21.6	2.8	<0.1	37.1
Copper (Cu) (mg kg^{-1})	6.6	10.3	44.8	73.1
Mercury (Hg) (mg kg^{-1})	0.1	<0.1	<0.1	<0.1
Manganese (Mn) (mg kg^{-1})	48.7	92.0	19.7	338.2
Nickel (Ni) (mg kg^{-1})	12.7	2.5	<0.1	22.9
Lead (Pb) (mg kg^{-1})	5.1	1.0	1.0	34.9
Zinc (Zn) (mg kg^{-1})	47.0	4.0	12.0	191.0

The values of ash content, the percentage of total carbon, hydrogen and nitrogen and heavy metals content expressed as mg kg^{-1} are reported in Table 3 per each studied material. Ash content was very high for green compost compared to the other materials. The percentage of carbon was similar for hemp, coir and grape marc and slightly higher when compared to green compost. Nitrogen content in grape marc and green compost resulted 4 times higher than in hemp and coir so that resulting C/N ratio was higher for these two last materials (94.8, 96.6, 25.3 and 14.8% for hemp, coir, grape marc and green compost, respectively). Such results suggest a possible greater resistance to microbial degradation but also the need of special attention in the nitrogen management during fertilization in order to avoid phenomena of N depletion from microorganisms. Compost showed high concentration of heavy metals, suggesting a bad quality of the primary source of materials for composting process. Copper (Cu) level resulted high even for grape marc and this is probably due to the vineyard management where copper-based fungicides were used.

CONCLUSION

The use of the studied organic by-products is possible in order to create substrates suitable for soilless plant cultivation but in many cases there are some limitations requiring a less applied percentage or a pre-treatment procedure, increasing the production costs. The suitability of marc may benefit from washing in order to reduce salt concentration and mixing with materials able to improve the physical characteristics. Green compost showed high heavy metals content limiting the application in soilless cultivations and strongly suggesting a better selection of source materials before the composting process. Also for coarse fraction of hemp, mixing with fine materials such as coir pith or peat could represent a way to increase the water retention that seems to be the main limiting factor. For this purpose, coir may improve the quality of alternative substrate mixes, thanks to the suitable pH and EC, the absence of phytotoxicity and the good physical characteristics, according to the proportion of pith and fiber. Results of this study will be helpful in the selection of proper materials to compose new growth substrates alternative to peat for plant cultivation.

SIGNIFICANT STATEMENTS

Peat is the main constituent for growing media but the high price of good quality peat and the availability in the near future due to environmental constraints are driving the study to investigate new alternative media. Recycled and reclaimed solid wastes and various organic residues generated by agriculture, industries and city are alternative source of materials for substrate production with the advantage of circular economy.

This manuscript reports interesting and novel results about the characterization of new materials and by-products as suitable alternative media to peat for a proper use in soilless plant cultivation.

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