Evaluation of the physicochemical properties of growing medias based on mixtures of rice husk biochar and compost inoculated with strains of *Trichoderma asperellum* and *Trichoderma virens* for soilless horticulture

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- Necessary content, namely research variables, issues and research problems in the title

Abstract

This study aims to develop a culture growing media with physico-chemical qualities compliant. Five growing medias based on Tricho-compost and rice husk biochar were formulated in varying proportions. The following formulations were used: 100% Tricho-compost (SA), 25% Tricho-compost and 75% biochar rice hull (SB), 50% Tricho-compost and 50% rice husk biochar (SC), 75% Tricho-compost and 25% rice husk biochar (SD), and 100% rice husk biochar (BC).

Physical parameters such as bulk density (BD), water holding capacity (WHC), total porosity (TP), air filled porosity (AFP), and chemical parameters including pH, electrical conductivity (EC), organic matter (OM), total nitrogen (N), P_2O_5, K2O have been analyzed. The results show that biochar-rich growing medias (SB, SC, BC) exhibit low BD (between 0,219 to 0,394 g/cm3), adequate TP (73,5% to 85,2%) and high AFP (20,73 to 29%), as well as good WHC (52,27 to 56,33%). Similarly, they have a higher K_2O content (1,6 – 2,18%) and a higher pH (7,9 -8,67). On the other hand, growing medias rich in Tricho-compost (SA, SD) are denser (BD between 0,610 and 0,626 g/cm3), less porous (PT and PA respectively between 57 and 62,4% and 8,93 and 10,87%). They also have richer N (1,38 – 1,78%) and, P_2O_5 (0,66 – 0,75%) a higher EC (3,31 – 3,97 (mS/cm). All growing medias meet the OM (> 40%) and NPK (<5%) content standards. SB and SC blends offer the best balance between physical and chemical properties. These results offer interesting prospects for the total or partial replacement of peat in soilless horticulture.

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Keywords: Tricho-compost, rice husk biochar, porosity, Air filled porosity, bulk density, Water holding capacity

1. INTRODUCTION

Peat is the most widely used growing media component in agriculture, due to its excellent combination of physicochemical properties (Bembli & M'Sadak, 2017) (Álvarez et al., 2017). However, peat-based growing media are not ecologically sustainable, and its extraction threatens the sensitive peatland ecosystem (Chrysargyris et al., 2018).

Given this situation, the search for sustainable alternatives is essential. This is why renewable materials from agricultural, industrial, and municipal waste streams have received particular attention (Barrett et al., 2016).

For this purpose, materials such as compost, coconut fiber, bark, and wood fibers show promising potential. They offer good physical properties and can partially or completely replace peat (Gruda, 2019).

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Choosing a growing medium for soilless vegetable production is very important. An optimal growing media must have a stable structure, high porosity, good water holding capacity, acceptable nutrient content, good absorption capacity, and be free of harmful microorganisms (Prisa & Caro, 2023). It must also provide support, good anchorage, and supply water and nutrients that are readily available to the plant. It is essential that it be homogeneous so that its components are evenly distributed, thus allowing for easy absorption by the roots (Prisa & Caro, 2023 ; Hazarika et al., 2022). The quality of the plants therefore depends directly on the physical, chemical and biological characteristics of the growing medias used as a growing media (M'Sadak et al., 2016).

However, the properties of alternative materials, such as composition, particle size, pH, aeration, nutrient content and mineral balance, vary considerably (Mathowa et al., 2017). For a mature compost, for example, to be usable fully and for safety, it is essential to control parameters such as pH, aeration percentage, sanitization, and mineral balance (M'Sadak & Ben M'barek, 2013).

For this purpose, it is essential to have a suitable growing media that is both affordable and lightweight, for optimal use and economical transport.

It is in this context that this present study takes place. It aims to contribute to the total or partial replacement of peat by developing an innovative growing media based on Tricho-compost and rice hull biochar. The objective is to formulate a growing media with compliant physico-chemical qualities, by exploiting renewable and local resources.

2. MATERIALS AND METHODS

2.1. Growing media preparation

A Tricho-compost under an aerobic system, initially composed (by weight) of 25% rice hull biochar, 60% cow manure, and 15% fresh neem leaves, was used. It was inoculated with three strains of *Trichoderma asperellum* and one strain of *Trichoderma virens* at the beginning of composting and at the beginning of the cooling phase. The composting process lasted 67 days. (Fall et al., 2025). From the compost and rice hull biochar produced, five growing medias were formulated:

- SA growing media: 100% Tricho-compost
- SB growing media: 25% Tricho-compost + 75% Rice husk Biochar
- SC growing media: 50% Tricho-compost + 50% Rice husk Biochar
- SD growing media: 75% Tricho-compost + 25% Rice husk Biochar
- BC Growing media: 100% rice hull biochar

2.2. Physical characterization of growing medias

The following parameters were measured: Bulk density, total porosity, air filled porosity, water holding capacity and particle size.

2.2.1. Apparent density

The bulk density is the ratio between the mass of the sample and the mass of a volume of water equal to the volume of the sample's envelope (Baize, 2018).

Bulk density was determined using the method of (Brewer et al., 2014). For this purpose, the samples were first dried in an oven at 80°C for 48 hours. A sample of known mass and volume of each growing media was placed in a cylinder, which was then compressed ten times. The apparent density was calculated as the ratio of the sample weight to the growing media volume after compression.

2.2.2. Total porosity and air filled porosity

Porosity is the ratio of the volume not occupied by solid matter to the total volume (Baize, 2018).

It was measured using the standard porosity test (M'Sadak et al., 2016). This test allowed us to determine the total porosity and the air filled porosity.

Total porosity is determined by the ratio of the volume added to the growing media at water saturation (Va) to the total volume (Vt). After approximately one hour, water was added to achieve adequate growing media saturation.

Total porosity (TP) = (Va / Vt) x 100

Air filled porosity (AFP) is determined by the ratio between the volume drained (Vr) through the drainage holes of the container under the effect of gravity forces and the total volume (Vt) after water infiltration for about 10 minutes.

AFP = (Vr / Vt) x 100

2.2.3. Water holding capacity

Water holding capacity was measured using the Keen Raczkowski box method described by (Upadhyay et al., 2020 ; Govindasamy et al., 2023). It was developed by Keen and Raczkowski in 1921.

For this purpose, Keen Raczkowski plates lined with filter paper and weighed using a precision electronic balance were used. The plates were filled with samples of the different growing medias, removing any excess with a spatula, and then weighed again. Next, the plates were placed on Petri dish lids that had been pre-filled two-thirds full with water and left to soak overnight. The following day, the plates were removed, and the excess water was drained by gravity, then weighed. Finally, the plates were placed in an oven at 105°C for three days and then weighed. The Water holding capacity was given by the following formula:

$$\mathbf{CR} = \frac{P2-P3}{P3-P1} \mathbf{x\ 100}$$

Where P1 is the weight of the empty box + filter paper, P2 is the weight of the box + filter paper + wet soil, and P3 is the weight of the box + filter paper + oven-dried soil.

2.2.4. Particle size

Particle size distribution is the measurement of the size of the particles in the growing media and is expressed as a weight ratio between elementary particles of different sizes (Fields et al., 2014). The material was air-dried and placed on a set of sieves with decreasing mesh sizes (2 mm, 1 mm, 0.5 mm, 200 µm). The sieves were shaken for 5 minutes using an orbital shaker, and the particle fractions retained on each sieve were weighed.

2.3. Chemical characterization of growing medias

2.3.1. pH

The pH was measured according to the international standard ISO 10390. For this purpose, 10 g of each sample were placed in 50 ml of distilled water. After stirring with an orbital shaker for one hour and allowing the mixture to stand for two hours, the pH was measured with a digital pH meter (Ben Si Said et al., 2022 ; Sani et al., 2023 ; Mageshwaran et al., 2024).

2.3.2. Electrical conductivity (CE)

Electrical conductivity (EC) is a measure of the concentration of soluble ions used to assess the salinity of the growing media (M'Sadak et al., 2013). Electrical conductivity (EC) is measured after dissolving 5 g of the previously dried sample in 50 ml of distilled water (Mageshwaran et al., 2024). After stirring with an orbital shaker for one hour, the solution was filtered and the EC was measured with a digital conductivity meter.

2.3.3. Organic matter

Total organic matter was determined by calcination at 550 °C for 2 hours. Carbon content was determined using the method by BLACK & WAKLEYmodified. Organic carbon is oxidized with a mixture of 1N potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4) d=1.84. Carbon content is determined by spectrophotometry at 600 nm. The percentage of organic matter in the soil is equivalent to the carbon content (Pauwels J.m et al., 1992).

2.3.4. Nitrogen

Total nitrogen was measured using the Kjeldahl method. Nitrogen mineralization was carried out in the presence of concentrated sulfuric acid (18N H_2SO_4), salicylic acid ($C_7H_6O_3$), hydrogen peroxide (H_2O_2), and selenium powder as a catalyst. This mineralization process transformed nitrogen into ammonium ions (NH_4^+), which were determined by spectrophotometry at a wavelength of 660 nm (Pauwels J.m et al., 1992).

2.3.5. Total phosphorus and total potassium

A flame absorption spectrophotometer was used to determine the total phosphorus and total potassium content after mineralization (Pauwels J.m et al., 1992).

2.3.6. Statistical analyses

The collected data were analyzed using R software. A one-way ANOVA was performed. Differences were considered significant at a probability level of $p < 0,05$. In cases of significant effects, a Tukey post-hoc test was applied to compare treatment means. The normality of residuals was verified using the Shapiro-Wilk test, and the homogeneity of variances using Levene's test. In cases of non-normality, the Kruskal-Wallis test was used.

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3. RESULTS

3.1. Physical parameters

The physical parameters measured in this research, including apparent density, water retention capacity, total porosity, and aeration porosity of the growing medias, are recorded in Table 1.

Analysis of variance (ANOVA) revealed a highly significant effect of growing media type ($p < 0.001$) on all physical parameters. Multiple comparisons using Tukey's post-hoc test allowed for the differentiation of performance groups between the various treatments.

Table 1 : Physical properties of growing medias

Growing media	BD (g/cm3)	WHC (%)	TP (%)	AFP (%)	Particle size 2-0.5 mm (%)
SA	0,626d	48,61a	57a	8,93a	80,25
SB	0,293b	54,15d	78,9d	25,70d	84,21
SC	0,394c	52,27c	73,5c	20,73c	83,19
SD	0,610d	51,79b	62,4b	10,87b	81,67
BC	0,219a	56,33rd	85,2e	29th	93,24

BD : Bulk density, WHC : Water holding capacity, TP : Total porosity, AFP : Air filled porosity.

Values followed by similar letters under the same column are not significantly different at P = 0,05.

3.1.1. Bulk density

Pure biochar BC exhibits the lowest BD (0,219 g/cm³). Growing media BC, formulated with 25% tricho-compost and 75% rice husk biochar, follows with 0,293 g/cm³, then SC, composed of 50% tricho-compost and 50% rice husk biochar, displays 0,394 g/cm³. Finally, SD, with 75% tricho-compost and

25% rice husk biochar, and SA, composed of 100% tricho-compost, show the highest BD, respectively 0,610 g/cm³ and 0,626 g/cm³, with no significant differences between them.

3.1.2. Water retention capacity (WHC)

Pure Tricho-compost SA exhibits the lowest WHC (48,61%), while biochar BC shows the highest (56,33%). Intermediate mixtures, SD, SC, and SB, follow with 51,79%, 52,27%, and 54,15%, respectively. These results demonstrate that all mixtures containing biochar outperform pure Tricho-compost in terms of WHC.

3.1.3. Porosity

3.1.3.1. Total porosity (TP)

Pure Tricho-compost has the lowest TP (57%), while pure rice hull biochar has the highest. The following, from lowest to highest, are SD (62,4%), SC (73,5%), and SB (78,9%).

The results demonstrate that biochar (BC) and the SB mixture exhibit TP of 85,2% and 78,9%, respectively. Mixtures with a high proportion of tricho-compost, particularly SA and SD, show significantly lower TP, which could limit their use as a growing growing media.

3.1.3.2. Air filled porosity (AFP)

The results show that rice hull biochar BC and the SB and SC mixtures exhibit AFP of 29%, 25,70%, and 20,73%, respectively. The growing medias with a high proportion of tricho-compost (SA and SD) show low porosities of 8,93% and 10,87%, which could create root aeration problems.

3.2. Chemical parameters

The chemical parameters measured in this research, including pH, electrical conductivity, total nitrogen, phosphorus, potassium, total organic matter, and the sum of total nitrogen, phosphorus, and potassium levels, are recorded in Table 2.

Analysis of variance (ANOVA) revealed a highly significant effect of growing media type ($p < 0.001$) on all chemical parameters. Multiple comparisons using Tukey's post-hoc test allowed for the differentiation of performance groups between the various treatments.

Table 2 : Chemical properties of the different growing medias

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Growing media	N (%)	P_2O_5 (%)	K_2O (%)	N + P_2O_5 + K_2O (%)	pH	CE (mS/cm)	MO (%)
SA	1,78d	0,75a	0,90a	3,43a	7,61d	4a	45,27d
SB	1,15b	0,46bc	1,60c	3,21b	8,31b	1,58d	53,41b
SC	1,36c	0,51ab	1,56c	3,43a	7,90c	2,45c	42,26d
SD	1,38c	0,66ab	1,26b	3,31ab	7,70d	3,31b	48,77c
BC	0,72a	0,37c	2,18d	2,87c	8,67a	0,6e	58,87a

MO: Organic Matter. EC: Electrical Conductivity. N: Total Nitrogen. P_2O_5: Phosphorus. K_2O: Potassium. Values followed by similar letters in the same column are not significantly different at P = 0,05.

3.2.1. pH

The results show four distinct and significantly different groups: BC (8,67) > SB (8,31) > SC (7,90) > SD (7,70) > SA (7,61). No significant difference was noted between SA and SD. Rice husk biochar noted the highest pH.

3.2.2. Electrical conductivity

Growing media SA exhibits the highest electrical conductivity (3,97 mS/cm), significantly different from the other growing medias. It is followed by SD (3,31 mS/cm), SC (2,45 mS/cm), and SB (1,58 mS/cm).

Growing media BC displays the lowest electrical conductivity (0,6 mS/cm). Mixtures with a high rice hull biochar content exhibit the lowest electrical conductivity (EC).

3.2.3. Organic matter

The results show that growing media BC has the highest organic matter content (58.87%), significantly different from all other growing medias. It is followed by SB (53.41%) and SC (48.77%). Growing medias SA (43.67%) and SD (42.26%) have the lowest organic matter content.

3.2.4. Total nitrogen

Growing media BC has the lowest total nitrogen content (0,72%), significantly lower than all other growing medias, while SA has the highest nitrogen content (1,78%).

SB (1,15%), SC (1,36%) and SD (1,38%) show total nitrogen levels that decrease with increasing levels of rice hull biochar in the growing media.

3.2.5. Phosphorus

The SA mixture has the highest phosphorus content (0,75%), followed by SD and SC. Pure rice husk biochar shows the lowest content (0,37%), while SB has an intermediate value.

3.2.6. Potassium

Contrary to the trend observed for nitrogen and phosphorus, potassium content increases with the proportion of rice hull biochar. Pure rice husk biochar (FB) has the highest content (2,18%), while pure tricho-compost (TC) has the lowest content (0,90%).

3.2.7. N+ P_2O_5 + K_2O content

Growing medias SA and SC exhibit the highest cumulative N+P+K content. Pure rice husk biochar BC shows the lowest content, while SB and SD have intermediate levels.

4. DISCUSSIONS

4.1. Bulk density (BD)

BD is a very important physical indicator for growing medias. Low density is desirable because it means the growing media is lighter, more porous, and offers better aeration for the roots. Excessive bulk density indicates compaction (Wilkinson et al., 2014). A negative correlation was observed between the proportion of rice husk biochar and the bulk density of the growing media. The higher the proportion of rice husk biochar, the lower the BD. This improvement in the bulk density of the growing medias is attributable to the rice husk biochar. Indeed, the higher the rice husk biochar content, the lower the bulk density, as noted (Nasution & Fitria, 2023 ; Kim et al., 2017). The BD of the culture medium influences plant growth. If it is too high, it can limit root growth due to reduced porosity (Jeyaseeli & Raj, 2010). Conversely, a very low BD can cause excessive aeration of the culture medium and simultaneously reduce the available water content Vaughn et al., (2013) cited by Kim et al., (2017). It has been observed that BD is inversely related to total porosity. This conclusion corroborates that of Tittarelli et al., (2009) and Raviv, (2019). For all growing medias, particles ranging in size from 0,25 to 2,00 mm represent more than 80% and are the optimal dimensions for plant growth because they retain sufficient water and also provide adequate gas exchange (Dispenza et al., 2016 ; Anbarasu et al., 2024).

However, among the growing medias tested, only SB, SC, and BC have a BD that is within the recommended range (< 400 kg/m³) for plant growth Abad et al., (2001), cited by Atzori et al., (2021).

4.2. Water holding capacity (WHC)

A good growing media must have good WHC and sufficient macropores to allow excess water to drain and prevent waterlogging (Wilkinson et al., 2014). The results showed that rice hull biochar increases growing media retention capacity. These results are consistent with those of (Asadi et al., 2021; Singh et al., 2017). Indeed, the addition of biochar improves the hydrophysical properties of growing media by increasing WHC, as concluded ("The Effect of Paper Sludge and Biochar Addition on Brown Peat and Coir Based Growing Media Properties," 2015).

In accordance with the acceptability threshold for the retention capacity of a culture growing media set at a value > 30% by M'Sadak et al., (2016), all growing medias have a consistent WHC. However, Dede & Oztekin, (2018) and Abad et al., (2001) recommend a retention capacity ≥ 60%, for a growing media.

4.3. Porosity

Large pores play an important role in allowing roots, gas, and water to penetrate the soil. The greater the density of pores (macropres), the more the soil can be exploited by plant roots (Scott et al., 1988). The results showed that rice hull biochar increases growing media porosity, which corroborates the findings of previous work (Singh et al., 2017 ; Asadi et al., 2021). This improvement in porosity could be due to the highly complex porous structure of rice hull biochar, as noted Abrishamkesh et al., (2015) and Munda et al., (2016). It should be noted that all growing medias meet the total porosity standards which must, according to Nzengue et al., (2024), be ≥ 50%.

Growing medias with the lowest aeration porosities are those with the finest particle size distribution, particularly SA and SD. This corroborates the findings of the work of M'Sadak & Bouallegue, (2015), which states that aeration porosity can decrease when the particle size components of composts are fine. It should be noted that optimal aeration porosities can vary considerably depending on the type of plant, the size of the container, and the irrigation frequency, as highlighted (Raviv, 2019). Tilt & Bilderbach, (1987), cited by El Sharkawi et al., (2014) recommended an acceptable aeration porosity for culture media ranging from 15 to 45%. To this end, while all growing medias meet the total porosity standards, only BC, SB, and SC exhibit an aeration porosity ≥ 15%. However, M'Sadak & Bouallegue, (2015), as well as Atzori et al., (2021) consider that the optimal aeration porosity for a growing media should be between 20% and 30%.

4.4. Electrical conductivity

Electrical conductivity represents the total amount of ions in solution. The higher it is, the more difficult it is for plants to absorb water Soltner, (2017) and constitutes a defect in its quality (Prisa & Caro, 2023). The results show that electrical conductivity varies with the proportion of rice husk biochar in the growing media. Indeed, it decreases with increasing amounts of rice husk biochar in the growing media, thus indicating the growing media's deficiency in soluble minerals. According to Bembli & M'Sadak, (2017) the optimal electrical conductivity of growing medias is between 1,5 and 2,25 mS/cm and should not exceed 2,5 to 3 mS/cm. An electrical conductivity below 1.5 mS/cm can result in low growing media fertility. Based on these values, only SB and SC exhibit compliant electrical conductivities.

4.5. pH

A tendency towards alkalization of the growing media proportional to the content of rice hull biochar was noted.

The pH of the growing media is an important factor that indirectly influences plant growth through its effects on the availability of mineral nutrients and microbial activity. According to (Soltner, 2017) it is between pH 6 and pH 7 that, the majority of nutrients are found in acceptable conditions for assimilation. At pH levels above 7, the bioavailability of certain trace elements such as iron, manganese, boron, copper, and molybdenum decreases, causing deficiencies in plants. It should be noted that all growing medias have pH levels above 7,5. This increase can be attributed to rice hull biochar, which, according to Kim et al., (2017) ; Singh et al., (2019) significantly increases the pH. However, the pH is easily modified to the desired levels by adding lime to make it more alkaline, or acid to make it more acidic (Raviv et al., 2019).

4.6. Nitrogen

The results showed that the higher the Tricho-compost content in the growing media, the higher the nitrogen content. This result is consistent with the work of Organo et al., (2022) which have shown that Tricho-compost improves nitrogen availability. Also, Sawadogo et al., (2021) studies have shown that *Trichoderma* improves the availability of phosphorus, nitrogen, and potassium. All growing medias have adequate nitrogen levels, in accordance with the current NF U44-551 standard for growing media, which mandates total nitrogen levels of less than 2,5%.

4.7. Phosphorus

Analyses have shown that Tricho-compost is significantly richer in phosphorus than rice hull biochar; therefore, the higher the Tricho-compost content in the growing media, the higher the phosphorus content. This is explained by the improved bioavailability of phosphorus in the compost due to Trichoderma, as noted Siddiquee et al., (2017). From the point of view of the phosphorus content of the growing medias, the NF U44-551 standard sets a content of less than 2%. All growing medias comply with this requirement.

4.8. Potassium

Compared to potassium in the growing medias, K_2O levels in the growing medias increased with increasing rice hull biochar content, demonstrating that the latter is a good source of potassium. This is perfectly consistent with the results of Kim et al., (2017) ; Singh et al., (2019) who concluded that rice hull biochar significantly increases potassium availability. Furthermore, Amassa and Manenoi, (2008) cited by (Atif et al., 2016) studies have shown that organic media have higher levels of phosphorus and potassium than commercial growing media such as peat. It should be noted that, according to standard NF U44-551, the potassium content of any growing medium must not exceed 2,5%, meaning that all growing medias have compliant levels.

4.9. N + P_2O_5 + K_2O

The results show a relationship between the proportion of Tricho-compost and the richness in major nutrients. Tricho-compost makes a significant contribution of nitrogen, phosphorus, and potassium, essential for plant growth (Komolafe et al., 2020). The NF U44-551 standard stipulates that, for growing media, the sum of the total nitrogen, phosphorus, and potassium content must not exceed 5%. Therefore, all growing medias comply with this requirement regarding the sum of their percentage content of N + P_2O_5 + K_2O.

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4.10. Organic matter content

The organic matter content is of fundamental importance for growing media fertility, due to its physical, chemical and biological effects . The organic matter content of the Tricho-compost (43,67%) testifies to its stability and maturity. According to M'Sadak & Bembli, (2018), the organic matter content should be between 35% and 45%. Growing medias richer in rice hull biochar (BC, SB, and SC) have higher organic matter levels than growing medias richer in tricho-compost (SA and SD). This is because composting significantly reduces the organic matter content M'Sadak & Ben M'barek, (2013), whereas rice hull biochar is rich in stable organic matter (Ahmadou et al., 2023). In accordance with the NF U44-551 standard, all growing medias have compliant organic matter levels, as they are greater than 40%.

5. CONCLUSION

This study demonstrates that it is possible to replace peat with innovative growing medias based on Tricho-compost and rice husk biochar. The SB (25% Tricho-compost and 75% rice husk biochar) and SC (50% Tricho-compost and 50% rice husk biochar) mixtures are distinguished by their physicochemical properties, including low bulk density, good porosity, satisfactory water holding capacity, and balanced nutrient content.

These formulations utilize local and renewable resources, thus contributing to sustainable agriculture while reducing the environmental impact associated with peat extraction. pH adjustments may be necessary depending on the crop, but these growing medias could represent a viable and promising alternative for soilless horticultural production.

However, it would be essential to confirm these conclusions by a study of the effect of these growing medias on vegetable crops.

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REFERENCES

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Abad, M., Noguera, P., & Burés, S. (2001). National inventory of organic wastes for use as growing media for ornamental potted plant production: Case study in Spain. Bioresource Technology, 77(2), 197–200. https://doi.org/10.1016/s0960-8524(00)00152-8.

Abrishamkesh, S., Gorji, M., Asadi, H., Bagheri-Marandi, G. H., & Pourbabaee, A. A. (2015). Effects of rice husk biochar application on the properties of alkaline soil and lentil growth. Plant, Soil and Environment, 61(11), 475–482 https://doi.org/10.17221/117/2015-PSE

Ahmadou, Y. Y. A., Simon, D. B., & Nguetnkam, J. P. (2023). Effet du biochar et de la poudre des balles de riz sur la productivité du maïs (zea mays) et les sols au Nord Cameroun. African and Mediterranean Agricultural Journal - Al Awamia, 139, 85-104. https://doi.org/10.34874/IMIST.PRSM/afrimed-i139.41154

Álvarez, M. L., Gascó, G., Plaza, C., Paz-Ferreiro, J., & Méndez, A. (2017). Hydrochars from Biosolids and Urban Wastes as Substitute Materials for Peat. Land Degradation & Development, 28(7), 2268–2276. https://doi.org/10.1002/ldr.2756

Anbarasu, M., Gurusamy, A., & Saravanan, S. (2024). Properties of different graded coir pith by Keen-Raczkowski box and Brunauer-Emmett-Teller analysis. Journal of Environmental Biology, 45(3), 357–362. https://doi.org/10.22438/jeb/45/3/MRN-5233

Asadi, H., Ghorbani, M., Rezaei-Rashti, M., Abrishamkesh, S., Amirahmadi, E., Chengrong, C., & Gorji, M. (2021). Application of Rice Husk Biochar for Achieving Sustainable Agriculture and Environment. Rice Science, 28(4), 325–343. https://doi.org/10.1016/j.rsci.2021.05.004

Atif, M. J., Jellani, G., Malik, M. H. A., Saleem, N., Ullah, H., Khan, M. Z., & Ikram, S. (2016). Different Growth Media Effect the Germination and Growth of Tomato Seedlings. Science, Technology and Development, 35(3), 123–127. https://doi.org/10.3923/std.2016.123.127

Atzori, G., Pane, C., Zaccardelli, M., Cacini, S., & Massa, D. (2021). The Role of Peat-Free Organic Substrates in the Sustainable Management of Soilless Cultivations. Agronomy, 11(6), 1236. https://doi.org/10.3390/agronomy11061236

Baize, D. (2018). Guide des analyses en pédologie: 3e édition revue et augmentée. Editions Quae. https://www.quae.com/produit/1590/9782759228379/guide-des-analyses-en-pedologie

Barrett, G. E., Alexander, P. D., Robinson, J. S., & Bragg, N. C. (2016). Achieving environmentally sustainable growing media for soilless plant cultivation systems – A review. Scientia Horticulturae, 212, 220–234 https://doi.org/10.1016/j.scienta.2016.09.030

Bembli, H., & M'sadak, Y. (2017). Comportement Agronomique Hors Sol Des Plants De Tomate Sur Substrats De Culture à Base De Tourbe En Mélange Avec Compost Sylvicole. Algerian Journal of Arid Environment, 7(1), 57-70. https://www.asjp.cerist.dz/en/PresentationRevue/11

Bembli, H., & M'sadak, Y. (2017). Évaluations directe et indirecte des substrats de culture issus de tourbe en mélange avec compost sylvicole pour la production des plants de Tomate. Agriculture, 8(1), 18–30. https://www.asjp.cerist.dz/en/article/31380

Ben Si Said, Z., Derridj, A., Rebbas, K., Adjout, M., Belkacemi, T., & Ramdane, R. (2022). Compostage, alternative pour valoriser les déchets de restauration des collectivités, cas du restaurant universitaire de Tizi-Ouzou (Algérie) [Unpublished doctoral dissertation]. Université Mouloud Mammeri de Tizi-Ouzou. https://hal.archives-ouvertes.fr/hal-03565397

Brewer, C. E., Chuang, V. J., Masiello, C. A., Gonnermann, H., Gao, X., Dugan, B., Driver, L. E., Panzacchi, P., Zygourakis, K., & Davies, C. A. (2014). New approaches to measuring biochar density and porosity. Biomass and Bioenergy, 66, 176–185. https://doi.org/10.1016/j.biombioe.2014.03.059

Chrysargyris, A., Antoniou, O., Tzionis, A., Prasad, M., & Tzortzakis, N. (2018). Alternative soilless media using olive-mill and paper waste for growing ornamental plants. Environmental Science and Pollution Research, 25(36), 35915–35927. https://doi.org/10.1007/s11356-017-1187-4

Dede, O., & Oztekin, M. (2018). Relationship between optical microscopic structure and physical characterization of organic wastes originated peat substitutes. Applied Ecology and Environmental Research. https://doi.org/10.15666/aeer/1602_11731184

Dispenza, V., De Pasquale, C., Fascella, G., Mammano, M. M., & Alonzo, G. (2016). Use of biochar as peat substitute for growing substrates of Euphorbia × lomi potted plants. Spanish Journal of Agricultural Research. https://doi.org/10.5424/sjar/2016144-9082

El Sharkawi, H. M., Ahmed, M. A., & Hassanein, M. K. (2014). Development of Treated Rice Husk as an Alternative Substrate Medium in Cucumber Soilless Culture. Journal of Agriculture and Environmental Sciences, 3(4), 131–149. https://doi.org/10.15640/jaes.v3n4a10

Fall, M., Sarr, S. M., & Gueye, N. (2025). Effet combiné de souches de Trichoderma asperellum et de Trichoderma virens sur la durée de maturité du compost. *JAPS ELEWA*, *65*(3), 12518–12530.

Fields, J. S., Fonteno, W. C., & Jackson, B. E. (2014). Hydration Efficiency of Traditional and Alternative Greenhouse Substrate Components. HortScience, 49(3), 336–342. https://doi.org/10.21273/HORTSCI.49.3.336

Govindasamy, P., Mahawer, S. K., Mowrer, J., Bagavathiannan, M., Prasad, M., Ramakrishnan, S., Halli, H. M., Kumar, S., & Chandra, A. (2023). Comparison of Low-Cost Methods for Soil Water

Holding Capacity. Communications in Soil Science and Plant Analysis, 54(2), 287–296. https://doi.org/10.1080/00103624.2022.2112216
Gruda, N. S. (2019). Increasing Sustainability of Growing Media Constituents and Stand-Alone Substrates in Soilless Culture Systems. Agronomy, 9(6), 298. https://doi.org/10.3390/agronomy9060298
Hazarika, M., Saikia, J., Gogoi, S., Kalita, P., Saikia, L., Phookan, D. B., & Kumar, P. (2022). Different growing media effect on seedling quality and field performance of Tomato (Solanum lycopersicum L.). The Pharma Innovation, 11(11), 308–314. https://www.thepharmajournal.com/archives/2022/vol11issue11/PartE/11-10-100-900.pdf
Jeyaseeli, D. M., & Raj, S. P. (2010). Physical characteristics of coir pith as a function of its particle size to be used as soilless medium. American-Eurasian Journal of Agricultural and Environmental Science, 8(4), 431-437. https://www.idosi.org/aejaes/8(4)10/contents.htm
Kim, H. S., Kim, K. R., Yang, J.-E., Ok, Y. S., Kim, W. I., Kunhikrishnan, A., & Kim, K.-H. (2017). Amelioration of Horticultural Growing Media Properties Through Rice Hull Biochar Incorporation. Waste and Biomass Valorization, 8(2), 483–492. https://doi.org/10.1007/s12649-016-9826-4
Komolafe, A. F., Adejuyigbe, C. O., Soretire, A. A., & Aiyelaagbe, I. O. O. (2020). Maturity indices of composting plant materials with Trichoderma asperellum as activator. Agricultura Tropica et Subtropica, 53(1), 19–27. https://doi.org/10.2478/ats-2020-0003
Mageshwaran, V., Tripathi, P., Vishvakarma, A. K., & Yadav, A. (2024). Comparative Efficacy Evaluation of Microbial Consortia for Rapid Composting of Paddy Straw. Journal of Pure and Applied Microbiology, 18(4), 2619–2635. https://doi.org/10.22207/JPAM.18.4.34
Mathowa, T., Tshipinare, K., Mojeremane, W., Legwaila, G. M., & Oagile, O. (2017). Effect of growing media on growth and development of sweet paper (Capsicum annum L.) seedlings. Journal of Applied Horticulture, 19(3), 200–204. https://doi.org/10.37855/jah.2017.v19i03.36
M'Sadak Y & Bembli H. (2018). *Evaluation physico-chimique et agronomique des substrats en mélange avec compost pour la production des plants de gombo (Abelmoschus esculentus)*. *8*(1), 80–99.
M'Sadak, Y., & Ben M'Barek, A. (2013). Caractérisation qualitative du digestat solide de la bio méthanisation industrielle des fientes avicoles et alternative de son exploitation agronomique hors sol. Revue des Energies Renouvelables, 16(1), 33–42. https://doi.org/10.54966/jreen.v16i1.36133
M'Sadak, Y., & Bouallegue, A. (2015). Study of opportunities of use of composts cunicoles for the aboveground production of tomato plants in Tunisia. Journal of Fundamental and Applied Sciences, 7(2), 244-259. https://www.asjp.cerist.dz/en/article/1000
M'Sadak, Y., El Amri, A., Majdoub, R., & El Ghorbali, L. (2016). Comportements physique et hydrique des substrats de culture destinés aux pépinières forestières modernes (Sahel Tunisien). Algerian journal of Arid Environment, 6(1), 96–107. https://dspace.univ-ouargla.dz/jspui/handle/123456789/14000
M'Sadak, Y., Elouaer, M.-A., & Dhahri, M. (2013). Production et croissance des plants de Gombo (Abelmoschus esculentus) sur substrats de culture issus d'un mélange de Tourbe et de Compost dans une pépinière maraîchère hors sol en Tunisie. Revue Marocaine des Sciences Agronomiques et Vétérinaires, 1(2), 5–9. https://www.agrimaroc.org/index.php/Actes_IAVH2/article/view/319
Munda, S., Nayak, A. K., Mishra, P. N., Bhattacharyya, P., Mohanty, S., Kumar, A., Kumar, U., Baig, M. J., Tripathi, R., Shahid, M., Adak, T., & Thilagam, V. K. (2016). Combined application of rice husk biochar and fly ash improved the yield of lowland rice. Soil Research, 54(4), 451–459. https://doi.org/10.1071/SR15295
Nasution, Y., & Fitria, F. (2023). Changes of Soil Density and Water Content at the Treatment of Compost Media and Husk Charcoal on Lettuce Plants in the Land Degradation. Jurnal Penelitian Pendidikan IPA, 9(6), 4353–4360. https://doi.org/10.29303/jppipa.v9i6.3571
Nzengue, E., Gnacadja, K. C., Mombo, S., Moundounga Mavouroulou, Q., Mandjedi-Mandjedi, C.-M., Bourobou, D. N., Biroungou, C., Zinga Koumba, C. R., Lépengué, A. N., & Mavoungou, J. F. (2024). Étude de l'impact des substrats locaux sur la germination et la croissance des plants de tomate de la variété BENTO 02 en pépinière au Gabon. Journal of Animal & Plant Sciences, 60(2), 11004–11014. https://doi.org/10.35759/JAnmPlSci.v60-2.1
Organo, N. D., Granada, S. M. J. M., Pineda, H. G. S., Sandro, J. M., Nguyen, V. H., & Gummert, M. (2022). Assessing the potential of a Trichoderma-based compost activator to hasten the decomposition of incorporated rice straw. Scientific Reports. https://doi.org/10.1038/s41598-021-03828-1
Pauwels, J. M., Van Ranst, E., Verloo, M., & Mvondo Ze, A. (1992). Manuel de laboratoire de pedologie. Methodes d' analyses de sols et de plantes, equipement, gestion de stocks de verrerie et de produits chimiques. Publications Agricoles (Belgium). Administration Generale de la

Cooperation au Developpement. No. 28. https://agris.fao.org/agris-search/search.do?recordID=XF2015000002
Prisa, D., & Caro, S. (2023). Alternative substrates in the cultivation of ornamental and vegetable plants. GSC Biological and Pharmaceutical Sciences, 24(1), 209–220. https://doi.org/10.30574/gscbps.2023.24.1.0268
Raviv, M., Lieth, J. H., & Bar-Tal, A. (2019). Soilless culture: Theory and practice. Academic Press. https://www.elsevier.com/books/soilless-culture/raviv/978-0-444-63696-6
Raviv, M., Lieth, J. H., & Bar-Tal, A. (2019). Soilless culture: Theory and practice (2nd ed.). Academic Press. https://www.elsevier.com/books/soilless-culture/raviv/978-0-444-63696-6
Sani, O. M., Ismaila, A. G., Adamou, Z., & Ibrahim, N. (2023). Evaluation de la phytotoxicité d'un compost préparé avec le phosphate calciné de Tahoua (Niger). International Journal of Innovation and Applied Studies, 39(3), 1075–1082. http://www.ijias.issr-journals.org/abstract.php?article=IJIAS-23-088-06
Sawadogo, J., Coulibaly, P. J. D. A., Traore, B., Bassole, M. S. D., Kabore, A., & Legma, J. B. (2021). Amélioration des propriétés physico-chimiques et microbiologiques des sols par des fertilisants biologiques sous cultures de la tomate en zone Soudano-sahélienne. Afrique SCIENCE, 19(4), 189–202. http://www.afriquescience.net
Scott, G. J. T., Webster, R., & Nortcliff, S. (1988). The topology of pore structure in cracking clay soil. I. The estimation of numerical density. Journal of Soil Science, 39(3), 303–314. https://doi.org/10.1111/j.1365-2389.1988.tb01217.x
Siddiquee, S., Shafawati, S. N., & Naher, L. (2017). Effective composting of empty fruit bunches using potential Trichoderma strains. Biotechnology Reports, 13, 1–7. https://doi.org/10.1016/j.btre.2016.11.001
Singh, A., Singh, A. P., & Purakayastha, T. J. (2019). Characterization of biochar and their influence on microbial activities and potassium availability in an acid soil. Archives of Agronomy and Soil Science, 65(9), 1302–1315. https://doi.org/10.1080/03650340.2018.1563291
Singh, C., Tiwari, S., & Singh, J. S. (2017). Impact of Rice Husk Biochar on Nitrogen Mineralization and Methanotrophs Community Dynamics in Paddy Soil. International Journal of Pure and Applied Bioscience, 5(5), 428–435. https://doi.org/10.18782/2320-7051.5870
Soltner, D. (2017). Les bases de la production végétale. Tome 1: Le sol et son amélioration. Editions Soltner. https://www.soltner.fr/agronomie/les-bases-de-la-production-vegetale-tome-i-le-sol-et-son-amelioration
Méndez, A., Paz-Ferreiro, J., Gil, E., & Gascó, G. (2015). The effect of paper sludge and biochar addition on brown peat and coir based growing media properties. Scientia Horticulturae, 193, 225–230. https://doi.org/10.1016/j.scienta.2015.07.032
Tittarelli, F., Rea, E., Verrastro, V., Pascual, J. A., Canali, S., Ceglie, F. G., Trinchera, A., & Rivera, C. M. (2009). Compost-based Nursery Substrates: Effect of Peat Substitution on Organic Melon Seedlings. Compost Science & Utilization, 17(4), 220–228. https://doi.org/10.1080/1065657x.2009.10702427
Upadhyay, K. P., Dhami, N. B., Sharma, P. N., Neupane, J. D., & Shrestha, J. (2020). Growth and yield responses of potato (Solanum tuberosum L.) to biochar. Agraarteadus | Journal of Agricultural Science, 31(2), 244–253. https://doi.org/10.15159/jas.20.18
Wilkinson, K. M., Landis, T. D., Haase, D. L., Daley, B. F., & Dumroese, R. K. (2014). Tropical Nursery Manual: A guide to starting and operating a nursery for native and traditional plants. United States Department of Agriculture Forest Service Agriculture Handbook 732. http://www.RNGR.net/tropical

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