Enhancing the Sustainability of Growing Media: Exploring Pine Bark as a Perlite Substitute in Coir-Based Substrates for Lettuce Cultivation

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Abstract

Increasing the sustainability of growing media constituents is a priority nowadays. This study aimed to evaluate whether pine bark can replace perlite in coir-based substrates. For this purpose, an experiment was carried out with four treatments: two coir-based mixes, one containing perlite and the other pine bark, and two electrical conductivities of nutrient solution (1.5 ± 0.2 and 2.5 ± 0.2 d*S* m^{-1}). Lettuce plants (*Lactuca sativa* L. cv. Godzilla) were grown in Styrofoam boxes filled with growing media containing, by volume, 80% coir, 12% compost, and 8% of either perlite or pine bark. The pine bark led to an increase in the electrical conductivity and bulk density of the mix. The presence of pine bark in the mix did not influence the effect of nutrient solution concentration on the average values of pH and electrical conductivity of the leachate. The electrical conductivity of leachate increased with the nutrient solution ion concentration. The presence of pine bark in the mix did not affect the shoot nutrient content of N, P, K, Ca, and Mg. Shoot iron and boron content were higher in plants grown with pine bark-containing substrates. Shoot N and P increased with a nutrient ion concentration. The presence of pine bark relative to perlite did not affect the influence of nutrient solution concentration on photosynthetic pigment contents, shoot dry weight, or yield (head fresh weight). This indicates the potential of pine bark as a sustainable alternative to perlite without compromising lettuce production.

Keywords: *Lactuca sativa L, soilless media, sustainable substrates, electrical conductivity, photosynthetic pigments.*

INTRODUCTION

Increasing the sustainability of growing media constituents used in horticultural production is currently a priority (Gruda, 2019). Pine bark stands out as an eco-friendly component of growing media, and Portugal is a producer of this sustainable option. Its use as a substrate component instead of perlite reduces the carbon dioxide emissions linked to the mining, expansion, and transportation processes associated with perlite. Perlite is a material that is energy intensive to produce and expansive (Savvas and Gruda, 2018). Overall, perlite and pine bark are employed to improve substrate aeration and drainage. However, these materials may differently influence the physical and chemical characteristics of growing media. They may affect pore size distribution in distinct ways, thereby influencing water dynamics in the growing medium. On the other hand, unlike perlite, pine bark is not chemically inert. Pine bark typically has a low pH and low cation exchange capacity (Martinez and Roca, 2011), which vary with particle size (Altland et al., 2014). Additionally, pine bark can degrade over time, leading to nitrogen immobilization (Jackson et al., 2009; Gruda et al., 2024). These differences can affect the influence of ion nutrient solution concentration on plants grown in coir-based mixes with perlite or pine bark, which in turn has a crucial impact on vegetable yield and nutritional value (Rouphael and Kyriacou, 2018; Gruda et al., 2024). Thus, this study aims to assess whether pine bark can replace perlite in coir-based blends and whether it affects the influence of nutrient solution concentration on lettuce growth. Specifically, it was investigated for its influence on pH and electrical conductivity of the leachate, photosynthetic pigment content, shoot nutrient content, and lettuce growth.

MATERIALS AND METHODS

Growth conditions and substrates

The experiment was conducted in a greenhouse located at the "Herdade Experimental da Mitra" (38°57′ N, 8°32′ W), University of Évora, Portugal. The greenhouse was covered with polycarbonate and had no supplemental lighting. Air temperatures inside the greenhouse ranged from 8 to 27 °C, and solar radiation ranged from 34 to 248 W $m^{-2} \cdot d^{-1}$.
The experiment comprised four different treatments: two coir-based mixes + compost with pine bark or perlite and two electrical conductivities (EC) of nutrient solution (1.5 ± 0.2 and 2.5 ± 0.2 d*S* m^{-1}) (Table 1). The constitution and proportion of the different components of the mixes are presented in Table 1. Following are the physical and chemical characteristics of the materials used, according to the manufacturer. The coir pith had a pH of 5.5 to 6.0, an EC greater than 1.5 d*S* m^{-1}, granulometry 0–10 mm, total porosity = 95% v/v, air = 25% v/v, and cation exchange capacity (CEC) within the range of 60–120 meq/100g. The compost (Nutrimais, Lipor Company, Baguim do Monte, Portugal) was manufactured with horticultural products, food scraps carefully selected from restaurants, canteens, and similar establishments, forest exploitation residues (e.g., branches and foliage), and green residues (e.g., flowers, grasses, and pruning). The EC and pH (1:5 compost:distilled water, *w/v*) were 5.4 d*S*.m^{-1} and 9.0, respectively. According to the manufacturer, the compost used in this study is free of pathogens. Perlite (Knauf, Dortmund, Germany) has particles from 2 to 6 mm (coarse perlite), is pH-neutral, and is chemically inert. The pine bark (Siro, Mira, Portugal) had particles with a diameter of 8 to 15 mm and a pH ($CaCl_2$) of 4.5. Pine bark had (expressed as a percentage of dry weight): organic matter (99.1%), C/N ratio (278), C (55.6%), N (0.20%), P_2O_5 (0.04%), K_2O (0.11%), and Mg (0.05%).

Table 1. Constitution and proportion (%, v/v) of the different components of the mixes

Mix	C[1]	Comp.[2]	P[3]	PB[4]
C + Comp + P	80	12	8	-
C + Comp + PB	80	12	-	8

[1]C – Coir, [2] Comp - Municipal solid organic waste, [3] P – Perlite. [4] PB – Pine bark.

On March 15, seedlings of lettuce (*Lactuca sativa* L. cv. Godzilla), type Batavia, 20 days after emergence, were planted into Styrofoam plant boxes in the central line of the boxes, spaced at 25 cm (16 plants/m^2). The boxes (100-cm long × 25-cm wide × 10-cm high) were filled with 14 L of each mix at a height of approx. 6.5 cm. Treatments were arranged in a randomized complete block design with five replicate boxes per treatment. The nutrient solution used contained 14 mmol L^{-1} NO_3-N, 6.3 mmol L^{-1} NH_4-N, 1.32 mmol L^{-1} P, 11 mmol L^{-1} K, 3.5 mmol L^{-1} Ca, 3.5 mmol L^{-1} Mg, 1.31 mmol L^{-1} S, 46 µmol L^{-1} B, 7.86 µmol L^{-1}, Cu chelated by EDTA, 8.95 µmol L^{-1} Fe chelated by EDTA, 18.3 µmol L^{-1} Mn chelated by EDTA, 1 µmol L^{-1} Mo, 2 µmol L^{-1} Zn chelated by EDTA, 2.1 mmol L^{-1} Cl and 0.7 mmol L^{-1} Na.

The two salinity levels were obtained by varying the concentration of the standard nutrient solution. From transplanting to 4 days after planting (DAP), the nutrient solution was applied with an electrical conductivity of 1.1 d*S* m^{-1} to all plants of the different treatments. After 4 days after planting, the nutrient solution was applied with an electrical conductivity (EC) of 1.5 ± 0.2 and 2.5 ± 0.2 d*S* m^{-1} until one day before harvest. The irrigation schedule was optimized for the coir + compost + perlite mix. It was based on substrate volumetric water content at Styrofoam box control, measured using a soil moisture probe (SM105T Delta devices, Cambridge, UK), and the volume of water drained. The nutrient solution was applied three to eight times daily and averaged 10 to 25% drainage (leaching fraction) for each application.

Measurements

Prior to planting, pH, electrical conductivity (EC), mass wetness, moisture content, total porosity, and bulk density of the mixes were measured. pH and EC were determined in the aqueous extract (1:5 substrate-to-water ratio, w/v). Moisture content, total porosity, and bulk density were measured using the porometer procedure outlined by Fonteno and Harden (2003), with four replications for each mix. Leachate from each planting box was collected five times during the crop cycle, and its pH and electrical conductivity (EC_W) were measured using a potentiometer (pH Micro 2000 Crison) and a conductivity meter (LF 330 WTW, Weilheim, Germany).

Lettuce plants (heads) were harvested at 38 days after transplanting on April 20, 2022. The heads of the plants were cut off above the surface of the media. One head from each box was washed, oven-dried at 70°C for 2–3 days, weighed, ground so that they would pass through a 40-mesh sieve, then analyzed for N, P, K, Ca, Mg, B, Fe, Mn, Zn and Na. See Machado et al. (2023) for a description of the procedures used for each analysis. The head samples, including inner, middle, and outer leaves, were collected in a 2 cm thick disc obtained by cross-cutting at a height of 6 cm from the base and cutting with a knife. Photosynthetic pigments, the chlorophyll a (Ch a), chlorophyll b (Ch b), and carotenoids (Cc) content were determined using the methodology described by Machado et al. (2023).

Data were analysed by analysis of variance using SPSS Statistics 29 software (Chicago, IL, USA). Means were separated at the 5% level using Duncan's new multiple range test.

RESULTS AND DISCUSSION

Initial growing media physicochemical characteristics

Pine bark increased the EC, bulk density, and moisture content of the mix while decreasing its pH and total porosity (Table 2). The average EC values of the mixes with pine bark and perlite were 3.01 and 2.55 d*S* m^{-1}, respectively (Table 2). Although these values differ, they fall within the adequate range for substrates (Bunt, 2012; Martínez and Roca, 2011). pH of the mixes with pine bark (7.51) and perlite (7.54) were higher than the upper limit of the range considered suitable for cultivating vegetables (5.5. to 6.8) (Adams, 2004). Pine bark increased the bulk density of the mix from 0.08 to 0.11 g/cm^3 and decreased the total porosity from 91.41% to 89.66% (Table 5). Despite the differences, both values are considered suitable for substrates, as total porosity values exceeding 85% are optimal (Bunt, 2012). Pine bark decreased the mass wetness of the mix, indicating lower water retention capacity per unit weight of substrate compared to a perlite-containing mix. The greater mass wetness in the perlite-containing mix could be due to the pine bark's comparatively lower water retention capacity compared to perlite (Martínez and Roca, 2011). The mix containing perlite exhibited a lower bulk density (0.08 g cm^{-3}) and a higher moisture content. This indicates that, for the same volume, the perlite-containing mix may retain more water. The greater mass wetness in the perlite-containing mix could be due to the pine bark's comparatively lower water retention capacity compared to perlite (Martínez, and Roca, 2011). Although the pine bark affected the mix properties, the changes were not substantial, indicating that a pine bark-containing mix can be suitable for growing lettuce.

Table 2. Initial media physicochemical characteristics

Mix	pH	EC (dS m^{-1})	Bulk density (g cm^{-3})	Mass wetness (g water/g substrate)	Total porosity (%)	Moisture content (%, w/w)
C[1] + Comp + P	7.54 b[2]	2.55 a	0.08 b	5.22 a	91.4 a	79.56 b
C + Comp + PB	7.51 a[2]	3.01 b	0.11 a	4.60 b	89.7 b	81.06 a
Significance	*	***	***	***	*	*

[1]- C – Coir. Comp - Municipal solid organic waste, P – Perlite, PB – Pine bark, [2] - means followed by different letters within a column are significantly different. *. and *** significant at p < 0.05 and 0.001 levels, respectively. Mean separation was performed using Duncan's multiple-range test. Means are based on five replicates.

Leachate pH and EC

The pH and EC_w of leachate were not affected by the interaction of the treatments ($p < 0.05$) at any of the sampling dates (Figure 1). Leachate pH was not affected by the mix. Leachate pH in the last two sampling dates decreased significantly ($p < 0.001$) with the increase of nutrient solution EC. This may result from an increased release of protons from the adsorption complex, likely triggered by the higher cation concentration in the incoming nutrient solution. Despite these differences, the pH levels of the leachate in the two mixes at the different sampling dates were higher than the optimal range for lettuce growth (5.5–6.8).

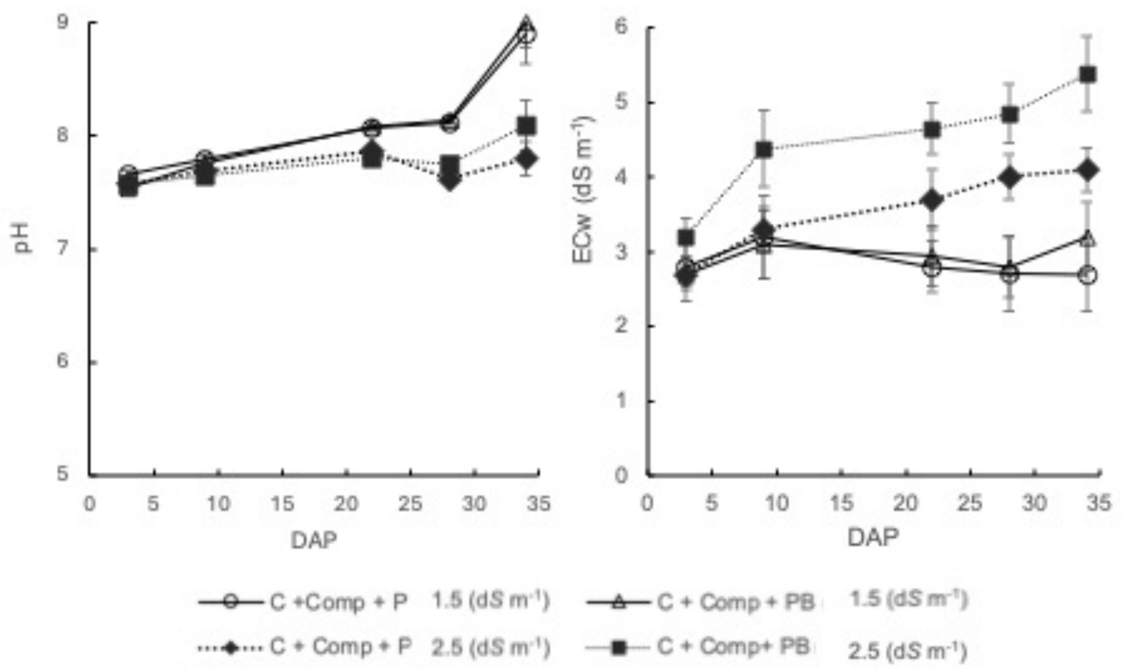

Figure 1 – Effects of the mix and of nutrient solution EC on leachate pH and EC_W. Each symbol represents the mean of five replicates, and the error bars represent ±1 standard error. (C – Coir, Comp – compost, P – Perlite, PB – Pine bark)

The presence of pine bark or perlite in the mix had no effect on the leachate EC_w, when the incoming solution had an EC of 1.5 dS m^{-1} (Figure 1). Both mixes showed relatively stable EC_w values in the leachate across all sampling dates. When a nutrient solution had an EC of 2.5 dS m^{-1} the leachate EC_W on the last three samplings was higher in the mix with pine bark than perlite, and higher than compared to a solution with an EC of 1.5 dS m^{-1}. When the nutrient solution had a salinity of 2.5 dS m^{-1} there was a clear upward trend in EC_W over time, which may indicate an accumulation of salts in the growing medium. The leachate EC_W for various sampling dates for both incoming nutrient solution ECs exceeded more than one unit of those of the respective incoming nutrient solutions. This may be due to the initial EC_w of the mixes of 2.55 and 3.01 dS m^{-1}.

Shoot nutrient Concentration

Shoot N, P, K, Ca, and Mg concentrations, except K, were not affected by the interaction of treatments (Table 3). Shoot K content in plants grown in the mix with pine bark increased with the ion concentration of the nutrient solution, while in those grown with perlite, it was not affected by the nutrient solution EC. The mix did not affect shoot macronutrient concentrations (Table 3).

Shoot N and P content increased with the rise in the EC of the nutrient solution. This may be due to the high availability caused by the high content in the nutrient solution and/or the lower pH of the root medium (Figure 1). Low pH can enhance the availability of P in the substrate (Altland and Buamscha, 2008). The application of a nutrient solution with 2.5 dS m^{-1} increased shoot N content by 25% relative to plants grown with a nutrient solution of 1.5 dS m^{-1}. Shoot Ca and Mg were not affected by the EC of the nutrient solution ($p <0.05$).

Shoot micronutrient and sodium content were not affected by the interaction of treatments. Plants grown with pine bark had higher shoot Fe and B than those grown in perlite (Table 3). Fe and B concentrations in blueberry leaves also increased with the addition of Douglas fir bark to the media (Kingston et al., 2017). Nutrient solution EC only affected shoot B content, which increased with the rise of the EC. Despite the high pH of root medium [high initial growing media pH (Table 1) and the pH of leachate (Figure 1), none of the plants in the treatments showed visual symptoms of any nutritional disorder. The high pH probably did not affect plant growth because the micronutrients applied except B and Mo were chelated by EDTA.

Table 3. Effects of mix and nutrient solution EC on shoot nutrient content.

Treatments	Shoot macronutrients (%)					Shoot micronutrients (µg·g^{-1})				
Mix (M)	N	P	K	Ca	Mg	Fe	B	Mn	Zn	Na[3]
C+ Comp + P[1]	4.0 b[2]	0.75 b	6.29 b	0.85 a	0,29 a	90.9 b	34.6 b	55.7 a	67.3 a	0.36 a
C+ Comp + PB	4.1 b	0.67 b	6.33 b	0.81 a	0.28 a	106.6 a	43.1 a	52.5 a	65.2 a	0.38 a
EC (dS m^{-1})										
1.5	3.6 c	0.65 b	6.01 b	0.85 a	0.28 a	99.8 b	35.9 b	52.5 a	63.7 a	0.39 a
2.5	4.5 a	0.78 a	6.60 a	0.81 a	0.29a	97.8 b	41.8 a	55.8 a	68.7 a	0.35 a
Significance										
M	NS	NS	NS	NS	NS	*	*	NS	NS	NS
EC	***	**	**	NS	NS	NS	*	NS	NS	NS
M x EC	NS	NS	*	NS	NS	NS	NS	NS	NS	NS

[1]- C – Coir. Comp – compost, P – Perlite. PB – Pine bark[2] - means followed by different letters within a column are significantly different. *. **. and *** significant at $p < 0.05$. 0.01. and 0.001 levels, respectively, NS—not significant. Mean separation was performed using Duncan's multiple-range test. [3]-Even though sodium is not considered a micronutrient, it has been included here for of convenience

Photosynthetic Pigments

Chl a and Chl b and Cc levels were unaffected by the interaction of treatments (table 4). This indicates that the effect of the EC of the nutrient solution on photosynthetic pigments has not been affected by the presence of perlite or pine bark in the mix. Chl a and b and Cc content were not affected by the mix or the EC of the nutrient solution. Shoot chl b levels exceeded those of chl a (Table 4). Although this deviates from the typical pattern, studies by Machado et al. (2023), Ozgen and Sekerci (2011), Kleinhenz et al. (2003), and Sapkota et al. (2019) also reported higher concentrations of Chl b compared to Chl a in lettuce.

Table 4. Effect of mix and nutrient solution EC on leaf photosynthetic pigments' content

Treatments	Photosynthetic Pigments (mg/100 g FW)			
	Chl a	Chl b	Total Chl	Cc
Mix (M)				
C + Comp + P[1]	3.27 a[2]	8.1 a	11.37 a	4.48 a
C + Comp + PB	3.10 a	7.8 a	10.86 a	4.17a
EC (d*S* m^{-1})				
1.5	3.35 a	8.2 a	11.55 a	4.02 a
2.5	2.99a	7.7 a	10.68 b	4.63 a
Significance				
M	NS	NS	NS	NS
EC	NS	NS	*	NS
M x EC	NS	NS	NS	NS

[1]- C – Coir. Comp – compost, P – Perlite, PB – Pine bark [2] - means followed by different letters within a column are significantly different. *. significant at $p < 0.05$. level, NS—not significant. Mean separation was performed using Duncan's multiple-range test.

Plant growth and yield

Shoot dry weight, leaf number, foliar area, and fresh yield (kg m^{-2}) were not affected by the interaction of treatments, neither by mix nor nutrient solution EC (Table 5).

Table 5. Effects of mix and nutrient solution EC on shoot dry weight, leaf number and area and head fresh yield.

Treatments	Shoot dry weight (g/plant)	Leaves (n°/plant)	Leaf area (cm^2/plant)	Head fresh yield (kg·m^{-2})
Mix (M)				
C[1] + Comp + P	24.5a[2]	37.2a	8854.9a	9.5a
C + Comp+ PB	23.8a	37.4a	8486.9a	9.8a
EC (d*S* m^{-1})				
1.5	23.9a	36.8a	8806.4a	9.7a
2.5	24.0a	37.8a	8534.8a	9.6a
Significance				
M	NS	NS	NS	NS
EC	NS	NS	NS	NS
M x EC	NS	NS	NS	NS

[1]- C – Coir. Comp – compost, P – Perlite, PB – Pine bark [2]Means followed by different letters within a column are significantly different. NS = not significant

The nutrient solution EC and pine bark affected shoot nutrient content (Table 3), but as plant growth was not affected, this indicates that shoot nutrient contents were in the sufficiency range for lettuce growth. The lettuce fresh yield was high, ranging from 9.5 to 9.8 kg/m^2 (Table 5). These results indicate that, from a productivity standpoint, pine bark has the potential to replace perlite in coir-based substrates. However, further studies are needed to assess its impact on quality.

CONCLUSIONS

Pine bark is a viable alternative to perlite in coir-based substrates for lettuce cultivation, as it supports similar growth and yield. Shoot iron and boron content were higher in plants grown with pine bark-containing substrates. Pine bark inclusion on coir-based substrates did not affect the influence of ion concentration in nutrient solution on photosynthetic pigment contents, shoot dry weight, or yield (head fresh yield). Shoot nitrogen, phosphorus, and boron content, as well as leachate electrically conductivity, increased with nutrient solution concentration.

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