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Pine Bark Compost as a Substrate in Nursery Forest Production

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Abstract

The quality of plants in the nursery depends mainly on the proper selection of the substrate, a factor that directly influences the quality and cost of production. To determine the suitability of organic materials as substrate components, it is essential to know their physical and chemical properties, allowing possible risks and restrictions of use to be assessed. This research determined the effects of incorporating pine bark compost as an alternative substrate in different volumetric proportions on the morphological and physiological indicators of plant quality in five forest species of national productive importance. Moss peat was replaced in two different proportions, compared with a control treatment that represents the most commonly used mixture in domestic containerized production. The results show that using pine bark compost in different proportions presents a viable alternative to the use of moss peat, reducing production costs. The plant quality obtained with pine bark compost at 20% or 50% of the content of the mixture is similar or superior for most morphological and nutritional indices of the species evaluated, establishing this compost as a sustainable and economically advantageous option for the production of forest plants in nurseries.

Keywords: *Pine bark compost, Alternative substrates, Plant quality, Nursery production, Peat moss.*

Introduction

The success or failure of reforestation plantations depends largely on the quality of the plant used and a quality plant can survive and grow optimally in the plantation land (Escobar-Alonso & Rodríguez-Trejo, 2019; Orozco et al., 2010). The quality of the plants produced in the nursery depends, among other factors, on the proper selection of the substrate, since the substrate is one of the factors that directly influence the quality and cost of production in the nursery (Arteaga Martínez et al., 2003; Sánchez-Córdova et al., 2016).

The use of waste in the formulation of substrates has a high environmental value, as it returns waste materials to the production cycle (Garibay et al., 2019). To establish the suitability and usefulness of organic materials as components of substrates, it is essential to know their physical and chemical properties, which allow us to anticipate possible risks and restrictions of use that must be considered in nursery production (Zapata et al., 2005).

The use of pine bark compost as an organic substrate allows the management of waste from different forestry activities, generating a useful product in horticulture and forest nurseries (Arrieta & Terés, 1993; PRODEFO, 2019), a single component does not have all the properties for nursery growth, so substrate mixtures provide much better conditions than a single component (Liévano et al., 2023). (Landis et al. (1990) indicate that the ideal characteristics of a substrate are a slightly acidic pH (PRODEFO, 2019; Torres et al., 2021), high CEC (Cation Exchange Capacity), low inherent fertility (since it is fertilized continuously), an appropriate balance of pore size (total porosity greater than 50%, aeration porosity of the order of 25%) and must be aseptic. (Rodríguez T., 2008) indicates that it must also be economical, available, uniform, with low density, dimensionally stable, durable, easily storable and mixable, facilitate the filling of containers, be rewettable and form a firm root ball. The objective of this work is to search for an alternative substrate in five forest species based on pine bark compost that is a feasible option in the production of plant in containers by reducing production costs, without reducing the morphological and nutritional quality of the forest plant produced.

A substrate provides support to the plant, it is a medium from which water and nutrients can be absorbed, which are provided by fertilization. There are various substrates or growth media with different physical

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and chemical properties. Among the most commonly used are vermiculite, perlite, and peat moss (Burés, 1997; PRODEFO, 2019). Its properties are then referred to considering the alternative substrate (Alonso Escobar, 2019), in this case pine bark compost.

It is an example of an alternative substrate and its use also has a high environmental and economic value, as it returns waste materials to the production cycle. It is a residue from the sawmilling process, which must go through a fermentation and sterilization process for use as a substrate (Juárez T. et al., 2001; Liévano et al., 2023). Compost raises its temperature by around 70°C, which destroys pathogens and weed seeds; therefore, it has appropriate characteristics to reduce the activity of phytopathogenic fungi and improve porosity (Landis et al., 1990; Mendiguren et al., 2012). It has a bulk density between 130 and 220 kg/m^{-3}, porosity around 90%, good aeration capacity, but with very low water availability (5.1% of available water released) contains between 45 and 60% organic matter, has a neutral to alkaline pH, high salinity (5.08 dS/m^{-1}, ratio 1: 2.5 vol.) and high content of phosphorus, potassium, calcium and micro-nutrients, nitrogen varies between 1.0 - 1.5%. (Patrón I. & Pineda P., 2010; PRODEFO, 2019; Sánchez-Córdova et al., 2016).

The target plant concept is a useful way to describe what type of plant is expected and determine its production in advance. Given the differences between species in their morphology and environmental production conditions, the target plant is variable; however, measurements help to know its physiological and morphological quality. The characterization of quality is based on two main types of attributes: morphological and physiological (Chavasse, 1980; Martínez-Nevárez et al., 2023).

Material attributes, direct and immediately measurable, refer to the reaction of the plant when subjected to particular environmental conditions. Among the morphological attributes are: height, root neck diameter and biomass (aerial and root) (Castro-Garibay et al., 2018; González Orozco et al., 2018; Thompson, 1985).

The physiological traits that are most used or have been used in the characterization of plant quality have been the concentration or content of nutrients and reserve carbohydrates in the tissues (Escobar-Alonso & Rodríguez-Trejo, 2019; Marshall, 1985).

Materials and Methods

The San Luis Tlaxialtemalco Nursery is part of the Natural Resources Commission of the Ministry of the Environment of the Government of the Federal District. Located in the Xochimilco Delegation and located between the coordinates 19º 15´ 54´´ north latitude and 99º 07´14´´ west longitude, at an altitude of 2230 m.

Three different mixtures were evaluated, each consisting of different substrates and proportions in volume. For this study, the main variable is the modification of the proportion of incorporation in the volume of pine bark compost. The treatments consist of pine bark compost, moss peat, perlite and vermiculite in the different proportions shown in Table 1; where T0 is the mixture used operationally in the nursery for the production of all species, and T1 and T2 are treatments that include pine bark compost in different proportions.

Table 1. Proportions of the components of the treatments

Treatment	Bark	Peat	Perlite	Vermiculite
T0*	0	50	20	30
T1	20	30	20	30
S2	50	0	20	30

** Mix Control*

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The species used were: *Abies religiosa, Quercus rugosa, Pinus ayacahuite, P. hartwegii.* And *P. montezumae,* the choice of these species was based on the amount they represent in the annual production of the nursery, since together they account for 70% of the total production

The experimental design was completely randomized, where each sample unit was a tray, and each replication consisted of a platform of 10 trays, which had 3 replications in total. The treatments were placed in groups of 40 plants per tray, which were randomly distributed with a total of 120 trays per species.

The variables that were evaluated, in the first case, were applied to the mixtures of each substrate and secondly to seedlings of each species per treatment in different stages of growth in the nursery. The treatments that were evaluated were designed based on the water retention capacity and pore space to retention capacity. To this end, 3 mixtures made up of different proportions of pine bark were analyzed.

The chemical characteristics of pH and electrical conductivity (EC) were determined for each selected mixture, and physical: real density, bulk density, granulometry and porosity.

The retention curve for the different types of soils is determined by means of a device called a pressure membrane. Only water whose hydrostatic stress is identical to the pressure exerted is retained by the soil (Garibay et al., 2019; Sánchez-Córdova et al., 2016).

3 evaluations were carried out during the production period of the species under study, in the case of diameter and height, 80 random samples were taken per treatment for the species of *Abies religiosa*, *Pinus yacahuite*, *P. hartwegii* and *P. montezumae*. While for *Quercus rugosa*, only 40 random samples were taken per treatment. The dry weight variables were taken from 10 random samples per treatment per species.

In the case of morphological indicators, the final evaluation was carried out at 295 days after sowing (DDS). Measurements were taken for root neck diameter (d), height (h), fresh root weight (PFR), fresh weight of aerial part (PFPA), dry weight of root (PSR),and dry weight of aerial part (PSPA).

In addition to the Slim Index (EI), and Dickson Quality Index (ICD) (Dickson et al., 1960b, 1960a). The first of them refers to the relationship between height and diameter at the height of the root neck, while the second encompasses several morphological attributes, expressed in the formula presented below

$$\boldsymbol{IE = \frac{h}{d}} \qquad ICD = \frac{PST}{IE + PSPA}$$

PSR

The variables were: diameter, height, aerial dry weight, root dry weight, aerial part/root ratio and nutrients. The statistical analysis was performed using SAS 9.0 software, performing the ANOVA procedure for the analysis of variance, and a comparison of Tukey means.

Results

Substrate mixtures using pine bark

It was found that mixtures made up of 20% and 50% pine bark compost had a greater number of pore spaces and retention capacity (Table 2). This in turn promotes better drainage by encouraging root formation and growth. On the contrary, the percentage of moisture retention capacity, which represents the water available in the substrate, is in good quantity for treatment two.

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Table 2. Retention capacity and pore space to the moisture retention capacity in the evaluated mixtures.

Mix No.	Holding capacity (%)	Pore space to holding capacity (%)
*0	41.6	16.0
1	40.9	18.2
2	33.6	19.7

* Control mixtures

In general, pine bark compost has very good aeration and water retention. The result obtained is that greater retention capacity is found in treatment 2, therefore, greater pore spaces at retention capacity. This is favorable for plant production (Garibay et al., 2019; PRODEFO, 2019); in the following two mixtures, they do not present significance since the percentage is not very variable.

Determination of the Physical-Chemical Characteristics of Substrates.

The 3 mixtures have a pH and electrical conductivity (EC) suitable for the development of seedlings. The pH at a general level is low, since the highest value was 3.97, which was found in Treatment 1 consisting of 20% pine bark compost and the highest electrical conductivity was that of Treatment 2 (Table 3). In the case of organic matter, all treatments presented good results, with treatment 3 obtaining the highest amount of organic matter. The cation exchange capacity is higher in the control. The bulk density is higher in treatment 2 as well as in the relative density. All three treatments are below the indicators established in accordance with NTEA-006-SMA -2006 (SMA EDO MEX, 2006).

Table 3. Physical-Chemical Analysis of Substrates

Indicator	Witness	T1	S2
pH	3.89	3.97	3.7
E.C., ds/m	0.93	1.64	1.34
M.O., %	2.94	3.20	3.66
CIC, meq/100g.	43.2	36.4	21.52
Dap, g/cm3 0.162 0.245 0.446 Dre, g/cm3 2.25 1.61 2.35			

Nutrient Content of Blends

Table 4. Nutrients present in the mixtures

Indicator	S0	T 1	T 2
Total N (%)	0.77*	0.56*	0.37*
Phosphorus (mg/kg)+	443.35**	400.68**	295.43**
Potassium (cmol/kg)+	3.25**	2.82**	2.78 **
Calcium (cmol/kg)++ 15.38*** 14.18*** 14.55*** Magnesium (cmol/kg)++ 4.95*** 3.41*** 3.75***			

Adequate* Low** High***. Taken from NTEA-006-SMA-2006 and NOM-021-SEMARNAT-2000.

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All 3 mixtures were at an adequate level of nitrogen. In the case of extractable phosphorus and exchangeable potassium, all three were below the adequate value in compost, which needs more than 0.1% of P and 0.25% of K according to NTEA-006-SMA-2006 (SMA EDO MEX, 2006). Interchangeable calcium and magnesium had high values, therefore, they are not completely available to plants. All mixtures were at adequate values in accordance with NOM-021-SEMARNAT-2000 (SEMARNAT, 2002). **Moisture Retention Curve**

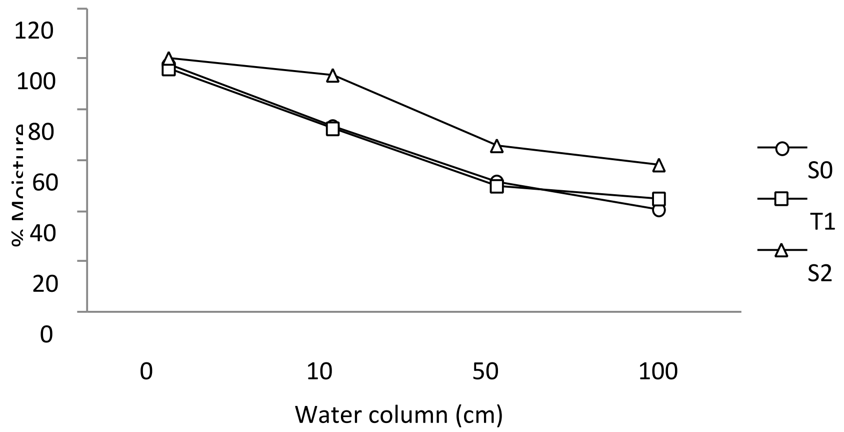

Figure 1. Moisture retention curve for each Treatment

The mixture of treatment 2, composed of 50% pine bark compost, retains a greater amount of moisture, at different levels of the water column, followed by treatment 1 and finally the control, which is at half the moisture retention.

Table 5. Water properties for each substrate

Treatment	AFD	AR	ADD	AND
Witness	21.74	10.74	40.71	26.81
T1	22.74	4.73	44.84	27.70
S2	27.96	7.85	58.07	6.12

†Readily Available Water (AFD), Reserve Water (AR), Hardly Available Water (ADD) and Unavailable Water (DNA).

Readily available water (DFA) was found in a higher proportion in the mixture used in treatment 2 with 27.96 % humidity and in low proportions in the control and treatment 1 with 21.74 % and 22.74 % respectively. The three mixtures, therefore, were found between 20 and 30%, which corresponds to the values suggested as optimal.

The highest value of reserve water (RA) was obtained by the control with 10.74 % humidity, followed by treatment 2 with 7.85 % and in a lower proportion with 4.73 % treatment 1. The three mixtures are in optimal values, which correspond to 4 to 10%.

Hardly available water (ADD) was found in a higher proportion in mixture 2 with 58.07 %; and the unavailable water obtained the highest value in the mixture of treatment 1 with 27.70 % and to a lesser degree in mixture 2 with 6.12 % of moisture.

Mixture 2, therefore, is the one with the most recommended values, since it has a greater amount of available water, while the amount of unavailable water is lower than the rest of the mixtures.

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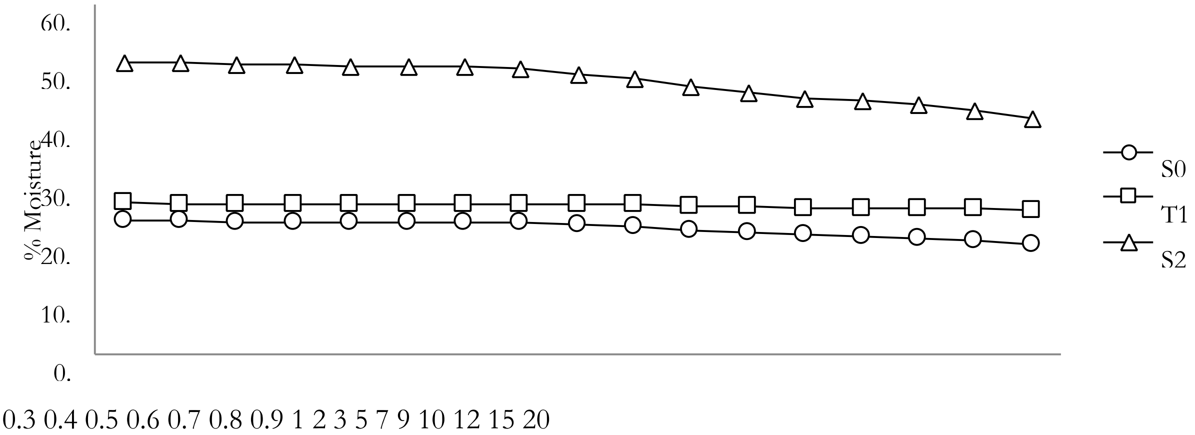

Figure 2. Moisture Release Curve

The release curve shows that treatment 2 has the highest field capacity with 50.18 %, followed by treatment 1 with 26.04 % and finally the control with 23.02 %.

Morphological Indicators

Table 6. Statistical significance (p) of the effect of 3 substrate mixtures (T0, T1 and T2) on the morphological characteristics of the plants of the different species produced in the nursery at the end of the production cycle

	Forest species				
Variable	***Abies religiosa***	***Pinus ayacahuite***	***Pinus hartwegii***	***Pinus montezumae***	***Quercus rugosa***
DCR†	0.0069	0.8954	0.0228	0.0447	0.9957
Height	0.0011	<.0001	0.3787	0.0391	0.1431
PSR	0.0121	0.3749	0.0108	0.0176	0.2895
PSA	0.0031	0.3980	0.0059	0.0903	0.1661
STOP	0.7724	0.0046	0.3693	0.2805	0.4823
IE	0.0257	<.0001	0.9168	0.3637	0.5179
ICD	0.1057	0.0228	0.0520	0.0545	0.2737

† DCR= root neck diameter, PSR=Root dry weight; PSA= air dry weight; EI= slenderness index; RPAR = airborne/root ratio; ICD= Dickson Quality Index.

The Significance Table indicates the modification of the morphological characteristics of the different species, which are influenced by the use of different mixtures of substrates (Table 7).

Table 7. Average values per substrate mixture in the morphological characteristics of the plants of

Abies religiosa at the end of the nursery production cycle.

	Plant Quality Indicator and Index						
Mixture	**DCR† (mm)**	**ALT (cm)**	**PSR (g)**	**PSPA (g)**	**RPA/R**	**IE**	**ICD**
S0	1.95 AB‡	9.78 b	0.271 b	0.828 b	3,211 to	5.07 b	0.14 to
T_1	2.14 to	14.04 to	0.448 to	1,297 to	3,305 to	6.66 to	0.18 to

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T 2	1.70 b	10.98 b	0.288 b	0.786 b	2,923 to	6.59 b	0.12 to

†Diameter (DCR), height (ALT), root dry weight (PSR), aerial part dry weight (PSPA), aerial/root ratio (RPA/R), slenderness index (EI), Dickson quality index (ICD) in response to 2 compost-based mixtures of pine bark in the final growth of *Abies religiosa*. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

The diameter variable presented better results in Treatment 1 with 2.14 mm; Height also presented good results with 14.04 cm in the same treatment. The dry weight of the root and the dry weight of the aerial part had good results for treatment 1 with 0.45 g and 1.30 g respectively. The aerial/root ratio does not show a statistically significant difference for each mixture. The highest value for the slenderness index (EI) was presented by treatment 1 with 6.66. The Dickson Quality Index (DCI) did not present a statistically significant difference between treatments, so any treatment is good, but in the case of treatment 1, it presented the highest values of diameter, height, root dry weight and air dry weight; therefore, this mixture would be suitable to achieve better results and with a lower expense with respect to the control.

Pinus ayacahuite

Table 8. Average values per substrate mixture in the morphological characteristics of *Pinus ayacahuite plants* at the end of the nursery production cycle.

Mixture	**Plant Quality Indicator and Index**						
	DCR† (mm)	**HEIGHT (cm)**	**PSR (g)**	**PSPA (g)**	**RPA/R**	**IE**	**ICD**
S0	3.22 a‡	29.67 to	1,210 to	3,170 to	2,693 to	9.33 to	0.37 b
T₁	3.29 to	26.44 to	1,242 to	3,036 to	2,546 to	8.01 to	0.41 ab
T 2	3.31 to	19.38 b	1,422 to	2,753 to	1.967 b	5.93 b	0.55 to

†Diameter (DCR), height (ALT), root dry weight (PSR), aerial dry weight (PSPA), aerial/root ratio (RPA/R), slenderness index (EI), Dickson quality index (ICD) in response to 2 compost-based mixtures of pine bark in the final growth of *Pinus ayacahuite*. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

In the case of Pinus ayacahuite, the diameter did not present a statistically significant difference. In height, both the control and treatment 1 had a statistically significant difference compared to treatment 2. For the dry weights of the root and the aerial part, there was no statistically significant difference. In the aerial/root ratio, treatment 2 obtained the lowest value with 1.97, as well as in the slenderness index, where its value was 5.93. The Dickson quality index was higher in treatment 2 with 0.55.

For this species, treatment 2 would be recommended, as it is the most economical in terms of substrate and because it presents results similar to the control mixture.

Pinus hartwegii

Table 9. Average values per substrate mixture in the morphological characteristics of *Pinus hartwegii plants* at the end of the nursery production cycle.

Plant Quality Indicator and Index							
Mixture	**DCR† (mm)**	**HEIGHT (cm)**	**PSR (g)**	**PSPA (g)**	**RPA/R**	**IE**	**ICD**
S0	4.54 a‡	7.15 AB	1,764 ab	3,204 to	1,852 to	0.63 to	2.07 AB

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T1	5.37 to	8.61 to	2,016 to	3,459 to	1,762 to	0.68 to	2.40 to
T 2	4.16 to	6.02 b	1,546 b	2,433 b	1,583 to	0.68 to	1.81 b

†Diameter (DCR), height (ALT), root dry weight (PSR), aerial dry weight (PSPA), aerial part ratio (RPA/R), slenderness index (EI), Dickson quality index (ICD) in response to 2 compost-based mixtures of pine bark in final growth of *Pinus hartwegii*. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

For the data of *Pinus hartwegii,* no statistically significant difference was found for the variable diameter and height, Treatment 1 obtained the best result with 5.37 mm and 8.61 cm., respectively. For root dry weight, Treatment 1 had the highest result with 2.02 g; while for the dry weight of the aerial part, the control and treatment 1 obtained the best result with 3.20 g and 3.46 g respectively. There was no statistically significant difference in the aerial-root dry weight ratio and the slenderness index. The Dickson quality index was highest in Treatment 1 with 2.40, followed by the Control with 2.07 and Treatment 2 with 1.81.

Treatment 1, which contained 20% pine bark compost, had the best results; Therefore, for this species it would be advisable to use this mixture, since it would reduce costs and obtain quality plant

Pinus montezumae

Table 10. Average values per substrate mixture in the morphological characteristics of *Pinus montezumae plants* at the end of the nursery production cycle.

		Plant Quality Indicator and Index					
Mixture	**DCR† (mm)**	**HEIGHT (cm)**	**PSR**	**PSPA**	**RPA/R (g) (g)**	**IE**	**ICD**
S0	4.54 a‡	7.15 AB	1,764 ab	3,204 to	1,852 to	0.63 to	2.07 AB
T1	5.37 to	8.61 to	2,016 to	3,459 to	1,762 to	0.68 to	2.40 to
T 2	4.16 to	6.02 b	1,546 b	2,433 b	1,583 to	0.68 to	1.81 b

†Diameter (DCR), height (ALT), root dry weight (PSR), aerial part dry weight (PSPA), aerial part-to-root ratio (RPA/R), slenderness index (IE), Dickson quality index (ICD) in response to 2 compost-based mixtures of pine bark in final growth of *Pinus montezumae*. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

In the case of *Pinus montezumae* , the diameter did not have a significant difference between mixtures. The highest height was obtained in Treatment 1 with 8.61 cm. Root dry weight was also higher in Treatment 1, with 2.01 g, with a statistically significant difference with Treatment 3. In the case of the dry weight of the aerial part and the slenderness index, there was no statistically significant difference. The Dickson quality index had a statistically significant difference between treatment 1 and treatment 2 and control, obtaining a value of 2.40.

In this species, the best results in terms of sapling quality were presented in the mixture of Treatment 1; however, the Witness presented good results.

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Quercus rugosa

Table 11. Average values per substrate mixture in the morphological characteristics of *Quercus rugosa plants* at the end of the nursery production cycle.

Mixture	Plant Quality Indicator and Index						
	DCR† (mm)	HEIGHT (cm)	PSR (g)	PSPA (g)	RPA/R	IE	ICD
S0	5.76 a‡	31.62 to	4,190 to	6,141 to	1,543 to	5.70 to	1.49 to
T_1	5.81 to	31.97 to	5.603 to	8,217 to	1,479 to	5.64 to	1.97 to
T_2	5.77 to	34.45 to	5,225 to	8,013 to	1,800 to	6.19 to	1.72 to

†Diameter (DCR), height (ALT), root dry weight (PSR), aerial part dry weight (PSPA), aerial part-to-root ratio (RPA/R), slenderness index (IE), Dickson quality index (ICD) in response to 2 compost-based mixtures of pine bark in the final growth of *Pinus montezumae*. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

For the data obtained in the laboratory, no statistically significant difference was found for the variables of diameter, height, dry weight, root and aerial part. In this case, Treatment 1 presented the highest Dickson quality index with 1.97, then Treatment 2 with 1.72 and finally the Control with 1.49.

For the data of *Quercus rugosa* , no statistically significant difference was found for the morphological indicator variables. Therefore, in this species it would be advisable to use the T2 mixture that contains 50% pine bark compost, since it reduces costs and presents similar results compared to the control.

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Nutritional status of forest species with different substrate mixtures.

Table 12. Statistical significance (p) of the effect of 3 substrate mixtures (T0, T1 and T2) on the concentrations of N, P, K, Ca and Mg of the different species at the end of the production cycle.

	Forest species				
Element	***Abies religiosa***	***Pinus ayacahuite***	***Pinus hartwegii***	***Pinus montezumae***	***Quercus rugosa***
N†	0.0814	<.0001	0.0099	0.0534	<.0001
P	0.0077	<.0001	0.0035	<.0001	<.0001
K	<.0001	<.0001	0.0818	<.0001	<.0001
Mg	0.0247	<.0001	<.0001	<.0001	<.0001
AC	<.0001	<.0001	<.0001	0.1168	<.0001

† N = nitrogen; P = Phosphorus; K = Potassium; Ca=Calcium and Mg=Magnesium

The Significance Table indicates the modification of the nutritional concentrations of the different species, which is influenced by the use of different mixtures of substrates, mainly by the modification of moisture absorption and retention characteristics (Table 13).

Abies religiosa

Table 13. Average values per substrate mixture in the nutritional concentration of *Abies religiosa plants* at the end of the nursery production cycle.

	Concentration g/$^{kg-1}$				
Mixture	**N†**	**P**	**K**	**AC**	**Mg**
S0	1,611 a‡	0.441 to	1,298 c	0.229 b	0.205 ab
T₁	1,537 to	0.428 b	1,333 b	0.256 to	0.203 b
T ₂	1,643 to	0.425 b	1,445 to	0.231 b	0.206 to

† N = nitrogen; P = Phosphorus; K = Potassium; Ca=Calcium and Mg=Magnesium. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

The nutritional concentration in the three mixtures is statistically very similar. In the case of phosphorus, treatments 1 and 2 are lower than the control, but the control is significantly lower in potassium with respect to treatment 2. The proportion of calcium and magnesium in the three treatments does not significantly influence the development of the seedlings, since, although statistically there is a significance, the values do not vary from each other.

Pinus ayacahuite

Table 14. Average values per substrate mixture in the nutritional concentration of *Pinus ayacahuite plants* at the end of the nursery production cycle.

Mixture	Concentration g/$^{kg-1}$				
	N	**P**	**K**	**AC**	**Mg**
S0	1,640 to	0.346 to	0.937 to	0.253 to	0.174 to
T₁	1,477 b	0.267 c	0.933 to	0.199 b	0.142 b

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T 2	1,276 c	0.284 b	0.907 b	0.194 b	0.139 b

† N = Nitrogen; P = Phosphorus; K = Potassium; Ca=Calcium and Mg=Magnesium. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

In the case of Pinus *ayacahuite* species, the control reaches the highest values of the elements evaluated, but statistically control 1, having a nitrogen concentration of 1.477 and a potassium of 0.933, is postulated for the second best option even though it has the lowest value in phosphorus, treatment 2 reached the lowest values and only in phosphorus reached a good place with 0.284.

Pinus hartwegii

Table 15. Average values per substrate mixture in the nutritional concentration of *Pinus hartwegii plants* at the end of the nursery production cycle.

	Concentration g/$^{kg-1}$				
Mixture	**N**	**P**	**K**	**AC**	**Mg**
S0	1,172 to	0.265 b	0.892 to	0.181 b	0.153 b
T1	1,152 to	0.265 b	0.863 to	0.174 c	0.155 b
T 2	1,008 b	0.274 to	0.876 to	0.203 to	0.166 to

† N = Nitrogen; P = Phosphorus; K = Potassium; Ca=Calcium and Mg=Magnesium. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

The nitrogen content was not statistically significant for the three treatments. In the case of phosphorus treatment 2, the highest value was 0.274 meq/g. Potassium did not have a statistically significant difference between treatments. In relation to the five elements, treatment 2 obtained the best result by reaching the highest values

Pinus montezumae

Table 16. Average values per substrate mixture in the nutritional concentration of *Pinus montezumae plants* at the end of the nursery production cycle.

	Concentration g/$^{kg-1}$				
Mixture	**N**	**P**	**K**	**AC**	**Mg**
S0	1,142 to	0.309 C	0.949 c	0.163 to	0.163 c
T1	1,116 AB	0.345 b	1.018 b	0.160 A	0.173 b
T 2	1.054 b	0.408 to	1,210 to	0.157 to	0.186 to

† N = Nitrogen; P = Phosphorus; K = Potassium; Ca=Calcium and Mg=Magnesium. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

The nutritional content was very similar in nitrogen, with the control value having 1,142 as the highest value, in the case of phosphorus and potassium were found in a higher proportion for treatment 2, as well as in the relationship of the five elements. For this reason, it is recommended to use it, which is made up of 50% pine bark compost.

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Quercus rugosa

Table 17. Average values per substrate mixture in the concentration of *Quercus rugosa plants* at the end of the nursery production cycle.

	Concentration g/$^{kg-1}$				
Mixture	**N**	**P**	**K**	**AC**	**Mg**
S0	2,962 to	0.387 to	1,545 to	0.407 c	0.283 to
T_1	2,574 b	0.310 b	1,381 b	0.439 b	0.269 c
T_2	2,150 c	0.299 c	1,281 c	0.473 to	0.278 b

† N = Nitrogen; P = Phosphorus; K = Potassium; Ca=Calcium and Mg=Magnesium. ‡Average values in the same column followed by the same letter are not significantly different (p=0.05).

The nutritional content in nitrogen, phosphorus and potassium was found to be the highest value for the control, followed by treatment 1 and, finally, treatment 2.

Discussion

The research, which seeks an alternative substrate to reduce production costs, finds broad support that the substitution of moss peat is a global need, given the environmental and economic implications of its use (Alonso Escobar, 2019). Studies in Pinus ponderosa confirm that the use of compost from wood waste and pine bark can generate savings in peat alone that exceeds $1,000,000 per year (Calvi, 2022), while other studies show that mixtures with sawdust and bark reduce production costs by up to 39.8% or even 50% (Garibay et al., 2019; González Orozco et al., 2018). This alternative does not compromise quality, since the plant quality obtained with pine bark compost is similar or better for most morphological and nutritional indices (Escobar-Alonso & Rodríguez-Trejo, 2019); This is consistent with findings that plants produced with compost are not of inferior forest value and may be slightly larger in size than those of traditional peat and sand substrates (Calvi, 2022). Finally, the use of these materials allows the management of waste from different forestry activities, offering a solution of high environmental and economic value (Liévano et al., 2023) for the large volume of pine bark generated, which otherwise leads to problems of space and destination (Arrieta & Terés, 1993).

Conclusions

Mixtures with pine bark compost represent an alternative to the use of imported materials such as peat, since they reduce production costs (Calvi, 2022).

The plant quality obtained either with the use of moss peat or pine bark compost at 20 or 50 % of the content of the mixture is similar or better in most cases, as seen in the morphological indices of the species evaluated.

The nutritional content is at statistically acceptable levels in the three treatments of each species, although this is not such an important factor since the values can be manipulated through their operational application in the nursery.

In *Abies religiosa* , treatment 1, consisting of 20% of the pine bark compost mixture, presented the best results for diameter, height, root dry weight, and aerial part dry weight. *Pinus ayacahuite* presented the best result by using 50% pine bark compost (T2) in most of the variables, although in the case of height, it obtained the lowest value with a statistically significant difference; however, it reached the minimum value established in the nursery for its field release.

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Pinus hartwegii obtained better results by using the mixture of 20% pine bark compost in height, root dry weight and Dickson quality index.

Pinus montezumae had better results in morphological indicators for the case of the control. Notwithstanding the above, in treatments 1 and 2, the required standard in diameter was reached.

Quercus rugosa did not present a statistically significant difference in morphological indicators between treatments, which means that in any of the 3 cases, plants with similar characteristics were obtained.

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