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PHYSICAL AND CHEMICAL PROPERTIES OF SUBSTRATE DERIVED FROM COFFEE RESIDUE FOR SEEDLING PRODUCTION

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Resumo

Propriedades físico-químicas de substrato a base de resíduos de café para produção de mudas. A produção de mudas está associada a qualidade do substrato utilizado. A caracterização das propriedades físico-químicas é parte fundamental para a escolha dos componentes e suas proporções na formulação de substrato. Assim, objetivou-se neste trabalho analisar as propriedades físicas-químicas de componentes e formulados com base em resíduos agroindustriais. Foram avaliados a qualidade do uso de três componentes, palha de café in natura, a palha de café carbonizada e a palha de café compostada, em 25 formulações distintas de substratos para a produção de mudas. Foram analisadas a densidade em base úmida e seca, porosidade total, espaço de aeração, água facilmente disponível, capacidade de retenção de água, condutividade elétrica e pH. O experimento seguiu delineamento inteiramente casualizado com três repetições, e os dados obtidos, foram analisados pela ANOVA e teste de Skott-knott (p<0,05). Todos os substratos apresentaram diferenças estatísticas entre si, para todas as variáveis estudadas. Os resíduos do processamento do café apresentaram boas características físicas e limitações na condutividade elétrica e pH. Os formulados apresentam características físicas e químicas variadas conforme seus constituintes e proporções. Três substratos se destacaram por apresentar boas características químicas e físicas, os quais tinham como base 30-40% de palha de café carbonizada ou compostada. Os resultados aqui obtidos irão funcionar como uma importante ferramenta para nortear a tomada de decisão quanto aos constituintes e proporções adequadas na formulação dos substratos para produção de mudas.
Palavras-chave: Substratos agroindustriais; meios de cultivo; palha de café.

Abstract

The physical-chemical properties of substrates based on coffee residues for seedling production were analyzed. The production of seedlings is associated with the quality of the substrates used. The characterization of the physical-chemical properties is a fundamental part of components and their proportions in formulating substrate selection. Thus, the objective of this work was to analyze the physical-chemical properties of components and formulations based on agro-industrial residues. The quality of the use of three components, fresh coffee straw, carbonized coffee straw, and composted coffee straw, in 25 different formulations of substrates for seedling production were evaluated. The dry density, current humidity, total porosity, aeration space, easily available water, water retention capacity, electrical conductivity, and pH were evaluated. The experiment followed a completely randomized design with three replications, and the data obtained were analyzed by ANOVA and the Scott-Knott test (p<0.05). All substrates had statistical differences among themselves, for all variables studied. Coffee processing residue presented physical and limited electrical conductivity and pH characteristics. Formulated products have physical and chemical characteristics depending on their constituents and proportions. Three substrates stood out for presenting good chemical and physical characteristics, which were based on 30-40% carbonized or composted coffee straw. The results obtained here will work as an important tool to guide decision-making regarding the constituents and adequate proportions in formulating substrates for seedling production.
Keywords: Agro-industrial substrates; growing medium; coffee straw.

INTRODUCTION

The substrate is a significant factor for the growth of seedlings in containers with a restricted volume, which has the function of supporting the seedling, providing adequate conditions for the growth and functioning of the root system, and at least partially determining the quality of the seedlings (KRATZ *et al.*, 2017). Physical, chemical, and biological characteristics are the main intrinsic factors of substrates which affect seedling growth (CUNHA *et al.*, 2022).

The properties of substrates are variable depending on their origin and the different proportions of their components, and therefore it is important to analyze their properties to attest to their quality (KRATZ *et al.*, 2017). The chemical properties of a substrate are pH, electrical conductivity, and/or total content of soluble salts (SCHAFER *et al.*, 2015). These characteristics are related to the availability of nutrients; however, it is a property that can be easily corrected with the use of acidity correctors and the addition of mineral fertilizers

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during the seedling production process (LUDWING *et al.*, 2020, REGAN, 2014). The physical properties of substrates are not easily corrected and are represented by wet and dry density, total porosity, aeration space, and available water (SCHAFER *et al.*, 2015).

Commercial substrates adhere to specific physical and chemical characteristics in accordance with current legislation. However, their availability is not universal across all regions of the country, leading to increased expenses in seedling procurement and production (SCHAFER *et al.*, 2015, SILVA *et al.*, 2020). In pursuit of these objectives, utilizing renewable residue of regional origin emerges as a viable alternative. This approach not only reduces acquisition costs, but also presents an intelligent solution for waste disposal (SILVA *et al.*, 2021).

Coffee straw is a byproduct obtained from processing fruit of the coffee tree, a crop cultivated on a large scale in the southern region of Minas Gerais (ALMEIDA *et al.*, 2020). The annual yield of coffee straw accounts for approximately 50% of the total coffee production, amounting to 1,530,310 million 60 kg bags in 2022 (CUNHA *et al.*, 2022; COMPANHIA NACIONAL DE ABASTECIMENTO, 2023). Several studies in the literature have demonstrated the potential use of this byproduct as a component of substrates for cultivating seedlings of forest species (CUNHA *et al.*, 2022, SILVA *et al.*, 2020, SILVA *et al.*, 2021).

The substrate quality determines the management of transparency and nutrition and influences the seedling production cycle, so that each species has its specificities regarding the characteristics of the cultivation medium (FERMINO *et al.*, 2018). Furthermore, different species have different criteria regarding the physical and chemical characteristics of the substrates. Therefore, the objective of this work was to (I) analyze whether coffee processing residues have good chemical and physical characteristics for composing substrates for seedling production; and (II) analyze the quality of the physical and chemical properties of the substrate constituents and its different formulations for seedling production based on agro-industrial waste. It is hypothesized that coffee straw is a great constituent for substrates, adding good chemical and physical characteristics.

MATERIAL AND METHODS

The physicochemical characteristics of three alternative substrate components derived from coffee processing were evaluated, namely fresh coffee straw (FCS), carbonized coffee straw (CCS), and composted coffee straw (CPCS). The methodology for creating the CCS and CPCS was followed in accordance with Silva *et al.* (2020). These materials were obtained through donations from coffee producers in the southern region of Minas Gerais.

A total of 25 substrate formulations were produced, incorporating varying percentages of the following compounds: bovine manure (BM), coconut fiber (BF), commercial substrate (CS) based on pine bark, carbonized rice straw (CRS) and pine bark, vermiculite, NPK, carbonized rice straw (CRS), carbonized coffee straw (CCS), fresh coffee straw (FCS), composted rice straw (CPRS), and composted coffee straw (CPCS) (Table 1). All materials and their mixtures underwent physical-chemical analysis at the Plant Substrates Laboratory of the Department of Horticulture and Forestry at the Faculty of Agronomy of the Federal University of Rio Grande do Sul.

Table 1. Composition of substrates using residues from coffee and rice processing, bovine manure, coconut fiber and commercial substrate used in the composition of the substrates.
Tabela 1. Composição dos substratos utilizando resíduos do processamento de café e arroz, esterco bovino, fibra de coco e substrato comercial utilizados na composição dos substratos.

Substrate	BM	CF	CS	CRS	CCS	FCS	CPRS	CPCS	Resume of treatments
S1	30	20		50					30BM/20CF/50CRS
S2	30	20		20	30				30BM/20CF/20CRS/30CCS
S3	30	20		30		20			30BM/20CF/30CRS/20FCS
S4	30	20		20		30			30BM/20CF/20CRS/30FCS
S5	30	20				50			30BM/20CF/50FCS
S6						100			100FCS
S7	30		20	30	20				30BM/20CS/30CRS/20CCS
S8	30		20	50					30BM/20CS/50CRS
S9	30		20	15	35				30BM/20CS/15CRS/35CCS

S10	30		20		50				30BM/20CS/50CCS
S11			100						100CS
S12		20	20				60		20CF/20CS/60CPRS
S13		20	40				40		20CF/40CS/40CPRS
S14		20	60				20		20CF/60CS/20CPRS
S15		20	80						20CF/80CS
S16		20	20					60	20CF/20CS/60CPCS
S17		20	40					40	20CF/40CS/40CPCS
S18		20	60					20	20CF/60CS/20CPCS
S19		20	20				30	30	20CF/20CS/30CPRS/30CPCS
S20					100				100CCS
S21								100	100CPCS
S22		60		40					60CF/40CRS
S23		80		20					80CF/20CRS
S24		60			40				60CF/40CCS
S25		80			20				80CF/20CCS

In which: BM: bovine manure, CF: coconut fiber, CS: commercial substrate, CRS: carbonized rice husk, CCS: carbonized coffee straw, FCS: fresh coffee straw, CPRS: composted rice straw, CPCS: composted coffee straw.
Em que: BM: esterco bovino, CF: fibra de coco, CS: substrato comercial, CRS: palha de arroz carbonizada, CCS: palha de café carbonizada, FCS: palha de café in natura, CPRS: palha de arroz compostada, CPCS: palha de café compostada.

The substrates were physically characterized using the following analyses: density on a dry basis (DD), using the self-compaction method (HOFFMANN, 1970); total porosity (TP); aeration space (AS); easily available water (EAW); current humidity (CH) and the water retention capacity (WRC) at 10 hPa pressure, determined using tension functions according to the principles of De Boodt and Verdonck (1972).

Assessments of electrical conductivity (EC) and hydrogen potential (pH) were considered for chemical analyses, both in a substrate dilution: water of 1:5 (v:v), according to IN no. 17/2007 (BRASIL, 2007). Data were analyzed in a completely randomized design (CRD) with three replications. The results obtained were analyzed using descriptive statistics (DE BOODT; VERDONCK, 1972; KÄMPF, 2005). Pearson's correlation analysis was performed. Among the physical and chemical characteristics of the substrate, no correlation was considered when $r = 0$; a weak correlation was considered when $0 < r < 0.4$; a median correlation when $0.4 \leq r < 0.6$; a strong correlation when $0.6 \leq r < 0.9$; a very strong correlation when $0.9 \leq r < 1$; and a perfect correlation when $r = 1$, as used by Cunha *et al.* (2022). A principal component analysis (PCA) based on the demonstration matrix was performed using the R OriginLab Version 8.6 software program to understand the similarity of characteristics between the substrates.

The data obtained were subjected to analysis of variance (ANOVA) using the F test (p=0.05), and when a significant difference was verified, the means were compared using the Scott-Knott test at 5% probability of error using the SISVAR version 5.6 software program.

RESULTS

The maximum minimum and average values found for the physical and chemical characteristics are found in Figure 1, being EC (0.9; 0.2; 1.6 mS cm^{-1}), pH (6.6; 4.4; 9.2 H_2O), DD (232.4; 81.5; 272.2 kg m^{-3}), CH (37.4; 1.3; 73.9%), TP (80.8; 9.12; 90.6%), AS (39.7; 28.2; 54.2%), WRC10 (41; 11.7; 57.3%), AR (29.8; 11.2; 39%), EAW (10.3; 0.4; 19.4%), respectively.

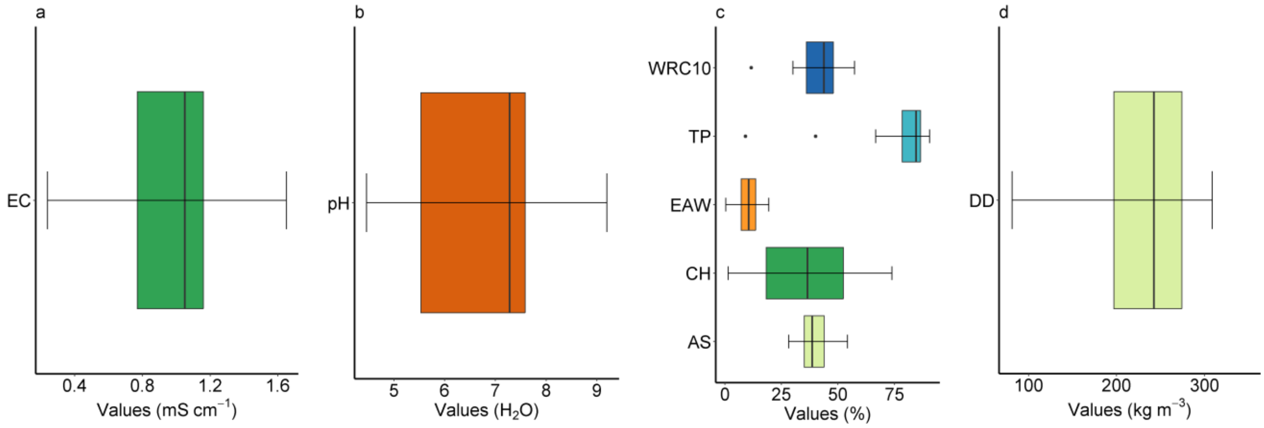

Figure 1. Boxplot of chemical characteristics (a, b) electrical conductivity (EC) and pH and physical characteristics (c, d) current humidity (CH), total porosity (TP), aeration space (AS), water retention capacity in the pressure 10 hPa (WRC10), easily available water (EAW) of the substrates and dry density (DD).

Figura 1. Boxplot das características químicas (a, b) condutividade elétrica (EC) e pH e das características físicas (c,d) umidade atual (CH), porosidade total (TP), espaço de aeração (AS), capacidade de retenção de água na pressão 10 hPa (WRC10), água facilmente disponível (EAW) dos substratos e densidade seca (DD).

All chemical and physical characteristics showed significant differences between the substrates studied, and the comparison of means is presented in Table 2. For the chemical characteristics, the pH values in water differed statistically from each other, and varied between acidic and basic substrates, with the S15 formula (20CF/80CS) being the most acidic (4.46), and S20 (100CCS) the most basic (9.20). The lowest average found for electrical conductivity was 0.2 mS cm^{-1} for S11 (100CS), and the highest was 1.7 mS cm^{-1}, for the S16 (20CF/20CS/60CCSP) treatment.

Table 2. Chemical and physical characteristics of the 25 substrates used, with different proportions of cattle manure (BM), coconut fiber (CF), commercial substrate (CS), carbonized rice husk (CRS), carbonized coffee straw (CCS), fresh coffee straw (FCS), composted rice straw (CPRS), composted coffee straw (CPCS), used in the composition of the substrates.

Tabela 2. Características químicas e físicas dos 25 substratos utilizados, com diferentes proporções de esterco bovino (BM), fibra de coco (CF), substrato comercial (CS), palha de arroz carbonizada (CRS), palha de café carbonizada (CCS), palha de café in natura (FCS), palha de arroz compostada (CPRS), palha de café compostada (CPCS), utilizados na composição dos substratos.

Resume of treatments	EC	pH	DD	CH	TP	AS	EAW	WRC10
	(mS cm^{-1})	(H_2O)	(kg m^{-3})	(%)				
30BM/20CF/50CRS	0,7 g	7,4 i	221,3 d	15,3 b	82,7 e	43,9 e	14,5 h	38,8 e
30BM/20CF/20CRS/30CCS	0,9 f	8,0 k	231,4 e	18,3 c	78,4 d	28,4 a	17,8 i	50,0 i
30BM/20CF/30CRS/20FCS	0,8 g	7,6 j	221,7 d	18,3 c	79,8 d	42,8 e	7,5 d	37 d
30BM/20CF/20CRS/30FCS	1,1 e	7,7 j	222,4 d	13,0 a	70,4 c	37,6 c	5,8 c	32,8 c
30BM/20CF/50FCS	1,1 e	8,0 k	203,7 d	17,8 c	66,8 b	36,6 c	4,1 b	30,1 b
100FCS	0,6 h	7,4 i	120,7 b	11,7 a	40,2 a	28,5 a	0,4 a	11,7 a
30BM/20CS/30CRS/20CCS	1,1 e	6,9 h	244,8 e	29,0 e	85,1 f	46,2 f	13 g	38,9 e
30BM/20CS/50CRS	0,9 f	7,3 i	240,1 e	41,0 i	86,9 f	41,0 d	15,2 h	46,0 h
30BM/20CS/15CRS/35CCS	1,1 d	7,6 j	283,0 f	26,7 d	79,8 d	28,7 a	17,2 i	51,1 i
30BM/20CS/50CCS	1,3 c	7,6 j	271,9 f	31,4 f	78,6 d	34,6 b	11,8 f	44,0 g
100CS	0,2 i	5,5 e	308,8 g	50,6 l	85,5 f	28,2 a	19,4 j	57,3 j
20CF/20CS/60CPRS	1,2 c	4,8 b	264,2 f	44,6 j	85,8 f	43,8 e	12,7 g	42,1 f

20CF/40CS/40CPRS	1,2 d	5,7 e	294,3 g	34,4 g	82,8 e	34,8 b	14,8 h	48,0 i
20CF/60CS/20CPRS	1,1 e	4,9 c	272,0 f	49,1 k	86,3 f	37,1 c	13,6 g	49,2 i
20CF/80CS	1,0 f	4,5 a	252,9 e	59,2 o	88,6 g	38,1 c	10,5 f	50,6 i
20CF/20CS/60CPCS	1,7 a	5,4 d	308,2 g	51,6 l	87,7 f	38,6 c	10,5 f	49,2 i
20CF/40CS/40CPCS	1,6 b	5,0 c	273,8 f	55,4 n	87,4 f	41,8 d	5,5 c	46,7 h
20CF/60CS/20CPCS	1,3 c	4,8 b	275,7 f	52,4 m	86,3 f	41,3 d	7,5 d	45,1 g
20CF/20CS/30CPRS/30CPCS	1,2 c	5,6 e	293,7 g	36,5 h	84,6 f	46,2 f	7,2 d	40,5 f
100CCS	0,8 g	9,2 l	177,2 c	1,4 b	68,6 b	37,1 c	1,5 a	31,4 b
100CPCS	1,1 e	7,5 i	467,0 h	16,6 c	71,1 c	35,1 b	7,2 d	36,0 d
60CF/40CRS	0,6 h	6,4 g	97,9 a	53,3 m	86,6 f	53,7 g	12,6 g	32,9 c
80CF/20CRS	0,6 g	6,2 f	81,5 a	70,7 q	90,1 g	54,2 g	11,3 f	35,9 d
60CF/40CCS	0,7 g	7,6 j	100,4 a	63 p	90,6 g	46,8 f	9,0 e	43,8 g
80CF/20CCS	0,8 g	7,4 i	83,9 a	73,9 r	90,4 g	46,1 f	8,9 e	44,7 g

In which: BM: bovine manure, CF: coconut fiber, CS: commercial substrate, CRS: carbonized rice husk, CCS: carbonized coffee straw, FCS: fresh coffee straw, CPRS: composted rice straw, CPCS: composted coffee straw. EC = electrical conductivity obtained in a 1:5 solution (v/v), pH = determined in water, dilution 1:5 (v/v), DD = dry density, CH: current humidity, TP = total porosity, AS = aeration space, EAW = easily available water, WRC10 = water holding capacity under suction of 10 cm of water column.
Em que: BM: esterco bovino, CF: fibra de coco, CS: substrato comercial, CRS: palha de arroz carbonizada, CCS: palha de café carbonizada, FCS: palha de café in natura, CPRS: palha de arroz compostada, CPCS: palha de café compostada, EC = condutividade elétrica obtida em solução 1:5 (v/v), pH = determinado em água, diluição 1:5 (v/v), DD = densidade seca, CH: umidade atual, TP = porosidade total, AS = espaço de aeração, EAW= água facilmente disponível, WRC10 = capacidade de retenção de água sob sucção de 10 cm de coluna de água.

Regarding the physical parameters of the substrates, the S22 (60CF/40CRS), S23 (80CF/20CRS), S24 (60CF/40CCS), and S25 (80CF/20CCS) substrates are similar to each other with the lowest values found for dry density (90.9 kg m^{-3}), while the highest average was for S21 (100CPCS) of 466.9 kg m^{-3}.

For current humidity values, the lowest and highest averages were 1.67 to 70.66% for the S6 (100FCS) and S23 (80CF/20CRS) substrates, respectively. The lowest average for total porosity was 40.2% for S6 (100FCS), while the S15 (20CF/80CS), S23 (80CF/20CRS), S24 (60CF/40CCS) and S25 (80CF/20CCS) substrates are similar to each other, with an average of 69.7%. In addition, the S2 (30MB/20CF/20CRS/30CCS), S6 (100FCS), S9 (30MB/20CS/15CRS/35CCS), and S11 (100CS) substrates are similar to each other for the aeration space, with the lowest average found of 28.4%. Furthermore, the S22 (60CF/40CRS) and S23 (80CF/20CRS) substrates are similar to each other and had a higher average of 53.9%. It was observed that the highest averages for these variables were found for treatments with different proportions of coconut fiber, coffee straw, and carbonized rice.

For EAW, S6 (100FCS) and S20 (100CCS) substrates did not differ from each other, and presented the lowest averages with an overall value of 3.79%. The largest averages found were for the S2 (30MB/20CF/20CRS/30CCS) and S9 (30MB/20CS/15CRS/35CCS) substrates, which do not differ from each other, with an overall average of 17.5%. Then, the lowest and highest averages for WRC10 were 11.7 to 57.3% for the S6 (100FCS) and S11 (100CS) substrates, respectively. The lowest water percentages found in the substrates were related to treatment S6 with 100% fresh coffee straw, which demonstrates the low capacity of this component to store water in the substrate.

The results regarding the correlation between the variables are found in Table 3. The only parameter which showed a strong negative correlation, meaning inversely proportional, was the pH with the current humidity (-0.65). The median negative correlations were between dry density parameters and aeration space (-0.46), and between pH with tension level 10 (-0.44) and total porosity (-0.49).

For positive correlations, meaning directly proportional variables, strong correlations were found between current humidity and total porosity (0.74), between water holding capacity and total porosity (0.74), and easily available water (0.76) (Table 3). Moreover, median positive correlations were found for current humidity with aeration space (0.50), and total porosity with aeration space (0.53) and easily available water (0.57) (Table 3).

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Table 3. Correlations between the physical and chemical properties of the 25 substrates used
Tabela 3. Correlações entre as propriedades físicas e químicas encontradas para os 25 substratos utilizados.

Variáveis	**EC**	**pH**	**DD**	**CH**	**TP**	**AS**	**EAW**	**WRC10**
EC	1,00	-0,32	0,5	0,01	0,14	-0,07	-0,11	0,24
pH		1,00	-0,29	-0,65	-0,49	-0,17	-0,25	-0,44
DD			1,00	-0,25	0,03	-0,46	0,22	0,43
CH				1,00	0,74	0,50	0,24	0,44
TP					1,00	0,53	0,57	0,74
AS						1,00	-0,13	-0,18
EAW							1,00	0,76
WRC10								1,00

In which: EC = electrical conductivity obtained in a 1:5 solution (v/v), pH = determined in water, dilution 1:5 (v/v), DD = dry density, CH: current humidity, TP = total porosity, AS = aeration space, EAW = easily available water, WRC10 = water holding capacity under suction of 10 cm of water column.
Em que: EC = condutividade elétrica obtida em solução 1:5 (v/v); pH = determinado em água, diluição 1:5 (v/v); DD = densidade seca; CH: umidade atual; TP = porosidade total; AS = espaço de aeração; EAW= água facilmente disponível, WRC10 = capacidade de retenção de água sob sucção de 10 cm de coluna de água.

Through the application of principal component analysis (PCA) as shown in Figure 3, the analyzed substrates were categorized into four distinct groups based on their physicochemical characteristics. Group 1 (S22, S23, S24, and S25) exhibited variations involving carbonized coffee or rice straws and coconut fiber. Group 2 (S1, S3, S4, S5, S6, and S20) displayed variations in the proportion of fresh coffee straw (FCS) or consisted of only one component, namely CCS and CPCS. Group 3 (S2, S9, S10, and S21) comprised a combination of BM and CS. Finally, group 4 (S7, S8, S11, S12, S13, S14, S15, S16, S17, S18, and S19) included a combination of composted coffee or rice straws.

Group 1 showed a negative correlation with the characteristics of electrical conductivity (EC) and dry density (DD). Group 2 showed positive results with pH and negative results with easily available water (EAW), water retention capacity under the attraction of 10 cm of water column (WRC10), and total porosity (TP). Group 3 showed a positive correlation between electrical conductivity (EC) and dry density (DD). Finally, group 4 showed a positive presentation with easily available water (EAW), water retention capacity under suction of 10 cm of water column (WRC10), Total Porosity (TP), and negative brightness with pH.

PCA component 1 explained around 36.45% of the data, while component 2 explained around 25.18% of the data. The highest values for each axis indicate a more representative variable, thus explaining the greater portion of the variance in the original set of data. In turn, the variables which obtained the greatest contribution for the x-axis were WRC 10, TP, EAW, and EC with an average of 42%. Then, the most developed variables for the e-axis were CH, DD, and AS, with an average of 52%.

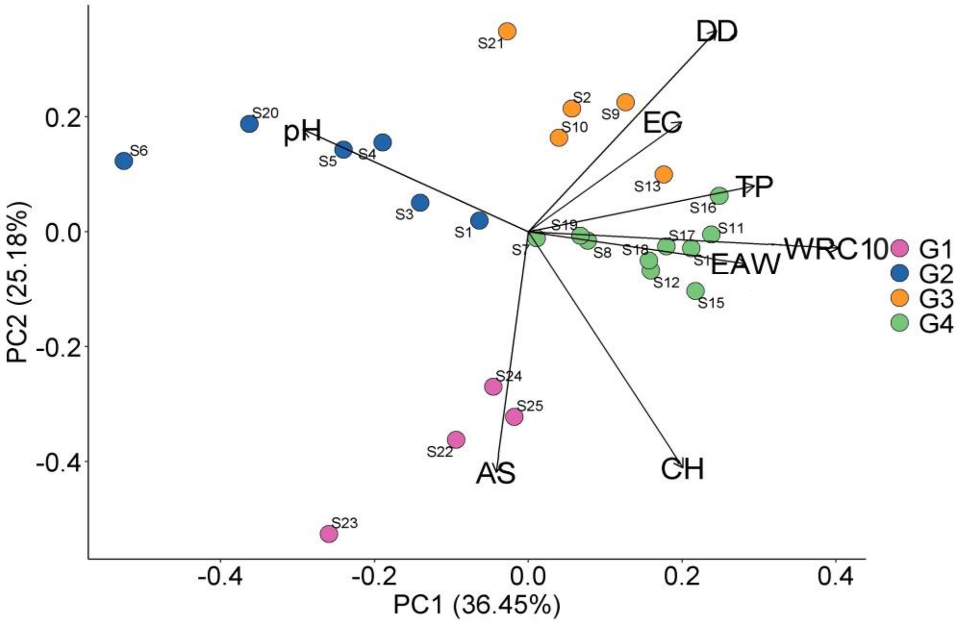

Figure 3. Principal component analysis (PCA) showing the performance of the 25 studied substrates in relation to chemical variables (EC = electrical conductivity obtained in a 1:5 (v/v) solution; pH

= determined in water, dilution 1:5 (v/v);) and physical (DD = dry density; CH: current humidity; TP = total porosity; AS = aeration space; EAW= easily available water; WRC10 = water holding capacity under 10 cm suction of water column.

Figura 3. Análise dos componentes principais (PCA) mostrando o desempenho dos 25 substratos estudados em relação as variáveis químicas (EC = condutividade elétrica obtida em solução 1:5 (v/v); pH = determinado em água, diluição 1:5 (v/v)) e físicas (DD = densidade seca; CH: umidade atual; TP = porosidade total; AS = espaço de aeração; EAW= água facilmente disponível; WRC10 = capacidade de retenção de água sob sucção de 10 cm de coluna de água.

DISCUSSION

Physical and chemical characteristics of substrates

Kämpf (2005) describes new ranges for the pH value in water, from extremely low (< 4.5) to extremely high (> 6.9), with the range from 5.2 to 5.5 being considered optimal for substrates without mineral soil. Optimal pH values for Regan (2014) are between 5.5 and 6.5. According to the authors' classifications, the developed substrates considered ideal for this parameter are S11 (100CS), S13 (20CF/40CS), S19 (20CF/20CS/30CPRS/30CPCS), S22 (60CF/40CRS) and S23 (80CF/20CRS), which indicates that these were balanced between the components.

Only five substrates which are based on FB/CS/(CPRS or CPCS) exhibited low pH values below 5.0. According to Ludwing *et al.* (2020), limestone can be utilized as a corrective for acidic substrates due to its low cost and the potential to increase the availability of Ca and Mg. The authors also emphasize that it is not recommended to use the substrate in the first week after applying limestone due to pH instability.

Among the tested components, it is possible to note that composted coffee straw (S20) has the highest pH value with 9.20, with no statistical difference between fresh coffee straw (S6, pH 7.38) and composted coffee (S21, pH 7.47). The majority (73%) of the formulated substrates presented basic values above the acceptable level of 6.5, according to Regan (2014). This result corroborates those observed by Kratz *et al.* (2017), in which the use of high proportions of straw in formulations results in more alkaline substrates. Alkaline substrates are not protected for the cultivation of most species, which makes their correction important. However, managing high pH is more difficult and costly, as it involves the use of acid-based fertilizers or the application of acidifiers, such as elemental sulfur (SCHAFER *et al.*, 2015).

Electrical conductivity is an indication of the amount of total soluble salt content in the solution extracted from the cultivation medium (SOUZA; SCHAFER, 2009). Increased salinity can cause damage to the root system, preventing the absorption of water and nutrients, affecting physiological activity, and consequently preventing plant growth (SCHAFER *et al.*, 2015). According to Regan (2014), electrical conductivity should not exceed the limit of 0.75 mS cm^{-1}, and Cavins *et al.* (2000) highlight that values above 1.10 mS cm^{-1} are considered excessive for most species grown in containers.

Among the evaluated components, only fresh coffee straw exhibited recommended values for EC. Carbonized coffee straw presented values slightly above the limit of 0.77 mS cm^{-1}, and composted coffee straw (1.07 mS cm^{-1}) displayed excessive EC values. Therefore, moderate use of these components is recommended. The S1 (30MB/20CF/50CRS), S6 (100FCS), S11 (100CS), S22 (60CF/40CRS), S23 (80CF/20CRS), and S24 (60CF/40PCA) substrates demonstrated values within the recommended range, while the S9 (30MB/20CS/15CRS/35CCS), S10 (30MB/20CS/50CCS), S12 (20CF/20CS/60CPRS), S13 (20CF/40CS/40CPRS), S16 (20CF/20CS/60CPCS), S17 (20CF/40CS/40CPCS), S18 (20CF/60CS/20CPCS), and S19 (20CF/20CS/30CPRS/30CPCS) substrates were deemed inappropriate due to excessive EC. In such cases, Schafer *et al.* (2015) suggest changing the substrate when possible, or leaching the salts is recommended when this is not possible.

Density is a crucial indicator of substrate weight, impacting the acquisition cost, handling within the nursery, and plant stability (MARTINEZ, 2002). According to Pagliarini *et al.* (2015), high-density values can lead to root system growth issues, while lower-density values can cause problems in plant fixation and container stability.

Kämpf (2005) stated that appropriate values for dry density must be defined according to the size of the container, and for tubes in trays must be found between 100 and 300 kg m^{-3}, thus 76% of the substrates evaluated meeting within the recommended range, except S11 (100CS), S16 (20CF/20CS/60CPCS), S21 (100CPCS), S22 (60CF/40CRS), S23 (80CF/20CRS) and S25 (80CF/20CCS), as found by Silva *et al.* (2021) on similar substrates. Composted coffee straw (S21) showed a higher density (466.97 kg m^{-3}), which highlights that this material should be mainly used as a complement in substrate formulations.

The density of the substrates is an important property which helps in the interpretation of other characteristics, such as the aeration space, as can be observed by the negative observation found between the dry density and the aeration space (-0.46). This result reinforces the hypothesis that substrates with higher density have less space between particles and greater resistance to root growth, while those that are less dense have lower support capacity and lower water retention capacity (FARIA *et al.* 2017). There are negative correlations between aeration space with easily available water, retained water, and the three levels of water tension, corroborating the observations of Faria *et al.* (2017). According to Silva *et al.* (2020), porosity presents an important relationship with the root system growth to provide ideal conditions for gas exchange of root respiration and microorganisms. Components based on coffee straws have moderate total porosity, with fresh coffee straws having 40.16% porosity. It is possible to note that the carbonization process (CCS, 68.56%) and composting (CPCS, 71.10%) increase the porosity of the component, with the latter being more efficient. According to Cunha *et al.* (2022), the presence of straw increases the macroporosity of the substrate, supporting its evolution.

Zorzeto *et al.* (2014) recommend aeration space values between 20 and 40% of the substrate volume; therefore, all of the substrates in this work fall within the recommended range. According to the authors, high values for this characteristic can cause water deficiencies, especially with infrequent irrigation, and low values can cause a lack of oxygen for root development.

The water characteristics show a positive correlation with total porosity, corroborating Bickel *et al.* (2022), who discusses that the quality and quantity of pores present in the substrate determine the distribution of solids, air, and water in the substrate. Faria *et al.* (2017) suggest values between 20 and 30% for easily available water, however none of the evaluated substrates present ideal levels for these characteristics. Few substrates present these characteristics at an optimal level, as Schafer *et al.* (2015) point out that only 22.1% of the substrates used in the southern region of Brazil are within the desired standard for EAW.

Regan (2014) indicates that the values regarding the water retention capacity in the substrate should present averages in the range of 45 to 65%. The carbonization and composting of coffee straws increase the water retention capacity for all stress levels when compared to fresh coffee straws. Of those formulated, only 40% meet the 10 cm tension level. In general, the lower the water retention, the greater the need for control frequency or greater volume of water applied, while in substrates with greater microporosity, there must be greater control over irrigation to avoid enchantment and reduction in root aeration (CUNHA *et al.*, 2022; KRATZ *et al.*, 2017).

Water retention has a positive impact on the dry density of the substrate. Substrates with greater water retention kept safely have greater density due to the increased weight of the particles (BICKEL *et al.*, 2022), resulting in greater weights, making transportation and handling within the pond difficult (MARTINEZ, 2002). There was no isolated component or formulation that presented optimal values for all physical and chemical characteristics. As components of the substrate formulation of residues from the coffee agroindustry, their strong points are their physical characteristics, generally highlighting density, porosity, and water retention. The biggest limitation is its tendency to alkalize the substrate and possible salinization when using carbonized or composted coffee straws.

Although the substrates have different characteristics, it was possible to group them into four large groups according to their physical and chemical properties. The substrates belonging to group 1 presented different proportions of coffee straw and carbonized rice in their composition, and were characterized by having lower dry densities. Therefore, the presence of charred straw can be correlated with the reduction in substrate density, as found by Rota and Pauletti (2008). The substrates also included the lowest electrical conductivity values, which are easily corrected through mineral fertilization based on the fertilization recommendation for producing seedlings of the species of interest. High EC values make management difficult and can cause damage to the root system and plant physiology (SCHAFER *et al.*, 2015).

Group 2 can be characterized by having the lowest percentage of available water and also the lowest water retention capacity under suction of 10 cm of water column. The relationship between this group and the two variables is consistent due to a positive correlation that both obtained of 0.76. Group 3 was characterized by having the highest levels of easily available water. Finally, group 4 was characterized by having high electrical conductivity for the most part, which may be related to the fact that these substrates present coffee straw or composted rice straw in their composition.

Characteristics of substrate components

The substrates containing coffee straw as a component generally exhibited excellent substrate density. The optimal levels for other physical properties varied depending on the proportions and combinations of the components. However, despite the potential of the residue in substrate composition, it does not provide favorable chemical characteristics to the substrate. According to Kämpf (2005), only substrates S19 (20CF/20CS/30CPRS/30CPCS) and S16 (20CF/20CS/60CPCS) demonstrated adequate pH.

Rice straw also provided excellent substrate density averages, which corroborates Cunha *et al.* (2022). According to Simões *et al.* (2012), rice straw increases macroporosity and reduces the density of substrates, resulting in high drainage and low nutrient retention. Therefore, the use of high proportions of this component implies the need for a greater number of applications and a greater concentration of nutrients in the substrate. The addition of cattle manure generally provided good density, substrate porosity, and remaining water, however, it increased the pH values of the substrate. This corroborates Carneiro and Vieira (2020), who describe that extinction acts as the organic part of the substrate, which provides improvements in physical and chemical characteristics through the reduction of apparent density, improving permeability, infiltration and water retention, controls temperature variation, in addition to providing the accumulation of organic N, helping to increase its mineralization potential, nutrient availability for plants, and providing the use of fertilizers.

Coconut fiber is an almost chemically inert material, has a physical characteristic of high porosity, is very light, and is obtained at a low cost through the industrial defibration of coconut straw (CALDEIRA *et al.*, 2014). According to Cunha *et al.* (2022), the component has great potential to be used in substrates for seedling production to provide high porosity and high moisture retention potential, as observed in the present work.

From the data analysis, it is inferred that there is no single ideal component, but rather a need to compose formulas that explore the best characteristics of each component. The chemical characteristics can be managed later in the substrate formulation, acquiring secondary importance, whereas the less manageable physical characteristics are highly important in the substrate formulation process. Therefore, the S2 (30MB/20CF/20CRS/30CCS), S9 (30MB/20CS/15CRS/35CCS), and S13 (20CF/40CS/40CPRS) formulas exhibited wet density, dry density, total porosity, aeration space, and adequate water retention capacity. Consequently, the group 3 of substrates stands out for presenting the best compositions of the different components studied. Although the S11 (100CS) and S8 (30MB/20CS/50CRS) substrates were not recommended, both presented average physical characteristics close to the indicated range.

Species grown in containers have different tolerance levels in terms of physical-chemical characteristics, making it important to investigate the different formulations within each species. Therefore, the restriction of the formulations in this work must be considered by species and also by factors such as the origin of the material, cultivation conditions, management techniques, location, and climate. The importance of using regional by-products is also highlighted to reduce the cost of purchasing components and helping to reduce the environmental liability of waste disposal.

CONCLUSIONS

- Coffee processing residues have good physical characteristics but have specific chemical characteristics. There is no isolated component that meets the quality standards recommended for seedling production. However, the S2 (30MB/20CF/20CRS/30CCS), S9 (30MB/20CS/15CRS/35CCS) and S13 (20CF/40CS/40CPRS) substrates generally showed better physicochemical characteristics.

REFERENCES

ALMEIDA, R. S.; NIERI, E. M.; MONTEIRO, E. C. S.; SILVA, O. M. C.; MELO, L. A. Reaproveitamento de resíduos de café em substratos para produção de mudas de *Joannesia princeps*. **Pesquisa Florestal Brasileira**, Brasília, v. 41, e201902047, p. 1-7, 2021.

BICKEL, K. B.; SANTOS, M. R.; BROCHIER, B.; FERNANDES. I. J.; MODOLO, R. C. Evaluation of a substrate-plant system containing efluent treatment plant sludge from a paint industry. **Mix Sust**, Florianópolis, v.8, n.1, p.117-133, 2022.

BRASIL. Ministério da Agricultura, Pecuária e abastecimento (MAPA). Secretaria de Defesa Agropecuária (SDA). Instrução Normativa SDA Nº 17 de 21 de maio de 2007. Métodos Analíticos Oficiais para Análise de Substratos e Condicionadores de Solos. Diário Oficial da União, Brasília, DF, 24 de maio 2007. Disponível em: <http://extranet.agricultura.gov.br/sislegis-consulta/servlet/VisualizarAnexo?id=14783>. Acesso em: 05 setembro de 2023.

CALDEIRA, M. V. W. *et al.* Crescimento de mudas de *Eucalyptus grandis* utilizando lodo de esgoto, fibra de coco e palha de café in natura. **Floresta**, Curitiba, v. 44, n. 2, p. 195-206, 2014.

CARNEIRO, R, S.; VIEIRA, C. R. Produção de Mudas de Espécies Florestais em Substrato Contendo Esterco de Aves ou Esterco Bovino. **Ensaios**, [*S.l.*], v. 24, n. 4, p, 386-395, 2020.

CAVINS, T.J.; WHIPKER, B.E.; FONTENO, W.C.; HARD¬EN, B.; MCCALL, I.; GIBSON, J.L. Monitoring and managing pH and EC using the PourThru Extraction Method. **Horticulture Information Leaflet** 590, New 7/2000. Raleigh: North Caroline State University, 2000. 17p.

COMPANHIA NACIONAL DE ABASTECIMENTO. **Acompanhamento da Safra Brasileira de Café Safra 2023**, maio 2023 Brasília, 2023. Disponível em https://www.conab.gov.br/info-agro/safras/cafe/boletim-da-safra-de-cafe. Acesso em: 14 ago. 2023.

CUNHA, F. L. SILVA, O. M. C.; ARAUJO, V. C.; VENTURIN, N. MELO, L. A. Palha de café carbonizada em substratos renováveis para produção de mudas de *Eucalyptus urophylla* e *Anadenanthera macrocarpa*. **Ciência Florestal**, Santa Maria, v. 32, n. 2, p, 548-572, 2022.

DE BOODT, M.; VERDONCK, O. The physical properties of the substrates in horticulture. Acta **Horticulturae**, Basel, 26, p.37-44, 1972.

FARIA, J. C. T. *et al.* Substrates formulated with organic residues in the production of seedlings of *Moquinias trumpolymorphum.* **Floresta**, Curitiba, v. 47, p. 523, 2017.

FERMINO, M.; ARAUJO, M. M.; AIMI, S. C.; TURCHETTO, F.; BERGHETTI, A. L. P.; ZAVISTANOVICZ, T. C.; MIETH, P.; GRIEBELER, A. M.; VILELLA, J. M. Reutilization of residues as components of substrate for the production of *Eucalyptus grandis* seedlings. **Cerne**, Lavras, v. 24, n. 2, p.80-89, 2018.

KÄMPF, A. N. Produção comercial de plantas ornamentais. Guaíba: Agropecuária, Porto Alegre, 2005. 256 p.

KRATZ, DAGMA; NOGUEIRA, ANTONIO CARLOS; WENDLING, IVAR; MELLEK, JOSÉ ELIAS. Physic-chemical properties and substrate formulation for *Eucalyptus* seedlings production. **Scientia Forestalis**, Piracicaba, v. 45, p. 63-76, 2017.

LUDWIG, F.; FERNANDES M. D.; GUERRERRO, A. C.; FERREIRA, G. A.; POHLMANN. Neutralização da acidez em substrato de casca de pinus com diferentes granulometrias. **Revista Eletrônica Cientifica da UERGS**, Porto Alegre, v. 6, n. 01, p. 01-08, 2020.

MARTÍNEZ, P. F. Manejo de substratos para horticultura. In: FURLANI, A. M. C. *et al.* **Caracterização, manejo e qualidade de substratos para a produção de plantas**. Campinas: Instituto Agronômico de Campinas, 2002. p. 53-76.

PAGLIARINI, M. K.; CASTILHO, R. M. M.; MOREIRA, E. R.; LVES, M. C. Caracterização física e química de substratos com diferentes proporções de resíduo de celulose. **Ornamental Horticulture**, Campinas, v. 21, n.1, p. 33-38, 2015.

ROTA, L. D.; PAULETTI, G. F. Efeito da adição de palha de arroz em substrato comercial a base de turfa na produção de mudas de *Viola tricolor* L. **Revista Brasileira de Agrociência**, Pelotas, v.14, n.3-4, p.45-48, 2008.

REGAN, R. P. Evaluating alternative growing media components. In: WILKINSON, K. M.; HAASE, D. L.; PINTO, J. R. (coord.). **National Proceedings: Forest and Conservation Nursery Associations**, 2013. Fort Collins (CO): USDA Forest Service; Rocky Mountain Research Station. 2014. Proceedings RMRS-P-72. p. 50-53.

SILVA, O. M. C.; HERNANDEZ, M. M.; ALMEIDA, R. S.; MOREIRA, R. P.; LELES, P. S. S.; MELO, L. A. Seedlings of tree species produced in substrates based on organic composts. **Floresta**, Curitiba, v. 51, p. 371-380, 2021.

SILVA, O. M. C.; HERNANDEZ, M. M.; ARAUJO, G. C. R.; CUNHA, F. L.; EVANGELISTA, D. V. P.; LELES, P. S. S.; MELO. L. A. Potencial uso da casca de café como constituinte de substrato para produção de mudas de espécies florestais. **Ciência Florestal**, Santa Maria, v. 30, p. 1161-1175, 2020.

SIMÕES, D.; SILVA, R. B. G.; SILVA, M. R. Composição do substrato sobre o desenvolvimento, qualidade e custo de produção de mudas de *Eucalyptus grandis* Hill ex Maiden × *Eucalyptus urophylla* S, T, Blake, **Ciência Florestal**, Santa Maria, v. 22, p. 91-100, 2012.

SCHAFER, G.; SOUZA, P. V. D.; FIOR, C. S. Um panorama das propriedades físicas e químicas de substratos utilizados em horticultura no sul do Brasil. **Ornamental Horticulture**, Campinas, v. 21, n. 3., p.299-306, 2015.

SOUZA, P. V. D.; SCHAFER. G. **Produção de Mudas de Tangerineiras**, In: Otto Carlos Koller, (Org,), Citricultura Cultura de Tangerineiras: Tecnologia de Produção. Pós-Colheita e Industrialização, 1ed. Porto Alegre: Editora Rígel, 2009, v. 1, p. 63-89.

ZORZETO, T. Q.; DECHEN, S. C. F.; ABREU, F. F. J. Caracterização física de substratos para plantas. **Bragantia**, Campinas, v. 73, n. 3, p. 300-311, 2014.