EVALUATION OF PHYSICAL AND CHEMICAL PARAMETERS OF SUBSTRATES AND FOOD WASTE COMPOSTS FOR APPLICATION IN GREEN ROOFS

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ABSTRACT

Green roofs play a fundamental role in contemporary urban planning, offering a wide range of environmental, social, and economic benefits that contribute significantly to the development of more sustainable and resilient cities. These systems help mitigate the urban heat island effect, improve air quality, increase urban biodiversity, reduce stormwater runoff, and enhance building energy efficiency. One of the key components of a green roof is the substrate layer, which is responsible for supporting plant growth, retaining water and nutrients, and ensuring proper drainage. Despite its importance, there is no standardized composition for the substrate, as it must be adapted to local conditions and specific project goals. Given this variability, the objective of the present study was to characterize and compare the main physical and chemical properties of three commercial substrates and two composts derived from food waste. The food waste samples were collected from restaurants and underwent different composting processes. The analysis included physical parameters (such as wet and dry bulk density and total porosity) and chemical parameters (pH and electrical conductivity), as well as moisture content, organic matter, and ash content. Among the commercial substrates analyzed, moisture and electrical conductivity values were the most divergent from the recommended standards. In the case of the food waste composts, the composting method was identified as the main factor influencing their properties. The findings of this research offer valuable information for selecting appropriate substrate materials, particularly in the context of green roof implementation, where substrate performance directly affects system success and long-term sustainability.

Key words: growing medium; properties; organic bioresurce.

1 INTRODUCTION

Substrate (growing medium) is the most importante component of the green roof system. An appropriate substrate is expected to provide permanent physical support for plants and possess a fine balance between free drainage and adequate plant available water and nutrient retention (Kader *et al.*, 2022).

The main components of commercial substrates include: inorganic matter (perlite, vermiculite, crushed bricks), organic matter (compost and peat), and alternative materials (recycled waste, plastic materials) (Farah *et al.*, 2024; Ampim *et al.*, 2010).

Composts are produced through the process of composting, which involves the decomposition of organic materials like plant matter, food scraps, or manure. Food waste compost can be a suitable and beneficial alternative to traditional green roof substrates, aligning with circular economy principles and supporting various Sustainable Development Goals (Zaman; Hardyanti; Purwono, 2021; Ripp *et al.*, 2020).

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The characteristics of the substrate vary according to its composition, proportion of components, origin, and form of raw material production. The main properties of substrates refer to physical, chemical and biological characteristics, and among these, the physical and chemical characteristics play an important role (Schafer and Lerner, 2022).

Some of the substrates contain either exclusive substances, custom mixtures of commercially accessible materials, or recycled waste materials for which data on its properties are not available. Others substrates are so highly diverse that no standardized composition information is applicable. Also, the regional context is important because it assists in the choice of substrate based on the climate of the considered region and the type of vegetation.

All available information regarding substrates can be used to optimize green roof design. Therefore, the objective of this study was to evaluate the physicochemical properties of three commercial and two composted substrates, specifically focusing on substrates manufactured from locally available materials.

2 METHODS

Methods of the European Standardization Committee, (CEN – Comité Européen de Normalisation) were used in the following determinations: electrical conductivity and pH (CEN- DIN EN. 13037; CEN-DIN EN. 13038); organic matter, ash content and particle density (CEN- DIN EN. 13039); dry density and total porosity (CEN- DIN EN. 13041). Moisture, wet apparent density and dry density were determided according to Brazilian legislation (Normative Instructions nº 17; Normative Instructions nº 31). All analyses were performed in triplicate, and the average and standard deviations were provided.

3 RESULTS AND DISCUSSION

Table **1**and **2** shows the physical and chemical properties of substrates and food waste composts, respectively. Some parameters were compared with general guidelines recommended values for selecting appropriate green roof substrates.

Table 1 – Physico-chemical properties of the COMMERCIAL SUBSTRATES

Physico-chemical parameters	COM1(*)	COM2(*)	COM3(*)
Moisture (%)	44.3 ± 0.250	27.4 ±0.737	70 ± 10.0
Organic matter (%)	38.7 ± 4.11	11.6 ± 1.29	67.0 ± 0.569
Ash content (%)	61.3 ± 4.11	88.4 ± 1.29	33.3 ± 0.666
Particle density (g/cm^3)	1.75 ± 0.067	2.45 ± 0.017	1.79 ± 0.01
Total porosity (%)	82.4 ± 3.06	61.9 ± 0.0449	94.4 ± 0.01
Wet bulk density (g/cm^3)	0.2868 ± 0.0080	0.9343 ± 0.0044	0.3333 ± 0.0002
Dry bulk density (kg/m^3)	159.7 ± 0.396	678.3 ± 27.4	100.0 ± 20.0
pH	7.17 ± 0.047	5.00 ± 1.00	5.21 ± 0.304
Conductivity (dS/cm)	0.6385 ± 0.0055	not determined	3.0001 ± 0.0001

(*) Each value represents the mean ± standard deviation of three replicates.

Tabela 2 – Physico-chemical properties of the food waste composts

Physico-chemical parameters	COMP1 (*)	COMP2(*)
Moisture (%)	9.61 ± 0.314	55.8 ±0.200
Organic matter (%)	96.7 ± 0.153	30.1 ± 4.77
Ash content (%)	3.29 ± 0.191	75.3 ± 0.656
Particle density (g/cm^3)	1.58 ± 0.01	2.09 ± 0.161
Total porosity (%)	86.5 ± 1.12	62.1 ± 2.80
Wet bulk density (g/cm^3)	0.2138 ± 0.0177	0.7883 ± 0.0017
Dry bulk density (kg/m^3)	1933.3 ± 1.281	348.4 ± 55.8
pH	6.00 ± 1.00	7.06 ± 0.207
Conductivity (dS/cm)	not determined	4.000 ± 0.001

(*) Each value represents the mean ± standard deviation of three replicates.

The moisture content is a crucial physical characteristic of a substrate, significantly impacting the availability of water and nutrients to plants, as well as the substrate's ability to provide adequate oxygen to the root (Fermino, 2003; Souza *et al*., 1995). The ideal moisture content for substrate, is generally between 20% and 60%, but this can vary slightly depending on the plant species and the type of substrate. For many plants, including flowers, trees, and shrubs, a range of 21-40% moisture is considered ideal, while vegetables often require a higher range of 41-80%. All substrates were within the ideal range, except sample COM3 and COMP1.

The higher moisture value of the commercil substrate COM3 is due to contain vermiculite in its formulation, which is a clay that has the capacity to retain large amounts of water (Costa *et al*, 2015). The food waste compost COMP1 presented a value much lower than the ideal value. This fact probably occurred because a dehydration process was applied to food waste compost after composting to obtain more compact product that can be easier to handle, store, and transport.

Organic matter and ash content in substrates are related, and this relationship is inverse. Ash, the mineral residue remaining after combustion, represents the non-organic material. High organic matter content correlates with lower ash content, and vice-versa. The relationship between ash and organic matter is important in green roofs because appropriate organic matter content is crucial for plant growth (Zorzeto *et al*., 2014; Nagase and Dunnett, 2011).

Samples COM3 and COMP3 present higher content of organic matter, while samples COM1, COM2 and COMP2 contains a greater proportion of non-organic materials. In the case of food waste compost samples (COMP1 and COMP2), the composting involves decomposition that leads to the formation of humic substances and previous study shows that the difference in values of organic matter content (and consequently the ash content) are related to the C/N ratio of the food waste (Guo; Liu and Wu, 2019; Kalamdhad *et al*., 2009).

Density, which expresses the relationship between the mass and volume of the substrate, presents significant importance, as it allows the conversion of moisture values into a volume basis. Wet or apparent density is the ratio of mass to volume based on the moisture present in the substrate. Dry density is the mass to volume ratio minus any moisture. High-density substrates can limit plant growth and and contribute to a heavier green roof system. Wet density value considered to be sufficient to support the plants ranges from 0.1-0.8 Kg/L (Singh; Sinju, 1998). Another study defined that the wet density requirement of an ideal substrate should be < 0.40 Kg/L (Abad *et al*., 2001). Considering the density on a dry basis, the most appropriate values depend on the size of the place where the substrate will be used, generally, the range is between 100 kg/m³ and 800 kg/m³ (Schafer and Lerner, 2022; Kämpf, 2005). All substrates presented adequate density values, with the exception of the food waste compost COMP1, which presented a dry density value much higher than that considered ideal, although it is within the German FLL Guidelines (FLL, 2018).

Particle density (Dp) takes into account the mass and volume occupied by the solid particles and excludes the volume occupied by air and water. The typical range of particle density for mineral and organic substrates is 2.5 to 2.7 g/cm3 and 1.3 to 1.5 g/cm3, respectively. Dp values of substrates COM2 and COMP2 are close to mineral substrate and the other samples have values close to organic substrate (Zorzeto *et al*., 2014; Martinez, 2002; Rowell, 1994; Boodt and Verdonck, 1972).

Total porosity (TP) is another important physical property that affects the aeration, drainage and water holding capacity of a substrate. The ideal range for TP is from 75% to 90% (Kämpf, 2005; Carrijo; Liz; Makishima, 2002; Verdonck and Gabriels, 1988; Boodt and Verdonck, 1972). COM2 and COMP2 substrates showed values below the minimum considered ideal, indicating that these substrates are more compacted than the others. This compaction reduces the volume of pore space within the substrate, leading to lower porosity (Negro *et al*., 2018).

The pH of the substrate is crucial for the health and growth of green roof plants. Optimal pH levels ensure the availability of essential nutrients, preventing leaf spotting, bronzing and mineral deficiencies. The pH range of 5.5 to 6.5 is considered ideal for organic substrates. A pH range of 6.0 to 7.0 is also acceptable and can provide adequate nutrient availability, particularly for mineral substrates (Kader *et al*., 2022). All the selected substrate exhibit their pH values within the acceptable range.

Electrical Conductivity (EC) is a metric for assessing and predicting salinity in green roof substrates. Salinity is a key factor in selection of the appropriate green roof substrate. Substrates with a high EC can damage the roots and reduce or even prevent absorption of water and nutrients. The maximum EC values recommended in commercialized substrates for most plants is 1.8 dS/m (Ansorena, 1994). EC of substrates can be classified according to Cavins *et al*., 2000. Considering this classification, the EC of commercial substrates is normal and high for COM1 and COM3, respectively. The high EC of COM3 is becuase vermiculite-based substrates can have a high potassium content. EC values of food waste composts are generally high due to presence of soluble salts as a common component. EC value until the standard limit 4.1 dS/m was considered to be tolerable by plants (Khater, 2012). The small particle size of the substrates COM2 and COMP1 did not allow correct measurement of conductivity.

4 CONCLUSÃO

The current experimental research study was conducted to evaluate the physicochemical characteristics of three commercial substrates and two food waste composts. Commercial substrates varied significantly in their properties, particularly in terms of moisture and salinity, requiring careful evaluation to ensure they are suitable for the specific green roof application. Food waste composts exhibited different characteristics due to the difference in the composting process. Using locally sourced substrates for green roofs offers a cost-effective and climate-appropriate solution. Understanding the properties of different substrate materials is crucial for optimizing plant growth and the overall performance of the green roof.

REFERÊNCIAS

ABAD, M.; NOGUERA, P.; BURES, S. National inventory of organic wastes for use as growing media for ornamental potted plant production: Case study in Spain. **Bioresource technology**, v. 77(2), p. 197-200, 2001.

AMPIM, P. A. *et al*. Green roof growing substrates: Types, ingredients, composition and properties. J. Environ. Hortic. v. 28, p. 244–252, 2010. doi:10.24266/0738-2898-28.4.244.

ANSORENA, J. M. **Substrates properties and characterization**. Madrid, España: Mundi-Prensa. 1994.

BOODT, M.; VERDONCK, O. The physical properties of the substrates in horticulture. Acta Horticulturae, v. 26, p. 37–44, 1972.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento (MAPA). Secretaria de Defesa Agropecuária. **Normative Instructions Nº 17**, de 21 de maio de 2007. Aprova os Métodos Analíticos Oficiais para Análise de Substratos e Condicionadores de Solos, na forma do Anexo à presente Instrução Normativa. Diário Oficial da República Federativa do Brasil, Brasília, DF, 24 maio 2007. Seção 1, p. 8.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento (MAPA). Secretaria de Defesa Agropecuária. **Normative Instructions N.º 31**, de 23 de outubro de 2008. Altera os subitens 3.1.2, 4.1 e 4.1.2, do Anexo à Instrução Normativa SDA n.º 17, de 21 de maio de 2007. Diário Oficial da República Federativa do Brasil, Brasília, DF, 24 out. 2008. Seção 1, p. 20.

CARRIJO, O. A.; LIZ, R. S. D.; MAKISHIMA, N. Green coconut husk fiber as agricultural substrate. **Horticultura Brasileira**, v. 20, p. 533-535. 2002.

CAVINS T. J. *et al*. Monitoring and managing pH and EC using the Pour Thru extraction method. **Horticulture information leaflet**, v. 590, p. 17, 2000. Raleigh: North Caroline State University.

CEN-DIN EN 13037 - COMITÉ EUROPEÉN DE NORMALISATION. Soil improvers and growing media. **Determination of pH**. Belgium, Brussels 2011a.

CEN-DIN EN 13038 -COMITÉ EUROPEÉN DE NORMALISATION. Soil improvers and growing media. **Determination of electrical conductivity**. Belgium, Brussels. 2011b.

CEN-DIN EN 13039 COMITÉ EUROPEÉN DE NORMALISATION. Soil improvers and growing media. **Determination of organic matter content and ash**. Belgium, Brussels. 2011c.

CEN-DIN EN 13041 - COMITÉ EUROPEÉN DE NORMALISATION. Soil improvers and growing media. **Determination of physical Properties: Dry bulk density, air volume, water volume, shrinkage value and total pore space**. Belgium, Brussels. 2011d.

COSTA, E. *et al*. Substrate from vermiculite and cattle manure for ornamental pepper seedling production. **Horticultura Brasileira**, v. 33 (2), p. 163-167, 2015. DOI: http://dx.doi.org/10.1590/S0102-053620150000200005.

FARAH, G. *et al*. Green roof substrates influencing the provision of ecosystem services: A review. **Journal of Environmental Chemical Engineering**, v. 12 (6), p. 114795, 2024.

FERMINO, M. H. **Analysis methods for physical characterization of plant substrates**. Doctoral Dissertation University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, 2003.

FLL, 2018. **Guidelines for the Planning, Execution and Upkeep of Green-Roof Sites**. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, Bonn, p. 2018.

GUO, X.; LIU, H.; WU, S. Humic substances developed during organic waste composting: Formation mechanisms, structural properties, and agronomic functions. **Science of The Total Environment**, v. 662, p. 501-51, 2019.

KADER, S. *et al*. Green roof substrates—A literature review. **Front. Built Environ**. v. 8, p. 1019362, 2022. doi: 10.3389/fbuil.2022.1019362.

KALAMDHAD, A. S. *et al*. Transformation during Rotary Drum Composting. Dynamic Soil, Dynamic Plant v. 3 (Special Issue 1), p. 93-98, 2009.

KÄMPF, A.N. Produção comercial de plantas ornamentais. **Guaíba: Agropecuária**, v. 2, p. 256, 2005.

KHATER, E. G. CHEMICAL AND PHYSICAL PROPERTIES OF COMPOST. **Misr Journal of Agricultural Engineering**, p. 1-14, 2012.

MARTÍNEZ, P. F. **Handling substrates for horticulture**. In: MILNER, L. D., FURLANI, A. M. C., BATAGLIA, O. C., ABREU, M. F., ABREU, C. A., FURLANI, P.R., QUAGGIO, J.A., &MINAMI, K. (Eds.) Characterization, management and quality of substrates for plant production. Brazil: Instituto Agronômico, Campinas, SP. 2002.

NAGASE, A.; DUNNETT, N. The relationship between percentage of organic matter in substrate and plant growth in extensive green roofs. **Landscape and Urban Planning**, v. 103 (2), p. 230-236, 2011.

NEGRO, S. R. L. *et al*. Correlations of soybean yield with soil porosity and bulk density of an Oxisol. **Pesq. Agropec. Trop., Goiânia**, v. 48, n. 4, p. 476-485, Oct./Dec. 2018. https://doi.org/10.1590/1983-40632018v4852654

RIPP, P. G. *et al*. Composting process in the production of lettuce seedling substrates: effect of covering and turning frequency. **Engenharia Agrícola**, v. 40, n. 5, p. 562-570, 2020.

ROWELL, D. L. **Soil science: Methods and applications**. New York: Longman Group. 1994.

SCHAFER, G.; LERNER, B. L. Physical and chemical characteristics and analysis of plant substrate. **Ornam. Hortic**. v. 28 (2), 2022 • https://doi.org/10.1590/2447-536X.v28i2.2496.

SINGH, B. P.; SINJU, U. M. Soil physical and morphological properties and root growth. **Horticultural Science**, v. 33, p. 966-971, 1998.

SOUZA, M. M.; LOPEZ, L. C.; FONTES, L. E. Evaluation of substrates for the cultivation of chrysanthemum white polaris in pots. **Revista Brasileira de Horticultura Ornamentais**, v. 1(2), p. 71-74, 1995.

VERDONCK, O.; GABRIELS, R. Substrate requirements for plants. **Acta Horticulturae**, v. 221(1), p. 19-23. 1988.

ZAMAN, B.; HARDYANTI, N.; PURWONO, P. Fast composting of food waste using thermal composter. **IOP Conf. Ser.: Earth Environ. Sci**. v. 896, p. 012013, 2021.

ZORZETO, T. Q. *et al*. Physical characterization of substrates for plants. **Bragantia**, v. 73(3), p. 300-311, 2014.