Application of hydrochar and biochar from biowaste and sewage sludge as a soil amendment on a sandy loam soil

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World population growth makes essential to ensure food security. FAO estimated the need for a 70% increase in food production by 2050 (79% by improving crops yields, 15% by increasing cultivated area and 6% through crops intensification). This involves an increase of 7.5% in greenhouse emissions from agriculture for the next ten years (FAO, 2023). Furthermore, an appropriate management of the waste generated in food production in a circular economy framework is required to reduce the environmental impact caused by landfill disposal and incineration of that waste. Hydrothermal carbonization (HTC) could be considered as a potential option since it is a sustainable thermochemical process for the conversion of wet organic wastes into a solid product (hydrochar), using mild temperatures (180 – 250ºC) and self-generated pressure; in contrast to pyrolysis which requires higher temperature, longer reaction times, with a previous drying of the waste and, hence, greater energy consumption. Hydrochar can be used in several fields such as in energy recovery or in agriculture.

The aim of this work is to compare the use of fresh and post-treated hydrochars (i.e., washing, aging and thermally treated) and biochar obtained from biowaste and sewage sludge as a soil amendment on a poor sandy loam soil, in terms of potential phytotoxicity throughout physical-chemical characterization and germination tests using tomato (*Solanum lycopersicum*).

HTC of waste feedstock from various sources, including garden and park waste (GPW), food waste (FW) and sewage sludge (SS) from a wastewater treatment plant in Madrid (Spain) are carried out at 180 ºC for 1 h, obtaining a solid referred as fresh hydrochar (FHC). Three different post-treatments were performed to remove, or limit, the formation of possible phytotoxic substances: washing with deionized water in a 1:10 (w:v) ratio three times, centrifuging and filtering the resulting suspension to obtain the washed hydrochar (WHC); the thermal post-treatment (650ºC, 90 min) in a rotatory reactor tube furnace with nitrogen atmosphere led to the thermically treated hydrochar (THC); and aging was performed putting HC in trays in a maximum height of 4 cm in contact with room atmosphere for 3 months, obtaining the aged hydrochar (AHC). Biochar (BC) was produced by pyrolysis at 900ºC for 90 min using the rotatory reactor tube furnace. The physical-chemical properties of the feedstocks, biochar and HCs determined were pH, EC, mineral element concentration by ICP-AES, proximal analysis (moisture, volatile matter (VM), fix carbon (FC) and ash) by thermogravimetric analysis and elemental composition (C, H, N and S).

The char was added at different doses (1, 3 and 5% dry weight) to a sandy loam soil from Burgos (Spain) to study their potential application as a soil amendment. 45 g of each mixture were transferred into Petri dishes (diameter = 8 cm), watered to 75 % of water holding capacity and stabilized at 28 ºC in dark for 1 week. Six replicates were set up for each of the five char samples. One of them was used for pH and EC measurement. Seeds of tomato (*Solanum lycopersicum*, Marmande RAF) were surface sterilized using sodium hypochlorite standard procedure. Ten tomato seeds were placed on the Petri dishes with bare soil and mixtures with HCs and BC. All dishes were incubated at 28 ºC for 3 days in darkness, and then transferred to a growth chamber set at 26 ºC/20 ºC with 13 h/11 h light/dark photoperiod. The number of germinated seeds were counted 5 days after sowing to calculate the germination index (GI, %) as the ratio of the germinated seeds to the total seeds in the dish.

Table 1 shows the physical-chemical properties of feedstocks and chars. The pH values of FHC, WHC and AHC were slightly lower than the pH of raw materials, probably due to the release of organic acids from decomposition of sugars during HTC, whereas chars obtained at high temperature (THC and BC) exhibited alkaline pH regardless feedstock used. This fact can be related to the increase of ash content and alkaline mineral element concentration with temperature (Suárez, 2023). BC and THC also showed the highest EC values among processed wastes as well as the lowest VM (%). VM affects plant growth and organic matter availability. Soil salinity could be also problematic for crop development (> 400 mS/m) (FAO, 1988), but no char exceeded the limit. A C/N ratio greater than 24 will result in N immobilization while lower ratios indicate minerailization processes driven by microorganisms. In this study, the C/N ratios were below threshold for all the chars tested (Celleti, 2021).

Table 1. Characterization of feedstocks, biochar and hydrochars.

Treatment		pH	EC (mS/m)	Moisture %	VM %	FC %	Ash %	C/N
Control	**Soil**	7.6 (0.1)	20.0 (1.9)	3.2 (0.1)	7.2 (0.1)	0.0 (0.1)	93.1 (0.1)	9.6 (0.1)
GPW	**Raw waste**	6.8 (0.1)	187 (6.2)	4.0 (0.1)	76.5 (0.1)	18.4 (0.1)	5.1 (0.1)	60.8 (0.1)
	BC	12.5 (0.1)	99.3 (8.4)	3.9 (0.1)	6.3 (0.1)	71.1 (0.1)	22.6 (0.1)	48.4 (0.1)
	FHC	5.5 (0.1)	38.5 (6.4)	3.8 (0.1)	74.1 (0.1)	22.6 (0.1)	3.3 (0.1)	44.7 (0.2)
	WHC	5.2 (0.1)	37.8 (7.4)	3.2 (0.1)	68.2 (0.1)	19.4 (0.1)	12.5 (0.1)	39.2 (0.0)
	AHC	5.5 (0.1)	9.0 (3.1)	4.3 (0.1)	73.3 (0.1)	19.9 (0.1)	6.8 (0.1)	44.2 (0.1)
	THC	11.2 (0.1)	115 (9.6)	0.3 (0.1)	22.5 (0.1)	55.7 (0.1)	21.8 (0.1)	47.6 (0.0)
FW	**Raw waste**	5.1 (0.1)	9.9 (0.3)	89.2 (0.1)	79.5 (0.1)	17.1 (0.1)	3.4 (0.1)	18.7 (0.1)
	BC	8.9 (0.1)	26.0 (1.5)	7.4 (0.1)	25.7 (0.1)	56.2 (0.1)	18.1 (0.1)	33.4 (0.1)
	FHC	4.6 (0.1)	4.9 (0.2)	2.8 (0.1)	73.7 (0.1)	23.7 (0.1)	2.6 (0.1)	19.5 (0.1)
	WHC	4.8 (0.1)	14.4 (2.1)	1.7 (0.1)	74.2 (0.1)	22.4 (0.1)	3.3 (0.1)	24.4 (0.2)
	AHC	4.7 (0.1)	23.1 (5.2)	2.7 (0.1)	74.5 (0.1)	20.4 (0.1)	5.1 (0.1)	21.3 (0.0)
	THC	9.0 (0.1)	60.1 (7.3)	2.4 (0.1)	22.4 (0.1)	63.6 (0.1)	14.0 (0.1)	20.4 (0.1)
SS	**Raw waste**	6.2 (0.1)	10.1 (0.1)	84.1 (3.5)	65.7 (0.1)	13.5 (0.1)	20.8 (0.1)	5.8 (0.1)
	BC	8.8 (0.1)	58.5 (2.5)	2.4 (0.1)	26,2 (0.1)	21,7 (0.1)	52,2 (0.1)	7.7 (0.0)
	FHC	4.9 (0.0)	37.5 (1.5)	1.5 (0.1)	54.0 (0.1)	4.7 (0.1)	41.2 (0.1)	9.8 (0.1)
	WHC	5.3 (0.0)	54.3 (1.6)	1.7 (0.1)	53.4 (0.1)	11.6 (0.1)	35.0 (0.1)	10.2 (0.0)
	AHC	4.9 (0.0)	39,8 (1.2)	2.5 (0.1)	55.8 (0.1)	8.7 (0.1)	35.3 (0.1)	9.6 (0.4)

Figure 1 shows tomato seeds germination 5 DAS, using several doses of HCs and BC as a soil amendment. Results were compared to the bare marginal soil (control), which has been assigned a germination index of 100%.

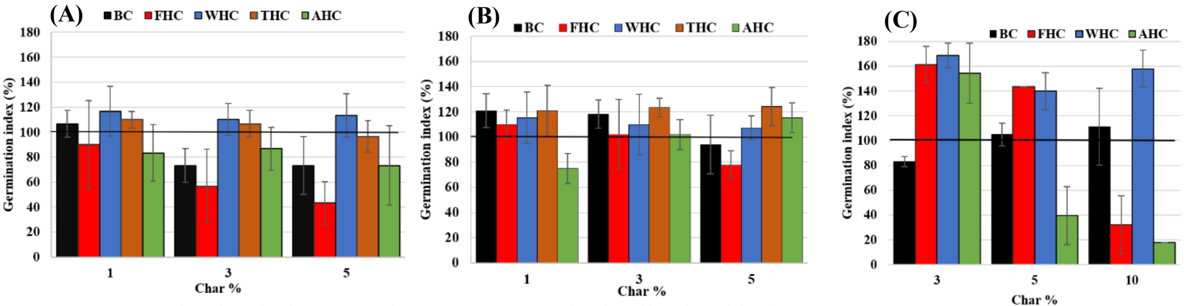

Figure 1. Germination index (%) of tomato on marginal soil using biochar and fresh and post-treated hydrochars obtained from GPW (A), FW (B) and SS (C). Black line indicates germination index on marginal soil (100%).

The washing treatment generally improved tomato seed germination in comparison with other HCs and BC for both biowaste and sewage sludge, regardless of the char dose used. In the case of using GPW (Fig. 1A) as feedstock, the higher GI values were obtained for WHC and THC. However, GI decreased as char dose increases for BC and FHC. The remarkable reduction of germination percentage observed for FHC was due to presence of phytotoxic compounds (data not shown), hence the interest in the application of post-treatments to remove them. As can be seen in Fig. 1B, the seed germination using BC, FHC, WHC and THC obtained from FW were similar for lower char percentages (1 – 3 %), but a significant reduction of GI was observed for BC and FHC at 5%. An opposite trend was found for AHC obtained from FW, i.e, higher GI was achieved as increasing the char dose. Fig. 1C shows no significant differences in GI when using 3 % of FHC, WHC and AHC. However, only WHC is a good option as a soil amendment for char doses higher than 5% with an increase near to 60 % with respect to control. This preliminary results would help in longer experiments where the effect in plant growth of the amendments could be seen.

The feedstocks used for producing HCs and BC strongly affect the characteristics of the products. Hydrochar shows better properties as a soil amendment than biochar prepared from the same waste. Chars from sewage sludge reach higher germination index as compared to control. Germination tests with tomato seeds using post-treated HC showed lower phytotoxicity than those with BC and FHC in the case of GPW. Washing is the best HC treatment for GPW and SS since allows higher amount of waste to be valorised. Germination index is not affected by the dose of HC or BC obtained from FW.

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