Characterization and application of hydrochars from Co-hydrothermal carbonization of biowaste and sewage sludge

L. Martinez-Sanchez[1]; M. Solana[1]; E. Esteban[2,4]; M. Reguera[3]; M. A. de la Rubia[1,4]; A. F. Mohedano[1,4]; E. Diaz[1,4]; M. Tobajas[1,4]

[1]Department of Chemical Engineering, Universidad Autónoma de Madrid, 28049 Madrid, Spain
[2]Department of Agricultural Chemistry and Food Science, Universidad Autónoma de Madrid, Spain
[3]Department of Biology, Universidad Autónoma de Madrid, Madrid, Spain
[4]Institute for Advanced Research in Chemistry, Universidad Autónoma de Madrid, Madrid, Spain
Keywords: tomato; germination test; waste valorization; nutrient recovery
Presenting author email: lydia.martinez@uam.es

Human activity has led to the generation of biowaste in a large scale. In order to reduce their environmental impact, these materials are considered potential resources for the production of energy and a variety of products such as catalysts, adsorbents or soil amendment. Hydrothermal carbonization (HTC) is a thermochemical technology considered as a good alternative that converts high-moisture waste into a carbonaceous material (called hydrochar, HC) at mild temperatures (180 – 250 ºC), autogenous pressure and short reaction time, without extra energy consumption for drying the raw material.

The aim of this work was the characterization of the hydrochars obtained by HTC and Co-HTC of food waste (FW), garden and park waste (GPW) and sewage sludge (SS), as well as those obtained after subjecting them to different post-treatments in order to improve the HCs properties for their application as a soil amendment for tomato (*Solanum lycopersicum*) cultivation.

HTC and Co-HTC were carried out in a 2-L PARR 4530 reactor at 180 ºC for 1 h. The solid obtained, called fresh hydrochar (FHC), was submitted to two treatments for hydrochar stabilization and reduction of the content of possible phytotoxic compounds: i) a washing using distillate water in three cycles with a 1:10 (w:v) ratio obtaining the washed hydrochar (WHC), and ii) a maturation treatment by spreading the FHC on trays in contact with air during 3 months resulting in the aged hydrochar (AHC). These hydrochars were compared with a biochar (BC) produced by pyrolysis at 650 ºC for 90 min using a rotatory reactor tube furnace. All HCs, BC and soil were characterized by determining elemental and mineral composition (CHNS analyzer and ICP-OES, respectively), and moisture, volatile matter (VM), fixed carbon (FC) and ash content via thermogravimetric analysis. The surface chemical composition of the chars was analyzed using Fourier Transform Infrared (FTIR). pH and electrical conductivity (EC) were also measured.

Three doses of each char (1%, 3% and 5% on a dry basis) were added to a calcareous agricultural soil from Albacete (Spain). 45 g of soil (control) and of each soil-char mixture were added to Petri dishes, watering up to 65% of the water holding capacity. Petri dishes were kept at 28 ºC for 1 week in darkness to stabilize the mixtures and, then 5 tomato seeds were added to all replicates (5 per test), maintaining the conditions for 4 more days. After this, they were transferred to a growth chamber set at 28 ºC/20 ºC with 14 h/10 h light/dark photoperiod for 3 days. 7 days after sowing the germination index (GI), fresh biomass and seedling length were measured.

Table 1 shows some of the properties of feedstocks, hydrochars and biochars. BC exhibits lower VM and higher FC content than HCs regardless of feedstock, which is associated with the higher stability of BC. Comparing HCs, those from SS show the lowest VM content and a significantly higher ash content due to its higher mineral concentration. This mineral content could provide a higher nutrient content to plants in HCs derived from SS, but it could also increase the presence of heavy metals. Although all the chars obtained were found to be suitable for agronomic use according to Spanish regulation (RD 1051/2022), Co-HTC of different wastes could improve the characteristics of the HCs such as stability and heavy metal content, for soil amendment use. Hydrochars from FW exhibit a C/N ratio close to the optimum value (21) (Adhikari et al., 2018), whereas the higher nitrogen content of SS decreases the C/N value almost fourfold in all chars produced from this waste. In contrast, the lower nitrogen content of GPW doubles the C/N ratio compared to the optimum in all chars from this source. It can also be seen that HCs show an acidic pH (4.6 - 5.5), while BC has a basic pH (> 9.4) in all cases. Czerwińska et al. (2024) found that HCs have a pH ranging from 5 to 7, regardless of the pH of the waste used in HTC. BCs consistently exhibit a basic pH in all cases. As the soil pH is 9.2, the application of HC as soil amendment could decrease pH and enhance nutrient availability for tomato plants. Regarding EC, values higher than 2.0 mS/cm (Bonarota, 2022) can negatively impact tomato plant growth. Chars from FW have the highest EC values compared to those from other wastes, especially BC, which will result in higher EC when added to the soil and could cause salinity problems.

Table 1. Main characteristics of feedstocks and carbonaceous materials

	Soil	FW				SS				GPW			
		FHC	**WHC**	**AHC**	**BC**	**FHC**	**WHC**	**AHC**	**BC**	**FHC**	**WHC**	**AHC**	**BC**
VM (%, d.w.)	39.7	82.8	83	90.7	50.2	64.5	65.9	45.6	23.8	94.3	94.8	86.1	42.9
FC (%, d.w.)	0.9	11.3	13.1	5.3	28.3	11.4	5.3	2	23.4	0	0.1	6.7	29.9
Ash (%, d.w.)	59.4	5	3.2	3.4	16.7	22.7	27.8	50.4	49.9	5.4	4.8	6.6	23.9
C/N	43.3	20.4	18.9	17.2	15.4	6.4	7.3	8.1	7.5	39.8	40.2	40	29.1
pH	9.2	5	4.7	5.5	9.4	4.6	4.8	5.1	9.4	5.2	5.1	5.3	10.2
EC (mS/cm)	0.2	5.3	8.4	11.9	45.8	5.1	0.7	2	0.7	1.8	0.3	2.9	3.7

All data show standard deviation ≤ 0.2.

Figure 1 shows an example of the germination index, fresh weight and seedling length for chars from FW. The lowest dose (1%) of all chars has similar GI to the control, however an increase in the char dose inhibits seed germination except for the 3% WHC. Regarding tomato seedlings growth, FHC, AHC and BC negatively affect plant growth as the dose applied increases. This could be related to the higher EC values observed for AHC and BC as well as the presence of phytotoxic compounds in FHC, found in its leachates. WHC does not decrease fresh weight per plant at the doses evaluated, but seedling length does, therefore only low doses of WHC are beneficial for the soil.

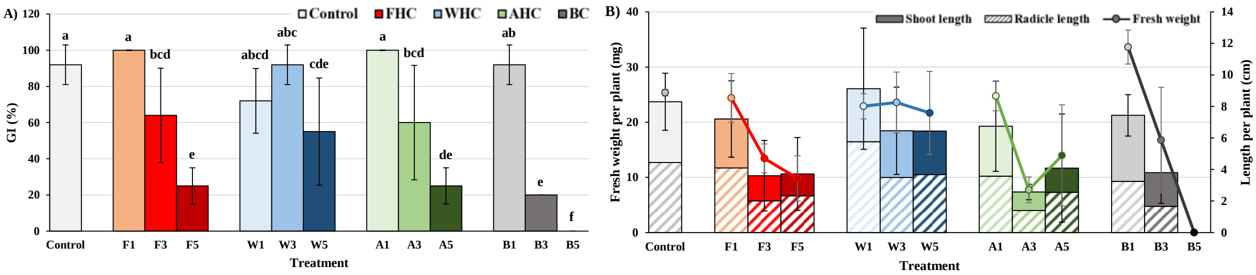

Figure 1. Germination index (%) of tomato plants (A) (lower-case letters represent statistically significant differences) and fresh weight (symbols) and length per plant (bars) (B) using soil amended with different chars from FW.

The application of HCs and BC from GPW as an amendment does not show significant differences compared to the control either in germination (GI = 95%) or in the growth of tomato seedlings (35 mg/plant). When using chars produced from SS, no significant differences are observed compared to the control in the germination index (GI = 85%) for all doses, except for FHC 5% which inhibits tomato seed germination. Furthermore, as the dose of char increases, the fresh biomass and seedling length decrease, becoming lower than that of the control in all cases, mainly for FHC.

In conclusion, although low doses of HC or BC from FW or SS do not have negative effect on GI, seedling growth is negatively affected except for GPW materials. An alternative to improve the quality of hydrochar as a soil amendment could be Co-HTC of the different feedstocks by taking advantage of the best characteristics of each waste type. Thus, Co-HTC from GPW with FW or SS reduced the need for the extra clean water required for GPW carbonization, while the characteristics of HC from SS could be improved by lowering the phytotoxic compounds and reducing the heavy metals content of the final chars.

Acknowledgements

The authors would like to thank Spanish MCIN/AEI/UE (10.13039/501100011033) through the TED2021-130287B-I00 and PID2022-138632OB-I00 projects. L. Martinez-Sanchez acknowledges financial support from the Madrid Regional Government (PIPF-2023/ECO-31000).

References

Adhikari, D. et al. (2018) Journal of Agricultural Chemistry and Environment 7, 117-132.
Bonarota M.S. et al (2022) AoB Plants, 14, 1-14.
Czerwińska, K. et al. (2024). Journal of Environmental Management. 365, 121637.
RD 1051/2022 (2022) Sustainable nutrition on agronomic soils. No 312 188873-188916.