Hydrothermal Carbonization of food waste: Influence of food waste composition and carbonization conditions on hydrochar for application in soils

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Challenges associated to find new ways of obtaining bio-fertilizers in a circular economy framework are concerning to the agricultural sector. In this way, hydrothermal carbonization of food waste has been well-studied and shown to be an advantageous and potentially sustainable approach to face this issue because of the obtention of hydrochar with interesting characteristics for potential soil applications. Knowledge of the relationship among food waste composition, carbonization conditions, and hydrochar properties would allow the design of larger scale carbonization systems. The overall goal of this work is to understand how food waste composition and carbonization conditions influence hydrochar properties and thus hydrochar use.

Different types of generic food types (e.g., meat (MT), vegetables (VG), fruit (FT), grain derivatives (GD), and daily commodities (DC)) were selected based on the most consumed food categories in the U.S.A, according to the U.S. Department of Agriculture. Thermochemical experiments were carried out in pressure steel reactors at different reaction temperatures (200, 225, 250 ºC) and times (4, 8, 16, and 24 h) using 160 g of own-moisture feedstock. After the reaction, the reactor was cooled at room temperature and the gas phase was extracted from inside the reactors through a gas valve. The slurry was vacuum filtered to separate hydrochar and process water. Hydrochars (Food acronym-T-t, being T referred to temperature and t to reaction time) were dried at 105 ºC for 24 h. In order to study the toxicity of the hydrochar used as a soil amendment, a sequential washing of 5 cycles (24 h each) with water (6:1 water:hydrochar v/w ratio) of the different hydrochars was performed to simulate the entrainment of the compounds contained in the hydrochar. Detailed analyses of the hydrochar, process water, and leachant, including yields, elemental (C, N, S, and H) and metal composition (by ICP-OES), were performed. The proximate composition of hydrochar (moisture, ash, volatile matter, and fixed carbon) was also analyzed. COD and pH of process water and leachant were determined, while leachant was also analyzed in terms of toxicity by means of an acute toxicity test (*Escherichia coli*) and a bioluminescence method (*Aliivibrio fischeri*).

Table 1. Feedstock moisture, hydrochar yield and COD of process water

Feedstock	Moisture (wt. %)	T (ºC) - t (h)	Hydrochar yield (%)	COD (mg/L)	T (ºC) - t (h)	Hydrochar yield (%)	COD (mg/L)	T (ºC) - t (h)	Hydrochar yield (%)	COD (mg/L)
MT	72.6	200 - 4	78.2	129.4	225 - 4	52.1	127.6	250 - 4	42.8	69.9
		200 - 8	56.4	109.9	225 - 8	46.1	84.7	250 - 8	41.0	69.2
		200 - 16	53.9	103.6	225 - 16	45.3	68.9	250 - 16	40.3	60.3
		200 - 24	46.2	89.5	225 - 24	43.3	64.6	250 - 24	39.3	53.7
VG	90.4	200 - 4	49.2	42.1	225 - 4	42.0	37.3	250 - 4	32.5	35.7
		200 - 8	40.5	34.6	225 - 8	37.7	34.7	250 - 8	28.2	33.9
		200 - 16	30.0	32.4	225 - 16	33.7	33.2	250 - 16	24.9	31.7
		200 - 24	29.6	32.3	225 - 24	30.5	33.0	250 - 24	24.6	27.1
FT	81.3	200 - 4	53.9	47.7	225 - 4	48.2	46.7	250 - 4	47.1	41.4
		200 - 8	52.6	42.4	225 - 8	45.6	41.7	250 - 8	42.7	38.0
		200 - 16	49.5	42.0	225 - 16	41.9	37.2	250 - 16	42.0	34.3
		200 - 24	47.3	41.4	225 - 24	41.6	37.9	250 - 24	40.1	33.8
GD	34.8	200 - 4	65.7	-	225 - 4	63.2	-	250 - 4	61.8	-
		200 - 8	64.6	-	225 - 8	62.4	-	250 - 8	60.7	-
		200 - 16	63.0	-	225 - 16	61.2	-	250 - 16	54.4	-
		200 - 24	63.0	-	225 - 24	59.9	-	250 - 24	50.8	-
DC	27.7	200 - 4	96.6	-	225 - 4	94.9	-	250 - 4	93.8	166.5
		200 - 8	95.3	-	225 - 8	94.9	-	250 - 8	84.7	164.7
		200 - 16	94.9	-	225 - 16	93.6	-	250 - 16	84.8	150.4
		200 - 24	94.8	-	225 - 24	91.8	166.9	250 - 24	83.8	132.2

Table 1 shows the hydrochar yield and the COD of the process water obtained during the tests. An increase in temperature (200 – 250 ºC) and time (4 – 24 h) of carbonization generally led to a decrease in hydrochar yield. For food waste derived from MT, VG and FT, a similar trend was observed, associated with a decrease of the hydrochar yield of 20 – 35%. For GD and DC, hydrochar yield was mainly unchanged with the carbonization temperature,

because the low moisture content of this waste limited its hydrothermal transformation, hindering the production of process water, which was only obtained for DC after 24 h HTC at 200ºC and at 250ºC in all cases. Particularly, hydrochar yield from DC was above 80% in all cases, indicating that this kind of food waste did not undergo a significant transformation under hydrothermal conditions. Additionally, hydrochar analysis indicated that hydrochar composition (nutrient content (at least 4 wt.% considering N, P, and K), organic C content (above 15 wt.%), and heavy metals concentration, in mg/kg (As (< 40), Cd (< 1.5), Cr^{6+} (< 2), Hg (< 1), Ni (< 50), Pb (< 120)) also complies with the limits stablished in the Regulation EU 2019/1009 on fertilizing product in Europe [1]. Generally, COD process water decreased as HTC temperature increased which, together with the decrease in solid mass yield, suggested that the rate of hydrolysis of organic matter in the feedstock was slower than the rate of organic decomposition in the process water [2].

Fig. 1 shows the evolution of toxicity derived from the sequential washing of vegetable-derived hydrochar, selected as reference feedstock. Regarding *Escherichia coli* tests, the toxicity of leachant obtained from washing of hydrochars obtained at low HTC temperature and carbonization times was above > 90% (very high toxicity). A lower toxicity was observed for the first leachant obtained at higher HTC temperatures with values between 50 – 65% in all cases. The sequential washing caused a decrease of leachant toxicity, obtaining values below 20% (values below 30% is considered as not toxic) after cycles 4 and 5. A similar toxicity trend was observed in *Aliivibrio fischeri* tests.

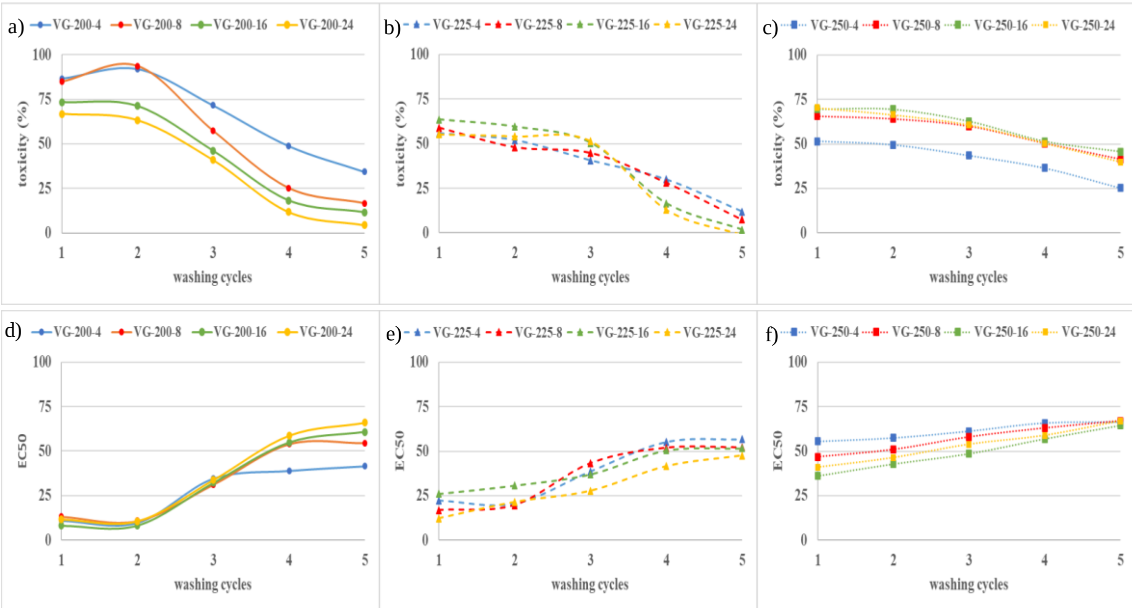

Fig. 1. Related toxicity of vegetable-derived hydrochars by *Escherichia coli* (a, b, and c) and *Aliivibrio fischeri* (d, e, and f) assays.

In the case of MT and GD hydrochars, the first and second washing cycle showed high toxicity (> 50%), diminishing their toxicity below 30 % after the fourth washing cycle. FT hydrochar hardly represented a danger to the soil since the toxicity observed was lower than 30% in all washing cycles. DC hydrochar supposed a risk to the soil at carbonization temperatures lower than 225 ºC, but 225 ºC (at reaction times longer than 16 h) and 250 ºC, resulted in a toxicity decrease, reaching acceptable toxicity values after the fourth cycle of washing. These results were validated by means of *Aliivibrio fischeri* test whose results showed similar trends.

According to preliminary results, there is a relationship between operating conditions of carbonization (temperature and time) and food waste composition on hydrochar characteristics and thus possible hydrochar soil applications. Results obtained from this work will be used to provide guidance on effective valorization of food waste.

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