

WASTES solutions treatments opportunities IV

Editors:

Cândida Vilarinho, Fernando Castro & Margarida J. Quina



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WASTES: SOLUTIONS, TREATMENTS AND OPPORTUNITIES IV

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Edited by

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Chemical evaluation of agro-industrial wastes for composting water hyacinth

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ABSTRACT: Water hyacinth (WH) waste removed from watercourses can be valued through composting. In this study it was determined the elemental composition of WH waste and other local organic residues to prepare suitable mixtures for composting. Rice husk, straw and wood-chip showed high C/N ratios (> 80). In turn, farmyard manures and vegetables displayed low C/N ratios (< 20). WH tissues showed increased C/N ratios with the aging process (from 17.4 to 37.1). WH tissues had low P ($< 2 \text{ g kg}^{-1}$) and high Fe ($> 5000 \text{ mg kg}^{-1}$) and Mn (2476.7-12885.8 mg kg^{-1}) concentrations. Fe and Mn levels were particularly high in the roots (31706.8 and 38335.2 mg kg^{-1} , respectively). Such high levels of Mn and Fe may impair the composting process and restrict the agricultural use of compost. Thus, the composting piles must be prepared from an optimized combination of organic materials that avoids either of those problems.

1 INTRODUCTION

Water hyacinth [*Eichhornia crassipes* (Mart.) Solms] is an invasive alien species of Portuguese aquatic systems, and is considered one of the 41 invasive alien species of concern of the European Union (European Union, 2014). In Portugal, water hyacinth's (WH) first sighting occurred in 1939 in the Tagus basin (Duarte, Agusti & Moreira, 1984) and, currently, it is present in almost all mainland regions (Minho, Douro Litoral, Beira Litoral, Estremadura, Ribatejo, Alentejo and Algarve) and even in an island of the Azores archipelago (Terceira) (Pádua et al., 2022). WH causes incalculable damages to ecosystems and hydraulic infrastructures, as well as high costs in its annual control, which is usually carried out by mechanical removal. This mechanical control generates huge amounts of WH waste, that currently do not have a destination, being usually left in piles on the river banks. Portuguese local authorities are desperately looking for a solution for the proper management of this waste.

The valorisation of WH waste through composting has been reported as the most promising technique (Singh and Kalamdhad, 2015). Using this technique, it is expected to contribute to an effective control of this invasive alien species and also to valorise its biomass by mixing it with other local organic materials. Its composting and subsequent use as an organic amendment in agriculture would be an important destination for WH biomass due to the limited availability of organic fertilizers in the Portuguese market and because a large part of the national territory has edaphoclimatic conditions that lead to soils with low levels of organic matter (Santos, 2015; Arrobas et al., 2018). This work's main goal was evaluating the physicochemical composition of WH waste and several other organic materials available in large quantities from agriculture, forestry and agrifood industry, with a view to establishing mixtures that could lead to obtaining a high quality compost for agricultural use.

2 MATERIALS AND METHODS

In July of 2021, WH waste, sampled at different growing stages, and other organic materials collected from local agricultural, livestock, forestry and agrifood industry activities were used for laboratory analysis. The type of organic materials and their origin are shown in Table 1.

Table 1. List of organic materials and water hyacinth (WH) waste and their origin.

Organic wastes	Type of facility	Location	
Chicken manure	Livestock	Alqueidão, Figueira da Foz	
Dairy cow manure (breastfeeding)		Maiorca, Figueira da Foz	
Dairy cow manure (pregnancy)		Bencanta, Coimbra	Lousã
Rabbit manure (organic farming)			
Rabbit manure (conventional farming)			
Swine manure			
Potato peel	Industrial	Tentúgal, Montemor-o-Velho	
Potato residue		Alqueidão, Figueira da Foz	
Rice husk			Vilela, Coimbra
Vegetables (mixture)			
Rice straw	Agricultural	Maiorca, Figueira da Foz	
Vegetables (branch)		Ferreira a Nova, Figueira da Foz	
Wood chip	Forestry	Bencanta, Coimbra	
WH – Roots	River	Ereira, Montemor-o-Velho	
WH – Young plants	River	Estação elevatória, Figueira da Foz	
WH – Full vegetative growth			
WH – Flowering			
WH – Full vegetative growth			Ereira, Montemor-o-Velho

The WH waste was sampled at two different points and in different phenological stages to understand the variability associated with the elemental composition of its tissues. These samples were collected with an average value of water content of 94.6%.

After sampling, organic wastes were oven-dried at 70°C to constant weight. Thereafter, samples were ground (1 mm mesh) and then analysed following the recommended in Decree-Law No. 103/2015 (Ministério da Economia, 2015), for total concentrations of carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), boron (B), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), cadmium (Cd), chromium (Cr), lead (Pb) and nickel (Ni).

The elemental composition of waste samples was determined by Kjeldahl (N), colorimetry (B and P), and atomic absorption spectrophotometry (Ca, Mg, K, Fe, Mn, Cu, Zn, Ni, Cr, Cd and Pb) methods, after the samples had been digested with HNO₃ in a microwave equipment. Organic C was determined by dry combustion (Themminghoff & Houba, 2004).

3 RESULTS AND DISCUSSION

3.1 Carbon and macronutrient concentration in water hyacinth and by-products

The results of the physicochemical analysis of C and macronutrients (N, P, K, Ca, and Mg) of the WH and organic waste samples are presented in Table 2.

The concentration of C varied between 258.8 g kg⁻¹ in WH root samples and 552.1 g kg⁻¹ in wood chips. However, most residues showed C concentrations varying between 400 and 500 g kg⁻¹. Compared to the macronutrients, C tends to vary little between organic materials, as it is a fundamental element of their structure (Weil & Brady, 2017), even though the WH roots showed the lowest value.

N concentration in organic materials showed a much greater variation than C concentration, with very contrasting values between the materials of different nature. As expected, WH roots showed the lowest value (1.9 g kg⁻¹), followed by rice husk (4.3 g kg⁻¹), rice straw (5.1 g kg⁻¹) and woodchips (6.9 g kg⁻¹). The material most concentrated in N was chicken manure, reaching 39.5 g kg⁻¹. Most of the other animal manures also have reasonably high levels of N, as well as the vegetables. In the case of WH, N concentration in aerial parts was relatively high, mainly in young plants (25.5 g kg⁻¹). The concentrations of N and C set the C/N ratio of the material,

which is a determining indicator for preparing the piles for composting (Afonso et al., 2021). High C/N ratio was found in rice husk (120.8) and straw (93.9) and wood chips (80.1). These organic materials can give some structure to the composting piles. Low C/N ratio was observed in chicken manure (11.2) and dairy cow manures (17.5-18.8). WH samples showed an increasing C/N ratio with the aging process (17.4-37.1) and root samples showed the highest C/N ratio (139.1).

P concentrations also varied considerably among the analysed organic wastes. Very low P values were found in lignin-rich materials, such as rice husk (0.4 g kg⁻¹), and very high P values in manures in which few lignified materials are used in the bedding, such as in manure from lactating cows (12.5 g kg⁻¹). WH samples showed a decreasing concentration of P with the aging process and root samples showed the highest P concentration (1.9 g kg⁻¹). Although P is not a determinant element in the preparation of compost piles, its concentration in the final product is important since most of Portuguese agricultural soils have low levels of P (Ferreira et al., 2018).

Regarding K concentration, it was also observed a great difference between sampled materials. Rice husk (4.0 g kg⁻¹), woodchip (4.2 g kg⁻¹) and then dairy cow manure of animals in pregnancy (6.6 g kg⁻¹) and in lactating (7.2 g kg⁻¹) phases were the materials with the lowest K concentration. High K levels were found in several other organic materials, mainly in fresh vegetable waste (32.0 g kg⁻¹) and rabbit manure (30.8 g kg⁻¹). In the case of WH, high levels of K were found in samples taken during the vegetative stages (28.2 to 47.3 g kg⁻¹), which were slightly lower than in flowering stage (13.2 g kg⁻¹).

Ca concentrations were particularly low in rice husk (1.0 g kg⁻¹) and potato residue (2.4 g kg⁻¹), and particularly high in rabbit (85.1 g kg⁻¹) and chicken (54.2 g kg⁻¹) manures. In WH samples, the Ca concentrations varied between 8.8 and 13.6 g kg⁻¹. Mg concentrations also showed great variation among the organic wastes analysed. Rice husk (0.6 g kg⁻¹) and woodchip (0.7 g kg⁻¹) were the materials with the lowest Mg content while vegetable branches (10.0 g kg⁻¹) showed the highest Mg concentration. All WH samples showed Mg concentration in the average range of the concentrations found in all the other organic wastes, with values varying between 4.5 and 6.3 g kg⁻¹. The levels of Ca and Mg in the final compost will be of great importance since soils in Portugal are mostly acidic (Santos, 2015).

Table 2 Concentration of carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) and C/N ratio in organic wastes collected from agricultural, livestock and agrifood industry activities and in water hyacinth (WH) waste.

Organic Wastes	C g kg ⁻¹	N	C/N Ratio	P	K g kg ⁻¹	Ca	Mg
Chicken manure	443.0	39.5	11.2	11.2	19.1	54.3	6.7
Dairy cow manure (breastfeeding)	453.9	25.1	18.1	12.5	7.2	41.8	8.7
Dairy cow manure (pregnancy)	438.0	25.1	17.5	11.8	6.6	50.8	7.4
Rabbit manure (organic farming)	477.1	16.5	28.9	3.4	29.1	13.5	2.9
Rabbit manure (conventional farming)	315.4	22.2	14.2	5.4	30.8	85.1	4.4
Swine manure	504.3	24.0	21.0	5.7	12.2	10.5	4.2
Potato peel	514.2	17.7	29.1	1.0	18.6	2.9	1.2
Potato residue	548.7	13.8	39.9	2.0	14.4	2.4	0.9
Vegetables (mixture)	513.1	27.6	18.6	3.5	32.0	3.3	2.0
Vegetables (branch)	443.1	20.2	21.9	8.5	22.8	35.5	10.0
Rice husk	520.6	4.3	120.8	0.4	4.0	1.0	0.6
Rice straw	476.3	5.1	93.9	0.6	14.4	2.3	1.0
Wood chips	552.1	6.9	80.1	0.5	4.2	6.2	0.7
WH – Roots	258.8	1.9	139.1	1.9	16.8	8.7	4.8
WH – Young plants	440.4	25.4	17.4	1.7	28.2	10.4	4.5
WH – Full vegetative growth (F da Foz)	418.1	18.2	32.1	1.6	36.6	8.8	6.3
WH – Flowering	426.9	12.3	34.8	1.0	13.2	13.6	5.0
WH – Full vegetative growth (Ereira)	416.7	20.7	37.1	1.7	47.3	10.0	5.0

3.2 Micronutrient concentration in water hyacinth and by-products

As observed for macronutrients, the analysed organic materials also showed evident differences in the concentration of micronutrients. The results are shown in Table 3.

Table 3. Concentration of boron (B), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) in organic wastes collected from agricultural, livestock and agrifood industry activities and in water hyacinth (WH) waste.

Organic wastes	B	Fe	Mn mg kg ⁻¹	Zn	Cu
Chicken manure	35.4	365.4	276.5	944.4	56.6
Dairy cow manure (breastfeeding)		1476.0	670.1	599.4	101.6
Dairy cow manure (pregnancy)	14.8	703.6	612.4	626.7	88.7
Rabbit manure (organic farming)	34.2	746.7	121.2	110.8	18.8
Rabbit manure (conventional farming)	24.6	1872.9	185.5	343.3	31.7
Swine manure	24.6	1300.4	269.9	522.6	54.2
Potato peel	17.4	716.2	47.5	455.1	7.5
Potato residue	10.1	321.3	30.2	3150.1	3.9
Vegetables (mixture)	19.4	213.1	82.6	67.5	5.3
Vegetables (branch)	91.8	226.3	117.3	82.9	4.6
Rice husk	4.5	303.1	142.7	47.2	1.4
Rice straw	6.0	176.8	130.3	9.6	7.3
Wood chips	11.7	548.5	135.5	30.6	3.6
WH – Roots	17.5	31706.8	38335.2	88.2	20.5
WH – Young plants	21.4	5178.3	9809.4	68.5	10.5
WH – Full vegetative growth (Figueira da Foz)	17.7	8380.4	12885.8	132.3	10.9
WH – Flowering	23.9	8611.1	2476.7	125.9	9.2
WH – Full vegetative growth (Ereira)	19.3	7979.3	6984.3	230.2	8.5

B concentration was low in both rice by-products, husk (4.5 mg kg⁻¹) and straw (6.0 mg kg⁻¹), reaching the highest values in the vegetable branches (91.8 mg kg⁻¹). The animal manures showed moderately high B levels (14.5 to 35.4 mg kg⁻¹), as observed in WH samples (17.5 to 23.9 mg kg⁻¹). The levels of B found in vegetable residues probably reflects the high levels of fertilization usually performed in these crops (Almeida, 2006). Rice, being a monocot usually shows low levels of B in its tissues in comparison to dicot ones (Fageria & Moreira, 2011).

Regarding the levels of Fe in organic residues, the lowest values were found in rice straw (176.8 mg kg⁻¹), followed by the other lignin-rich materials and vegetable residues. Among manures, there was still a relevant variation. For instance, chicken manure registered 365.4 mg kg⁻¹ and rabbit manure 1872.9 mg kg⁻¹. In the WH samples, Fe values ranged from 5178.3 to 31706.8 mg kg⁻¹. The very high concentration of Fe in the roots seems also to be the reason for the high values found in the remaining samples of the WH aerial tissues. These results seem to indicate that WH plant has an exclusion mechanism as a mean of reducing toxic levels of Fe in the shoots, as reported for other crops (Rodrigues et al., 2021).

The lowest Mn concentration was recorded in potato residues (30.2 mg kg⁻¹). The remaining horticultural by-products still showed low Mn values compared to the other organic waste. The manures showed higher values than the previously mentioned organic materials. However, the highest values were found in WH samples (6984.3 to 38335.2 mg kg⁻¹). These particularly high Mn levels in the WH samples seem also to be due to the contribution of the roots, which registered 38335.2 mg kg⁻¹, which also suggests, as for Fe, an exclusion mechanism that limits the concentration of the element in the shoot. The high levels of Mn and Fe in roots is certainly due to the reduction conditions of the growing medium (Afonso et al., 2020), probably caused by the WH itself as a mean of competing with the other vegetation in the ecosystem.

The Zn levels in the samples varied greatly between organic materials, from 9.6 mg kg⁻¹ in rice straw to 3150.1 mg kg⁻¹ in potato residues. Animal manures showed very high levels of Zn. In WH samples, Zn concentrations varied between 68.5 and 230.2 mg kg⁻¹, the highest values being recorded in samples from Ereira. The concentrations of Cu were particularly low in lignin-rich by-products, such as rice husk (1.4 mg kg⁻¹) and woodchip (3.6 mg kg⁻¹), but also in the residues of vegetables and particularly in the branches (4.6 mg kg⁻¹). Cu levels were higher in animal manures, especially in those produced by dairy cows in pregnancy (88.7 mg kg⁻¹) and lactating (101.6 mg kg⁻¹) stages. In WH samples, Cu concentrations varied between 8.5 and 20.5 mg kg⁻¹, with the highest values observed in root samples (20.5 mg kg⁻¹).

3.3 Concentration of heavy metals in water hyacinth and by-products

Cd, Cr, Pb and Ni are commonly named as heavy metals, as they can have toxic effects on food chains, even though Ni is an essential nutrient for higher plants (Macedo, 2016). The concentrations of the four elements in the sampled organic wastes are shown in Table 4.

Table 4. Cadmium (Cd), chromium (Cr), lead (Pb) and nickel (Ni) concentration in organic wastes collected from agricultural, livestock and agro-industrial activities and in water hyacinth (WH) waste.

Organic wastes	Cd	Cr	Pb	Ni
	mg kg ⁻¹			
Chicken manure	0.58	6.92	0.84	0.94
Dairy cow manure (breastfeeding)	0.49	18.47	0.98	1.63
Dairy cow manure (pregnancy)	0.36	5.40	0.84	1.25
Rabbit manure (organic farming)	0.36	12.17	0.72	0.37
Rabbit manure (conventional farming)	0.08	13.00	1.36	0.62
Swine manure	0.02	13.36	1.32	1.10
Potato peel	0.11	8.94	1.18	4.34
Potato residue	0.21	8.05	1.31	2.82
Vegetables (mixture)	0.07	10.50	1.15	0.14
Vegetables (branch)	0.13	5.60	0.88	30.94
Rice husk	0.53	10.17	1.11	1.17
Rice straw	0.47	10.46	0.76	0.73
Wood chips	0.42	21.63	0.44	0.42
WH – Roots	0.30	22.49	8.96	140.24
WH – Young plants	0.38	15.42	0.94	35.45
WH – Full vegetative growth (Figueira da Foz)	0.39	16.83	1.48	21.73
WH – Flowering	0.52	15.06	5.55	4.79
WH – Full vegetative growth (Ereira)	0.66	16.50	1.65	36.51

Cd levels in sampled organic residues were below 0.7 mg kg⁻¹. Some of the variations found seemed to be related to the nature of the residue. For instance, in manures, it ranged from 0.02 mg kg⁻¹ (swine) to 0.58 mg kg⁻¹ (chicken). In rice by-products, Cd values were high in straw and husk (0.47 and 0.53 mg kg⁻¹, respectively). In the WH samples, the highest value of Cd (0.66 mg kg⁻¹) was registered in the samples from Ereira.

Cr concentrations in the organic materials were below 25 mg kg⁻¹. The highest values of Cr were recorded in samples of wood chip (21.63 mg kg⁻¹) and WH roots (22.49 mg kg⁻¹) which showed to be relatively higher than in manures and vegetable residues.

Pb levels were below 1.5 mg kg⁻¹ in most materials. However, it should be noted the observation of relatively high values in some WH samples, such as in those from Foja (5.55 mg kg⁻¹) and, above all, in the samples in which the roots were analysed separately (8.96 mg kg⁻¹).

Ni concentrations were lower in horticultural by-products, rice straw, woodchip and animal manures, with values below 5 mg kg⁻¹. Very high values were recorded in vegetable branches, reaching 30.94 mg kg⁻¹. WH samples showed high levels of Ni (> 20 mg kg⁻¹), excepting of flowering plants from Figueira da Foz (4.79 mg kg⁻¹). WH roots showed high Ni concentration, with an average value of 140.24 mg kg⁻¹.

The levels of Cd, Cr, Pb and Ni observed in these materials should not pose problems for the composting process. However, the presence of heavy metals in compost can place restrictions on its use according to national legislation (Decree-Law n° 103/2015), due to the risk of contamination of soils and agricultural products. Nevertheless, the values observed in this study, and after the materials be balanced in the composting piles composition, should not be an obstacle to obtaining a compost of high quality.

4 CONCLUSIONS

In this study, water hyacinth waste and a wide range of organic residues, collected in the Coimbra region, were characterized in order to evaluate their potential to be part of composting piles. The sampled organic materials were quite different from each other, providing useful information on how the composting piles can be prepared. The collected organic materials showed

very different carbon/nitrogen ratios, which is one of the main indicators used to establish the composting mixtures. Several composting mixtures can be set up, for instance, i) water hyacinth waste, dairy cow manure, potato residue and rice straw or ii) water hyacinth waste and wood-chips. The concentration of other macro and micronutrients as well as heavy metals also varied in all sampled materials. Based on these results, the concentration of heavy metals in the final composts should be monitored, since their presence may restrict the use of compost in agriculture. Manganese levels will perhaps be the ones that deserve the most attention.

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