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Influence of the composition of the initial mixtures on the chemical composition, physicochemical properties and humic-like substances content of composts

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Abstract

The influence of the proportion of C- and N-rich raw materials (initial C/N ratio) and bulking agent on the chemical functional groups composition, humic-like substances (HS-like) content and physicochemical properties of composts was assessed. To achieve these goals, seven initial mixtures (BA1–6 and C1) of dog food (N-rich raw material) were composted with wheat flour (C-rich raw material). Composts were analyzed in terms of chemical functional groups, physicochemical, maturity and stability parameters.

The C-rich raw material favored the formation of oxidized organic matter (OM) during the composting process, as suggested by the variation of the ratios of the peaks intensity of FT-IR spectra, corresponding to a decrease of the polysaccharides and an increase of aromatic and carboxyl-containing compounds. However, although with high proportion of C-rich raw material, mixtures with low initial C/N seems to have favored the accumulation of partially oxidized OM, which may have contributed to high electrical conductivity values in the final composts. Therefore, although favoring the partial transformation of OM into stabilized HS-like, initial mixtures with high proportion of C-rich raw material but with low initial C/ N led to unstable composts.

On the other hand, as long as a high percentage of bulking agent was used to promote the structure of biomass and consequently improve of the aeration conditions, low initial C/N was not a limiting factor of OM oxidation into extractable stabilized humic-like acids.

1. Introduction

Composting is a biotechnological aerobic process where different microbial communities mineralize part of the organic matter (OM) and contribute to the humification of the recalcitrant compounds (Epstein, 1997). Usually, the mixture formulations for composting are based on the physical and chemical properties of the raw materials (Barrena et al., 2011; Bernal et al., 2009) in order to adjust the moisture content and the ratio of carbon/nitrogen (C/N) to optimal values capable of favoring the growth and activity of microbial populations (Soares et al., 2013). According to Epstein (1997), raw materials, temperature, aeration, moisture content and C/N ratio are the major factors affecting the final quality of the compost. The effect of raw materials on the composting process was studied by Chang and Hsu (2008). These authors demonstrated that in comparison with substrates rich in carbohydrates or fat, mixtures of food wastes rich in protein, derived from soy, fish and meat meals, supported higher temperature and pH values and shorter periods of time to reach maturity. According to Kumar et al. (2010), high moisture content in food waste or low nitrogen content of green waste may result in long treatment time or low degradation efficiency. In general, an initial C/N ratio of 25–30 is considered to be the most adequate to obtain a compost with high final quality (Haug, 1993). However, some studies have shown that composting can be carried out effectively at a lower C/N of 15 (Huang et al., 2004; Zhu, 2007). The quality criteria for compost are established in terms of nutrient content, humified and stabilized OM, the maturity degree, the hygienisation and the presence of certain toxic compounds such as heavy metals, soluble salts and xenobiotics (Bernal et al., 2009). The acceptable values for the quality parameters, such as electrical conductivity, ammonium nitrogen and the presence of heavy metals, depends on the in- tended applications of the product, namely its use as landfill cover or in agriculture (DG ENV.A.2, 2001; EC, 2006). Recently our team showed that humic-like substances (HS-like), which can be further used as liquid organic amendments, could be recovered from low quality composts (Silva et al., 2013). Although there are several ongoing studies on the optimization of the operational composting conditions, the information regarding the influence of these conditions on the content and characteristics of HS-like is scarce (Barje et al., 2012; Qi et al., 2012). The knowledge of key factors that influence humification would allow the improvement of the composts quality in terms of HS-like content. Therefore, in this study, the influence of the composition of initial mixtures, i.e. the proportion of C- and N-rich raw materials, bulking agent and, thus, C/N ratio on the chemical functional groups composition, physicochemical properties and HS-like content was investigated.

2. Materials and methods

2.1. *Composts*

Seven composts herein designated by BA1–6 and C1 were studied. These composts were obtained from commercial dog food (DF) pellets composted with different proportions of wheat flour (WF) in order to obtain different initial C/N ratios. Rice husks (RH) were used as bulking agent. DF (N-rich raw material) and WF (C-rich raw material) were chosen because their composition was known and homogenous (Chang et al., 2005; Chang et al., 2006; Chang and Hsu, 2008; Vinnerås et al., 2003), and exempt of toxic compounds. Hence, it was possible to assess variations on the composts properties due to their initial proportion while maintaining all the characteristics derived from the raw materials. DF pellets presented the following qualitative composition: cereals, vegetable substances, meat, animal sub-products, minerals substances, oils and fats. Bulking agents, used to provide the optimum free air space and to regulate the water contents of the wastes to be composted, are typically inexpensive waste materials with low biodegradability that are readily available (Iqbal et al., 2010). In the present study, it was used rice husks, as reported before by different authors (Chang et al., 2005; Chang and Hsu, 2008; Chang and Chen, 2010; Iqbal et al., 2010; Soares et al., 2013). The physicochemical characterization of the raw materials and bulking agent is described in Table 1. These materials were used to prepare seven composting mixtures: six mixtures with a C/N ratio lower than 20 and one mixture with a C/N ratio higher than 20 (Table 2). The composts were produced in laboratory reactors of 20 L. The room temperature (25 ºC) was maintained during the process using a temperature controller (3200 PID Eurotherm). Temperature was measured daily, with a probe (TempTec) in the middle of the composting mixture. An aeration device was installed at the bottom of the composting reactors to maintain the aerobic conditions; the air was supplied using an air pump at a rate of 4 L/min and maintained until the end of the thermophilic phase. The mixtures were manually turned every 3 days for a period of 30 days and then weekly up to the maturation phase. The moisture content was initially adjusted to approximately 50–60%, and maintained through the addition of water until the end of the thermophilic phase. According to the temperature profile (data not shown), when the temperature reached values near room temperature (25 ºC), the composts were left to mature for a period of 30 days. Therefore, the end of composting process was at day 120 for mixtures BA1, BA2, BA4, BA5, at day 140 for mixtures BA3 and BA6 and at day 240 for mixture C1. Samples of about 2 kg were collected from the top to the bottom of each mixture, homogenized and stored at 4 ºC.

2.2. *Physicochemical characterization of composts*

The parameters used to characterize composts BA1–6 and C1 were moisture, OM, total organic carbon (TOC), total nitrogen (TN), ammonium nitrogen content (NH_4^+–N), pH, electrical conductivity (EC) and C/N ratio. Moisture content was determined from the weight loss after drying the sample at 105 ºC for 24 h (EN 13040, 1999). The OM content was quantified by weight loss after ignition of dry sample, in a furnace at 550 ºC for 8 h (EN 13039, 1999). The TOC was estimated by multiplying the OM content by the empirical coefficient 0.5 (Zucconi and de Bertoldi, 1987). The TN content was determined by the modified Kjeldahl digestion method (EN 13654-1, 2001).

Ammonium nitrogen (NH_4^+–N) was determined according the methodology described by Cunha-Queda (1999). 50 g of wet sample were extracted with 200 mL of 2 N KCl. The suspension was stirred for 1 h, centrifuged at 3500 rpm for 30 min, and the supernatant was filtrated through a 25 1m paper filter (Schleicher&Schuell). An aliquot of 50 mL of supernatant was distilled in an alkaline medium [40% (m/V) NaOH] and the NH3–N was received in 4% (m/V) acid boric; the quantification was done by titration with 0.05 N HCl. pH and EC measurements were performed by electrometric determination in aqueous extracts (1:5, w/V) of the samples (EN 13037, 1999; EN 13038, 1999).

The maturity of composts was assessed using humification parameters and indices. Extraction and fractionation of HS-like were carried out according to the methodology described in the Spanish official method for the analysis of fertilizing organic products (R.D. 1110/12, July 1991), which consists of successive treatments of the compost with an alkaline solvent. Briefly, the HS-like extract (HE) was obtained by shaking 10 g dry compost with 120 mL of 0.1 M pyrophosphate–KOH (pH 13) for 1 h. After three cycles of centrifugation, addition of alkaline solvent and shaking, the dark-colored supernatants were pooled, allowed to settle overnight, and centrifuged for 20 min at 4000 rpm. The resultant HE was fractionated by addition of 1.5 mL 96% H_2SO_4 (pH 2), to separate the insoluble fraction, the humic-like acid substances (HA), from the soluble fulvic-like acid substances (FA). HA was dissolved in distilled water. The total organic carbon content of HE, HA and FA was determined by dichromate oxidation and sulfuric acid method (Yeomans and Bremner, 1988). Results were expressed as the percentage of total organic carbon of the parent compost in each fraction (HEC, HAC and FAC). The humifica- tion indices were calculated according the following equations (Roletto et al., 1985):

$$\text{Degree of Polymerization (DP)} = \text{HAC}/\text{FAC} \qquad (1)$$

$$\text{Humification Ratio (HR)} = 100 \times \text{HEC}/\text{TOC} \qquad (2)$$

$$\text{Humification Index (HI)} = 100 \times \text{HAC}/\text{TOC} \qquad (3)$$

$$\text{Percentage of Humic-like Acids (PHA)} = 100 \times \text{HAC}/\text{HEC} \qquad (4)$$

The chemical functional groups in composts were identified and quantified based on Fourier Transform Infrared Spectroscopy (FT-IR). The FT-IR absorbance of aliphatic groups (Cal, 2930 cm^{-1}), aromatic compounds (Car, 1650 cm^{-1}), aromatic com- pounds including the lignin (Car-lig, 1510 cm^{-1}), alkyl and carboxylate groups (Calk, 1384 cm^{-1}), carboxylate groups (Ccarb, 1235 cm^{-1}) and polysaccharide compounds (Cpol, 1030 cm^{-1}) were used to calculate the ratios between 1650/2930, 1650/1510, 1510/2930, 1384/2930, and 1030/1235 (Amir et al., 2010; Castaldi et al., 2005).

The stability of composts was assessed using the self-heating test (SH) according to Laga-Merkblatt M10 (1995) and the respiration activity after 4 days (AT4) according to DIN 19737 (2001) methodology.

All the analyses were performed in triplicate.

2.3. *Statistical analyses*

Data were subjected to one-way analysis of variance (ANOVA) and the Newman–Keuls test was used to separate the means. All statistical analyses were carried out using Statistica 6.0. Principal Components Analyses (PCA) were performed in order to compare the composts based on their chemical functional groups composition, obtained by the ratio between main peaks of FT-IR, and physicochemical properties. Canonical Correspondence Analyses (CCA) were carried out in order to assess the influence of initial C/N ratio and percentage of raw materials (explanatory variables) on the variance of the (i) chemical functional groups composition, (ii) the physicochemical properties and (iii) the maturity and stability properties of composts. The significance of the relationship be- tween the variance of the chemical functional groups composition, the physicochemical and the maturity, stability properties of composts (principal matrix) and the initial C/N ratio and percentage of raw materials (second matrix) was tested by Monte Carlo permutations test (n = 499). Explanatory variables included in CCA analysis were selected by manual forward selection including the Monte Carlo permutations test. These multivariate analyses were per- formed with the software package CANOCO version 4.5.

3. Results

3.1. *Identification of chemical functional groups of composts*

The FT-IR spectra of the composts (Supplementary Figs. S1–2) displayed bands at 2930–2855 cm^{-1} (aliphatic C–H stretching in CH$_2$ and CH$_3$), 1660–1640 cm^{-1} (overlap of several stretching bands of C=O of amide I, carboxylates, aldehydes and quinones in conjugation with olefinic and aromatic compounds, C=N of heterocyclic and C=C of olefinic compounds), 1550–1510 cm^{-1} (C=C skeletal stretching of aromatic compounds such as lignin), 1460– 1360 cm^{-1} (overlap of several bending bands such as in aliphatic CH$_2$, CH$_3$, and phenolic OH, and C=O stretching of carboxylates), 1260–1200 cm^{-1} (amides III, C–O of carboxylic acids, aromatic ethers C–O–C), 1100–1030 cm^{-1} (C–O stretching of polysaccharides) (Smidt and Parravicini, 2009; Coates, 2000). The intensity of these bands varied for different composts. To get additional insights about the influence of the composition of the initial mixtures on the chemical functional groups, composts were compared based on the ratios described in Section 2.2 (Table 3).

The PCA analysis of these data revealed that the ratios Car/Car- lig and Cpol/Ccarb were contributing most to the variation among the chemical functional groups composition of the studied com- posts (Supplementary Fig. S3). Composts BA1, BA2 and BA4, for which highest values of these ratios were found (~1.8–2.1 and 4.6–6.6, respectively), were separated from all the others over principal component 1 (axis 1). On the other hand, compost C1 was separated from BA3, BA6 and particularly BA5 over axis 2, mainly due to its highest Car/Cal ratio (~2.2).

3.2. *Influence of the composition of the initial mixtures on the chemical functional groups composition of composts*

To assess the influence of the composition of the initial mixtures, i.e. the initial C/N ratio and the proportion of the C- and N- rich raw materials and of the bulking agent on the chemical functional groups composition of composts, a CCA analysis was performed (Fig. 1). This multivariate analysis could explain 86% of the variation found among the composts, and permitted to distinguish composts C1, BA3 and BA6 from all the others over axis 1. The ratios Calk/Cal and Cpol/Ccarb were the major factors of variation among in the analyzed composts. Composts C1, BA3 and BA6 showed the highest (~1.3–3.2) Calk/Cal and the lowest (~2.1–3.6) Cpol/Ccarb ratios (Table 3). The proportion of C-rich raw material correlated positively with the separation of composts C1, BA3 and BA6. In opposition, the proportion of N-rich raw materials correlated with the differentiation of composts BA1, BA2, BA4 and BA5.

3.3. *Influence of the composition of the initial mixtures on the physicochemical properties of composts*

Based on the physicochemical properties, the most distinct composts were C1, BA3 and BA6, as revealed by the PCA and CCA biplots, which could explain 85.5% of the variation found (Supple- mentary Figs. S4 and Fig. 2). Moisture, TN, final C/N ratio and EC values were the parameters that contributed most to differentiate the studied composts. Composts BA3 and BA6 showed the highest values of EC (8.8 and 9.4 mS cm^{-1}, respectively) and final C/N (7.3 and 9.0, respectively). In opposition, composts BA3 and BA6 showed the lowest moisture (~28 and 23%, respectively) and TN values (4.8 and 4.6% d.m., respectively). On the other hand, com- post C1 showed the highest values of moisture (68%) and TN (7.7% d.m.) and the lowest (5.2) final C/N value (Table 4). However, composts C1, BA3 and BA6 showed the highest values of OM (78.9, 82.7 and 80.1% d.m., respectively) (Table 4).

3.4. *Influence of the composition of the initial mixtures on the maturity and stability of composts*

Considering the maturity (HS-like content) and stability parameters examined, the SH degree and AT4 were those that contributed most to differentiate composts C1, BA4 and BA5 from all the others (Fig. 3). These three composts showed, respectively, the highest (V) and lowest (~9–12 mgO_2 g^{-1} d.m.) values of these parameters (Table 5). In addition, compost C1 and BA5 showed the highest values of DP (0.44 and 0.52, respectively) and PHA (33.2% and 27.6%, respectively) (Table 5). On the other hand, composts BA3 and BA6 showed the highest contents in HEC (~11.5% d.m.) and HR (30.4% and 27.9%, respectively) (Table 5). The HAC content contributed to the separation of compost C1 (3.0% d.m.) from BA4 and BA5 (1.3% and 2.3% d.m.) over axis 2 (Table 5 and Fig. 3). Again, C1 could be distinguished from all the BA (1–6) composts due to its highest initial C/N ratio, and from BA4 and BA5 due to its higher proportion of C-rich raw material.

4. Discussion

The specific composting conditions that optimize the transformation of organic raw materials into HS-like are still not fully understood (Barje et al., 2012; Qi et al., 2012). This study aimed at assessing the effect of the proportion of bulking agent, C- and N-rich raw materials and C/N ratio on the final properties of composts. Variation among the composts was found for each set of parameters used in the comparisons.

During composting, due to microbial activity, part of the readily oxidisable OM is mineralized into CO_2, water vapor and inorganic substances, and is assimilated to form biomass, while the remaining recalcitrant OM undergoes humification (Senesi, 1989; Epstein, 1997). The humification process leads to the formation of compounds with increasing molecular weight, concentration of oxygen (carboxylic, phenolic, ethers and esters groups) and nitrogen (amides groups) containing functional groups and aromatic characteristics (Ait Baddi et al., 2004; Senesi, 1989; Senesi and Plaza, 2007). Therefore, methods capable of detecting these functional groups, such as FT-IR, have been employed to follow the humification process in composts (Ait Baddi et al., 2004; Amir et al., 2005, 2010; Shirshova et al., 2006; Smidt et al., 2008).

Composts C1, BA3 and BA6 showed the lowest Cpol/Ccarb and highest Calk/Cal ratios. In all the composts, the decrease in the content of readily oxidisable OM, such as the starch (polysaccharide) present in the wheat flour and eventually other compounds rich in aliphatic carbon, was probably concomitant with the increase in the content of transformation products rich in alkyl and carboxyl groups. Therefore, it is suggested that the oxidation of the raw materials occurred more extensively in C1, BA3 and BA6 than in the other composts. Given the difference in the initial C/N ratio of these composts (~14 in BA3 and BA6, and 24 in C1), it was possible to conclude that the high percentage of the C-rich raw material (20% in BA3 and BA6, and 77% in C1) seems to favor the oxidation of OM during the composting process. On the other hand, the higher values of final C/N and EC in BA3 and BA6 than in compost C1 permitted their distinction. The final C/N values of BA3 and BA6 composts (7.3 and 9.0, respectively) were similar to those found by others authors for food wastes composts (Sung and Ritter, 2008). Given the final OM content of composts BA3, BA6 and C1 was similar (~79–83% d.m.), the high final C/N values found in BA3 and BA6 were due to their lower final values of TN (4.8 and 4.6% d.m.) than in C1 (7.7% d.m.). Since BA3 and BA6 contained more N-rich raw materials (75% and 70%, respectively) than C1 (18%), the lower final TN content could not be explained by the scarcity of raw materials rich in N. Thus, it is possible to conclude that low initial C/N may favor N losses, as suggested before (Goyal et al., 2005; Tiquia and Tam, 2002; Zhu, 2007) although this condition did not inhibit the composting process, as reported before (Kumar et al., 2010; Zhu, 2007).

The release of mineral salts due to the decomposition of organic matter and the concentration effect due to a net loss of dry mass, led to an overall increase in the values of EC (Tables 1 and 4). These effects were reported before (Bernal et al. 2009; Bustamante et al., 2012; Silva et al., 2009). Besides the inorganic substances, such as nitrates and sulfates, the increase of organic acids (e.g. acetic acid) during composting (Hernández et al., 2006), due to microbial oxidation of OM, may contribute to increase the EC values. In this study, the EC values found in all composts, and particularly in BA3 and BA6 (8.8 and 9.4 mS cm^{-1} respectively) were higher than the upper limit (4 mS cm^{-1}) considered tolerable by plants of medium sensitivity (Lasaridi et al., 2006). Such high EC values may be related with the accumulation of partially oxidized OM, such as low molecular weight organic acids (Hernández et al., 2006). These organic acids, although contributing to raise the Calk/Cal ratio and lower the Cpol/Ccarb ratio may have contributed to the low SH degree (II) and high AT$_4$ (~25–27 mgO$_2$ g^{-1} d.m.) of composts BA3 and BA6. The partially oxidized OM may have been extracted with the HS-like, contributing to the high HEC content (~12% d.m.) and HR index (~30% and 28%, respectively) of composts BA3 and BA6. In summary, the presence of high percentage of C-rich raw materials favors OM oxidation, which eventually became highly stabilized. Indeed, compost C1 was the one with the highest Calk/Cal and Car/Cal ratios and HAC content. However, low initial C/N seems to favor the accumulation of partially oxidized OM, leading to non-matured and unstable final composts.

Interestingly, when the maturity and stability parameters were used to assess the extent of humification, among composts BA1–6, BA5 was the most similar to C1. Indeed, BA5 and C1 had similar PHA and DP indices (~28% and 33%, and 0.52 and 0.44, respectively), which are indicative of a high content in HA. However, the high degree of OM condensation suggested by these commonly used parameters to assess the maturity of composts were not corroborated by the Car/Cal, Car-lig/Cal and Calk/Cal ratios of BA5 when compared to C1. These results suggest that only certain substances present in the initial mixtures with a high percentage of N- rich raw materials (BA5) were oxidized into stable HS-like when compared to the composts with an initial mixture richer in C raw materials (C1). Composts BA5 and BA2 had similar initial C/N ratios (16.3 and 14.5, respectively) but differed in their RH content (10% and 5%, respectively).

However, compost BA2 showed a higher Cpol/Carb ratio than BA5 (~4.6 and 2.4, respectively). Accordingly, the PHA and DP indices of compost BA2 (~19% and 0.3, respectively) were lower than in BA5. Thus, the results of this study suggest that low initial C/N is not inhibitory of OM oxidation into extractable stabilized HAC, when aeration is promoted by a high content of bulking agent.

5. Conclusions

Results indicated that the HS-like content was influenced by several factors, such as the initial C/N ratio and the proportion of raw organic materials. C-rich raw materials favored the formation of oxidized OM during the composting process. However, low initial C/N hampered a complete stabilization of OM, which contributes to reduce the quality of the final composts due to their low N content, high EC and consequent low stability. Nevertheless, composts with these characteristics could be used as a source of HS-like to be further used as organic amendments.

Low initial C/N is not inhibitory of OM oxidation into extractable stabilized HAC, as long as a higher percentage of bulking agent is used to promote the structure of biomass and to improve aeration.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.wasman.2013. 09.011.

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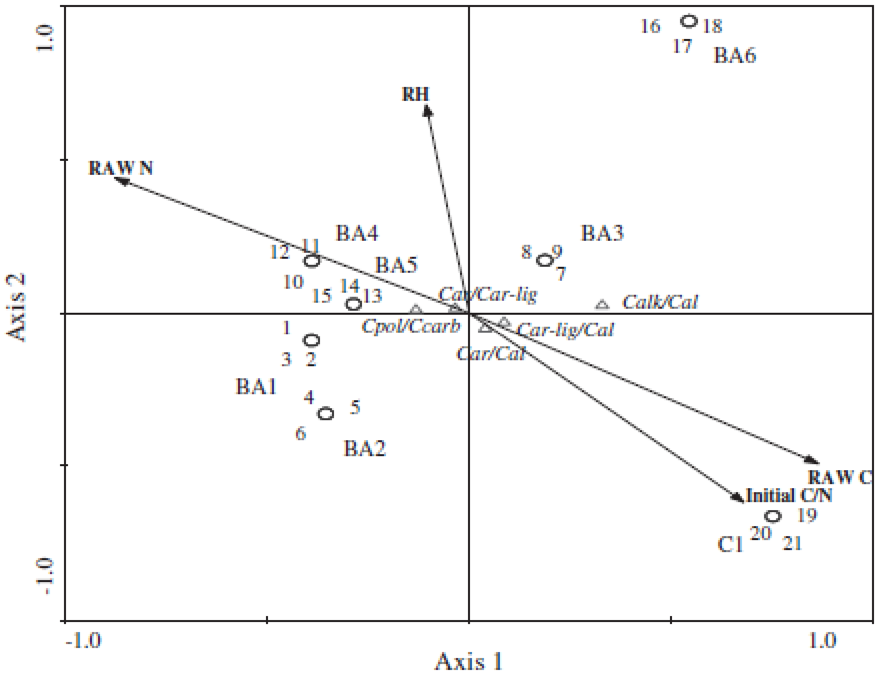


Fig. 1. Canonical correspondence analysis biplot of ratios between main peaks of FT-IR spectra (83.7% could be explained by axis 1 and 2.3% by axis 2) in function of the initial C/N ratio and percentage of raw material of the respective composts. The species-environmental correlations for axis 1 and 2 were, respectively, 0.964 and 0.639. Only the variables significantly (p < 0.05) explaining the observed ratios between the main peaks of FT-IR spectra variation are shown. RH – rice husks; Car –aromatic compounds (1650 cm^{-1}); Car-lig – aromatic compounds including the lignin (1510 cm^{-1}); Cal – aliphatic group (2930 cm^{-1}); Calk – alkyl and carboxylate groups (1384 cm^{-1}); Ccarb – carboxylate group (1235 cm^{-1}); Cpol – polysaccharide compounds (1030 cm^{-1}); 1–3 – BA1 triplicates; 4–6 – BA2 triplicates; 7–9 – BA3 triplicates; 10–12 – BA4 triplicates; 13–15 – BA5 triplicates; 16–18 – BA6 triplicates; 19–21 – C1 triplicates.

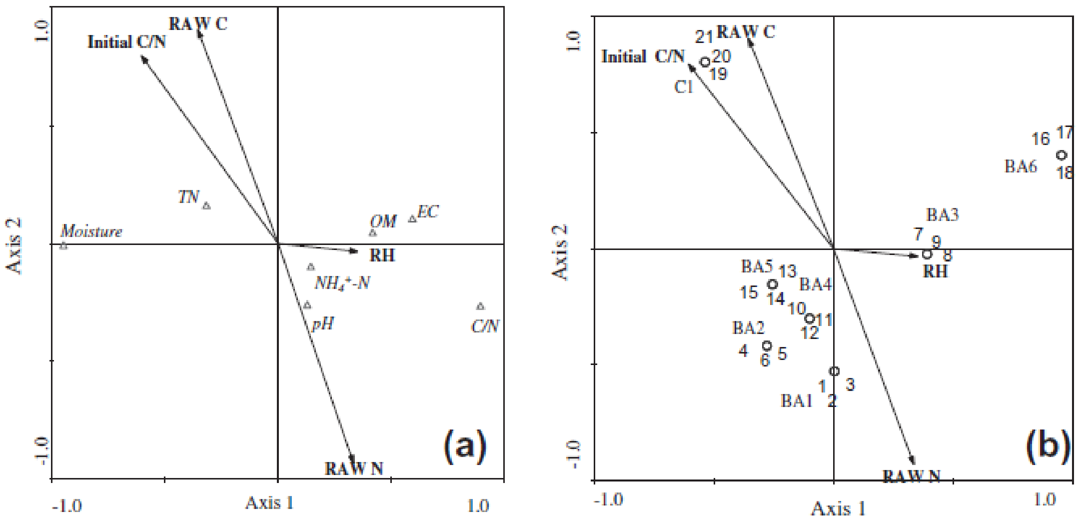


Fig. 2. Canonical correspondence analysis biplot of physicochemical parameters (83.5% could be explained by axis 1 and 2% by axis 2) in function of the initial C/N ratio and percentage of raw materials of the respective composts: (a) representation of physicochemical parameters distribution; (b) representation of composts distribution. The species-environmental correlations for axis 1 and 2 were, respectively, 0.940 and 0.786. Only the variables significantly ($p < 0.05$) explaining the observed physicochemical properties variation are shown. RH – rice husks; EC – electrical conductivity; OM – organic matter; TN – total nitrogen; 1–3 – BA1 triplicates; 4–6 – BA2 triplicates; 7–9 – BA3 triplicates; 10–12 – BA4 triplicates; 13–15 – BA5 triplicates; 16–18 – BA6 triplicates; 19–21 – C1 triplicates

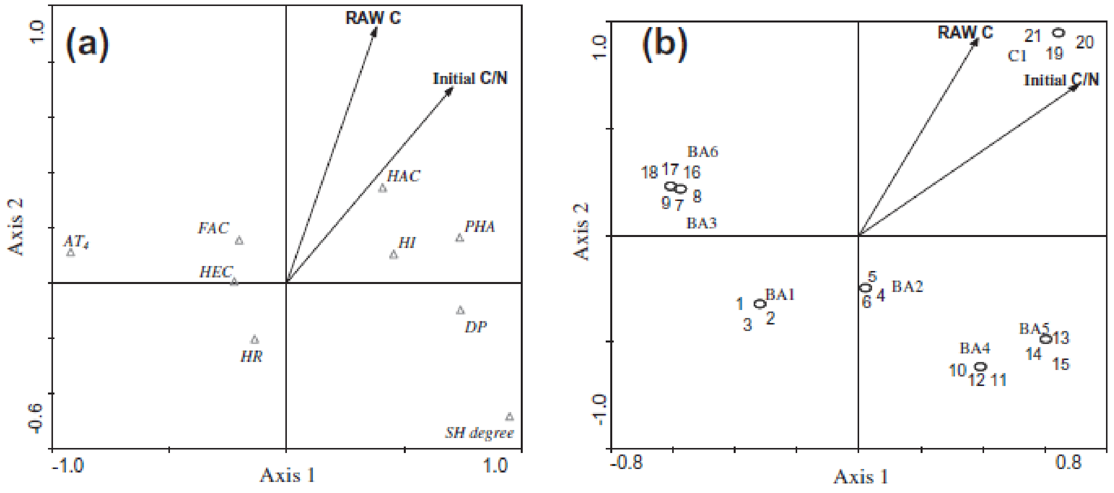
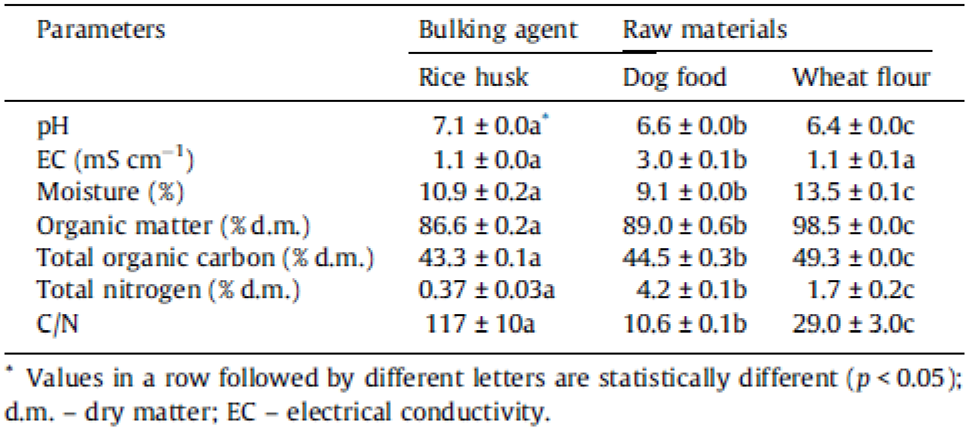


Fig. 3. Canonical correspondence analysis biplot of maturity and stability parameters (77.9% could be explained by axis 1 and 7.7% by axis 2) in function of the initial C/N ratio and percentage of raw materials of the respective composts: (a) representation of maturity and stability parameters distribution; (b) representation of composts distribution. The species-environmental correlations for axis 1 and 2 were, respectively, 0.959 and 0.862. Only the variables significantly ($p < 0.05$) explaining the observed

maturity and stability properties variation are shown. SH – self-heating; AT4 – respiration activity after 4 days; HEC – humic-like extract carbon; HAC –humic-like acid carbon; FAC – fulvic-like acid carbon; DP – degree of polymerization; HI – humification index; HR – humification ratio; PAH – percentage of humic-like acids; 1–3 – BA1 triplicates; 4–6 – BA2 triplicates; 7–9 – BA3 triplicates; 10–12 – BA4 triplicates; 13–15 – BA5 triplicates; 16–18 – BA6 triplicates; 19–21 – C1 triplicates.

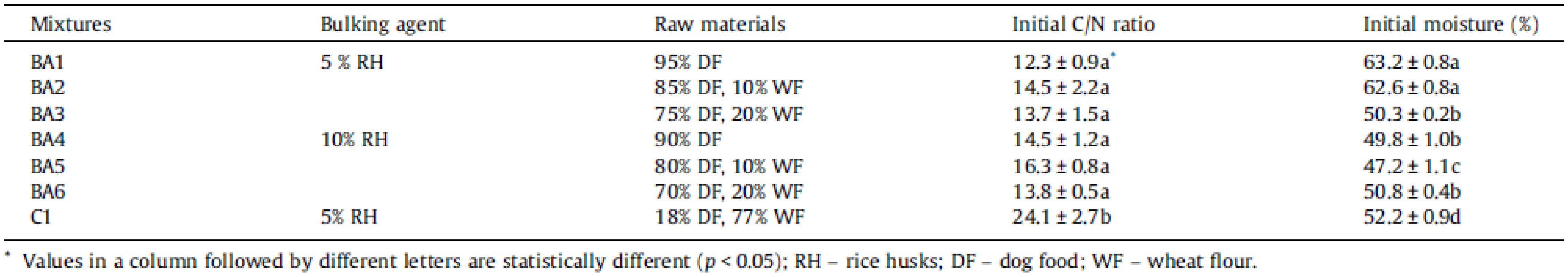
Table 1. Physicochemical characteristics of the raw materials (dog food and wheat flour) and the bulking agent (rice husk) used to produce the compost.



Parameters	Bulking agent	Raw materials	
	Rice husk	Dog food	Wheat flour
pH	7.1 ± 0.0a[*]	6.6 ± 0.0b	6.4 ± 0.0c
EC (mS cm^{-1})	1.1 ± 0.0a	3.0 ± 0.1b	1.1 ± 0.1a
Moisture (%)	10.9 ± 0.2a	9.1 ± 0.0b	13.5 ± 0.1c
Organic matter (% d.m.)	86.6 ± 0.2a	89.0 ± 0.6b	98.5 ± 0.0c
Total organic carbon (% d.m.)	43.3 ± 0.1a	44.5 ± 0.3b	49.3 ± 0.0c
Total nitrogen (% d.m.)	0.37 ± 0.03a	4.2 ± 0.1b	1.7 ± 0.2c
C/N	117 ± 10a	10.6 ± 0.1b	29.0 ± 3.0c

[*] Values in a row followed by different letters are statistically different ($p < 0.05$); d.m. – dry matter; EC – electrical conductivity.

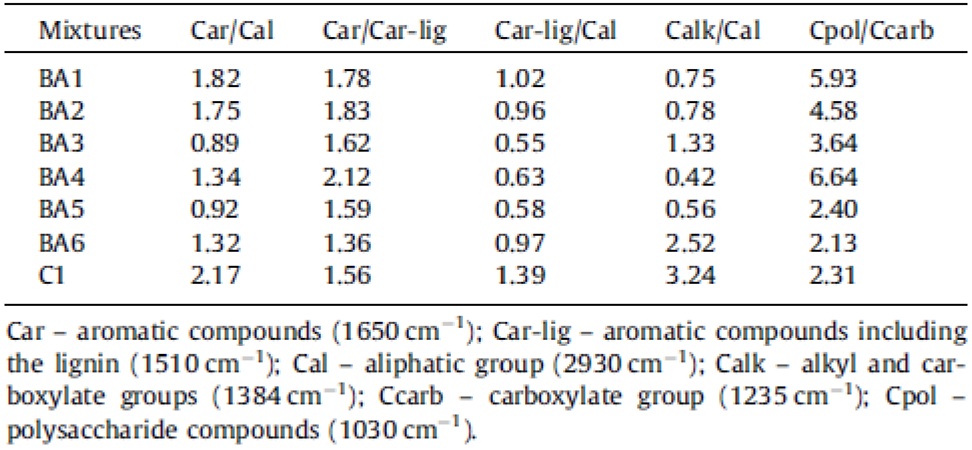
Table 2. Composition of the mixtures to produce BA1-6 and C1 composts.



Mixtures	Bulking agent	Raw materials	Initial C/N ratio	Initial moisture (%)
BA1	5 % RH	95% DF	12.3 ± 0.9a[*]	63.2 ± 0.8a
BA2		85% DF, 10% WF	14.5 ± 2.2a	62.6 ± 0.8a
BA3		75% DF, 20% WF	13.7 ± 1.5a	50.3 ± 0.2b
BA4	10% RH	90% DF	14.5 ± 1.2a	49.8 ± 1.0b
BA5		80% DF, 10% WF	16.3 ± 0.8a	47.2 ± 1.1c
BA6		70% DF, 20% WF	13.8 ± 0.5a	50.8 ± 0.4b
C1	5% RH	18% DF, 77% WF	24.1 ± 2.7b	52.2 ± 0.9d

[*] Values in a column followed by different letters are statistically different ($p < 0.05$); RH – rice husks; DF – dog food; WF – wheat flour.

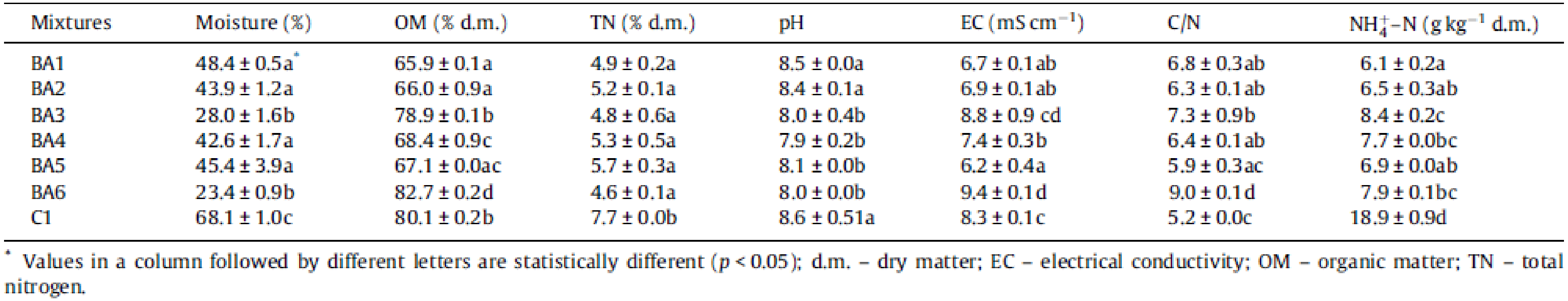
Table 3. Ratios between the main peaks of FT-IR spectra.



Mixtures	Car/Cal	Car/Car-lig	Car-lig/Cal	Calk/Cal	Cpol/Ccarb
BA1	1.82	1.78	1.02	0.75	5.93
BA2	1.75	1.83	0.96	0.78	4.58
BA3	0.89	1.62	0.55	1.33	3.64
BA4	1.34	2.12	0.63	0.42	6.64
BA5	0.92	1.59	0.58	0.56	2.40
BA6	1.32	1.36	0.97	2.52	2.13
C1	2.17	1.56	1.39	3.24	2.31

Car – aromatic compounds (1650 cm^{-1}); Car-lig – aromatic compounds including the lignin (1510 cm^{-1}); Cal – aliphatic group (2930 cm^{-1}); Calk – alkyl and carboxylate groups (1384 cm^{-1}); Ccarb – carboxylate group (1235 cm^{-1}); Cpol – polysaccharide compounds (1030 cm^{-1}).

Table 4. Physicochemical properties of the composts.



Mixtures	Moisture (%)	OM (% d.m.)	TN (% d.m.)	pH	EC (mS cm^{-1})	C/N	NH_4^+–N (g kg^{-1} d.m.)
BA1	48.4 ± 0.5a[*]	65.9 ± 0.1a	4.9 ± 0.2a	8.5 ± 0.0a	6.7 ± 0.1ab	6.8 ± 0.3ab	6.1 ± 0.2a
BA2	43.9 ± 1.2a	66.0 ± 0.9a	5.2 ± 0.1a	8.4 ± 0.1a	6.9 ± 0.1ab	6.3 ± 0.1ab	6.5 ± 0.3ab
BA3	28.0 ± 1.6b	78.9 ± 0.1b	4.8 ± 0.6a	8.0 ± 0.4b	8.8 ± 0.9 cd	7.3 ± 0.9b	8.4 ± 0.2c
BA4	42.6 ± 1.7a	68.4 ± 0.9c	5.3 ± 0.5a	7.9 ± 0.2b	7.4 ± 0.3b	6.4 ± 0.1ab	7.7 ± 0.0bc
BA5	45.4 ± 3.9a	67.1 ± 0.0ac	5.7 ± 0.3a	8.1 ± 0.0b	6.2 ± 0.4a	5.9 ± 0.3ac	6.9 ± 0.0ab
BA6	23.4 ± 0.9b	82.7 ± 0.2d	4.6 ± 0.1a	8.0 ± 0.0b	9.4 ± 0.1d	9.0 ± 0.1d	7.9 ± 0.1bc
C1	68.1 ± 1.0c	80.1 ± 0.2b	7.7 ± 0.0b	8.6 ± 0.51a	8.3 ± 0.1c	5.2 ± 0.0c	18.9 ± 0.9d

[*] Values in a column followed by different letters are statistically different ($p < 0.05$); d.m. – dry matter; EC – electrical conductivity; OM – organic matter; TN – total nitrogen.

Table 5. Maturity and stability degree of the composts.

Mixtures	HEC (%, d.m.)	HAC (%, d.m.)	FAC (%, d.m.)	DP	HR (%)	HI (%)	PHA (%)	AT_4 ($mgO_2\ g^{-1}$ d.m.)	SH degree
BA1	8.6 ± 0.0a*	1.6 ± 0.0a	5.3 ± 0.1a	0.31 ± 0.01a	26.1 ± 0.1ab	4.9 ± 0.1a	19.0 ± 0.4a	18.8 ± 0.7a	IV
BA2	10.5 ± 0.3b	2.0 ± 0.1b	6.8 ± 0.3b	0.29 ± 0.02a	31.9 ± 1.0c	5.9 ± 0.4b	18.5 ± 0.7a	21.8 ± 0.4b	IV
BA3	11.8 ± 0.5c	2.2 ± 0.1c	8.1 ± 0.1c	0.27 ± 0.02ab	30.4 ± 1.3c	5.7 ± 0.3b	18.7 ± 1.5a	26.9 ± 0.0c	II
BA4	7.3 ± 0.3d	1.3 ± 0.1d	5.3 ± 0.2a	0.24 ± 0.02b	21.4 ± 0.9d	3.8 ± 0.4c	17.6 ± 1.5a	8.8 ± 0.2d	V
BA5	8.3 ± 0.3a	2.3 ± 0.0c	4.4 ± 0.2d	0.52 ± 0.02c	24.6 ± 0.9ae	6.8 ± 0.1d	27.6 ± 0.7b	8.8 ± 0.3d	V
BA6	11.5 ± 0.1c	1.7 ± 0.1a	7.3 ± 0.1e	0.24 ± 0.01b	27.9 ± 0.3b	4.2 ± 0.2c	15.0 ± 0.7c	25.4 ± 1.1e	II
C1	9.1 ± 1.1a	3.0 ± 0.1e	6.8 ± 0.2b	0.44 ± 0.03d	25.9 ± 2.8de	7.5 ± 0.3e	33.2 ± 2.7d	12.3 ± 0.6f	V

* Values in a column followed by different letters are statistically different ($p < 0.05$); d.m – dry matter; HEC – humic-like extract carbon; HAC – humic-like acid carbon; FAC – fulvic-like acid carbon; DP – degree of polymerization; HI – humification index; HR – humification ratio; PAH – percentage of humic-like acids; SH – self-heating; AT_4 – respiration activity after 4 days.