COMPOSTING OF BREWERY WASTES WITH AGRICULTURAL AND FOREST RESIDUES

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1 INTRODUCTION

Spain is the third beer producer of the European Union, together with Poland and behind United Kingdom and Germany (Food and Agriculture Organisation, 2009). Bagasse (BG) and yeast waste (YW) are the main organic residues produced by the brewery industry. In 2008, Spain produced $34{,}350 \times 10^3$ hectolitres of beer, which generated 688,546 tonnes of BG and 86,047 tonnes of YW (Food and Agriculture Organisation, 2009; Canales et al., 2005). Several methods have been proposed for BG disposal including feedstuff (Fillaudeau et al., 2006), bioplastic (Yu et al., 1999) production and treatment by anaerobic fermentation (Fillaudeau et al., 2006). Other studies have been focused on the YW disposal, such as livestock feed (Fillaudeau et al., 2006), heavy metal biosorbent production (Chen and Wang, 2008) and the recovery of high value-added compounds, used in food, cosmetic and pharmaceutical industries (Canales y col., 2005). However, relatively little research have been carried out on the composting of brewery wastes. Sanchez-Monedero et al. (2001) composted brewery sludge (sludge resulting from the depuration of brewery wastewater) with sorghum bagasse and pine bark and Garcia-Gomez et al. (2005) composted BG with others lignocellulosic materials. The aim of this work was to study the evolution of some parameters describing the stabilisation and maturity of brewery wastes when composted with agricultural and forest residues.

2 MATERIALS AND METHODS

2.1 Composting procedure

Two different piles were prepared with mixtures of BG, banana waste (BW), pine chip (PC) and YW. The main characteristics of the initial materials were: for BG, pH 4.9, 4.72 dS m^{-1} electrical conductivity (EC), 81.5% organic matter (OM), 40.4% total organic carbon (C_T) and 3.40% total nitrogen (N_T); for BW, pH 5.5, 1.34 dS m^{-1} EC, 87.2% OM, 42.1% C_T and 1.63% N_T; for PC, pH 5.3, 0.20 dS m^{-1} EC, 86.6% OM, 53.9% C_T and 0.28% N_T and for YW, pH 4.4, 5.52 dS m^{-1} EC, 87165 mg O_2 L^{-1} chemical oxygen demand (COD) and 5250 mg L^{-1} suspended solids (SS). The mixtures were prepared in the following proportions, on a fresh weight basis:

Pile 1: 50% BG + 25% BW + 25% PC
Pile 2: 50% BG + 25% BW + 25% PC + 1.7 litres of YW per kg of mixture

The moisture of the piles was controlled by adding the necessary amount of water once a week to obtain a moisture content between 40 and 60%. In pile 2, 0.16 litres of yeast waste per kg of mixture was added on the first day, and the remaining volume, up to the total of 1.7 L kg^{-1}, was added gradually up to 65 days of composting. The mixtures were composted in a turned windrow composting system. The piles were turned weekly until day 91, in order to improve both the homogeneity of the material and the bio-oxidative degradation of the organic matter.. The bio-oxidative and mature phases lasted 126 and 60 days, respectively. The samples were taken by mixing seven subsamples from seven sites of the windrow, from the whole profile (from the top to the bottom of the windrow). Each sample was air-dried and ground to 0.5mm for analysis.

2.2 Analytical methods

In the starting materials and in the composting samples, EC, pH, COD, SS, OM, ash, N_T, C_T, humic acid-like carbon (C_{HA}), fulvic acid-like carbon (C_{FA}) and cation exchange capacity (CEC) were determined according to Bustamante et al. (2007, 2005), while the germination index (GI) was calculated using seeds of *Lepidium sativum* L. (Zucconi et al., 1981). Losses of OM were calculated from the initial (X_1) and final (X_2) ash contents according to the equations of Paredes et al. (2001):

$$\text{OM-loss (\%)} = 100 - 100\,[X_1\,(100 - X_2)]\,/\,[(X_2\,(100 - X_1)]$$

3 RESULTS AND DISCUSSION

Both piles showed a typical composting temperature trend, reaching thermophilic temperatures (>40ºC) during the first two weeks of composting and maintaining the thermophilic phase for approximately 35 days (Figure 1a). Pile 1 reached higher temperature values than pile 2. However, in both piles, the temperature exceeded 55°C for more than two weeks, which presumably ensured the maximum pathogen reduction, following European guidelines on compost sanitation (European Commission, 2001).

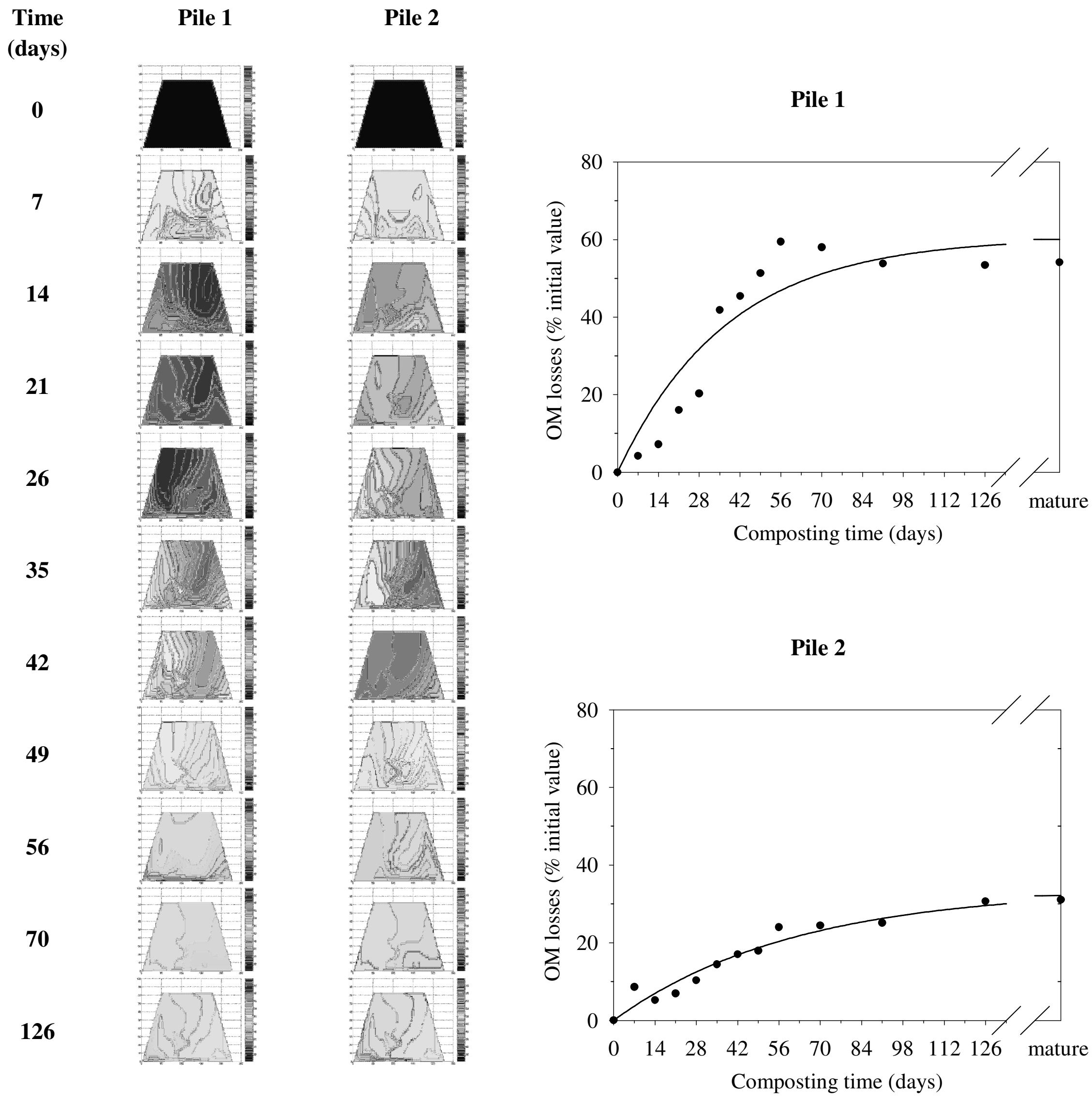

FIGURE 1 **Temperature development (a) and organic matter losses (b) during the composting of the two studied blends. Lines on graphs represent curve-fitting.**

The degradation of organic matter during composting, as determined by OM loss, followed a first-order kinetic equation:

$$\text{OM loss} = A\,(1 - e^{-kt})$$

where A is the maximum degradation of organic matter (%), k the reaction rate constant ($days^{-1}$) and t the elapsed composting time (days). Curve fitting of the experimental data gave the following parameter values (standard deviation in brackets):

Pile 1: $A = 60.6$ (6.1) $k = 0.0266$ (0.0068) RMS = 0.8629 $F = 76.55^{***}$ SEE = 8.36

Pile 2: $A = 33.8$ (2.7) $k = 0.0164$ (0.0026) RMS = 0.9452 $F = 208.00^{***}$ SEE = 2.34

where SEE is the standard error of estimation. All equations were significant at $P < 0.001$. The OM degradation kinetics of both piles fitted satisfactorily this equation. The A value obtained in pile 1 was close to 59.8–68.4%, the range found by Paredes et al. (2001) in a composting experiment of agroindustrial and urban wastes with olive mill wastewater. However, the value of this parameter in pile 2 was lower than those found by the previously mentioned authors. The YW addition in pile 2 decreased the rate of OM degradation in comparison to pile 1, as it is demonstrated by the lower values of k and the product of $A \times k$. The lower values of OM degradation and rate of OM degradation recorded in pile 2 could be due to the higher values of salinity observed in this mixture (Table 1), which could inhibit microbial growth. This fact was also observed by Diaz et al. (2002) in an experiment of grape marc composting with increasing amounts of beet vinasse (liquid residue from the sugar industry with high salt content).

TABLE 1 **Evolution of physico-chemical parameters during the composting process.**

Days	pH	EC ($dS\ m^{-1}$)	C_T (%)	N_T (%)	C/N	C_{HA} (%)	C_{FA} (%)	CEC[1] ($meq\ 100\ g^{-1}$)	GI (%)
Pile 1: BG + BW + PC									
0	6.1	2.98	47.0	2.36	19.9	3.28	4.62	52.7	81.3
7	4.7	3.65	45.4	2.56	17.7	3.50	4.53	n.d.	99.8
21	6.2	3.13	40.9	2.75	14.9	3.70	2.97	n.d.	89.7
35	6.5	2.72	39.6	3.16	12.5	n.d.	n.d.	n.d.	86.5
49	6.7	2.68	38.9	3.32	11.7	n.d.	n.d.	n.d.	83.6
70	6.6	3.23	38.7	3.89	9.9	n.d.	n.d.	n.d.	97.6
126	6.4	3.03	37.6	3.92	9.6	6.01	2.28	128.6	88.6
mature	6.6	3.08	38.1	4.07	9.3	6.28	2.27	131.7	95.8
Pile 2: BG + BW + PC + YW									
Days	**pH**	**EC ($dS\ m^{-1}$)**	**C_T (%)**	**N_T (%)**	**C/N**	**C_{HA} (%)**	**C_{FA} (%)**	**CEC[1] ($meq\ 100\ g^{-1}$)**	**GI (%)**
0	5.92	3.70	42.5	2.87	14.8	3.24	4.65	62.9	99.2
7	4.90	5.04	43.0	3.15	13.7	2.79	6.81	n.d.	39.1
21	4.82	5.25	41.2	3.03	13.6	2.82	7.98	n.d.	32.2
35	5.34	5.39	42.1	3.30	12.8	n.d.	n.d.	n.d.	50.8
49	4.59	5.71	43.2	3.84	11.3	n.d.	n.d.	n.d.	60.2
70	4.76	5.88	40.2	4.34	9.3	n.d.	n.d.	n.d.	23.5
126	5.07	4.75	41.9	4.62	9.1	3.52	9.59	86.0	68.2
mature	5.72	5.26	41.8	4.70	8.9	3.81	9.59	83.7	50.4

[1]Ash-free material.

BG: bagasse; BW: banana waste; PC: pine chip; C_T: total organic C; N_T: total nitrogen; C_{HA}: humic acid-like C; C_{FA}: fulvic acid-like C; CEC: cation exchange capacity; GI: germination index; n.d.: not determined

The pH in pile 1 initially decreased, probably due to the generation of acid-type organic compounds of low molecular-weight via the decomposition of the most-easily-degradable OM fraction (Table 1). Then, this parameter increased, as a consequence of the degradation of acid type compounds, such as carboxylic and phenolic groups, and the mineralisation of proteins, amino acids and peptides to ammonia (Bustamante et al., 2007). The pH in pile 2 initially also decreased, probably due to a similar formation of organic acids. However, in this pile this parameter did not then increase during composting, which could be related to the addition of YW with acidic pH or the nitrate formation (Bustamante et al., 2007). The EC also increased during composting because of the production of inorganic compounds, as a result of OM degradation, and the increase in the relative concentration of ions due to the loss of weight of the pile. The higher EC in the pile containing YW was clear from the beginning of the process, and was probably due to the soluble salts provided from YW. This EC increase during composting of mixtures of organic wastes with agroindustrial wastewater has been observed by others authors (Paredes et al., 2001 (olive mill wastewater); Diaz et al., 2007 (beet vinasse); Bustamante et al., 2007 (vinasse from distillery)).

N_T concentrations increased during the process in both piles (Table 1), most probably as a consequence of a concentration effect caused by the reduction in the pile weight, as it has been observed in other composting experiments (Paredes et al., 2001; Bustamante et al., 2007). In addition to the reduction of the Corg concentration in both piles, another consequence of the organic matter degradation was that the C/N ratio fell sharply in both mixtures from the beginning of the process until day 70. Then, it remained steady and after the two months of maturation fell to around 9, which suggested that both composts showed an acceptable degree of maturation (Bernal et al., 1998).

In pile 1, the C_{FA} content fell during composting (Table 1), indicating the degradation of easily bio-degradable organic compounds associated with the fulvic acid fraction, which are produced during the humification of organic matter. Also in this pile, the C_{HA} concentration increased during composting, as a consequence of the C_{FA} decreasing. However, the addition of YW in pile 2 reduced the C_{FA} transformation to C_{HA} and increased the C_{FA} content, probably due to the presence in this liquid waste of soluble organic compounds. Another parameter used as an indicator of the humification process is the CEC. This parameter increased during composting, showing the humification due to the formation of carboxyl and/or hydroxyphenolic functional groups (Lax et al., 1986). At the end of the maturation phase, the CEC values indicated a good degree of maturity in the composts elaborated, since these values were higher than those established by Iglesias Jiménez and Pérez García (1992) (CEC > 67 meq 100 g^{-1} OM). It is interesting to point out that during the maturation period the CEC increased hardly in pile 2, prepared with YW. This fact was also observed by Paredes et al. (2001) in a composting experiment, where the effect of olive mill wastewater addition in composting of agroindustrial and urban wastes was studied. The GI increased in the pile 1 throughout composting, being greater than 50% from the beginning of the process, the limit established by Zucconi et al. (1981), indicating the absence of phytotoxins in this compost. However, in the pile 2, this parameter decreased during composting probably due to its high value of salinity, as a consequence of the YW addition in this pile. Despite this fact, the final value of GI in compost 2 was > 50%, indicating the physiological compatibility with plants of this compost.

4 CONCLUSIONS

According to the results obtained, it can be concluded that composting can be considered as an alternative for the treatment of brewery waste, obtaining a compost with possible use as soil amendment. The addition of YW to pile 2 produced lower temperature values than in the pile watered with water, but, in general, the temperature profile of both piles was very similar. Also, the addition of YW in pile 2 produced a lower degradation of organic matter, higher EC values, as well as lower pH values than in pile 1. Moreover, the addition of this effluent also reduced the C_{FA} transformation to C_{HA}, increased the C_{FA} content and hardly the CEC and produced a longer persistence of phytotoxicity. However, both composts showed C/N ratio < 12, germination index > 50% and increases in the cation exchange capacity, which revealed the stabilisation and humification of the organic matter and the reduction of the phytotoxicity during composting.

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