Meat Waste as Feedstock for Home Composting: Effects on the Process and Quality of Compost

Francesco Storino[*1], Joseba S. Arizmendiarrieta[2], Ignacio Irigoyen[2], Julio Muro[2], Pedro M. Aparicio-Tejo[1]*

[1] Department of Environmental Science

[2] Department of Agricultural Production

Public University of Navarre (UPNA-NUP), Pamplona, Spain

[*] corresponding author. E-mail: francesco.storino@unvarra.es

Abstract

Home composting is a powerful tool, which is spreading in different parts of the world, to reduce the generation of municipal waste. However, there is debate concerning the appropriateness, in terms of domestic hygiene and safety, of keeping a composter bin in the household deputed to kitchen waste of animal origin, such as meat or fish scraps and pet droppings. The purpose of our work was to study how the addition of meat scraps to household waste influences the composting process and the quality of the final compost obtained. We compared four raw material mixtures, characterized by a different combination of vegetable and meat waste and different ratios of woody bulking agent. Changes in temperature, mass and volume, phenotypic microbial diversity

(by Biolog ™) and organic matter humification were determined during the process. At the end of the experiment, the four composts were weighed and characterized by physicochemical analysis. In addition, the presence of viable weed seeds was investigated and a germination bioassay was carried out to determine the level of phytotoxicity. Finally, the levels of pathogens (*E. coli* and *Salmonella* spp.) were also determined in the final compost.

Here we show that the presence of meat waste as raw feedstock for composting in bins can improve the activity of the process, the physicochemical characteristics and maturity of the compost obtained, without significantly affecting its salinity, pH and phytotoxicity. Pathogen levels were low, showing that they can be controlled by an intensive management and proper handling of the composter bins.

Keywords

Home composting; Waste prevention; Meat waste; Compost quality; Human pathogens

1. Introduction

The last report of The World Bank estimates that the current worldwide average generation rate of Municipal Solid Waste (MSW) per capita corresponds to approximately 1.2 kg per person per day and that by 2025 this will likely increase to 1.42 kg/person/day, reaching 2.2 billion tons of waste per year on a global scale (Hoornweg and Bhada-Tata, 2012).

In accordance with the last trend of environmental policies, composting is a valuable way of waste treatment that contributes to reduce organic waste destined to landfill disposal or incineration. Home and community composting have proven to be a sustainable strategy for food waste management that can reduce costs and environmental impact due to collecting, transport and treatment of MSW (Barrena et al., 2014). In addition, home-made compost usually presents better characteristics than full-scale compost because it is made by source-separated household

waste (Dimambro et al., 2007). However, in general a long duration time is required in home composting to fulfill the typical reference quality limits that are adoptable for compost (Tatàno et al., 2015).

A handful of studies exist concerning meat waste as feedstock for composting. In fact, the presence of meat scraps in household compost is the subject of extensive debate that needs to be further investigated.

Concerning the legal aspects, the disposal of meat waste for composting at a home-scale is more or less regulated in the majority of countries. In European countries it is controlled under the Animal By-Products regulation (Regulation EC 1069/2009). According to this regulation, only a few European countries prohibit the inclusion of meat waste in home composting, while most countries do not regulate the utilization of meat waste when it is composted at home or on a community scale. It is quite obvious that specific legal rules for self-composting are needed to clear the picture. In the United States, instead, single state regulation concerning home composting is missing, since the utilization of meat waste for composting *in situ* is at the discretion of the local authorities that can either allow it or not (Platt et al., 2014).

On the downside, the possible development of odors or presence of insects and rodents are the main issues of some local authorities and composters associations that often discourage the use of meat waste as feedstock for home composting (Duplessis, J. and Nova Environcom, 2006; MAGRAMA, 2008; VLACO 2012; USDA). Moreover, although the compost obtained from source-separated food waste is generally considered a high quality compost, some authors have reported problems concerning the quality of the compost obtained by kitchen and catering waste containing meat scraps in terms of sanitation (Harrison, 2004), phytotoxicity, heavy metals (Zheljazkov and Warman, 2004), pH and salinity (He et al., 1995; Dimambro et al., 2007).

On the bright side, however, home and community composting can be considered as a legitimate alternative for the treatment of meat waste, which constitutes a traditional component of household food waste. To ensure the effectiveness of home composting as an efficient management tool of organic waste it is essential, in fact, that more kinds of household organic waste can be processed, including waste of animal origin. The composting of meat scraps could thus be added to the various kinds of household organic waste that are already efficiently composted at a decentralized level, relieving the community from the costs and management of such a problematic source of organic matter.

Moreover, the utilization of meat waste as composting feedstock may also improve the composting technique. As previously described (Smith and Jasim, 2009; Adhikari et al. 2012; Barrena et al. 2015), thermophilic temperatures were frequently not reached in home composting, entailing subsequent problems like pests and a deficient control in the vitality of weed seeds. Thus, the presence of meat waste in household composting may be an opportunity to increase the temperatures during the process with positive consequences on the control of weed germination and diffusion of pathogens and vectors of plant diseases in the final composts. An experiment of synthetic food composting (Chang and Hsu, 2008) demonstrated that increasing the protein ratio on feedstock materials promoted high temperature and CO_2 production during the process, increasing microbial activity. In addition, the intake of high-protein feedstock shortened the initial acidification that brought, in turn, to a higher final pH of the compost.

Currently, the composting of animal by-products at an industrial-scale has been proven to be successful on a larger kind of animal feedstock, such as butchery and household meat waste (Schaub and Leonard, 1996; Vidussi and Rynk, 2001; Arvanitoyannis and Ladas, 2008), livestock carcasses (Imbeah, 1998; Stanford et al., 2000; Kabalsi et al., 2005) or fishery offal (Liao et al., 1997; Laos et al., 2002). The way in which this model can be applied to small–scale composting and the best practices to ensure a correct and safe composting process need to be investigated.

The opportunity to use meat waste in home composting requires scientific studies that endorse it to guide users concerning the aspects behind a better management of the composting operation. Here we show the effects of the utilization of household meat waste as feedstock for composting at a small scale on the evolution of the composting process and quality of the final compost obtained.

2. Materials and Methods

2.1. Experimental design and setup

The experiments were conducted at the experimental farm of the Public University of Navarre, in Pamplona, Spain. In this experimental trial 320 L composter bins (Komp 320, Container Trading WFW GmbH, Austria) were used. Each bin was characterized by 4 trapezoidal dark-green plastic sides with vents to provide improved aeration, a hinged lid at the top to fill the bin and an open panel at the bottom to retrieve the compost. Each bin presented a square base of 76x76 cm and was 86 cm high.

The composter bins were fed with food waste: vegetal food waste and meat waste (if required by the treatment). Vegetal food waste was delivered from a local street market and from the farm and composed of fruit and vegetable scraps, mixed with leaves and grass clippings (dry content matter of mix 15-85%). The composition of vegetal waste was very heterogeneous depending on the availability of fruit and vegetables in the market, which simulated household behavior. Meat waste consisted in raw meat scraps of edible parts, fat and bone of cattle, pigs and poultry, suitable for human consumption similar to household food waste.

Food waste was mixed with vegetal bulking agent. Chipped pruning residues of winter wood were provided by the garden service of the Pamplona City Council and were added as bulking agent (dry matter 55-60%) to favor aeration and prevent leachate formation. For all treatments

the bulking agent was replaced, following the first addition of waste, by commercial compost without sifting to promote the activation of the composting process (5 kg/bin).

Four different raw material mixtures of waste were evaluated and compared:

-"M0B1" (Meat0, Bulking agent1): only vegetal feedstock. Vegetal food waste was added and mixed to the bulking agent in a volume ratio of 1:0.6.

-"M1B1" (Meat1, Bulking agent1): low dosage (5%) of meat waste (fresh weight) was added to the vegetal food waste (ratio food waste/bulking agent 1:0.6 of volume).

-"M2B1" (Meat2, Bulking agent1): high dosage (15%) of meat waste (fresh weight) was added to the vegetal food waste (ratio food waste/bulking agent 1:0.6 of volume).

-"M2B2" (Meat2, Bulking agent2): like M2B1, but with a double ratio of bulking agents (ratio food waste/bulking agent 1:1.2 of volume). The double amount of woody materials was introduced as treatment with the aim to observe if it produced an improvement in the composting conditions, by increasing aeration and avoiding leachate formation. A good aeration and porosity of material during composting usually prevents the establishment of anaerobic conditions and increases ventilation and aerobic respiration activity of microorganisms.

Four repetitions for each treatment were performed on a randomized-block experimental scheme. The experimental unit was a single composter bin; a total of 16 bins were employed throughout the experiment.

Food waste was weighed and added to the bins on a weekly basis during the first 6 weeks ("feeding phase"). In total 120 kg of food waste was added to each bin. The total amount of meat waste was 6 kg per bin in M1B1 treatment and 18 kg in M2B1 and M2B2. The amount of food waste added weekly decreased during the course of the experiment due to the progressive

reduction of empty space in the bin. A summary of the amount of weekly additions of food waste is reported in Table 1.

The experimental trial evaluated the first 24 weeks of the composting process. The 6 weeks of the feeding phase followed by the 18 weeks when no waste was added to the compost for all treatments. Moisture content during composting was monitored qualitatively twice a week using the "fist test". This involves squeezing a compost sample in the fist; if water emerges from the fist, then the sample is too wet. The moisture content is suitable (approximately 50-60%) if the pressed sample does not release water but remains compact; if it crumbles apart when released, it is too dry (FCQAO 1994). During the last weeks of the process the handling of the bins was reduced to the minimum, consisting only of manual turning and watering when compost humidity was less than 50%. According to the results of the Dewar self-heating test, the composting process was considered ended 18 weeks after the last waste addition, when all the compost reached the Rottegrade degree of V. The resulting composts were sampled, taking 6 sub-samples for each bin at three different depths. Subsequently, the sub-samples were mixed and reduced to one final sample of 3 L using the quarter method (TMECC, 2002). In the end, the final sample was sieved on a 16 mm mesh and characterized by physicochemical analysis.

2.2. Evolution of the composting process

Throughout the composting process, the temperature inside each bin was measured by using a digital stem thermometer that was placed in the middle of the bin's content. The temperature was measured in 4 points of the composting material within the bin. The first and second points were placed, respectively, at 20 and 40 cm from the ground, in correspondence with the ventilation holes of the bin. The third point was at the top of the material inside the bin. Because of the limited depth reached by the pin of the thermometer (20 cm), the temperature in the fourth

point was measured approximately in the center of the decomposing organic waste. Finally, the average value of the 4 measurements was calculated and reported as the result.

The number of thermophilic days (NTD) was calculated as the number of days during which the compost's temperature was higher than the thermophilic threshold (45ºC). The thermophilic heat sum (THS) was calculated as the sum of the daily difference between the temperature reached by the compost and 45ºC.

Compost volume variations were determined by measuring the height reached by the compost inside the bin. Volume losses were calculated as percentage in ratio between the final compost volume and the sum of volume gain following each waste addition (Breitenbeck et al., 2004). Weight loss ratio was calculated in the same way. Losses were calculated using the following equations:

-Weight loss ratio = 100 [1 – final weight/(previous phase weight intake + sum of weight intakes)];

-Volume loss ratio = 100 [1 – final volume/(initial volume + increments of volume by intake)];

Stability and maturity of composts were determined in the intermediate and final samples of waste composted. The degree of maturity of compost for each treatment was estimated by the Solvita® kit test (Wood Ends Research Laboratory, USA) 14 weeks after the last waste addition. The stability of compost was estimated by determining the Rottegrade Index by the self-heating Dewar test following the EN standard method (EN-16087-2:2011) at 24 weeks of the process, considering the composting process finished 18 weeks after the last waste addition.

Phenotypic variability of the microbial community during the composting process was studied by comparing the three indexes provided by Biolog analysis (Frac et al. 2012) performed

after 11 weeks without waste addition. The Ecoplate Biolog TM contains 30 wells with different carbon sources and one control well without a carbon source. The tetrazolium dye present on the plates is reduced with NADH product of microbial activity, resulting in a purple coloration whose intensity depends on the metabolic profile of a microbial community (Garland and Mills, 1991). The number of used substrates (NUS) was counted for each plate. The overall metabolic activity in a plate was expressed as average well color development (AWCD), an index correlated with the optical density of all wells of the plate (Riddech et al., 2002). The Shannon index (H), which is correlated with the relative absorbance of a single well compared to the whole plate, was used as a measure of diversity of the extent of utilization of particular substrates (Stefanowicz, 2006). All indexes were measured at 24, 48 and 72 hours after sample preparation.

2.3. Characterization of compost

At the end of the maturation phase, composts were sampled for the last time and dried at open air for one week. Physicochemical analyses were conducted in air-dried grinded samples of compost sieved through a 16 mm mesh. Moisture and dry matter content of the final composts were determined in no sieved samples during the experimental trial by drying at 70ºC until the constant weight was reached (TMECC 2002). Electrical conductivity and pH of samples of the final compost were determined in water extract 1:5 vol (TMECC, 2002). Density of compost was determined following the German official method (FQCAO, 1994).

Total N, total C (TC) and organic C (TOC) were determined by the LECO elemental analyzer. Samples of compost were placed into a microwave digester with HNO_3 and H_2O_2 without being further milled, and were subsequently analyzed by ICP-OES to determine the concentrations of nutrients and trace elements (Al, As, P, B, Be, Bi, Ca, Cd, Co, Cu, Fe, Li, Ni, P, Pb, Sb, Se, Ti, Tl, V and Zn).

An analysis of the humic substance of composts was performed to characterize the organic matter and observe differences of humification extent among the composts. The analysis of the humic substance is largely employed to study the quality of the compost and its value as organic fertilizer; the degree of organic matter humification is, in fact, an indicator of compost stability and, consequently, reflects a better agricultural quality of compost (Bernal, 2009). During humification, that occurs through the composting process, the microbial degradation of recalcitrant fractions of organic matter and the following reactions of condensation and polymerization decrease in less polymerized compounds (fulvic acids) and increase in the fraction of humic acids of higher molecular weight (Iglesias-Jimenez and Perez-Garcia, 1992). Total humic extract and humic acids content of compost were determined by the sequential fractionation procedure described by Dabin (1971) and Duchaufour (1977). The total humic extract was obtained from extractions with $Na_4P_2O_7$ and NaOH. The humic acids fraction was precipitated from the total humic extract with HCl (pH 1–2). The organic carbon (Corg) content of the different fractions was determined by dichromate oxidation and Mohr salt titration following the Walkley–Black method (Walkley and Black, 1934). The weight of each fraction was calculated by assuming 58% of total C while 77% of organic C was oxidized (Nelson and Sommers, 1982). The total humic extract for carbon is denominated alkali-extractable organic carbon (Cex). The fulvic acid carbon (Cfa) was calculated by subtracting the humic acid carbon (Cha) from Cex. Indexes used for evaluation of the humification level in the material during composting in this study were calculated following the equations reported by Bernal et al. (2009):

– Humification ratio (HR): Cex/TOC X 100;

– Humification index (HI): Cha/TOC X 100;

– Percent of humic acids (PHA): Cha/Cex X 100;

– Polymerization index (PI): Cha/Cfa.

2.4. Phytotoxicity

Potential phytotoxicity was quantified by two germination bioassays. The first bioassay, conducted following the Italian official method UNI 10780:1998 (modified), was performed using the commercial seeds of cress cv. Alenois (*Lepidium sativum* L.). The compost (200 g) was moistened at 85% with deionized water and left standing for 2 hours. It was further centrifuged (6,000 rpm, 15 minutes) and filtered through a filter paper with the help of a vacuum-pump. A control treatment was prepared with deionized water. The compost extract obtained was used at different dilution rates. For each experimental unit (bin) three samples were analyzed. Ten seeds of cress were placed in 9 cm Petri plates with 5 ml of compost extract and placed in a germination chamber at 27°C for 24 hours in absence of light. In addition, a second bioassay was performed with lettuce cv. Solana (*Lactuca sativa* L.) seeds. In this case, the plates were incubated for 48 hours at 16°C. Differences with control in terms of number of geminated seeds and roots length were expressed in germination index (IG_e; Zucconi et al. 1981). The phytotoxicity was indicated by values of IG_e <60.

2.5. Weed seed control

Weed seed vitality loss during composting was evaluated by two tests.

The first of these, a devitalizing seed test, was carried out by incubating some weed seeds into the composting bin in order to observe the possible effects of their germination capacity. At the fourth week of the experimental trial a wire mesh container with 100 seeds of *Vicia sativa, Onobrychis vicifolia, Melilotus officinalis, Agropyrum cristatum, Cynodon dactylon* and *Plantago lanceolata* and 40 seeds of *Lupinus luteus* was introduced into the center of the compost of each bin. At the end of the trial the mesh was opened and the seeds placed in Petri plates with moist paper and incubated at 20ºC with no light for 12 days, following the indication of ISTA

(1985). The same number of seeds, but without being composted, was placed in the same conditions as control group.

The second test consisted in the incubation of the obtained compost in pots at the end of the maturation phase, in order to observe the possible presence of seeds capable of germinating and plant parts capable of sprouting. Four 45 g samples of final compost were mixed with peat and perlite at different ratios and were incubated in 8 L pots for 30 days in a heated glass greenhouse with natural light and regular watering in optimal conditions for germination (method adapted from FCQAO 1994). Germinated seeds were counted distinguishing between monocotyledonous and dicotyledonous plants.

2.6. Human pathogens

In terms of human health risks two indicators were utilized in this work to determine the inactivation of pathogens during composting, following the legal requirements in Europe: *Salmonella* spp. CFU (Colony Forming Units) in 25 g samples and *Escherichia coli* MPN (Most Probable Number) in 1 g samples. Human pathogen levels were determined by analyzing samples of the final compost. *Salmonella* spp. analysis was performed by using a technique of pre-enrichment, selective isolation and identification by automated immunoassay analyzer VIDAS (adapted from ISO 6579). *E. coli* analysis was performed by using the horizontal method of MPN (ISO 7251) in bright green broth, isolation on selective media and biochemical confirmation.

2.7. Data analysis

Statistical analysis was performed using SPSS 21.0 statistical software for Windows. A one-way analysis of variance (one-way ANOVA) was used to compare means among samples, while the Student-Newman-Keuls test was used as a post-hoc test. The significance level was set at 0.05 ($p<0.05$).

3. Results and Discussion

3.1. Process control

The composting process ended well with no difficulties in all the bins. Although the composters were located outdoors, we did not observe an increase of insects or rodents due to the presence of decomposing meat. A typical ammoniac odor was slightly detected for a few days following the first addition of meat waste since the process had not reached the range of thermophilic temperature, which however disappeared in the following inspections.

Thermophilic temperatures appeared during the bins' feeding phase. Temperature was the parameter that was most influenced by the presence of meat waste (Figure 1). The mixture (control treatment) without meat waste (M0B1) was characterized by the lowest temperatures, reaching values above 45ºC (Table 2). In contrast, the temperatures recorded for the other three mixtures (experimental treatments) fed with meat waste exceeded 55ºC. Significant differences were observed between the M1B1 and M2B1 treatments, showing that the temperatures reached during the experiment depended on the ratio of meat waste delivered to the bins. The number of thermophilic days (NTD) and thermophilic heat sum (THS) followed the same trend, with higher values for M2B2 followed by the M2B1 treatment (Table 2). The addition of bulking agent allowed a good aeration during composting, favoring microbial respiration and augmenting exothermic activity of the decomposition process. Double bulking agent ratio generally increased the temperature trend, which reached values even above 55ºC. As reported by Smith and Jasim (2009), the ideal thermophilic temperatures during the composting process at a small scale are sometimes difficult to be reached if only vegetable residues are composted. On the contrary, all the bins filled with meat waste reached thermophilic temperatures in our experimental trial.

Nevertheless, a higher porosity and aeration entailed a greater sensibility in the variation of moisture. When the moisture of the compost decreased, limiting the process, also the temperature

decreased, which was all the more evident in the treatment with double bulking agent ratio (M2B2) where the highest decrease of temperature was observed; likewise, M2B2 increased the temperature quickly when enough moisture was provided by watering again (Figure 1).

During the experiment, large losses of water were actually observed for all treatments. Nine irrigations were made to avoid a standstill of the decomposition process when the moisture of the composting material was less than 50%. For practical reasons, watering was performed simultaneously on all treatments but different volumes (15–20 L) of water were fed on the basis of the specific needs of each bin as deduced from the results of the "fist test". All bins exposed to roughly the same treatment showed similar moisture levels and received an almost equal amount of water. Leachate production was not observed during the experimental trial.

Bin composting was efficient in treating the total amount of 120 kg of household organic waste in 24 weeks. Due to the gas losses produced throughout the process, both the volume and weight were reduced by almost half (Figure 3). These losses could be due to microbial activity (C and N gas emissions) and evaporation of water. The weight loss rates were between 51.5 and 69.9%. The treatments with meat and low rate of bulking agent (i.e. M1B1 and M2B1) presented a greater weight loss due to the increased decomposition activity during composting, while M2B2 presented a lower weight loss even when compared to M0B1. The volume loss rate was statistically lower only in the M2B2 treatment (Figure 3). This percentage was calculated using the data of volume and weight of compost without sieving. Although the higher aeration in M2B2 should have increased aerobic decomposition (according to temperature trend), the loss ratios were the lowest due to the high proportion of woody material whose decomposition was more difficult. No significant differences were observed between M1B1 and M2B1 for both parameters, indicating a greater influence of the dose of bulking agent than that of meat waste (Figure 3).

Dewar test's results recorded a good stability degree for all composts obtained (Rottegrade Index V: "finished compost: very stable, well-aged compost"). All composts presented an average value of the Solvita maturity index corresponding to compost in the curing phase with reduced management requirements. Although no significant differences were found between treatments in terms of average of Solvita index, the ranges of the Solvita index for the 4 repetitions of each treatment were different, showing better maturity of the M1B1 and M2B1 treatments (index range values 6-7) than M0B1 and M1B1 (range 5-6). Like the weight and volume loss ratios, the Solvita index range was higher with the combination of meat waste and low rate of bulking agent.

Although composition of feedstock was different for each treatment, no significant differences between treatments were observed concerning the Biolog® principal indexes (AWCD, NUS, H), which are associated with microbial profiles of carbon source utilization (Table 3). Therefore, according to the Biolog results, the addition of meat waste did not affect the phenotypic diversity of the microbial population.

3.2. Physicochemical characteristics of compost

In our experimental conditions, all composts presented sub-alkaline pH and electrical conductivity under the recommended limits for composting as growing media (Wrap, 2011). According to our results (Table 4), pH and conductivity values were more dependent on the dose of bulking agent than that of meat waste, decreasing their value with the increase in woody material ratio. Treatment with double ratio of pruning residues (M2B2) presented, in fact, the lowest values of pH and conductivity while no differences were observed among the remaining treatments.

Compost density ranged from 285 to 308 kg/m^3, with no differences among treatments. No differences were found among treatments also concerning dry matter content (Table 4).

The values in total nitrogen content and C/N ratio were according to those reported in the literature for household composting in bins (Preston et al., 1998. Karnchanawong and Suriyanon, 2011; Adhikari et al., 2013). Treatments with meat as feedstock presented from 25 to 50% more nitrogen in the final compost compared to vegetable compost alone (Table 4). In contrast, C/N ratio passed from values higher than 13 for the vegetable treatment (M0B1) to values lower than 12 with the addition of meat waste. Thus, the presence of meat waste in the compost determined the increase in nitrogen content and decrease in C/N ratio.

In terms of organic matter and humic substance parameters, the carbon of humic substance represents a very high percentage of organic carbon. Total organic carbon (TOC) contents presented the same trend as total carbon (Table 4). M2B2 showed the highest carbon content because of the higher woody material ratio. On the contrary, the treatment without meat (M0B1) showed the lowest carbon content. Contrary to previous findings concerning MSW composting (Iglesias-Jimenez and Perez-Garcia, 1992; Francou et al., 2005), in our experimental conditions the humification ratio (HR), which represents the humic substance extraction percentage, was higher than 35% of TOC (Table 4). Nevertheless, HR does not represent the humification level because it depends on alkali-extractable carbon, a very heterogeneous mixture of components some of which are already present from the very beginning of the composting process (Cheftez et al., 1996). The humification index (HI), instead, can be used as a good marker of maturity of the compost, since it increases with the process of decomposition. HI expresses the humic acids (HA) content of organic carbon, a value that increases over time during composting. The largest proportion of HA was found in compost with 15% meat and a high dose of bulking agent (M2B2). HI results were statistically higher for treatments with 15% of meat waste (M2B1 and M2B2), and the index reached its peak when meat waste addition was combined to high bulking agent ratio (M2B2; Table 4). The percentage of humic acids in Total Humic Extract (PHA) and Cha/Cfa ratio reflected the same trend. The highest values of these indexes in the M2B2 treatment showed

that meat waste addition associated with a higher aeration increased the levels of organic matter humification (Table 4).

The ratio between humic and fulvic carbon (PI) also increases during the composting process. This parameter is largely utilized to quantify the level of humic substance's polymerization. During the composting process, fulvic acids are the first to be formed, in which aliphatic chains predominate over aromatic rings; humic acids form at a later stage by condensation of the aliphatic chains, increasing the volume of aromatic nuclei (Stevenson, 1994). While the fulvic acid fraction decomposes the humic acids level remains stable (Cheftez et al., 1996). In our experimental conditions, humic acids (HA) predominated over fulvic acids (FA), showing that the compost obtained had reached a good level of maturity.

Elemental content (Table 4) presented no significant differences among treatments for P, Ca, Fe, B and Mo contents in composts, while significant differences were found for K, Mg, S, Mn, Na and Sr. Sulfur content in compost increased with meat addition to feedstock. Potassium and sodium concentration was significantly higher in M1B1 and M2B1 treatments while M2B2 showed the lowest concentration of Mg, Mn, Na and Sr. Our results show that meat addition can increase the contents of certain nutrients, a trend that can be counteracted by a higher proportion of bulking agent.

No significant differences among treatments were found in content of potentially toxic elements. In general the concentrations of trace elements were very low compared to industrial compost (Barrena et al., 2014) and comparable to that described for home composting (Smith and Jasim, 2009; Adhikari et al., 2012). The concentrations of As, Co, Se and Sb were particularly low, less than the limit of analytical detection (<0.5 mg kg-1). All the composts presented a content in heavy metals that was significantly below the limits proposed for compost by the European Commission (European Commission, 2014) and corresponded to compost "Class A"

(suitable for organic agriculture) according to the Spanish regulations (Real Decreto 506/2013). Finally, the addition of meat waste had no influence in terms of concentration in heavy metals of the compost obtained.

3.3. Phytotoxicity

In terms of compost's phytotoxicity, negative effects of meat addition on pH, salinity and heavy metals content were previously ruled out.

According to these conclusions the results of the germination bioassay (Table 5) showed that meat addition did not increase the compost's phytotoxicity. All compost extracts showed phytotoxicity when applied without dilution. At the opposite, no phytotoxic effects were observed when the compost extracts were employed at maximum dilution (1:3). Phytotoxicity of compost extracted of water decreased with dilution in all treatments except for M0B1. Diluted extract at 50% (1:1) showed phytotoxicity only for M0B1 treatment in lettuce. Only extract of M2B2 (in cress) and M0B1 (in lettuce) with dilution 3:1 showed an average value of IGe over 60 (no phytotoxicity) but no significant differences were observed among treatments because of the high variability of the results obtained. Finally, it should be stressed that the potential phytotoxicity of compost may be of concern particularly when utilizing compost for the production of pot plants and if used undiluted or in large amounts in the growing media formulation (Tatáno et al., 2015).

3.4. Weed seeds control

The ability of seeds to germinate can decrease during the composting process because of the high temperature reached (Grundy et al., 1988). Concerning the devitalizing seed test, home composting in bins was shown to be effective on the control of the vitality of weed seeds present in the raw feedstock, independently from the addition of meat waste. Among all the seeds collected at the end of the composting process, only one seed (*O. vicifolia*), which was found in

a bin of M2B2 treatment, was capable of germinating (Table 6). Probably the high temperatures at the center of the compost proved to be effective for the loss of vitality of weed seeds also in the M0B1 treatment.

A different conclusion was reached concerning the other test, i.e. the incubation of the obtained compost in pots (Table 7). In this case, germinated seeds were observed during the incubation of compost in pots. A high proportion of viable seeds present in the initial feedstock were tomato seeds, described as heath-tolerant seeds (Alvarado and Bradford, 1988). Seeds capable to germinate were clearly present in larger proportion in the compost of M0B1 treatment; this result clearly suggests that the increase in temperature due to the addition of meat waste can be useful in the germination control of weed seeds.

It is possible to conclude, by comparing the results of both tests, that the home composting process reached a temperature that was high enough to devitalize seeds; however, the lack of uniformity of the turning operation could not rule out the presence of seeds that were capable of germinating in the compost obtained, especially when no animal waste was added and the temperature profile in the bin was not so high. In the devitalizing seed test, during composting, the mesh was placed in the center of the bin where the temperature was higher. In this test the high temperature was confined to the center of the bin where seeds lost their vitality, whereas lower temperatures were observed in the more external layers, which remained cold, so that seeds did not lose their vitality. To achieve the devitalizing requirement heat needs to be distributed from the center to the periphery; frequent turning is recommended to ensure that the cooler layers of the compost are incorporated in the center of the bin in order to expose the whole compost to the action of high temperatures (Adhikari et al., 2012). The importance of turning has been shown to increase temperature during home composting in bins (Illmer and Schinner, 1997; Alexander, 2007).

3.5. Levels of human pathogens

The levels of studied human pathogens observed in the compost of each treatment are presented in Table 8. *Salmonella* spp. was not detected in any 25 g samples of the composts, even when meat waste was added. Background levels of *E. coli* were not closely examined in this study but might be a key in understanding the source of contamination of the compost.

Escherichia coli counts presented a high variability even between bins of the same treatment. Vegetable compost (M0B1) did not show the presence of *E. coli* in 1 g samples for all repetitions (Table 9). Composts obtained with meat waste showed the presence of *E. coli*, that exceeded the limits included in the technical purpose of European Commission (2014) for biowaste composted, only in two out of twelve bins. The first concerned one of the four repetitions of the compost obtained with 5% of meat waste (M1B1 treatment) that showed *E. coli* levels higher than 1000 MPN/1g. The second, with a similar result, concerned the sample (corresponding to one bin) with 15% mixture of meat waste and high dosage of bulking agent (M2B2).

Our results were not in line with the conclusions of previous studies carried out by Harrison (2004) and Adhikari et al. (2012). In Harrison's study (2004) on the hygienic condition of home-made compost in the State of New York, it was shown that composts without meat scraps presented significantly higher *E. coli* levels than composts with meat waste addition. The results described by Harrison (2004) also showed a higher correlation between *E. coli* count and compost turning frequency than *E. coli* and presence of meat waste in the feedstock. Compost turning, as well as the addition of bulking agent, increases the aerobic conditions, allowing the microbial activity and reaching higher temperatures during composting. In our experimental study *E. coli* was found to not have a response pattern based on meat waste dosage or bulking agent ratio. Despite the high temperature reached during composting, *E. coli* was detected in the final compost. Harrison (2004) argues that it is difficult to correlate the temperature with the presence

of these microorganisms in such a process of transformation of the organic matter and suggests that the mechanism for the removal of fecal pathogens during composting is a complex mix of concomitant factors and not simply the result of a thermal physical environment.

The long duration of the composting process is the key factor that should reduce the pathogens load. A 2002 research sponsored by the Nordic Council of Ministers found consistently high concentrations of *E. coli* in household waste composts that were actively composted for shorter periods of time, compared to those that were composted for longer periods (Christensen, 2002). A study carried out concerning the hygienic aspects of home composting in Germany indicated an appropriate composting time to be up to one year (Oberfeld, 1997) to guarantee sanitation of the product obtained. In the evaluation of risks for human health other factors come into play like pathogenic load decay during compost storage or during time between the application and crop yield (Gale, 2004).

The safety of compost obtained at home is also due to the efficient operational management of bins. Often this depends on the correct transfer of waste to the bins that implies know-how and knowledge by users. *E. coli* presence in home-made compost may occur since most systems are not highly managed. The optimal conditions in the moisture of materials and efficient turning during composting have an important role to achieve a uniform and complete sanitization operated by high temperatures (Davis and Kendall 2005). Likewise weed seeds control, the importance of turning during composting has to be taken into account. The top layer of compost in the bin never reaches thermophilic temperatures and contaminates the bottom layers. Due to the heavy dependency on ambient temperature, the terminal insulation of bins might also help to maintain uniformly high temperatures of the compost inside. Although the regular and effective turning of compost is indispensable in order for the entire material within the bin to be exposed to high temperatures, it is possible, however, that the conventional turning with the manual screw used in this trial could have re-inoculated the sanitized layer with the non-sanitized compost. Further

research is required concerning the development of a more efficient system to turn the compost in the bin, by employing rotary drums or earthworm populations. According to our results the increment of bulking agent ratio (M2B2 treatment) increased the temperature during composting but was not enough to ensure that the overall compost was exposed to optimal thermophilic conditions.

In sum, the addition of meat as feedstock for home composting can slightly increase the presence of *E.coli*. However, the sanitary safety of compost can be improved through the proper management of the bins, with a correct control in moisture, regular and intensive turnings and long residence time of waste in composters.

4. Conclusions

The addition of meat waste as feedstock for composting in bins increased the temperature during aerobic decomposition. Consequently, several parameters were affected under higher temperature. The home-made compost obtained with meat waste reached maturity more quickly and presented a higher organic matter humification. Animal protein addition also increased nitrogen content, reducing C:N ratio of the final compost and increased K, Mg, Mn, Na, Sr and S. In addition, meat waste did not affect the volume losses during composting, and the density or final moisture of the compost obtained. Electrical conductivity and pH of compost were more influenced by the addition of bulking agent than that of meat waste. In general, compost made in bins with household meat waste showed a better quality than that of vegetable content alone whilst the utilization of meat feedstock did not increase phytotoxicity, salinity, viable seeds presence, pH or heavy metals content. From the viewpoint of hygiene and health, meat offal could slowly increase *E.coli* levels in the final compost. However, the proper handling and intensive turning of the compost to ensure that all the waste material is exposed to high temperatures as well as the

proper management of the composting operations can reduce the presence of coliforms under safety levels.

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Table 1.
The weight (kg) of food waste additions for each treatment during composting.

		Treatments			
week	waste addition	M0B1	M1B1	M2B1	M2B2
1st	vegetal	30	30	30	30
	meat	0	2	4	4
2nd	vegetal	28	28	28	28
	meat	0	1	4	4
3th	vegetal	25	25	23	23
	meat	0	1	3.5	3,5
4th	vegetal	16	16	10	10
	meat	0	1	3.5	3,5
5th	vegetal	13	10	8	8
	meat	0	0.5	2.5	2,5
6th	vegetal	8	5	3	3
	meat	0	0.5	0.5	0,5
7th	maturation phase	-	-	-	-
24th	compositing finished	-	-	-	-
total vegetal		120	114	102	102
total meat		0	6	18	18

Table 2.
Effect of feedstock composition on temperature during composting.

	M0B1	M1B1	M2B1	M2B2	Ambient air
Average Temperature (ºC)	33.3 ±0.6 d	38.7 ±0.7 c	42.7 ±0.7 b	46.0 ± 1.4 a	17.6
Maximum Temperature (ºC)	46.9 ±3.9 c	58.2 ±3.0 b	61.3 ±0.7 b	66.5 ±1.3 a	24.4
NTD [a]	0.8 ±0.5 d	10.5 ±2.6 c	32.5 ±4.4 b	45.0 ±6.3 a	-
THS [b]	3 ±3 d	67 ±17 c	191 ±45 b	350 ±56 a	-

Mean values ± SD (n = 4). Different letters within lines indicate significant differences (SNK test, $p \leq 0.05$, n = 4)

[a] Number of Thermophilic Days (T > 45ºC)

[b] Thermophilic Heat Sum: THS = Σday (T-45ºC)

M0B1M1B1M2B1M2B2

Table 3.
Effect of feedstock composition on the phenotypic variability of the microbial community during composting (Ecoplate Biolog ™ test results).

	M0B1	M1B1	M2B1	M2B2
Average Well Color Development:				
24 h	0.25 ±0.04	0.24 ±0.02	0.34 ±0.05	0.51 ±0.15
48 h	1.01 ±0.04	1.04 ±0.14	1.18 ±0.10	1.16 ±0.09
72 h	1.27 ±0.06	1.30 ±0.18	1.49 ±0.08	1.33 ±0.13
Number of Used Substrates:				
24 h	27.3 ±2.1	27.0 ±1.7	27.6 ±1.2	24.7 ±4.0
48 h	30.3 ±0.6	30.0 ±0.1	29.6 ±0.6	29.3 ±1.2
72 h	30.3 ±0.6	30.7 ±0.6	29.9 ±0.6	29.7 ±0.6
Sharon Index (H):				
24 h	2.87 ±0.03	2.76 ±0.03	2.74 ±0.1	2.73 ±0.6
48 h	3.15 ±0.02	3.11 ±0.04	3.15 ±0.03	3.11 ±0.5
72 h	3.24 ±0.02	3.21 ±0.04	3.24 ±0.01	3.21 ±0.3

Mean values ± SD (n = 4). No significant difference was found (SNK test, $p > 0.05$, $n = 4$)

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Table 4.
Characteristics of compost obtained among treatments with different feedstock composition.

	M0B1	M1B1	M2B1	M2B2	limit value
pH	8.82 ±0.03 a	8.93 ±0.06 a	8.79 ±0.08 a	8.27 ±0.22 b	<9 [b]
EC (µS/cm)	1229 ±193 a	1243 ±45 a	1464 ±129 a	792 ±120 b	<1500 [b]
BD (kg/m^3)	304 ±14 a	286 ±50 a	285 ±24 a	308 ±20 a	<550 [b]
Dry matter [a] (%)	86.1 ±13.4 a	85.7 ±7.8 a	85.4 ±5.4 a	85.0 ±9.2 a	>60 [c]
Total N (%, db)	2.01 ±0.07 d	2.50 ±0.11 c	2.76 ±0.08 b	2.99 ±0.15 a	No value
C:N ratio	13.3 ±0.8 a	12.1 ±0.6 b	11.4 ±0.4 b	11.7 ±0.5 b	No value
TC (%, db)	26.9 ±0.9 c	30.1 ±0.9 b	31.4 ±1.5 b	34.1 ±1.3 a	No value
TOC (%, db)	25.8 ±1.1 c	28.1 ±1.6 b	29.9 ±1.6 b	34.0 ±0.9 a	>20.3 [c]
Cex (%, db)	9.4 ±0.2 d	10.1 ±0.2 c	11.5 ±0.3 b	12.8 ±0.3 a	No value
Cha (%, db)	5.03 ±0.15 d	5.45 ±0.14 c	6.58 ±0.27 b	7.89 ±0.24 a	No value
Cfa (%, db)	4.35±0.09 c	4.67 ±0.09 b	4.88 ±0.15 a	4.90 ±0.12 a	No value
HR (%)	36.4 ±0.9 b	36.0 ±0.7 b	38.3 ±1.0 a	37.6 ±0.8 ab	No value
HI (%)	19.5 ±0.6 c	19.4 ±0.5 c	22.0 ±0.9 b	23.2 ±0.7 a	No value
PHA (%)	53.6 ±0.3 c	53.9 ±0.3 c	57.4 ±1.0 b	61.7 ±0.6 a	No value
PI	1.16 ±0.01 c	1.17 ±0.01 c	1.35 ±0.02 b	1.61 ±0.01 a	No value
P (%, db)	0.51 ±0.04 a	0.58 ±0.03 a	0.61 ±0.09 a	0.57 ±0.05 a	No value
K (%, db)	1.25 ±0.05 b	1.50 ±0.08 a	1.43 ±0.08 a	1.14 ±0.10 b	No value
Ca (%, db)	4.37 ±0.92 a	4.24 ±0.16 a	3.98 ±0.08 a	3.64 ±0.10 a	No value
Mg (%, db)	0.32 ±0.01 b	0.34 ±0.02 a	0.33 ±0.02 ab	0.30 ±0.02 c	No value
S (%, db)	0.34 ±0.01 c	0.41 ±0.02 b	0.44 ±0.02 a	0.41 ±0.01 b	No value
Na (%, db)	0.27 ±0.02 b	0.37 ±0.02 a	0.36 ±0.03 a	0.23 ±0.002 c	No value
Sr (mg kg^{-1}, db)	213 ±10 b	236 ±12 a	217 ±16 ab	204 ±13 c	No value
Fe (mg kg^{-1}, db)	2233 ±327 a	2566 ±552 a	2056 ±260 a	2180 ±140 a	No value
Mn (mg kg^{-1}, db)	98 ±5 a	104 ±6 b	104 ±6 b	88 ±5 a	No value
Cd (mg kg^{-1}, db)	< 0.5 a	< 0.5 a	< 0.5 a	< 0.5 a	<0.7 [d]
Cr (mg kg^{-1}, db)	13 ±1 a	11 ±2 a	11 ±3 a	17 ±6 a	<70 [d]
Cu (mg kg^{-1}, db)	34 ±3 a	33 ±2 a	30 ±3 a	32 ±2 a	<70 [d]
Ni (mg kg^{-1}, db)	4.1 ±0.4 a	3.6 ±0.5 a	3.8 ±0.7 a	3.7 ±0.4 a	<15 [d]
Pb (mg kg^{-1}, db)	12 ±3 a	10 ±3 a	8 ±1 a	9 ±1 a	<45 [d]
Zn (mg kg^{-1}, db)	131 ±12 a	115 ±12 a	105 ±14 a	124 ±19 a	<200 [d]
Al (mg kg^{-1}, db)	0.32 ±0.03 a	0.31 ±0.04 a	0.32 ±0.05 a	0.30 ±0.04 a	No value
B (mg kg^{-1}, db)	34 ±2 a	37 ±2 a	36 ±2 a	33 ±2 a	No value
Li (mg kg^{-1}, db)	4.46 ±0.32 a	4.51 ± 0.38 a	4.65 ±0.52 a	3.96 ±0.54 a	No value
Mo (mg kg^{-1}, db)	<0.05 a	0.62 ± a	0.71 ± a	0.57 ± a	No value
Ti (mg kg^{-1}, db)	36 ±3.1 a	35 ±4.2 a	37 ±3.3 a	34 ±3.4 a	No value
Tl (mg kg^{-1}, db)	1.4 ±0.3 a	2.3 ±1.4 a	2.4 ±0.7 a	0.9 ±0.6 a	No value
V (mg kg^{-1}, db)	10.3 ±1.0 a	9.8 ±0.8 a	10.1 ±0.9 a	9.4 ±0.8 a	No value

Abbreviations: db: dry basis; BD: bulk density; EC: electrical conductivity; TC: total carbon; TOC: total organic carbon; Cex: total humic carbon; Cha: humic acid carbon; Cfa: fulvic acid carbon; HR: humification ratio; HI: humification index; PHA: humic acid percentage; PI: polymerization index.

Means values ± SD (n = 4). Different letters within lines indicate significant differences (SNK test, $p \leq 0.05$, n = 4)

[a] Before sieving
[b] Target values suggested in ‘‘Guidelines for the specification of quality compost for use in growing media’’ (Wrap, 2011)
[c] Real Decreto 506/2013 Calculated from organic matter limits >35%, db, presuming it contains 58% C (Tatáno et al., 2015)
[d] Real Decreto 506/2013 (Class A Compost)

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Table 5.
Index of germination (IG_e) results by bioassay among treatments with different feedstock composition (Phytotoxic when IGe < 60).

	M0B1	M1B1	M2B1	M2B2
Lepidium sativum				
without dilution	34.8 ±3.8 a	24.7 ±5.8 a	33.2 ±2.8 a	37.3 ±6.3 a
dilution 3:1	54.7 ±13.0 ab	50.1 ±7.9 ab	34.6 ±8 b	64.3 ±5.9 a
dilution 1:1	70.1 ±12.3 a	99.8 ±15.3 a	72.6 ±8.4 a	79.2 ±6.0 a
dilution 1:3	84.2 ±12.7 ab	63.7 ±9.0 b	96.7 ±4.5 a	84.3 ±13.1 ab
Lactuca sativa				
without dilution	34.4 ±1.9 a	30.7 ±2.0 a	34.6 ±2.1 a	31.3 ±1.8 a
dilution 3:1	65.8 ±14.7 a	43. 9 ±8.3 a	43.5 ±9.4 a	45.5 ±7.1 a
dilution 1:1	58.7 ±3.8 b	73.5 ±3.6 a	71.3 ±4.3 a	79.5 ±4.5 a
dilution 1:3	83.9 ±6.3 a	90.0 ±3.8 a	93.8 ±4.2 a	97.1 ±7.4 a

Mean values ± SD (n = 20). Different letters within lines indicate significant differences (SNK test, $p \leq 0.05$, n =4)
Dilution ratio = Compost Extract: Water

Table 6.
Results of the devitalizing seed test (weed seeds incubation in composting bins).

Weed	weed seeds/bin	control seeds germinated	seeds geminated (and treatment)
Cynodon dactylon	100	17	0
Onobrichis vicifolia	100	33	1 (M2B2)
Vicia sativa	100	63	0
Plantago lanceolata	100	45	0
Melilotus officinalis	100	43	0
Agropyrum cristatum	100	18	0
Lupinus luteus	40	12	0

Table 7.
Results of the incubation of compost in pots for the control of weed seed germination.

	M0B1	M1B1	M2B1	M2B2
Dicotyledons	41	36	28	17
Monocotyledons	8	3	6	4

Reported results are the sum of 4 pots for each treatment

Table 8.
Levels of *Salmonella* spp. and *E. coli* in compost of each bin among treatments with different feedstock composition.

Treatment	Repetition (Bin)	*Salmonella* spp. (CFU/25g)	*E. coli* (MPN/g)
M0B1	1	0	<3
M0B1	2	0	<3
M0B1	3	0	<3
M0B1	4	0	<3
M1B1	1	0	<3
M1B1	2	0	4
M1B1	3	0	>1000
M1B1	4	0	43
M2B1	1	0	43
M2B1	2	0	150
M2B1	3	0	75
M2B1	4	0	23
M2B2	1	0	460
M2B2	2	0	240
M2B2	3	0	>1000
M2B2	4	0	28

1

Fig. 1.

Composter bin utilized in the experiment (Komp 320, Container Trading WFW GmbH, Austria).

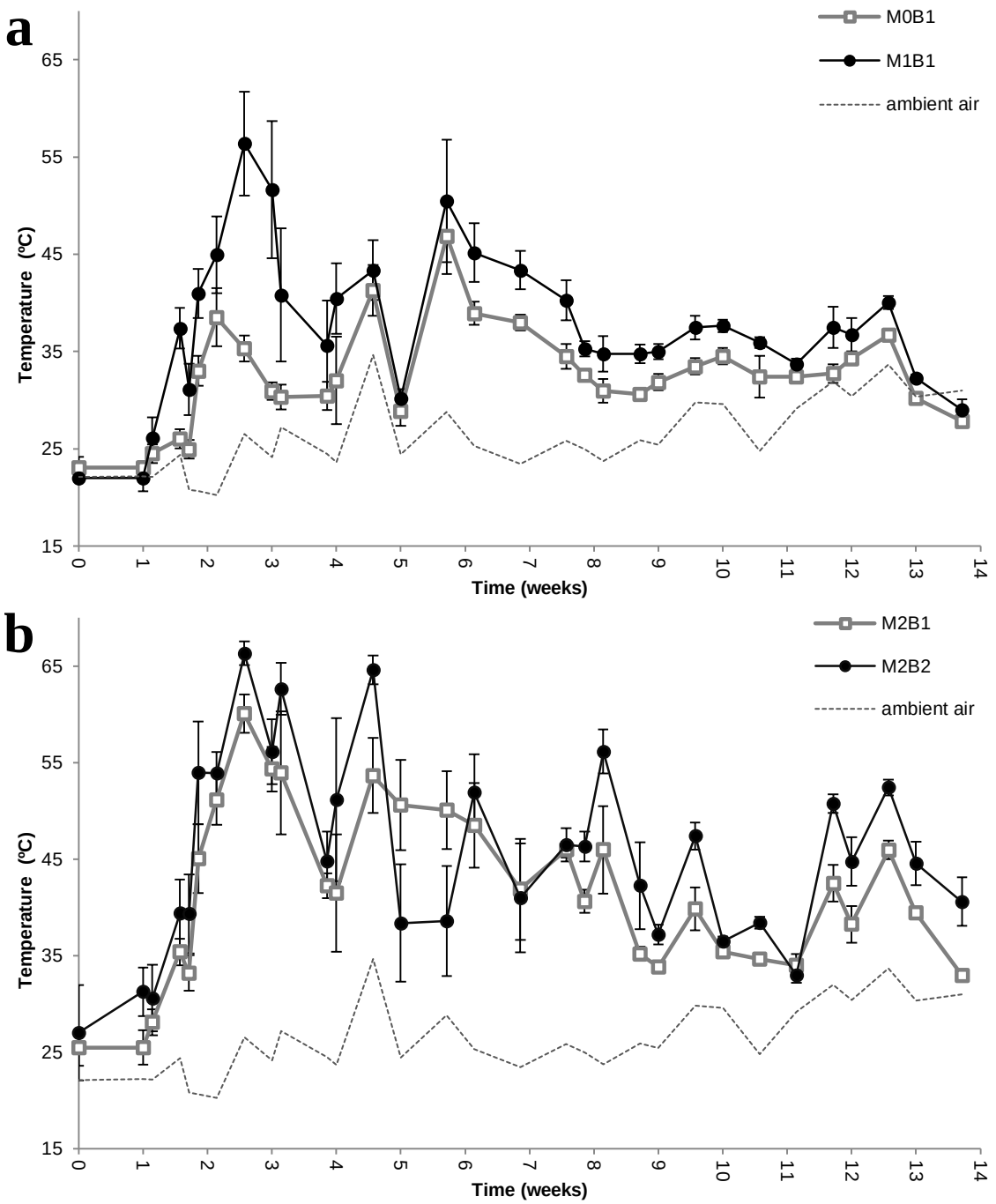

Fig. 2.

Temperature trend during the first 14 weeks of the composting process in bins of the four different mixtures of waste utilized in the experiment (SE values in vertical bars).

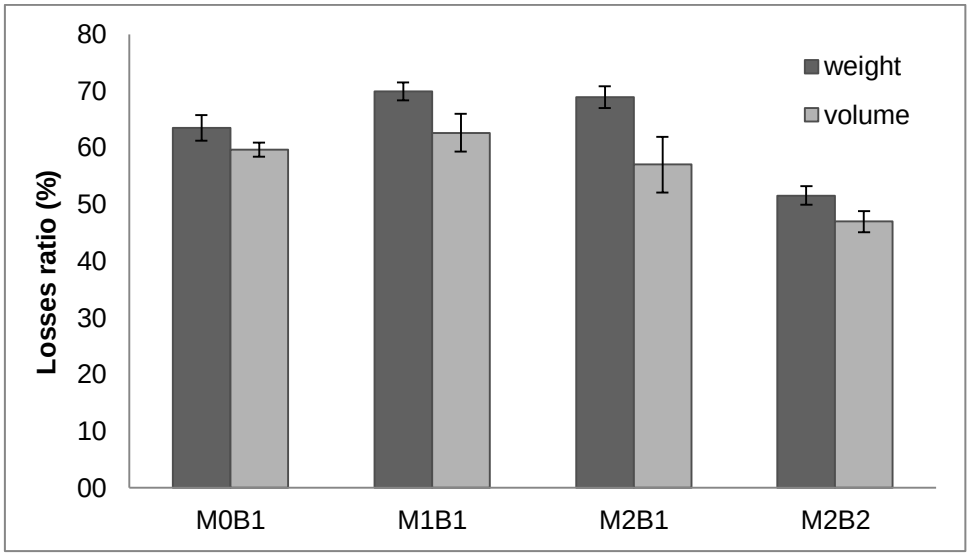

Fig. 3. Effect of feedstock composition on weight and volume loss ratio during composting in the four different mixtures of waste utilized in the experiment (SD values in vertical bars).