

Co-composting cow manure with food waste: The influence of lipids content

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Abstract— Addition of an oily waste to a co-composting process of dairy cow manure with food waste, and the influence in the final product was evaluated. Three static composting piles with different substrates concentrations were assessed. Sawdust was also added to all composting piles to attain 60% humidity at the beginning of the process. In pile 1, the co-substrates were the solid-phase of dairy cow manure, food waste and sawdust as bulking agent. In piles 2 and 3 there was an extra input of oily waste of 7 and 11% of the total volume, respectively, corresponding to 18 and 28% in dry weight. The results showed that the co-composting process was feasible even at the highest fat content. Another positive effect due to the oily waste addition was the requirement of extra humidity, due to the hydrophobic properties of this specific waste, which may imply reduced need of a bulking agent. Moreover, this study shows that composting can be a feasible way of adding value to fatty wastes. The three final composts presented very similar and suitable properties for land application.

Keywords—Cow manure, composting, food waste, lipids content.

I. INTRODUCTION

Solid waste generation has become a significant management problem in many developed countries. Special emphasis should be put on effective management of manure waste, since its share in the total organic waste collected in Europe reaches 91%, exceeding significantly other shares, which amount to 4%, 2% and 3%, respectively, for organic fraction of municipal solid waste, sewage sludge and industrial organic waste [1]. It is well known that the disposal of animal and food wastes is becoming increasingly difficult and expensive [2].

Among the available technologies to recycle organic solid waste, composting is often presented as a low-technology and low-investment process to add value to organic solid waste through conversion into an organic fertilizer known as compost. In fact, the compost is a valuable resource for tackling land degradation and addresses many of the concerns highlighted in the EU Thematic Strategy for Soil Protection such as soil fertility, microbial biodiversity, erosion, water

infiltration and carbon sequestration.

Composting is a bio-oxidative process involving the mineralization and partial humification of the organic matter, leading to a stabilized final product, free of phytotoxicity and pathogens and with certain humic properties [3]. Conversely, un-stabilized or immature compost application to agricultural soil may cause phytotoxicity and adversely affect the environment [4].

Solids separation technology of animal manure gives farmers with highly intensive livestock production an opportunity to reduce their overall environmental impact. Manure solids separation can produce a liquid fraction containing soluble components such as mineral nitrogen (N), and potassium (K), and a solid dry matter rich fraction containing the majority of the organic matter, including a significant proportion of phosphorus (P) [5]. Actually, the organic matter and nutrients content of the solid fraction can be valuable in composting processes and its fibrous structure with high porosity also favors air transfer to the composting pile. After composting, it can be used as a soil conditioner agent, organic fertilizer or component of compost-based plant growth medium, potentially replacing peat-based products. This is particularly important in Southern European climate, where soils are deficient in organic matter [6]. In fact, composting could be an alternative treatment method for the solid fraction of cow manure, promoting weight and volume reduction and stabilizing the organic matter and facilitating transportation of the final product over longer distances [5].

Composting is also a commonly used approach for recycling municipal organic waste, which is composed mostly of food waste [7]. Food waste adds up for 20–45% in Asia and European nations [8]. However, food waste characteristics can vary from one location to the next and with months, compost recipes need regular adjustments [8]. Existing designs of composting plants usually perform poorly or even fail, when applied to new substrates such as food waste with high moisture and fat contents [9]. The main problem associated with food waste composting is the fermentation of carbohydrates and fats, which lowers the pH of the process leading to retarded decomposition efficiency [10]. Fat from food processing industry is a waste considered difficult to be composted. Therefore, organic wastes rich in lipids are not typically composted [11]. However, fats, oils, and grease residues have a high-energy content. In fact, lipids contain twice the energy of other organic materials, like sugars and starch [12], which makes them ideal substrates for aerobic

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composting [11]. This high-energy content represents a clear advantage for processes where thermophilic temperatures are desirable to achieve pathogen content reduction [13]. In addition, at high temperatures the reaction rates are faster, thus resulting in shorter residence times [11]. However, the main problems associated with fat composting are low water content and solubility, lack of porosity and a relatively low biodegradability of some fats. Composting of fats as single substrate is difficult, due to the nutritional lacks of fats, especially low contents of nitrogen and phosphorous in relation to a high carbon content [14]. This usually implies that a co-substrate is necessary to compensate the C/N ratio of the initial mixture. Among the substrates co-composted with fats, different types of sludge are used, because of their typical low C/N ratio [15].

The addition of a bulking agent for composting optimizes substrate properties such as air space, moisture content, C/N ratio, particle density, pH and mechanical structure, affecting positively the decomposition rate. In this sense, lignocellulosic agricultural and forestry by-products are commonly used as bulking agents. The most used are wood chips and sawdust. Normally, bulking agents have low moisture and high organic carbon contents and high C/N ratios, which can compensate for the low values of the animal manures [16]. Adhikari et al. [7] stated that the formula required to successfully compost food waste relies heavily on the type, particle size and quantity of bulking agent used. Once added the bulking agent should correct the formula's moisture content to fall within a range from 60% to 80% [17]. Moreover, absorbs part of the leachate produced during the decomposition process, to keep the mixture moist, and sustain an active microbial activity. The bulking agents will act as a buffer against the organic acids produced during the early stages of composting, and, thus, help maintain the mixtures pH within a range from 6 to 8 [17]. An optimal composting mixture of 50% food waste, 40% manure, and 10% bulking agent was found in a previous in-vessel composting study [18].

The aim of this study was to assess the co-composting of solid-phase from dairy cow manure with food waste in order to evaluate: (1) the influence of the food waste lipid content to be co-composted; (2) if co-composting is a suitable technology to recycle fat-substrates (3) if the addition of this co-substrate can improve the process. Changes in food waste fat content were simulated by adding oily waste from a canned fish industry.

II. MATERIALS AND METHODS

A. Composting material and bulking agent

Two co-substrates were used in the co-composting process. (i) Cow manure, collected in a dairy farm in the suburbs of Braga (Portugal). The collected cow manure solid-phase was composed of feces and straw bed after screening with an aluminum sieve of 2.5 mm mesh size (Oy Scanteknik Ab, Finland); (ii) food waste, which was a composite sample (one week based) from the waste produced in the canteen of the

University of Minho, located in "Campus de Gualtar", Braga, Portugal. The food waste was crushed to 1-3 mm particle size and stored at 4 °C during 5 days, until the end of the collecting process. An oily waste collected in a canned fish processing industry was used to simulate the variation of fat content in the food waste. The bulking agent used was sawdust collected in a carpentry/sawmill located in the suburbs of Braga (Portugal). The main characteristics of each composted material are presented in Table I. The long chain fatty acids (LCFA) content of the cow manure, oily and food waste are also depicted. The sawdust density was 0.29 kg/L.

TABLE I
CHARACTERIZATION OF COW MANURE, FOOD WASTE, OILY WASTE AND
SAWDUST USED IN THE COMPOSTING ASSAYS

Organic residue	Cow manure	Food waste	Oily waste	Sawdust
Chemical Oxygen Demand (COD) (g/kgwaste)	39±8	327±73	2690 ± 61	192 ± 16
Moisture content (%)	88	77	2	8
Organic Carbon (% dry weight)	49	53	55	54
Total Kjeldahl Nitrogen (TKN) (g/kg waste)	2	13	1.7	18
Fat Content (%)	0.2	2	87	
Long Chain Fatty Acids (LCFA)	Cow manure (gCOD/kgTS)	Food Waste (gCOD/kgTS)	Oily Waste (gCOD/kgwaste)	Sawdust
Myristic acid (C14:0)	3±1	0	19± 1	ne
Palmitic acid (C16:0)	14±4	14 ± 4	260± 7	ne
Palmitoleic acid (C16:1)	0	0	27± 1	ne
Stearic acid (C18:0)	26±9	6 ± 2	75± 2	ne
Oleic acid (C18:1)	0	16 ± 5	891± 17	ne
Linoleic acid (C18:2)	0	8 ± 2	790± 33	ne

ne-not evaluated.

B. Composting experiments at laboratory scale

Three static 30L composting piles with different concentrations of oily waste were assayed in this study, with a cow manure/food waste ratio of 1 w/w. The humidity was set at 60% in the initial stage of the process, in all composting piles, which justified the addition of sawdust as an absorbent. In pile 1 the substrates added were food waste and cow manure with sawdust as bulking agent. In piles 2 and 3, besides this same mixture, some oily effluent was added as indicated in Table II.

TABLE II
PILES INITIAL COMPOSITION

Organic residue	Pile 1	Pile 2	Pile 3
Cow manure (kg)	5.0	4.75	4.55
Food waste (kg)	5.0	4.75	4.55
Oily waste (kg)	0	0.8	1.3
Sawdust (kg)	3.5	2.5	2.0
Moisture content (%)	60	60	60
Fat content added (%)	0	7	11
Fat content added (% dry weight)	0	18	28
C/N	20	23	25

The mixtures were revolved manually at 1 week intervals for a period of 103 days. Beforehand, the composting mixtures were randomly sampled at five different places, in the core and in each edge of the pile. The samples were manually homogenized and used for further analysis.

C. Analytical Methods

Temperature and pH were measured in a daily bases at a depth of 40–60 cm in 5 different places. One measurement was made in the center and the other four in each extremity of the composters. pH and temperature measurements were performed with a pH meter from HANNA Instruments (pH/Temperature meter HI 99121).

The moisture content was estimated by the weight loss after drying at 105°C [19]. Organic carbon was analyzed by ignition at 550 °C for 4 h [20]. TKN was determined by direct digestion using selenium as catalyst.

The total fat content was extracted with diethyl ether in a Soxtec System HT2 1045 extraction unit produced by Tecator [21].

LCFA (lauric (C12:0), myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0), oleic (C18:1) and linoleic (C18:2) acids) analyses were performed as described in Neves et al. [22].

The electrical conductivity (EC) was measured in 1/10 solid/liquid aqueous extract with an InoLab conductivity meter from WTW.

A differential-selective plating method was used for routine analysis and quantification of *Escherichia coli* (*E. Coli*) survival assays. Samples were serially diluted up to 10^{-5} , and spread-plated on MacConkey agar containing sorbitol (sorbitol-MacConkey agar, SMAC). After, the plates were incubated at 30°C for 24 hours for further quantification. On this medium, the wild-type *E. coli* strain grows as pink (sorbitol-positive) colonies.

Germination index assays were performed at the end of the composting process, using *Lepidium sativum* seeds, according to Alburquerque et al. [23].

Heavy metals (chromium, cadmium, zinc, copper, lead, mercury and nickel) analyses were done as follows. Solid samples were submitted to microwave assisted acid digestion according to EPA 3051 [24]. Afterwards, heavy metals ions concentration was measured using a Varian Spectra AA-400,

atomic absorption spectrophotometer (AAS) by acetylene flame emission at the correspondent wavelengths.

D. Statistical analysis

Single factor analysis of variances (ANOVA) was used to determine if significant differences existed between results obtained under different experimental procedures. Statistical significance was established at a $P < 0.05$ level.

III. RESULTS AND DISCUSSION

A. Changes in physicochemical parameters during composting

The temperature and pH profiles of the three composting piles, with different inputs in lipids are depicted in Fig. 1. Through the entire process there was no statistical difference between the pH and temperature values of the three piles, $P=0.19$ and $P=0.30$, respectively.

A pH in the range 6.7–9.0 supports good microbial activity during composting. Optimum values are between 5.5 and 8.0 [25], which were observed during the experiment.

Temperature is one of the main parameters to evaluate evolution of the composting process, since it determines the biological reactions rate, as well as the sanitation capacity of the process.

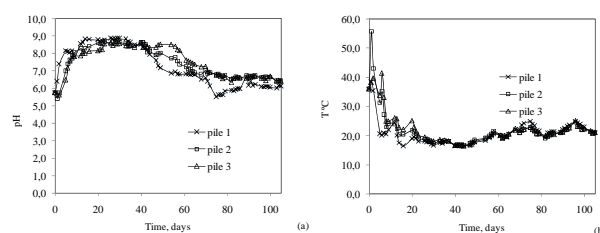


Fig. 1 pH (a) and temperature profile in the three composting piles.

The effect of fat addition in the temperature profile can be observed in Fig. 1 (b). Although, the hygienization temperatures were not achieved, the highest temperatures were attained in the piles with fat addition. Thus, in order to increase composting temperatures of low energy substrates, as manure, fat addition can be a good approach.

From a biological point of view, there are three significant temperature intervals that govern different aspects: temperatures above 55 °C maximize sanitization, between 45 and 55 °C improve the degradation rate and between 35 and 40 °C increase microbial diversity [26]. In the present situation, the compost would not meet PAS 100 [27] critical limits (2 days at >60 °C or 1 hour at >70 °C; BSI, 2002 [27]; or 7 days at >65 °C; BSI, 2005 [27]). However, *E. coli* survival assays were performed after 5 days and up to 89 days and, as observed in Fig. 2, after 19 days no *E. coli* was detected in the three piles. Pietronave et al. [28] reported that indigenous microflora of matured compost played an important role in *E. coli* suppression. However, their study relied on inoculating pathogenic strains into compost, which may potentially affect the outcome since inoculants are far

less likely to survive than indigenous populations. According to the Portuguese legislation, the compost of the three piles could be used as agricultural land, since it requests for the absence of *E.coli* [29].

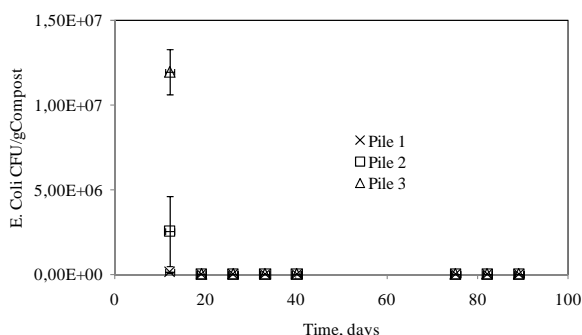


Fig. 2 Results of *E. coli* survival assays in the tree piles.

The initial moisture content of the three piles was very similar and in the optimal range suggested for composting microbial activity (60%). However, in the piles with fat addition the moisture content decreased to values lower than 40% (Fig 3 (a)) and no water was added to correct this parameter. This moisture decrease can be justified by the hydrophobic nature of fat, which might reduce the water retention capacity of the organic matrix. This is indicative that fat addition can reduce the need of bulking agents, since sawdust was added in the beginning of the experiment in order to set the humidity in the optimal range.

The C/N ratio evolution with time is represented in (Fig. 3 (b)), showing that all piles attained values representative of a mature compost [30]. Some authors suggest as mature compost criterion a C/N ratio lower than 15:1[31]. Piles 2 and 3 achieved this ratio after 15-20 days and before pile 1. Although, they have started with a slightly higher C/N ratio (Table I). So, fat addition was not impeditive of a faster achievement of compost maturity. On the contrary, its addition contributed to an increase in the C/N ratio, which improved the process development.

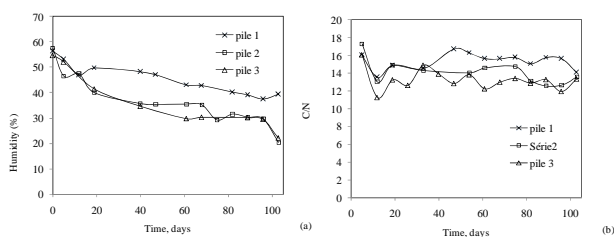


Fig. 3 Humidity (a) and C/N ratio (b) time profiles of the composting piles

The fat extraction data was very similar in the three piles after 20 days of composting as shown in Fig. 4 (a). In fact, as for all the other parameters analyzed, the significant differences between the piles were observed before day 20. This indicates that the fat waste is bio-degraded in the first 20

days, as can be confirmed by Fig. 4 (b), (c) and (d). The major fatty acids detected in pile 1 were C16:0 and C18:0, whereas in piles 2 and 3 it was C18:1, followed by C16:0 and in small concentration C18:0. This is in accordance with the type of wastes used (Table I). The major LCFA concentration detected was in pile 3, as expected, since this was the pile where the fatty waste was added in higher concentration. The highest LCFA reduction in pile 2 (52%) was detected between day 19 and 26, while in pile 3 this occurred between day 12 and 19 corresponding to a 45% reduction. Hence, the major LCFA degradation occurs around the first 20 days.

Nevertheless, at the end of the composting process the three piles presented very similar values. Inevitably the LCFA were converted to short-chain fatty acids and did not delay the composting process.

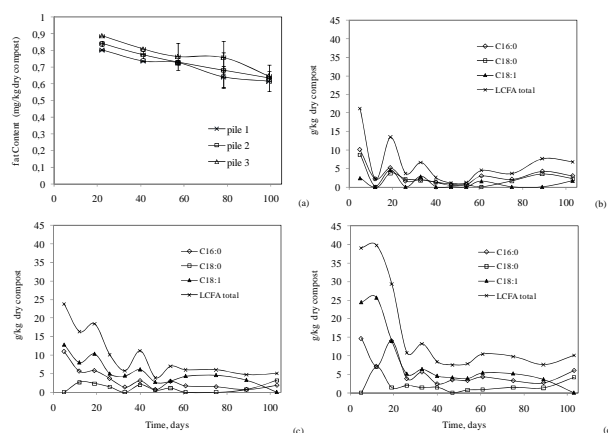


Fig. 4 Fat (a) and LCFA content in pile 1(b), pile 2 (c) and pile 3 (d). All the tree piles presented a similar high volume reduction around 60%. It is noteworthy that the mass reduction was almost 50% in the first 25 days.

B. Final Compost Characteristics.

In compliance with the current legislation in Portugal regarding heavy metals content [29], all the compost produced could be applied in agriculture as their values are below the maximum permitted level (Table III).

Electrical conductivity (EC) is an extremely useful and easy measure to use for monitoring agricultural soils. It indicates the level of dissolved salts by measuring the ability of a solution to carry an electric current by ions. A high electrical conductivity will stress the plants and cause productivity losses. Compost conductivity is of great importance from an agricultural point of view, since it can be a limiting factor of plant growth and seed germination. All the three composting piles presented values lower than 8 mS/cm, which has been reported as the limit to avoid negative effect on soil microbial populations and on organic matter biotransformation [32]. The piles with higher fat content presented a slightly higher value. However, as confirmed by the germination index, such values do not represent phytotoxicity.

It is generally considered that phytotoxicity is eliminated when GI reaches 80–85% [33]. Table III shows the number of the *Lepidium sativum* seeds germinated in each substrate as well as the results of relative germination index. The values higher than 100% were compared with the control assay (germination in deionized water).

There was very good seed germination in all compost samples. These results indicate a sufficient stabilized product without the presence of any toxic substances for these seeds [34].

TABLE III
COMPOST FINAL COMPOSITION IN HEAVY METALS, CONDUCTIVITY AND GERMINATION INDEX

	Pile 1	Pile 2	Pile 3
Chromium (mg/kg dry compost)	36	111	59
Cadmium (mg/kg dry compost)	0	1	2
Zinc (mg/kg dry compost)	227	161	325
Copper (mg/kg dry compost)	22	36	56
Lead (mg/kg dry compost)	0	0	0
Mercury (mg/kg dry compost)	0	0	0
Nickel (mg/kg dry compost)	24	0	0
EC (mS/cm)	3.0	3.6	3.6
Germination Index (%)	111	100	110

IV. CONCLUSIONS

An oily waste was added to a co-composting process of cow manure solid-phase with food waste and sawdust as bulking agent, to study the effect of high fat content.

The results show that the composting process was not impaired by an increase in fat content at least to 28% dry weight. Moreover, an increase in fat concentration seems to require a higher moisture concentration due to the hydrophobic properties of this specific component, and this may imply a reduced need for a bulking agent. This finding should be further analyzed in order to decrease the cost associated to previous dewatering in aerobic stabilization processes.

This study shows a good approach to add-up value to fat wastes, since they are normally considered not easily treatable wastes.

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