Performance of compostable baby used diapers in the composting process with the organic fraction of municipal solid waste

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Abstract

In modern societies, disposable diapers constitute a significant percentage of municipal solid wastes. They have been traditionally landfilled or incinerated as only limited recycling processes are being implemented in some parts of Europe. With the implementation of separated collection systems for the organic fraction of municipal solid wastes (OFMSW) and the need to preserve the environment, compostable diapers have appeared in the market to avoid the main environmental impacts associated to non-biodegradable disposable diapers. In this study, a full-scale composting of door-to-door collected OFMSW with a 3% (w/w) of compostable diapers has also been carried out. Previously, lab-scale experiments confirmed that almost 50% of carbon of compostable diapers is emitted as CO_2 under aerobic controlled conditions. The results obtained at full-scale demonstrate that both the composting process and the final end product (compost) are not altered by the presence of compostable diapers in crucial aspects such as pathogenic content, stability and elemental composition (including nutrients and heavy metals). The main conclusion of this study is that the collection of the OFMSW with compostable diapers can be a new way to transform this waste into high-quality compost.

Keywords: composting; compostable diapers; biodegradation; compost quality; municipal waste.

1. Introduction

Waste generation is one of the most important environmental problems of modern societies, in particular those associated to biodegradable waste. In consequence, it is important to develop new products with enhanced biodegradability that may substitute some current products that are of low biodegradability and tend to accumulate in the environment.

Although diaper waste is mainly composed of organic matter (cellulose pulp, faeces and urine) (Colón et al., 2011), it is generally collected together within the refuse fraction and disposed of in municipal waste deposits or incinerators (Manfredi et al., 2010). The main environmental problems due to the landfill of waste with high content of biodegradable materials are methane emissions that contribute to global warming, possible percolation of leachate to groundwater, land occupation, noise and bad odours (Smith et al., 2001). On the other hand, waste incineration can produce air pollution (NO_x, SO_2, HCl, particles and dioxins), the emission of greenhouse gases (CO_2 and NO_2), and ashes that have to be managed as hazardous wastes (Smith et al., 2001), but there are mitigation strategies to solve that problem depending on the technology used and local regulations.

Additionally, the European Union Landfill Directive (The Council of the European Union, 1999) requires significant restrictions on the disposal of biodegradable materials in landfills. According to this Directive, by 2016 the biodegradable municipal waste going to landfills must be reduced to 35% of the total amount (by weight) of biodegradable municipal waste produced in 1995. A proper management of diapers could contribute to the achievement of such goal.

Regarding the generation of diapers, the average weight for a used disposable diaper is 212 g according to experimental data based on the average weight of 610 diapers collected in the municipalities of Mancomunitat La Plana (Spain) between the 18th and the 24th of February 2008. In the EU-27, 20,621 millions of baby diapers were used in year 2009 (Eurostat, 2009), which implies around 4.3 million tons of waste (according to the above diaper average weight), and 1.7% of total municipal waste generation in this area. Although this generation takes place mainly in households, nurseries concentrate a significant percentage of the generation, and therefore they are a strategic key element to introduce alternatives to conventional disposable diapers, such as reusable or compostable diapers. However, the coverage of preschool services is very different between countries. Table 1 shows an estimation of total used diapers and diapers used in nurseries in different European countries. It is important to note that there are important differences among the countries analysed. Although we have not conducted a deep study on this point, probably they are related to different social, economical and cultural aspects.

There are two alternative options to normal disposable diapers: reusable diapers and compostable diapers. Reusable diapers are washed after each use, whereas compostable diapers must be collected along with biowaste and managed in biological treatment facilities, especially composting plants. In the case of disposable diapers, the legal recommendations consider that they should be collected with rejected materials (Catalan Waste Agency, 2009a). Today, there is an increasing number of commercial compostable diaper brands, although reliable figures or percentages of use are still not available. However, it is important to know the real performance in terms of biodegradability of a new product before it is available in the market.

Although this is not the main objective of this study, Hakala et al. (1997) undertook a comparative Life Cycle Assessment (LCA) between conventional and compostable diapers. In this case, the considered compostable diaper used polylactic acid (PLA) as a substitute for polypropylene (PP) and polyethylene (PE). The differences found in the impacts of the conventional and the compostable diapers were small.

The main impacts of compostable diapers were found to occur during the agricultural production of the raw materials and during its fermentation to lactic acid (eutrophication emissions and energy consumption). Contrarily, compostable diapers waste can be converted into compost, which can be used to enhance soil quality and to partly substitute mineral fertilisers. Thus, the amount of landfill waste is substantially reduced. Another advantage is that the biopolymer is made of annually renewable raw-material.

The main impacts of conventional diapers were hydrocarbon emissions to air and water from the PP and PE production lines and the impacts of landfills or incineration facilities that treat them when they end up as wastes.

When interpreting the results from Hakala et al. (1997), a number of factors have to be taken into account. The biopolymer production sector has undergone a huge evolution in the last few years (Wee et al., 2006; Madhavan Nampoothiri et al., 2010), and this might suggest that the impact of current biopolymers could be lower. The life cycle assessment of PLA presented by Vink et al. (2003) established a potential reduction in the energy use from 54 MJ/kg PLA to about 7 MJ/Kg PLA, and a reduction of greenhouse gases from +1.8 to -1.7 kg CO_2 equivalents/kg PLA. In recent years, the unitary weight of regular diapers has decreased an average of 30 %, mainly due to the reduction of cellulose (EDANA, 2008; Hakala et al., 1997). On the other hand the most growing component was superabsorbent polymer (SAP). According to compostable diapers manufacturers' information, SAP has been completely substituted by biopolymers based on starch, which greenhouse gases emissions are neutral.

In consequence, the objectives of this research are: i) to analyze the biodegradability of two brands of available compostable diapers, ii) to study at full-scale the performance of the composting process of used baby compostable diapers collected in a nursery with the OFMSW iii) to evaluate the quality of the end product with and without diapers as control experiment.

2. Material and Methods

2.1. Lab-scale experiments

Two lab-scale experiments were carried out in order to evaluate the biodegradability of two commercial compostable diapers (D1 and D2) during approximately 600 hours. Along with these experiments, a control without diapers was also carried out. Unused diapers were utilized to carry out the lab-scale experiment and the experimental conditions adjusted for optimal composting.

The following steps were followed in this assay:

1. The compostable diapers (about 0.5 kg of each commercial brand, D1 and D2) were manually shredded to <1 cm pieces, according to previous observations in composting plants processing disposable diapers (Colón et al., 2011).
2. Shredded diapers (42.80 g) were mixed with stable compost coming from the composting plant of Mancomunitat la Plana (100 g, dry matter basis) to obtain a mixture consisting of 30% (weight percentage) of compostable diapers and 70%

(weight percentage) of compost. This ratio was selected to have enough inoculum (stable compost) and to observe significant differences in CO_2 production in relation to control experiments. Moisture content was adjusted by using the fist test according to The US Department of Agriculture and the US composting council (2001), each sample was moistened by adding 325 g of water. Porosity was adjusted to 50% according to Ruggieri et al. (2009). An Erlenmeyer glass flask reactor of 1 L capacity was filled with the final mixture. Duplicates for each compostable diapers were prepared.

3. An Erlenmeyer glass flask reactor was filled with the same compost coming from the composting plant of Mancomunitat la Plana previously moistened to adjust the moisture content to 50%. This flask was considered the control experiment. Duplicates for the control were also prepared.
4. During all respiration tests, moistened air at the same temperature of the material is used, so moisture material is only changing ± 2% (Ponsá et al., 2010).

The emissions of CO_2 were on-line measured using the respirometer described in the analytical methods section and following the methodology developed by Ponsá et al. (2010). The difference between the CO_2 emitted by the samples with diapers (D1 and D2) and the control samples (without diapers) were considered the CO_2 emitted due to the biodegradation of the diapers.

The grams of C emitted were calculated according to Equation (1):

$$X\,\mathrm{g}\ \mathrm{CO_2} \times \frac{1\ \mathrm{mol}\ \mathrm{CO_2}}{44.01\ \mathrm{g}\ \mathrm{CO_2}} \times \frac{1\ \mathrm{mol}\ \mathrm{C}}{1\ \mathrm{mol}\ \mathrm{CO_2}} \times \frac{12.01\ \mathrm{g}\ \mathrm{C}}{1\ \mathrm{mol}\ \mathrm{C}} = X\ \mathrm{g}\ \mathrm{C} \qquad \text{Eq. (1)}$$

whereas the total mass of C in the diapers were calculated using a total carbon analyzer.

2.2. Full-scale experiment

2.2.1. Compostable diapers supply

To obtain a representative sample of used compostable diapers, during 11 working days, 75 children of the Nova Espurna nursery from Lliçà d'Amunt (Barcelona, Spain) used compostable diapers instead of conventional disposable ones. Two different brands of compostable diapers (D1 and D2, with the highest production in Spain) were used, 35 children used an amount of 558 D1 diapers whereas 40 children used an amount of 542 D2 diapers. This experiment on the use of compostable diapers was undertaken in order to gather a sufficient number of them to carry out a full-scale composting experiment.

The diapers were collected every day. In order to slow down their biodegradation before entering the composting facility, the collected diapers were kept in a cold-storage room at 10 ºC.

2.2.2. Composting facility

The full-scale experiment was carried out in the composting plant of *Mancomunitat La Plana*. This plant is located in Malla (Barcelona, Spain) and receives organic waste from door-to-door collection schemes. The plant is located in a rural area with a Mediterranean climate. The present capacity of the plant is close to 2,500 t/year. The waste to be composted is disposed of in open trapezoidal containers made of concrete with three perforated pipes in their floors to provide aeration and to collect leachate, which is stored in a separate tank and recirculated to the decomposition process to maintain adequate moisture levels (4-6 weeks). Afterwards, the curing stage is carried out in turned piles (8-12 weeks).

2.2.3. Experimental set-up

Two different processes were carried out with and without the addition of compostable diapers. Only one replication could be carried out at full-scale for both experiments because of the large amount of materials required.

The following steps were followed to build the two piles:

1. The main substrate for composting was the source-selected OFMSW coming from the municipalities with a door-to-door collection system. This substrate was composed of kitchen residues and garden trimmings. The average level of impurities of this OFMSW was lower than 1% (Catalan Waste Agency, 2009a). The main characteristics of the used feedstock are shown in Table 2. The OFMSW was mixed with the appropriate weight of bulking agent to ensure a volumetric ratio 1:1, although this meant that the weight ratio was slightly different in both mixtures (with and without diapers) as the bulking agent used is not completely homogenous. Notwithstanding this, the differences in the air-filled porosity of both samples were minimal (less than 5%).
2. The OFMSW (19,575 kg) was mixed with a bulking agent (8,500 kg) consisting of shredded pruning wastes in a volumetric ratio 1:1 to ensure an adequate level of porosity. This mixture was considered the composting experiment without diapers. The dimensions of the pile were approximately: height: 1.5-2 m, width: 4-5 m and length: 10 m.
3. The OFMSW (5,380 kg) was mixed with compostable diapers (160 kg, 51% of D1 and 49% of D2) to obtain a 3% weight percentage of diapers in the OFMSW,

which is considered representative of the Catalan use of diapers in relation to the generation of the OFMSW (Catalan Waste agency, 2009b; Colón et al., 2011). At the same time, the necessary amount of bulking agent (2,830 kg) was also added in a volumetric ratio 1:1. The resulting mixture was considered the composting experiment with diapers. The dimensions of the pile were approximately: height: 1.5-2 m, width: 4-5 m and length: 5 m.

Both mixtures (with and without diapers) were composted in the same static forced-aerated composting reactor for 41 days (active decomposition stage). The composting reactor was divided in two parts and it was separately filled with the two mixtures. After this period, the curing phase was carried out in two separated turned piles for 65 days. During the curing phase the piles were turned once a week and moistened when necessary using a Backhus turner Model 15.5 (Edewech, Germany), which is able to turn and add moisture at the same time. After the curing process, the material was sieved to 10 mm to obtain the final compost.

To monitor the composting process of both materials during the force-aerated decomposition stage, temperature was continuously measured on-site (at two different material depths: 0.4 and 1 m), in two different points for both parts of the reactor (with and without diapers). During this period, the average temperature is presented. During the curing phase the temperature was manually measured at days 73 and 106 of the complete composting process (including active aeration stage) using a temperature probe (Pt-100; Desin Instrument, Barcelona, Spain).

Sampling for analysis of both materials was carried out at days 1, 21, 41, 73 and 106 in both piles. Four sub-samples of 5 kg of the whole material were extracted from four points of each pile. The sub-samples were manually mixed to obtain a representative sample of each pile. Moisture, organic matter content and the respiration index were determined in an aliquot of at least 1 kg of this representative sample.

2.3. General analytical methods

Total carbon (TC), dry matter (DM) and moisture content, organic matter content (OM), pH, electrical conductivity, total Kjeldahl nitrogen, C/N ratio and bulk density were determined in triplicates from representative samples following the standard methodology proposed by the US Department of Agriculture and US Composting Council (2001).

Air filled porosity (AFP) was *ex situ* measured with a constant volume air pycnometer developed by Ruggieri et al. (2009). AFP is presented as an average of a triplicate measure.

Heavy metal content (nickel, lead, copper, zinc, mercury, cadmium, chromium and chromium VI) was determined in final compost samples by an external laboratory using atomic absorption spectrometry (Applus S.A., Lleida, Spain). Pathogen indicators (*Salmonella* and *E. coli*) were also analysed in an external laboratory by using the membrane filter enumeration method (Applus S.A., Lleida, Spain).

To monitor the activity and stability of the material, the dynamic respiration index (DRI) and the cumulative CO_2 production (AT_n) were determined. In this study, DRI and AT_n were determined following the methodology proposed by Ponsá et al. (2010). Briefly, it consists of two glass flask reactors, a thermostatic bath at 37ºC, a control cabinet, an oxygen and dioxide carbon sensor, an air supply system based on mass flow-meters and a personal computer unit. DRI was expressed as mg of oxygen consumed per g of organic matter and per hour (mg O_2 g^{-1} OM h^{-1}) and it is presented as an average of a duplicate measurement. It corresponds to the average value of maximum respiration activity during 24 hours. AT_n was expressed as g of carbon dioxide produced per g of dry matter (mg CO_2 g^{-1} DM), where n is the number of hours of the experiment, and it is also presented as an average of a duplicate measurement.

3. Results and discussion

3.1. Lab-scale experiments

Figure 1a shows the CO_2 evolution during the whole respiration experiment. High values of CO_2 were emitted during the first 300 h by the experiments D1 and D2, and they clearly show a considerable biodegradation of compostable diapers. On the contrary, the CO_2 emissions of the control experiment were very low and are related to the high stability of the used compost (respiration index of 0.8 mg O_2 g OM h^{-1}). It has to be pointed out that stable compost was used as a co-substrate with the aim to maximize the difference between CO_2 emissions of D1, D2 and control. This first period of high degradation is followed by a period where D1 and D2 experiments have low CO_2 emissions, which are very close to the base line emissions produced by the control experiment. One possible hypothesis to explain the rapid decrease of microbiological activity in samples D1 and D2 could be the lack of nutrients in the sample, mainly nitrogen, resulting from a high C/N ratio because of the addition of high amounts of C (compostable diapers are mainly made of biodegradable carbon). However, to confirm this point, specific analysis on nitrogen content and a complete balance of this compound including ammonia emissions should have been carried out.

Figure 1b shows the cumulative production of CO_2 during the entire experiment. The CO_2 emitted by the biodegradation of diapers (both cellulose and biodegradable polymers) corresponds to 8.04 and 7.91 g of C respectively, which means a degradation of the initial C diaper content of 44.72 and 44.00%, respectively. These results are summarized in Table 3. The lack of nutrients, the mesophilic temperatures and the use of a static system may be the causes of observing this non-complete biodegradation. Improving these points, as it occurs in a full-scale facility, could enhance the biodegradation of diapers. Recent studies have shown that, even at lab scale, the biodegradation of disposable diapers can reach values near 90% using controlled and favourable conditions (Espinosa-Valdemar et al., 2011). This would be in accordance to the EN 13432 standard for biodegradable plastics. Although this standard is not achieved with compostable diapers at lab scale, the main objective was to observe their biodegradation in a shorter time. According to manufacturers' information, the biodegradation reached for compostable diapers considering the time requirements of EN 13432 standard is over 95%.

3.2. Full-scale experiment

In general, similar patterns during the composting of the OFMSW with and without compostable diapers were obtained, as it has been observed with other biodegradable polymers used at field scale (Klauss and Bidlingmaier, 2004).

Figure 2 shows the temperature profile measured during the composting process, temperature followed the typical pattern of a composting process and thermophilic temperatures were achieved in both cases during several days (Barrena et al., 2006a; Ruggieri et al., 2008; Pognani et al., 2012). A second peak in temperature was observed after 20 days of experiment for both materials, which probably was due to a change in the aeration rate. Thus, it can be concluded that the totality of the material was exposed to temperatures that assure the material hygienisation (destruction of pathogens and viable weed seeds) following the criteria based on time-temperature conditions proposed by the US Environmental Protection Agency (1995) and the European Commission (2000).

During all the composting period, the moisture content was in the range of 40-60%. Moisture did not present a clear trend during the decomposition stage because of the inherent plant operation (intermittent leachate recirculation). During the curing phase, moisture content was maintained around 50% through the addition of tap water when necessary in order to maintain the proper development of composting microbial communities. Moreover, the composting process took place during winter conditions, and rainfall did not allow the compost to dry during the last days.

Organic matter content showed a continuous decrease during the entire period of composting, and a reduction from 74 % to close to 50 % at the end of the composting process was measured. As expected, the decrease of OM occurs during both the thermophilic and the curing stage (Colón et al., 2011).

Figure 3 presents the evolution of the dynamic respiration index. As observed, the most important part of the biological activity reduction occurred during the high active decomposition stage (41 days) when the DRI decreases from 4-5 mg O_2 g^{-1} OM h^{-1} to a value close to 2 mg O_2 g^{-1} OM h^{-1}. After this initial period, a slower decrease of respiration activity was observed until the end of the process (day 106) reaching a final value near to 1 mg O_2 g^{-1} OM h^{-1}, which is similar to that of stable compost (Barrena et al., 2006b; Ponsa et al., 2010). This approximately corresponds to a biodegradation near 90% when considering the OFMSW and compostable diapers reduction in respiration activity (Ponsá et al., 2008; Colón et al., 2011).

Table 4 shows the complete characterization of the final compost obtained with and without compostable diapers. Again, the values observed between both composts were very similar. Only relatively small differences were observed in some parameters. These differences can be related to the inherent heterogeneity of the starting material and some possible small differences in the performance of the composting process, since at full-scale it is practically impossible to conduct both experiments under the same exact conditions (Ruggieri et al., 2008). The general conclusion is that both products are sanitized, stable and of good quality. In both composts, an organic matter content higher than 35%, a total nitrogen content over 2%, and a C/N ratio lower than 20, along with a high degree of stability (DRI ≤ 1 mg O_2 g^{-1} OM h^{-1}) make this material a high quality compost useful for any agronomic application.

Regarding sanitation, this has been highly effective and none of the pathogenic microorganisms used as indicators have been detected in significant amounts. It is evident that the temperature reached and the natural decay of pathogens has a positive effect on sanitation and no problems due to addition of diapers have been observed (Gerba et al., 1995).

In relation to heavy metals content, it is clear that the levels detected for both materials are low. The sole exception is the presence of lead in the final compost without diapers that is slightly above the limit for Class A compost in the European legislation. It is important to remark the low zinc content in the compostable diapers compost, since zinc is commonly used in pomades for baby skin care (Runeman, 2008; Visscher, 2009) and as supplement for baby milk powder (Ikem et al., 2002). This point was hypothesized by Colón et al. (2011) as one of the possible reasons of the relatively high amounts of zinc found in the final compost during the composting of the OFMSW with conventional disposable diapers. In this study, the main conclusions were that disposable diapers did not alter the performance of the composting process, but some characteristics of the end product were different. In general, regarding heavy metal concentrations, the differences found between both composts seem to be related to the sample inherent variability of the OFMSW and the proposed collection system. This has been previously observed when composting the OFMSW, a fraction of municipal solid waste that presents a high level of heterogeneity (Colón et al., 2011; Catalan Waste Agency, 2011; Huerta-Pujol et al., 2011).

Although the complete biodegradation of diapers did not occur, the majority of diapers were biodegraded, although a reliable confirmation of this point should be carried out using labelled C-14 and following CO_2 emissions, which is practically impossible at full scale. In fact, only some small parts of non-biodegraded diapers were visually observed after the composting process. However, these parts were easily separated passing the material through a mesh of 10 mm, which is typically used in the final steps of refining compost. Afterwards, these remaining pieces of non-biodegraded diapers can be recirculated to the next process without major concerns, as they do not contain any non-biodegradable part.

4. Conclusions

Baby disposable diapers account for a significant percentage of municipal solid waste, around 1.7% in the UE-27 (in 2009). Currently, diapers cannot be recycled and the totality of them ends up in landfills or incinerators.

An experience was carried out in a nursery with two commercial compostable diapers and then their biodegradability was analysed by means of a composting process with the OFMSW. Collection and treatment of compostable diapers jointly with the source-separated OFMSW does not imply any change in the operation and process of composting of this municipal solid waste stream.

In lab-scale experiments, which can present some limitations compared to full-scale results, degradation values close to 45% of the initial carbon content were observed.

The composting process of the OFMSW with compostable diapers at full-scale has shown no technical problems in the biological process in terms of stability, quality and sanitation of the resulting compost. No pathogenic microorganisms have been detected when composting compostable diapers, a relevant point when considering possible legal restrictions in the collection and treatment of the OFMSW containing used diapers.

We consider that the use of compostable diapers is a real alternative to disposable diapers as no technical problems have been observed and a significant amount of organic matter can be recovered. Nevertheless, a complete LCA of all the process in terms of sustainability and environmental impact and a rigorous economical analysis should be the object of further studies to confirm the suitability of this emerging option.

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Table 1. Estimation of diapers used in licensed child care units by country (%) (2009).

Country	Used diapers (millions)	Percentage of 0-3 years olds using licensed child care arrangements	Diapers used in licensed child care arrangements * (millions)	Diapers used in licensed child care arrangements (%)
Denmark	252.21	83.00	52.25	20.72
Sweden	423.31	66.00	69.24	16.36
Norway	233.15	44.00	25.41	10.90
Finland	229.82	35.70	20.39	8.87
Netherlands	709.97	29.00	51.21	7.21
Belgium	487.00	27.60	33.18	6.81
France	3,140.93	27.00	208.34	6.63
United Kingdom	3,015.00	26.00	191.14	6.34
Portugal	400.74	25.00	24.95	6.23
Italy	2,199.33	18.70	102.10	4.64
Ireland	279.00	15.00	10.10	3.62
Austria	299.80	10.00	7.54	2.52
Hungary	375.55	9.30	8.78	2.34
Germany	2,647.16	8.60	56.48	2.13
Czech Republic	455.20	0.50	0.54	0.12

Source: Own elaboration based on Environment Agency (2004), OECD (2006) and Eurostat (2009).

* Considering that in average children go to the nursery 5 days a week and use 2 diapers per day. For those children between 1 and 2 years old, the average number of school days of primary school in the OECD countries – 187 days per year (Spanish *Ministerio de Educación*, 2010) or 37 weeks per year – has been considered. Children less than 1 year old are considered to attend the nursery 21 weeks per year.

Table 2. Properties of the used organic fraction of municipal solid wastes once mixed with bulking agent in a volumetric ratio (1:1).

Parameter	Value
Dry matter content (%)	40.7
Organic matter content (%, dry basis)	73.0
pH (1:5 w:v extract)	4.7
Elec. conductivity (1:5 w:v extract, mS cm^{-1})	4.4
Nitrogen (Kjeldahl) (%, dry basis)	1.8
C/N ratio	23.0
Respiration index (mg O_2 g^{-1} OM h^{-1})	4.3
Bulk density (kg L^{-1})	0.5
Air-filled porosity (%)	50.0
Impurities (%)*	<1

* Impurities were determined by manual separation. They mainly correspond to plastics and paper.

Table 3. Degradation of compostable diapers during the lab-scale incubation experiments.

Sample	Total solids (g)	Total diapers C (g)	AT_n (g CO_2 g^{-1} DM)	CO_2 emitted (g)	C emitted (g)	C emitted by diapers (g)	C biodegraded (%)
Control	100.00	0	0.12 ± 0.04	11.8 ± 0.2	3.2 ± 0.1	-	-
D1	142.80	17.9 ± 0.2	0.29 ± 0.01	41.2 ± 0.6	11.3 ± 0.2	8.0 ± 0.2	44.7 ± 0.2
D2	142.80	17.6 ± 0.6	0.29 ± 0.03	40.8 ± 0.8	11.1 ± 0.3	7.9 ± 0.3	44.0 ± 0.4

Table 4. Properties of the final compost obtained with and without diapers. Class A compost requirements according to Spanish legislation are also shown (*Ministerio de la Presidencia*, 2005).

Parameter	Composts without diapers	Compost with diapers	Spanish legislation (Class A)
Dry matter content (%)	60.28	50.23	60-70
Organic matter content (%, dry basis)	47.37	54.09	>35
pH (1:5 w:v extract)	7.86	8.06	No value
Elec. conductivity (1:5 w:v extract, mS cm^{-1})	3.51	2.76	No value
Nitrogen (Kjeldahl) (%, dry basis)	2.31	2.10	No value
C/N ratio	11.64	14.62	<20
Respiration index (mg O_2 g^{-1} OM h^{-1})	0.98	1.06	No value
Bulk density (kg L^{-1})	0.38	0.40	No value
Air filled porosity (%)	60	58	No value
E. coli (CFU g^{-1})	40	37	<1,000
Salmonella (presence/absence in 25 g)	absence	absence	absence
Nickel (mg kg^{-1}, dry matter basis)	21	8	25
Lead (mg kg^{-1}, dry matter basis)	49	12	45
Copper (mg kg^{-1}, dry matter basis)	56	31	70
Zinc (mg kg^{-1}, dry matter basis)	176	120	200
Mercury (mg kg^{-1}, dry matter basis)	0.06	0.08	0.4
Cadmium (mg kg^{-1}, dry matter basis)	0.3	0.2	0.7
Chromium (mg kg^{-1}, dry matter basis)	15	14	70
Chromium VI (mg kg^{-1}, dry matter basis)	<0.50 (absence)	<0.50 (absence)	<0.50

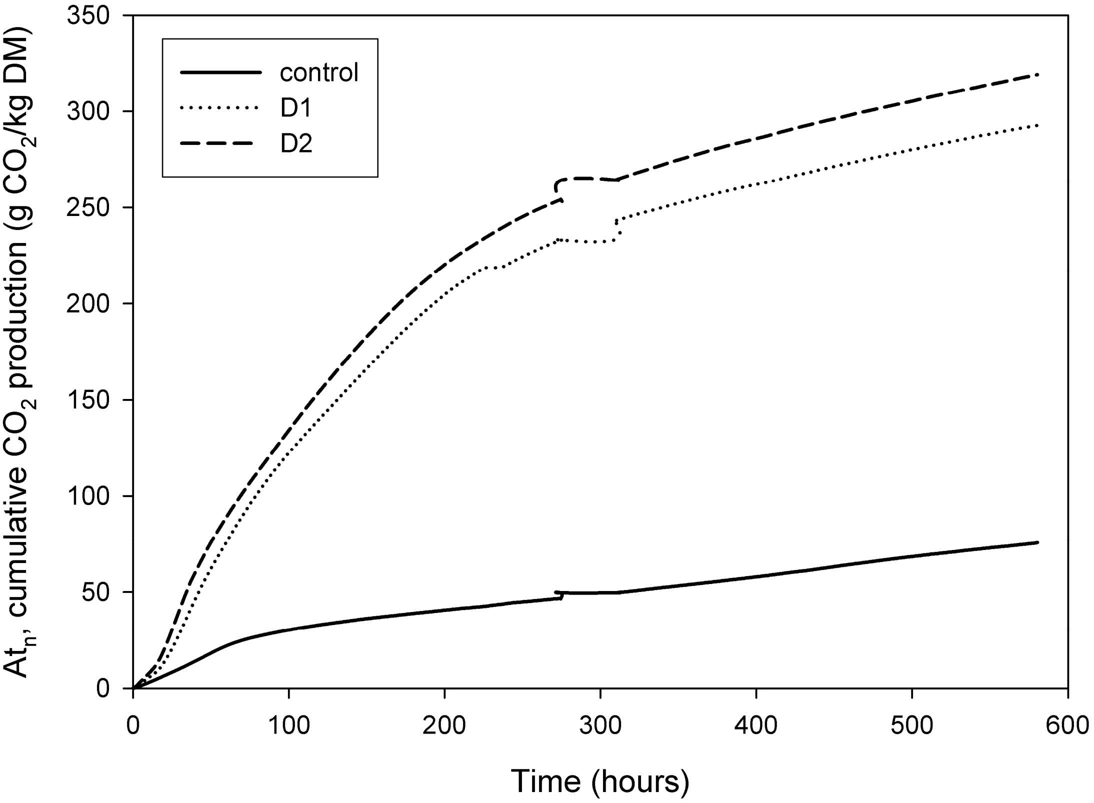
Legends to figures

Figure 1. Cumulative CO_2 production during the laboratory analysis of compostable diapers respiration.

Figure 2. Temperature profile measured during the full-scale composting process. Environment temperature was within 10 and 20ºC.

Figure 3. Evolution of respiration index during the composting process of the organic fraction of municipal solid wastes, with and without diapers (standard deviation for respiration index triplicates is represented for each point). Vertical dotted line separates decomposition (forced aeration process) from maturation (turned pile process) stages.

Fig. 1



350
300
250
200
150
100
50
0
At_n, cumulative CO_2 production (g CO_2/kg DM)
0
100
200
300
400
500
600
Time (hours)
control
D1
D2

Fig. 2

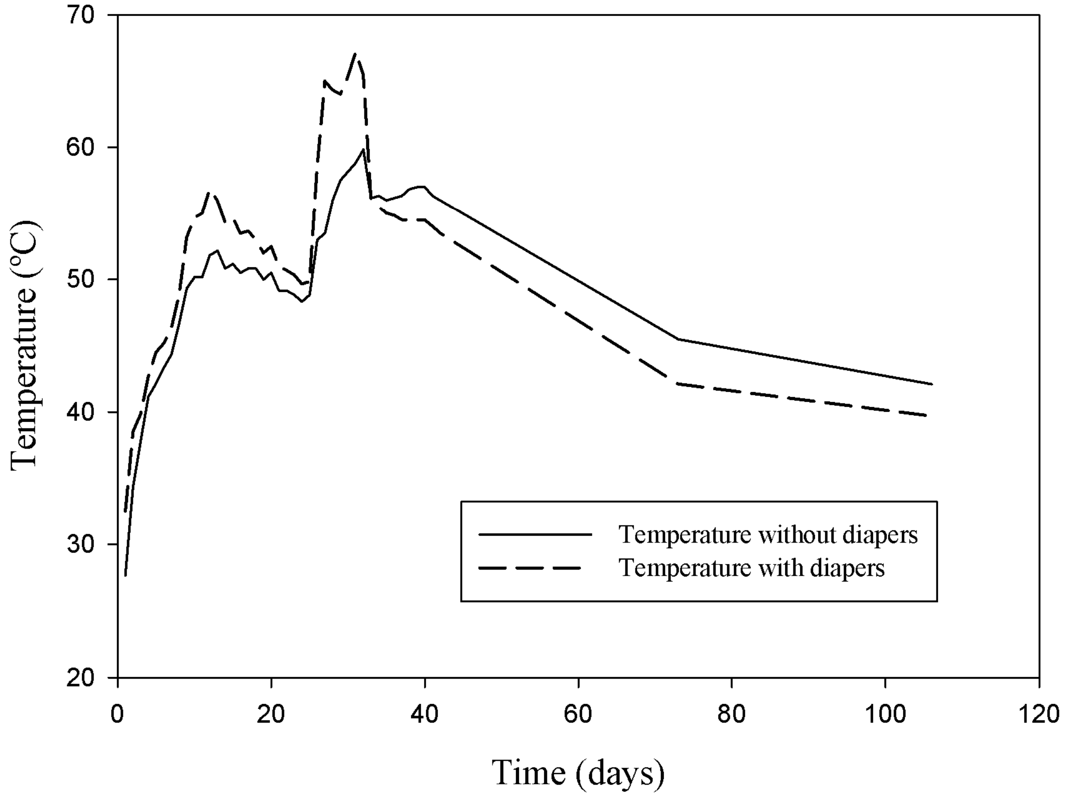
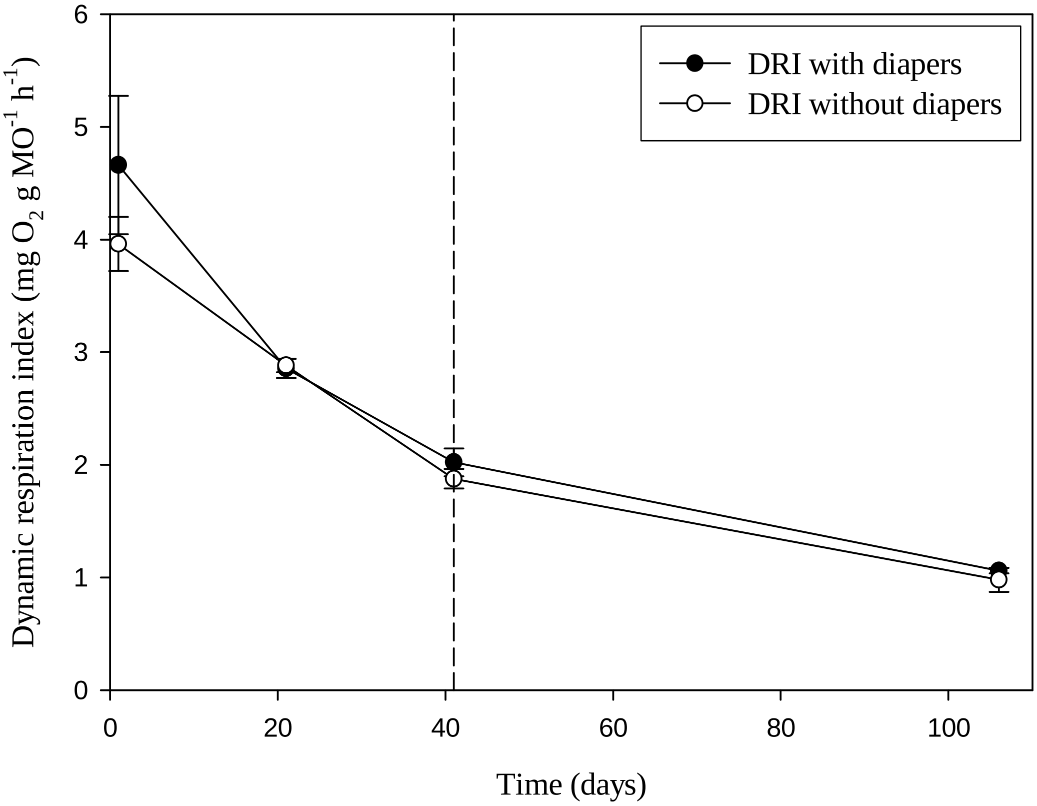

70
60
50
40
30
20
Temperature (°C)
0
20
40
60
80
100
120
Time (days)
Temperature without diapers
Temperature with diapers

Fig. 3


Dynamic respiration index (mg O2 g MO-1 h-1)
6
5
4
3
2
1
0
0
20
40
60
80
100
Time (days)
DRI with diapers
DRI without diapers