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Monitoring of the composting process of different agroindustrial waste: Influence of the operational variables on the odorous impact

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ABSTRACT

Composting is a conventional but economical and environmentally friendly way to transform organic waste into a valuable, organic soil amendment. However, the physico-chemical characterization required to monitor the process involves considerable investment in terms of cost and time. In this study, 52 samples of four compostable substrates were collected randomly during the composting process and analyzed physico-chemically. The physico-chemical characterization was evaluated and reduced by principal component analysis (PCA) (PC1 + PC2: 70% variance). Moreover, a study of the relationship between odor and the raw material and odor and the operational variables was carried out at pilot scale using PCA and multivariate regression. The substrates were grouped by PCA (PC1 + PC2: 87% variance). The odor emission rate (OER) and dynamic respirometric index (DRI) were found to be the most influential variables in the sample variance, being relevant to identify the different emission sources. Dynamic respirometry and multivariate regression could be suitable tools to predict these odor emissions for the majority of compostable substrates, identifying successfully the emission source.

1. Introduction

Due to the increasing amount of waste generated and the treatment methods currently established under the legislation on waste recycling and recovery as an alternative to landfilling disposal with a view to environmental protection (Council Directive, 1999), composting is a sustainable technique as it permits the stabilization and valorization of organic waste. Composting is an aerobic process of biological degradation carried out under controlled conditions to transform organic waste, resulting in a stable and sanitized organic amendment, widely known as compost. Moreover, the use of compost as fertilizer has numerous advantages as it improves soil structure, increases the soil organic matter, provides some plant nutrients and enhances plant growth (Paredes et al., 2005). However, the use of immature compost can result in adverse environmental effects due to the production of phytotoxic compounds (Tang et al., 2006), the dispersion of potentially pathogenic microorganisms (Bustamante et al., 2008), and nitrogen immobilization (Kato et al., 2005), especially in the case of compost with a high C/N ratio. Immature compost can also damage crops by competition for oxygen between microbial biomass and plant roots or seeds (Brewer and Sullivan, 2003; Gómez-Brandón et al., 2008).

The stability and maturity of compost cannot currently be established by a single variable (Bernal et al., 2009). Traditionally, the quality and maturity of compost has been determined by a combination of physico-chemical variables (Ciavatta et al., 1993), and respirometric variables, such as the specific oxygen uptake rate (SOUR), the cumulative oxygen demand at 20 h (OD_{20}) (Scaglia et al., 2007), the dynamic specific oxygen uptake rate (DSOUR) (Iannotti et al., 1993), and the dynamic respirometric index (DRI) (Adani et al., 2001), among others. In general, respirometric techniques are based on either O_2 consumption or CO_2 pro-

Abbreviations: C_{IC}, soluble inorganic carbon (%); C_{OXC}, oxidable organic carbon (%); C_{TC}, soluble total carbon (%); C_{TOC}, soluble total organic carbon (%); DRI, dynamic respirometric index (mg O_2/kg OM·h); DSOUR, dynamic specific oxygen uptake rate (mg O_2/g OM·h); ND, undetermined; NH_4^+, ammoniacal nitrogen (%); OC, odor concentration (ou_E/m^3); OD_{20}, cumulative oxygen demand at 20 h (mg O_2/g OM); OER, odor emission rate (ou_E/s); OFMSW, organic fraction of municipal solid waste; OFMSW-OPW, organic fraction of municipal solid waste with orange peel waste; OM, organic matter (%); PC, principal component; PCA, principal components analysis; Q, airflow ($m^3\ s^{-1}$); SFWSL, strawberry extrudate, fish waste and sewage sludge; SL, sewage sludge; SOUR, specific oxygen uptake rate (mg O_2/g OM·h); SPSS, statistical package for the social sciences; TKN, total kjeldahl nitrogen (%); TN_S, total soluble nitrogen (%); VS, volatile solids (%).

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duction by unstable biowaste under aerobic conditions. However, methods based on O_2 consumption are the most widely used to determine the biological activity of a material (Adani et al., 2003; Barrena et al., 2005).

On the other hand, due to the importance that odor impact acquired in 2001 when it was included in the second draft of the Biowaste Directive (European Commission, 2001), recent research has advocated dynamic olfactometry as an alternative technique to monitor composting process (González et al., 2016; Gutiérrez et al., 2016). Odor monitoring reduces the number of analyses, the time spent and costs (Sironi et al., 2010). The use of this technique is not independent of the quantification of the variables considered in the current regulations on quality compost as organic amendment. Alternatively, this technique followed by dispersion models allows the odor impact of a process to be quantified.

In fact, dynamic olfactometry was established in European standard EN-13725 (2003), as the reference method to determine odor concentration in terms of European odor units per cubic meter (ou_E/m^3), and is now accepted worldwide. The identification of unpleasant odors is a subjective perception, which can be evaluated using different methods. Zhou et al. (2016) identified the fecal odorants by using Gas Chromatography Mass Spectrometry. Lewkowska et al. (2016) presented basic information on the characteristics of odors from wastewater treatment lines and wastewater processing through the field olfactometry technique. However, the knowledge to identify the odorous emissions from different sources has not been solved yet (Hayes et al., 2017).

On the other hand, it is worth noting that due to the complexity of the conventional procedures and tools used in laboratories, hundreds of measurements are taken during a single experiment. As a result, the task of analyzing the data obtained in a set of experiments, particularly high-dimensional data, has become a challenge. These procedures can be tedious and expensive, so it is of great interest to find alternative methods in order to optimize the number and type of analyses and variables. Multivariate data analysis can be used to efficiently reduce most data into fewer variables without a significant loss of information. Specifically, principal components analysis (PCA) is a linear unsupervised technique that is very useful for analyzing and reducing the dimensionality of original numerical variables into a new reduced-dimensionality ($p < n$) (Prieto-Moreno et al., 2015). PCA is often used to visually inspect the evolution of observations over short time periods (Gutiérrez et al., 2015). In addition, PCA can be applied to the data in order to find a new coordinate system in which the input data can be expressed with much fewer variables (principal components) without significant error (Sorzano et al., 2000), and compare the relationships between the variables evaluated. This data processing method can be used in fields as diverse as herbs and herbal teas (Kara, 2009), olive mill wastewater (Raja et al., 2010), or the detection of contaminants in agro-food products (Fernández et al., 2015). Some authors have used PCA to evaluate the volatile organic compounds during the composting process (Delgado-Rodríguez et al., 2012; Nicolas et al., 2000). However, to be best of our knowledge, PCA could be used to reduce the number of analysis in the physico-chemical characterization.

The purpose of this study is twofold. The first objective is to classify the unpleasant odorous impact generated from the different emission sources depending on the organic waste and the operational variables. The evaluation of the physico-chemical variables and the operating conditions have been proposed to achieve this fact. Thus, the odor emissions are correlated to the follow-up variables of the composting process (temperature (°C), DRI (mg O_2/kg OM·h) and the airflow (m^3/s) used to aerate the material) by multivariate regression. The second objective is to estimate the odor emissions from the different compostable substrates in order to identify its origin or source.

2. Materials and methods

In this research study, 52 samples of compostable substrates of different origins and at different stages of maturity (10–239 days) were selected in order to monitor and evaluate the composting process. The solid samples were collected during consecutive composting stages from two different composting systems: (1) windrow/pile systems aerated by turning processes and tunnels processes at full scale; and (2) simulations of composting processes at pilot scale in which odor emissions were evaluated using a dynamic respirometer (Respirometer 3022).

It is worthy note that the turning process was carried twice a week during the intensive phase of microbiological degradation (hydrolytic stage) and once every two weeks during the maturity stage. Moreover, physico-chemical variables such as moisture, volatile solids, nitrogen content, among others, and operational variables such as temperature, dynamic respirometric index and airflow were determined in order to monitor adequately the composting process of the different compostable substrates.

2.1. Compostable substrates

The four compostable substrates were: the organic fraction of municipal solid waste (OFMSW) (Gutiérrez et al., 2014), a mixture of OFMSW with 10% orange peel waste (wet weight) (OFMSW-OPW) (Siles et al., 2016), sewage sludge with bulking agent (SL, 2:1 vol ratio) and a mixture of strawberry extrudate, fish waste, sewage sludge and bulking agent (SFWSL, 190:1:22:90 ratio, dry weight) (Serrano et al., 2014). The strawberry production was established around 312,500 tons in 2013 in order to produce marmalade, yogurt, among others (FAOSTAT). However, the strawberry processing requires an adequate recovery such as composting process or anaerobic digestion (Serrano et al., 2014). It should be noted that the bulking agent was used only in SL and SFWSL wastes. The OFMSW consisted of different percentages of organic matter, glass, plastic, papel-card and others, being the organic matter the most abundant components (63%). The generation of MSW is around 20,000,000 tons per year in Spain (OECD, 2013). Finally, according to the data of the National Sludge Registry, 1,200,000 tons of SL are produced in Spain annually (in dry matter) (MAPAMA, 2012).

2.2. Physico-chemical characterization

Moisture (%), volatile solids (% VS), oxidable organic carbon (% C_{OXC}), organic matter (% OM), phosphorous (% P_2O_5) and nitrogen content (as% TKN and% NH_4^+) were analyzed in the solid fraction, while soluble total organic carbon (% C_{TOC}), soluble inorganic carbon (% C_{IC}), soluble total carbon (% C_{TC}), soluble total nitrogen (% TN_S), pH and conductivity (dS/m) were measured in the aqueous extract (1:25 v/v ratio) following the methodology proposed by the US Department of Agriculture and the US Composting Council (2002). Table 1 shows the range of variability of the physico-chemical variables of the four compostable substrates evaluated during throughout the composting process.

In order to verify the quality of the data obtained, linear relationships were established between the most relevant physico-chemical variables, such as VS (%) determined by calcination and organic matter (% OM) calculated from the oxidable organic carbon (% C_{OXC}) multiplied by the Waksman coefficient (1.724) (Waksman and Stevens, 2000), and between VS (%) and TKN (%) or P_2O_5 (%). To do so, the four compostable substrates were grouped as OFMSW, SL and OTHERS depending on their composition.

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