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Slaughterhouse by-products composting: can microorganisms inoculum addition mitigate final compost odor emission?

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ABSTRACT

Small slaughterhouses generate biowaste, which for economic reasons, is generally destined for composting. Inoculating appropriate microorganisms can improve biodegradation efficiency and mitigate odor generation during the composting process and can give rise to composts with neutral or pleasant odors. Therefore, the aim of this study was to compare the odor intensity reduction of compost generated with and without a formulated inoculum (*Saccharomyces cerevisiae*, *Bacillus subtilis*, and *Rhodopseudomonas palustris*). A set of experimental data was collected and analyzed according to the German "Verein Deutscher Ingenieure" odor protocol. The results showed that adding microorganisms was effective in reducing unpleasant odors in all three composts generated from swine, cattle, and poultry slaughterhouse by-products during both summer and winter seasons. Additionally, soil odor was predominant in composts that were inoculated in the two tested seasons (i.e., summer and winter). On the other hand, composts without inoculation had odors similar to peat for swine compost, ammonia for cattle compost, and manure for poultry compost, regardless of the season tested. Overall, composting process with appropriate inoculum can help in the correct disposal of slaughterhouse wastes by transforming organic matter into composts, which can have economic and environmental value as a soil conditioner and/or fertilizer.

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Composting; odor emission; inoculum; agro-industrial waste; slaughterhouse waste

Introduction

The animal protein industry plays a significant role in the global economy, providing food for millions of people worldwide.[1] However, the improper management of waste produced in slaughterhouses, including fat, blood, bones, belly, manure, sludge, and wastewater, is an environmental problem observed in many countries.[2–4] Thus, while in developed countries the disposal of slaughterhouse waste is well regulated and aims to reuse this waste, in developing countries there are different sizes of slaughterhouses which, depending on the amount of waste and the industrial technologies available, can reuse this waste (as is the case with large agroindustries).[2,3] But there are also small slaughterhouses that are looking for the cheapest and easiest method of disposing of their waste.[4] In this way, large agroindustries generate little waste that cannot be reused and the most frequent destinations of this "waste of waste" is incineration or placement in landfills. Small slaughterhouses generally seek to the lowest cost method, favoring composting, which is a low-cost option in terms of infrastructure and labor and which provides the recycling of nutrients to the soil, which must be done well to avoid environmental problems and generate a useful product.[2]

Thus, although slaughterhouse waste can have a variety of destinations and recovery options (i.e., animal food, pharmaceuticals, cosmetics and bioplastics products), composting destination can have negative impacts to the environment and public health *via* vectors for the spread of diseases such as typhoid fever, dysentery, cholera and hepatitis from the transmission of pathogens.[2,5–6] In addition, if the biodegradation process is not efficient, the biodegradation of these wastes can produce bad odors (e.g., ammonia and sulfur compounds) and greenhouse gases (e.g., methane).[3,5,7]

The science of odors, known as osmology, defines volatile emanation from materials that can be perceived by living beings' smell system as odor. This physico-chemical and organoleptic characteristic of compounds is very important for life, as many organisms have developed odor detection systems.[8–10] However, the determination of odor quality (e.g., fragrancy, nuisance, and toxicity) is a complex issue where esthetic and physiological factors play important roles in odor perception.[11,12] Thus, dynamic olfactometry with the involvement of odor panelists is generally used to

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determine odor thresholds.[13,14] In the field of environmental science, mitigating the malodorous compounds emitted into the atmosphere is one of the main challenges of the biodegradative process.[7,12,15]

An alternative destination for non-edible organic waste is composting, which is a sustainable, efficient, and low-cost recycling process in terms of infrastructure and labor.[12,16–19] The compost produced can be used as fertilizer due to the presence of mineral salts and humus, which, when applied to the soil, helps improve the physico-chemical and microbiological soil characteristics and also promote carbon sequestration, mitigating climate change.[16,20,21] However, the composting process has its limitations regarding the biodegradation process (e.g., time and efficiency of composting, generation of odors) and regarding the quality of the compost generated (e.g., detection of thermotolerant pathogens, low nutritional value, odor).[2,16,22] Generally, composting problems can be avoided by good management of the composting process, which includes control of different physico-chemical conditions such as temperature, aeration, moisture, C/N ratio, pH, and the surface area of organic particles.[7,17,23–26] Faulty management of composting process affects degradative efficiency and thus can generate bad odors that spread throughout the composting area generating complaints from people in the neighborhood.

In this sense, addition of an inoculum with bacteria increases the efficiency of biodegradation in terms of the time required for composting and the quality of the compost,[27–29] and it is possible that this improvement is also reflected in the reduction of bad odor intensity during the biodegradation process and in the compost generated. Here, bad odors (or unpleasant odors) means a stinking, fetid, noisome, putrid, rank, or fusty odor. In this sense, the goal of this article is to compare the composting process of three different types of slaughterhouse by-products (i.e., poultry, swine, and cattle residues) with and without the application of a formulated inoculum in terms of bad odor reduction of the final compost generated under two different climatic seasons (i.e., winter and summer). With this study, we also sought to see whether the applied inoculum is efficient in degrading different types of slaughterhouse by-products.

Material and methods

Composting process

The slaughterhouse by-products of swine, poultry, and cattle animals were obtained from the Instituto Federal Catarinense (IFC) slaughterhouse, located in Camboriú City (SC, Brazil). For this study, 200 kg of each type of biowaste, including heads, feathers, and white animal organs such as those from the tract and tubular digestive contents, as well as organs and glands (pancreas, salivary glands, and adrenal glands), reproductive tract, hemolymphatic system (spleen, lymph nodes, and blood vessels), lungs, and fat, were used. The composting windrow for each animal by-product was prepared based on the "UFSC Method" described by Inácio and Miller.[17] In this method, the waste (45% of the windrow mass) is arranged in layers alternating with structuring material (50% of the windrow mass), always assembling a lateral wall from the latter (Fig. 1). The windrow was assembled using grass scrap structuring material (*Zoysia japonica*) and hat leaves (*Terminalia catappa*) resulting from pruning and clearing the IFC gardens. To select biodegradative microorganisms, a semi-mature compost from a permanent windrow was used as an initial source of inoculum. This windrow was prepared by composting food waste from the IFC restaurant. The size of the animal residue composting windrow varied from 1.0 m to 1.2 m at the base and a standard height of 75 cm. A total of 12 windrows were assembled (3 biowaste types, 2 seasons, with and without inoculum). Whenever the mean internal temperature of the windrow displayed a 10 °C difference from the ambient temperature, biomass turning was performed. A total of 6 turning over were carried out until compost maturation. After each turning over, the biomass windrow was reassembled to the original dimensions except for the shortened length due to the decrease in original waste volume.

Inoculum compositium and development

Based on a literature review, a good inoculum composition for slaughterhouse waste includes *Bacillus subtilis*, *Rhodopseudomonas palustris*, and *Saccharomyces cerevisiae. Bacillus subtilis* is a common bacterium in water and soil that accelerates the metabolization of sugars, fats, starches and proteins and which, due to its thermophilia, has been used to reduce the proliferation of insect larvae during the composting process, and the incidence of phytopathogenic vectors.[30,31] In relation to the *R. palustris*, this is a common bacteria in water and soil, recognized for its biodegradation power, used to accelerate the metabolization of fats, proteins, sugars and nitrogenous compounds, especially nitrosamines, and organo-chlorines, helping to eliminate odors.[30,32] The third component of the developed inoculum is the fungus *S. cerevisiae*, which is used to accelerate the metabolization of carbohydrates, especially sugars and starches and, as it is a yeast, it has a high fermentation capacity. It produces alcohols, mainly ethanol, which, when forming an azeotropic mixture with water, facilitates the removal of moisture by evaporation, helping to eliminate odors.[33,34] With respect to the inoculum development envolving these microorganisms, numerous patents have already been developed to speed up the composting process. Thus Li et al.[35] patented a microbial decomposer inoculant for the production of organic fertilizer, using *R. palustris* and *S. cerevisiae*, resulting in high-quality fertilizer, reducing the maturation time of the compost. Li et al.[36] patented a microbial inoculant to reinforce and promote the organic composting process using strains of *R. palustris, S. cerevisiae, B. subtilis, Bacillus licheniformis* and *Candida tropicalis*. According to the authors, the mixture of strains generates high colonization in organic waste, strong adaptability, eliminating odors with a rapid biodecomposition process. In another study, Chen [37] patented a method of preparing microbiological organic fertilizer as an inoculant for composting kitchen waste, animal

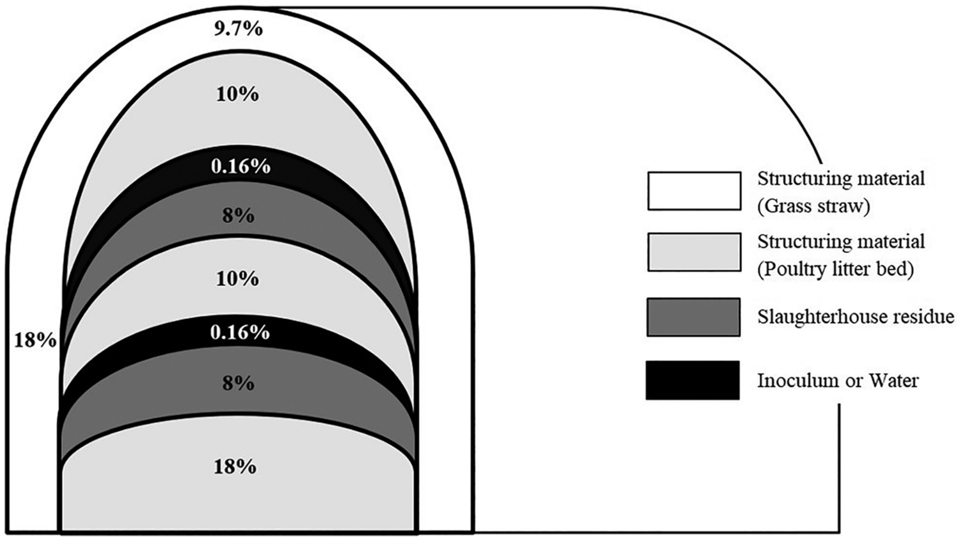

Figure 1. The scheme for assembling a static windrow with passive aeration for the composting of different slaughterhouse wastes using straw and poultry litter as structural materials.

waste and crop straw. The inoculum contains activated carbon, animal excreta, biogas residues and a bacterial mixture, including *R. palustris, B. subtilis, Bacillus thuringiensis, Nocardia, Lactobacillus* sp. and *Pseudomonas* sp. The composting process with the inoculum results in a microbiological organic fertilizer that optimizes the physical, chemical and biological conditions of the soil for better vegetative development. Li et al.[38] patented an inoculant using strains of *B. subtilis* and *S. cerevisiae* as agents that inhibit the growth and spread of pathogens. The authors describe the result of mixing strains as a physical and chemical optimizer of soil properties, promoting excellent vegetative development, quality, resistance to stress, increasing crop yield. The development of the inoculum used in this study includes several steps, which were previously described in detail.[28] In the first step, a composting windrow was assembled to capture microorganism colonies, while in the second step, the physico-chemical composition of the inoculum was determined. The third step involved scaling up the inoculum, and the fourth step was using the inoculum in the composting process.

Inoculum efficiency assessment in the composting process

This experiment was conducted using a composting windrow assembled according to the scheme shown in Figure 1, which was described in detail in a previous work.[28] The outermost layer of the composting windrow was made from corn straw, while the inner part was made from a poultry litter bed that had been stabilized for four months. The inoculum was applied as a solution in a ratio of 1 liter to 50 kg of slaughterhouse waste. Composting windrows, both with and without inoculum (control), were carried out during summer and winter to evaluate the adaptability and development of the inoculum under two opposite environmental conditions.

Biomass turning over occurred on the same day for composting windrows with and without inoculum. The inoculum (and water for the control windrows) was applied on the day the windrows were assembled and afterward on the days when biomasses were turned over. The time to obtain the compost varies between different types of waste, between seasons and also with the addition or not of the inoculum. Thus, to ensure that the composts were truly mature, composting of the three types of biowaste was allowed to evolve for up to 180 days. Physico-chemical analysis of the composts was performed according to the protocols of APHA, AWWA, WPCF.[39]

Sensory odor analysis and statistical treatment

Odor evaluation was conducted using the direct method (dynamic olfactometry), with human olfaction as a sensor, according to the published methodology of Mori et al.[40] and VDI [13] with slight modifications described below. Dynamic olfactometry was the most appropriate method in terms of infrastructure available for odor intensity analysis and also to achieve the objective of this work. A group of 14 people (7 men and 7 women), aged from 14 to 66 years and without training for sensory analysis, was invited to participate in the analysis. Some of the reasons to consider including participants of different ages and genders were: (i) Varied olfactory sensitivity; (ii) Differences in perception between genders; (iii) Representativeness of the target population; (iv) Variation in personal experience; (v) Assessment of social acceptability; and (vi) Possible behavioral differences. The evaluations were conducted in a room at 24 °C. Two hundred and fifty grams of each compost sample were placed into sealed 500 mL glass flasks, which were then sealed for 24 h. Some methodological aspects were considered when filling the flasks for sensory analysis: (i) Sample quantity (250 grams – is representative of the quality of the compost and also has the texture, and all the components that are part of the compost, in addition to allowing easy handling); (ii) Sealing period (24 h – equilibrium and stability of the gas phase, minimization of bias due to temporal standardization). After 24 h, the flasks containing the samples were made available to the evaluators on a table (see Fig. 2).

To perform odor identification and odor intensity evaluation, initially the meaning of each category used in the VDI scale was explained in detail. After that, the evaluators were exposed to the different standard odors of natural soil, cattle manure, green grass, swine manure, ammonia, mold, poultry manure and peat. Then, each evaluator stood in front of a table with one sample, opened the flask, sniffed it, and then closed it. Each evaluator smelled 12 flasks, writing down on a card the result of their perception of the type and intensity of the odor based on the VDI scale that includes seven categories of odors:

- 0 = Not Perceptible: No perceptible odor.
- 1 = Very Weak: Extremely weak odor, almost imperceptible.
- 2 = Weak: Perceptible odor, but very weak.
- 3 = Discreet: Odor present discreetly.
- 4 = Strong: Clearly perceptible odor of moderate intensity.
- 5 = Very Strong: Pronounced, unpleasant and very intense odor.
- 6 = Extremely Strong: Extremely strong odor, which can be considered very unpleasant.

To "validate" the findings the group of evaluators then met and discussed which of the most obvious odors were found in each compost sample. To meet the necessary assumptions for the application of analysis of variance, the data were evaluated for their normality (using the Shapiro–Wilk test) and homoscedasticity (using the Brown–Forsythe test), and when at least one of these assumptions was not met, the analysis was conducted using the GLM (Generalized Linear Model) module. According to Myers et al.,[41] GLM does not require that the data follow a normal distribution because it explores the apparent distribution of the data. In addition, constant variance is not a problem in GLM, which bases its analysis on the natural variation of the data distribution.[41] The variance analyses were conducted in a factorial scheme (factorial ANOVA) using the statistical package Statistica version 6.0 (Statsolf, Tulsa, USA). Only effects with significant differences were illustrated using unbalanced statistical means.

Results and discussion

Compost physico-chemical characteristics

The slaughterhouse by-products of the same animal are extremely heterogeneous in their chemical constitution (e.g., fats, proteins, keratin) and homogenization was carried out in a blender to analyze the samples, but these materials were not homogenized at the beginning of the composting process. Elemental chemical analysis showed the following constitutions: poultry waste (C:$N = 9.4$; $N = 9.1\%$; $p = 2.5\%$; $K = 2.2\%$), pig waste (C:$N = 12.1$; $N = 7.3\%$; $p = 5.5\%$; $K = 3.3\%$), and bovine waste (C:$N = 14$; $N = 7.0\%$; $p = 4.6\%$; $K = 2.9\%$). The temperature profile of some composting process for swine and cattle waste, including the ambient and internal windrow temperatures in the winter or hot season with and without inoculum were published in previous works.[28,29]

The physico-chemical characteristics of final composts are showed in Table 1. Data for swine and cattle composts come from previously published works.[28,29] All the composts reached a pH around six to seven units, while moisture content was generally greater than 50%. According to Schnitzer et al.,[42] humic acids associated with soil colloids form insoluble complexes at pH under 6.5, allowing the immobilization and/or accumulation of these complexes in acid soils. All composts achieved an organic carbon (OC) value over 10%, but the production of humic acids was relatively high, according to CEC values, which were higher in compost generated with inoculums addition. All others measured composts components (i.e., N, Ca and Mg) showed similar concentration between different composts. The P_2O_5 level of all composts (between 1.1 and 2.3%) is medium., as well

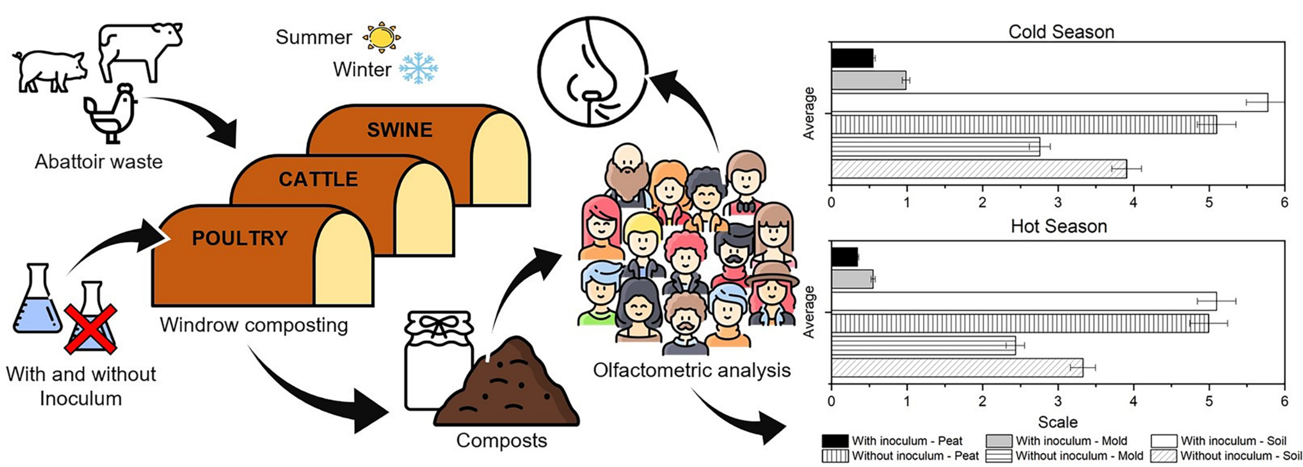

Figure 2. Schematic steps for generating composts for sensory analysis.

Table 1. Mean physico-chemical characteristics of composts generated by composting of cattle, swine and poultry biowaste.

	Swine[a]		Cattle[a]		Poultry	
Parameter (unit)	Without inoculum	With inoculum	Without inoculum	With inoculum	Without inoculum	With inoculum
pH (a.u.)	6.7 ± 0.1	7.0 ± 0.1	6.2 ± 0.1	6.3 ± 0.1	6.1 ± 0.1	6.4 ± 0.1
OC (%)	16.4 ± 2.1	14.3 ± 1.9	11.3 ± 1.1	11.7 ± 1.2	12.3 ± 1.3	10.5 ± 1.2
Moisture (%)	48 ± 3	58 ± 3	58 ± 6	62 ± 7	55 ± 7	61 ± 8
CEC ($Mmol_c.kg^{-1}$)	641 ± 22	707 ± 25	510 ± 41	589 ± 52	550 ± 22	572 ± 27
N (%)	1.0 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	1.1 ± 0.1	0.9 ± 0.1
P_2O_5 (%)	2.3 ± 0.2	1.9 ± 0.2	1.1 ± 0.1	1.2 ± 0.1	1.3 ± 0.1	1.5 ± 0.2
K_2O (%)	1.8 ± 0.2	1.7 ± 0.2	1.3 ± 0.2	1.4 ± 0.2	1.2 ± 0.2	1.0 ± 0.2
Ca (%)	0.3 ± 0.02	0.5 ± 0.03	0.3 ± 0.01	0.4 ± 0.02	0.4 ± 0.02	0.4 ± 0.02
Mg (%)	0.5 ± 0.06	0.3 ± 0.02	0.2 ± 0.02	0.3 ± 0.04	0.3 ± 0.03	0.2 ± 0.02

Note: CEC: cation exchange capacity; OC: organic carbon; a.u.: arbitrary units.
[a]Data from Batista-Barwinski et al.[28,29]

Table 2. Analysis of variance in a factorial scheme for Inoculum, Season, and Waste type factors and their interactions to evaluate composting evolution.

Factors	DL	*p*
Inoculum (A)	1	*
Season (B)	1	*
Animal waste (C)	2	*
(A) × (B)	1	*
(A) × (C)	2	*
(B) × (C)	2	*
(A) × (B) × (C)	2	*
Error	24	

Note: Data of three types of residues (poultry, cattle and swine) were pooled in this analysis.
*Significant difference (α = 0.001). DL = degree of liberty: factor number -1.

Table 3. Normality test (Shapiro–Wilk test) and homoscedasticity test (Brown–Forsythe test) on the perception of odors of the compost generated from swine, cattle and poultry slaughterhouse waste.

		Normality	Homoscedasticity
Compost	Variables	*P*	*P*
Swine	Soil	0.037**	1.000 n.s.
	Mold	0.000*	0.240 n.s.
	Peat	0.000*	0.781 n.s.
Cattle	Soil	0.0002*	0.034290*
	Grass	0.00027*	1.000000 n.s.
	Ammonia	0.00001*	0.421197 n.s.
Poultry	Soil	0.000*	0.876 n.s.
	Mold	0.000*	0.611 n.s.
	Manure	0.000*	0.345 n.s.

*Significant difference (α = 0.001); **significant difference (α = 0.01); ***significant difference (α = 0.05);n.s. = not significant (α = 0.05).

also K_2O (between 1.0 and 1.8%), while Ca and Mg are classified at low levels (< 0.55%) according to the Kiehl fertilizer classification.[43]

The presence of inoculum, biowaste type, and their interactions, as well as other physico-chemical factors, guide the composting evolution and determine odor quality. Literature data shows a high correlation between humidity and internal windrow temperature, which are related to the rate of organic material decomposition.[44] Chemical attributes, such as pH and organic matter quality, and macroclimatic variables are usually able to explain the overall variation of activity and microbial biomass composition levels in the decomposition rate of organic material in windrows.[45]

To verify the influence of different factors on composting evolution, an analysis of variance was performed by pooling the composting data of three types of residues (poultry, cattle, and swine). The results are presented in Table 2.

Table 2 shows that the three factors studied (presence or absence of inoculum, season of the year, and type of waste), as well as all their interactions, influence the biodegradation evolution and the odor emitted by the generated compost. For example, it was reported that biological compost stability influences odor molecule production measured by electronic nose during food-waste high-rate composting.[46]

The studied inoculum, composed of three types of microorganisms, was shown to be more efficient for composting swine slaughterhouse wastes, and higher efficiency was achieved during the summer season. After this biodegradation evolution overview, the odor quality of different composts was assessed, and the main results are presented below.

Sensory odor analysis

Odor emissions from composting are a common source of annoyance that significantly impacts air quality. Good management of composting operations can help minimize odor impacts, although odor generation cannot be avoided.[47,48] To prevent and abate odor, appropriate inoculants should be used, and correct operational conditions (e.g., frequent compost aeration turning over) should be adopted.[47]

In this study, sensory odor analysis was performed by evaluators using a VDI scale ranging from 0 to 6. The score data for swine, cattle, and poultry compost odors did not display normal distribution or homoscedasticity. Therefore, the analysis was conducted using the GLM module. The results of the analysis of variance of the collected data are presented in Table 3.

Starting with an overview of the results, it can be observed that the presence of inoculum use in the composting beds significantly influenced the perception of soil, mold, and peat odors in the compost generated by swine waste, soil, grass, and ammonia odors in the compost generated by cattle waste, and soil, mold, and manure odors in the compost generated by poultry waste (see Table 4). Moreover, it was found that the soil and mold odors of composts generated by swine and poultry waste, and soil and ammonia odors of compost generated by cattle waste, are significantly affected by the composting period, which is not the case for the peat odor of swine compost, grass odor of cattle compost, and manure odor of poultry compost. Interestingly, only the soil

Table 4. Analysis of variance on the significance of factors and relationships between inoculum, season, and their interactions (factorial ANOVA).

Factors		Significance								
		Swine			Cattle			Poultry		
	DL	Soil	Mold	Peat	Soil	Grass	Ammonia	Soil	Mold	Manure
Inoculum (A)	1	*	*	*	*	*	*	*	*	*
Season (B)	1	*	*	n.s.	*	n.s.	*	*	*	n.s.
(A) × (B)	1	n.s.	*	n.s.	*	*	*	*	*	*
Error	48	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Note: Data of three types of composts generated by poultry, cattle, and swine wastes were pooled in this analysis.
*Significant difference (α = 0.001); n.s. = not significant (α = 0.05).

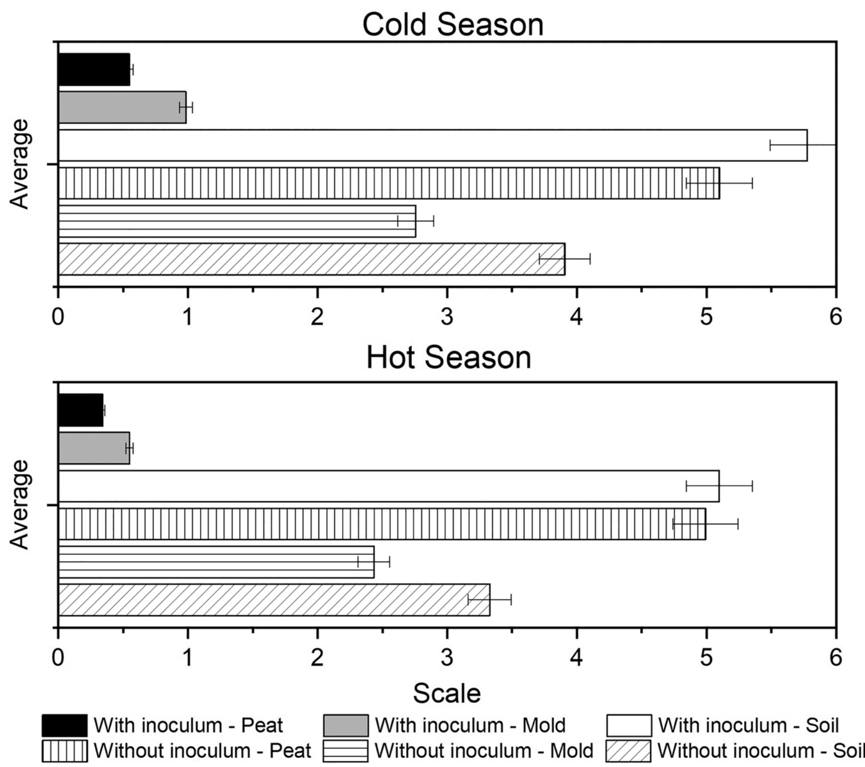

Figure 3. Mean and standard deviation in the VDI scale quantification of the main odors identified in the swine compost generated in the summer and winter, with and without inoculum application ($n = 14$).

and peat odor in swine compost were not related to the presence of inoculum and the season of the year in which the experiment was conducted, which differs from the other compost odors identified and influenced by the presence of inoculum and the season of the year observed in cattle compost (soil, grass, and ammonia) and poultry compost (soil, mold, and manure).

A more detailed and specific analysis of the different compost odors can be found in Figures 3–5. These figures illustrate that the odor profiles of composts generated from different waste materials biodegraded with inoculum are similar, regardless of the season of biodegradation, as evaluated by the VDI odor intensity.[13] Specifically, composts generated from swine waste biodegraded with inoculum (Fig. 3), cattle (Fig. 4), and poultry (Fig. 5) in both seasons showed a predominant soil odor characteristic, with peat, grass, and mold odors being the least predominant, respectively. In contrast, swine compost generated without inoculum in both seasons presented a predominant peat odor, with mold odor being less predominant (Fig. 3). Cattle compost (Fig. 4) generated without inoculum in both seasons presented a predominant ammonia odor, with grass odor being less predominant. Finally, poultry compost (Fig. 5) generated without inoculum in both seasons showed a predominant manure odor, with mold odor being less predominant.

The peat odor observed in swine compost generated with inoculum addition is similar to decomposing leaves, while the mold odor of compost generated without inoculum addition represents the microbiological activity of the decomposition. Both odors are typical of material still in decomposition, but in different stages. For swine compost (Fig. 3), the mean VDI intensity perception of soil odor resemblance was 5.10 for the compost prepared in summer with inoculum and 3.33 for the compost prepared without inoculum. For compost prepared in winter, the mean values were 5.78 with inoculum and 3.91 compared to compost prepared without inoculum (unbalanced means, with a 0.95 confidence interval). For mold odor resemblance, these values were 0.6 in summer with inoculum, and 2.44 for summer without inoculum, while in winter, the values were 1.0 with inoculum, and 2.77 without inoculum. Finally, peat odor

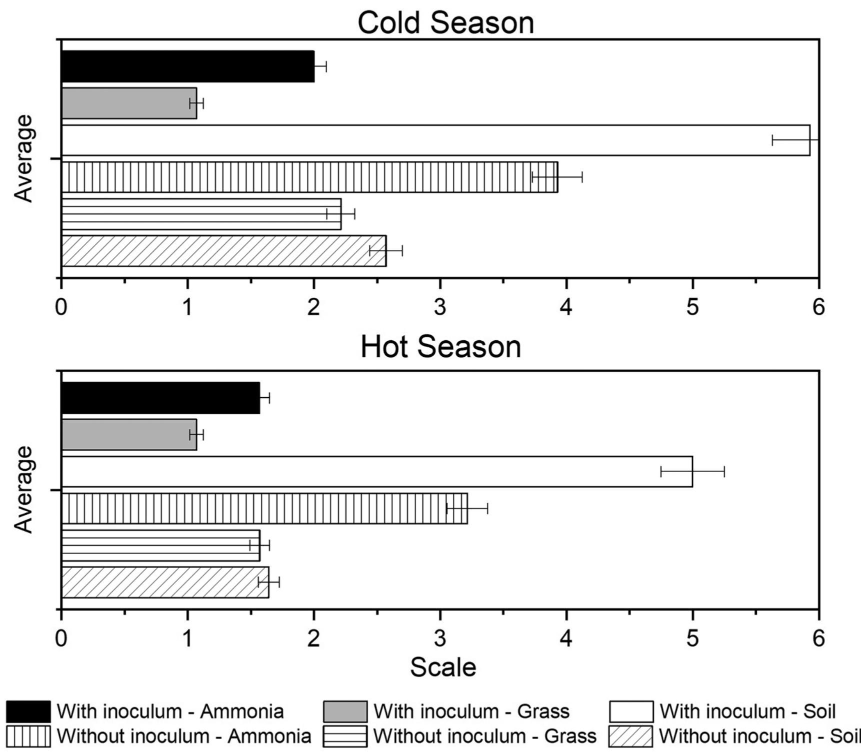

Figure 4. Mean and standard deviation in the VDI scale quantification of the main odors identified in the cattle compost generated in the hot and cold season of the year with and without inoculum application ($n = 14$).

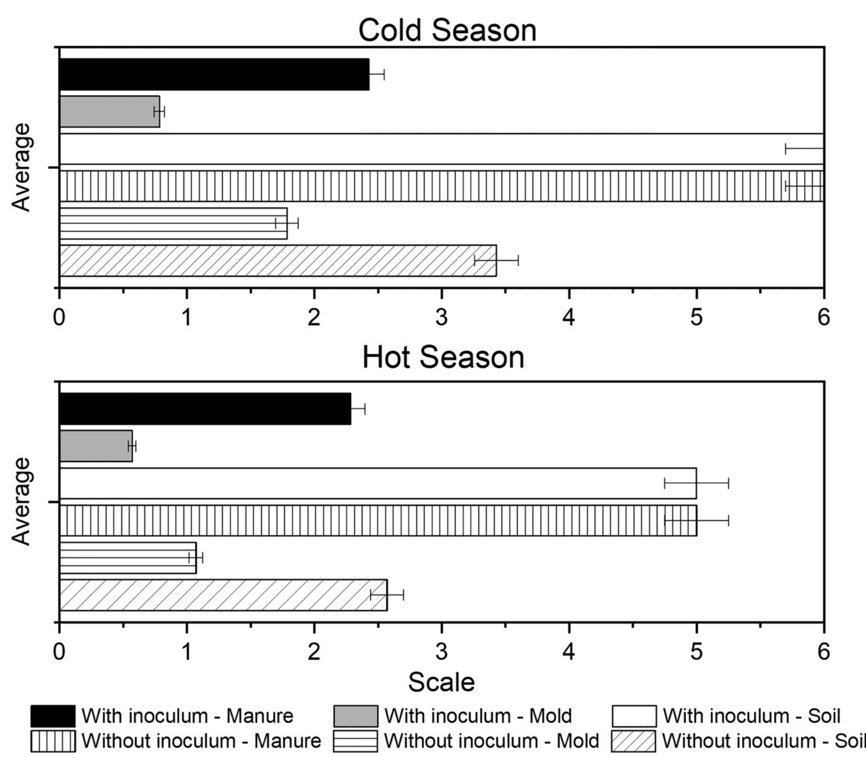

Figure 5. Mean and standard deviation in the VDI scale quantification of the main odors identified in the poultry compost generated in the hot and cold season of the year, with and without inoculum application ($n = 14$).

resemblance showed values of 0.37 for summer with inoculum, and 5.00 for summer without inoculum. For winter, these values were 0.58 with inoculum, and 5.10 without inoculum. Composts without unpleasant odors are an indication of the chemical stability of the material obtained. However, stability can be related to other chemical parameters, such as C:N ratio and CO_2 evolved from finished compost, and water-soluble C and the C:N_w ratio.[49,50] In this sense, soil odor is less offensive (i.e., soil odor) where the C/N ratio is lower (C/N ratios of 15–16) than compost with peat odor, where C/N ratios of 22–23 were found in both seasons. This difference is probably due to the lower decomposition of the organic matter of the swine slaughterhouse waste.

The composts generated from cattle waste biodegraded with inoculum (Fig. 4) in both seasons showed a predominant soil odor characteristic, while composts generated without inoculum addition in both seasons showed an ammoniacal odor, which can be compared to the mold odor, representing the microbiological activity of decomposition. Grass odor was the least predominant compost odor in both seasons, with and without inoculum addition.

Thus, from cattle compost (Fig. 4), the mean VDI intensity perception of soil odor resemblance was 5.0 for the compost developed at the hot season with inoculum and 1.7 for the compost developed without inoculum, while for the compost developed in the cold season, mean values were 5.9 for the compost generated with inoculum and 2.6 for the compost developed without inoculum (unbalanced means, confidence interval of 0.95). For grass odor resemblance, these values were 1.1 for the hot season with inoculum, and 1.6 for the hot season without inoculum, while for the cold season, the values were 1.1 with inoculum and 2.2 without inoculum. Finally, for ammonia odor resemblance, these values were 3.2 for the hot season without inoculum, and 1.6 for the hot season with inoculum, while for the cold season, the values were 2.0 with inoculum and 3.9 without inoculum.

Briefly, Figure 4 shows that the ammoniacal odor is much more expressive in the non-inoculated compost, whereas the soil odor appears to be more expressive in compost generated with inoculum, indicating its effectiveness in promoting improved decomposition of the cattle slaughterhouse residue, attenuating offensive odor, and confirming the biodegradation efficiency when inoculum is used. Again, chemical analysis showed that the compost generated with inoculum addition (C/N ratios of 16–17) presents a higher C/N ratio than compost originated without inoculum addition (C/N ratios of 10–12), which allows deducing that the less offensive odor observed from compost with inoculum is possibly due to higher decomposition of the organic matter present in the cattle slaughterhouse waste.

In the poultry compost (Fig. 5), the identified odors were mold, soil, and manure. Again, the soil odor predominates in the compost generated with inoculum addition in both tested seasons, while the manure odor was described as the most offensive in composts generated without inoculum addition in both seasons. The mold odor was the least predominant in composts generated with or without inoculum addition in both seasons.

The mean VDI intensity perception of soil odor resemblance was 5.00 for the compost developed at hot season with inoculum addition and 5.0 for the manure odor of compost developed without inoculum, while for the soil odor compost developed at cold season the VDI mean intensity values were 6.00 with inoculum and 6.0 for manure odor in the compost developed without inoculum (unbalanced means, confidence interval of 0.95), as shown in Figure 5. The values for mold odor resemblance were 0.58 and 1.08 for hot season with and without inoculum addition, respectively, and 1.80 and 0.82 for cold season without and with inoculum addition, respectively. Manure odor with inoculum at both seasons showed a VDI intensity of around 2.45.

Correlating this VDI odor analysis with the results of physicochemical analysis, higher levels of CEC values were found in the hot season windrows with and without inoculum, while lower values of CEC were found for the compost developed at cold season. Chemical analysis of C/N ratio showed that the compost generated with inoculum addition (C/N ratios of 15–18) presented a higher C/N ratio than compost originated without inoculum addition (C/N ratios of 22–23), confirming that the less offensive odor observed from compost with inoculum is possibly due to higher decomposition of the organic matter present in the poultry slaughterhouse waste.

Table 5 summarizes the C/N ratios in the samples used for VDI analysis, but it should be remembered that no single parameter can be taken as an index of compost maturity.

In general, Table 5 shows that composts generated with inoculum addition had a lower C/N ratio than those generated without inoculum addition in both tested seasons, except for the compost generated with cattle waste. Several authors have used the C/N ratio as a parameter to evaluate the maturation of organic compounds,[16,17] and it is generally accepted that a low C/N ratio (< 20) is ideal for a well-stabilized compost (humified compost), while a C/N ratio > 20 may indicate that the compost is not stabilized, i.e., it still undergoes strong action from decomposing microorganisms. According to Kiehl,[16,43] the nitrogen content at the end of the composting process is always greater than that found in a fresh substrate to be composted. This relative increase is due to the fact that other components of the substrate are lost by volatilization, carbon dioxide, and water, while nitrogen remains in the compost mass and microbial biomass, except when a low C/N ratio is present under weak aeration, which promotes NH_3 volatilization, as was apparently the case with cattle waste.

As previously observed, there was a widespread reduction of unpleasant odors generated from swine, cattle, and poultry waste composting processes. Thus, the biodegradation inoculum composed of *B. subtilis*, *R. palustris*, and *S. cerevisiae* proved to be efficient in reducing unpleasant compost odors.

The conversion of the ammonia odor (NH_3) into a neutral odor was identified in the literature by spraying enzymes

Table 5. Mean swine, cattle and poultry C/N ratios found just before sensory analysis in composts developed in hot and cold seasons and with and without inoculum addition.

	Summer		Winter	
Compost	With inoculum	Without inoculum	With inoculum	Without inoculum
Swine	16	22	15	23
Cattle	17	12	16	10
Poultry	15	18	22	23

from microorganisms effective in landfill waste from Taiwan.[27] Such enzymes come from *B. subtilis*, *Bacillus amyloliquefaciens*, *B. licheniformis*, *Bacillus megaterium*, and *Bacillus pumilus*. *B. subtilis* has already been identified as an odor-reducing agent in animal waste, and it was reported that this microorganism acts on the organic matter decomposition of animal litter, resulting in the reduction of ammonia odor, leading to greater animal welfare and improvement of meat quality.[51] A patent using *B. subtilis* was registered for the purpose of reducing the ammonia odor from animal waste using animal litter (straw surface, paper, wood, or pallet).[52] The inhibitory effects of ammonia and fatty acids on the methanogenic step of the composting process, as well as in the foaming in the digesters, can be mitigated by co-digestion using the addition of sewage sludge.[53] The relationship between bacterial community structure and odor emission was examined using extended local similarity analysis (eLSA) during the degradation of pig carcasses in soil and compost.[54] In the composting system, *Carnobacteriaceae*, *Lachnospiaceae*, and *Clostridiales* were highly correlated with the emission of sulfur-containing odors, while *Ruminococcaceae* was associated with the emission of nitrogen-containing odors. According to the eLSA applied in the study, the emission of organic acids was closely related to *Actinobacteria*, *Sporacetigenium*, *Micromonosporaceae*, and *Solirubrobacteriales* in the composting system.[54]

The ability of *R. palustris* to biodegrade the skatole (3-methylindole) compound is one of the main substances responsible for emitting bad smells resulting from animal and human feces. Sharma et al.[55] investigated this microorganism in a pure culture of purple non-sulfuric photosynthetic bacteria isolated from a swine waste treatment pond. Identification of the organism was confirmed by 16rRNA analysis, UV-visible spectroscopy, and the structure of the organism cell by electron microscopy, all of which confirmed it to be *R. palustris*. This bacterium significantly reduced the level of 3-methylindole by > 48% in 72 h of the total present, and that was further decreased to about 93% after 21 days. This demonstrates the potential for the remediation of escatol by *R. palustris*, which can be used in various industrial and animal waste treatment plants.[55]

In addition to *R. palustris*, other non-sulfuric photosynthetic purple bacteria from the *Rhodobacteraceae* family, such as *Rodobacter* sp., are being identified as odor-reducing agents in animal waste treatments.[56] *Rodobacter* sp. is also used in conjunction with *R. palustris*, effectively acting to reduce offensive odors.[57] However, the use of inoculum may be controversial, whether commercial or not, because composting is a process involving a large number of species of microorganisms that interact and compete strongly in the process of succession. The use of appropriate inoculum is crucial to perform an efficient composting process.[23,58]

Conclusions

Composting is an interesting and environmentally friendly process used by small slaughterhouses to recycle organic waste. It is an inexpensive process in terms of infrastructure and labor and provides nutrient recycling to the soil. However, composting systems located near human habitation must pay attention to avoid generating unpleasant or offensive odors, which may require stricter control of composting performance. In the present study, different biodegraded wastes (i.e., swine, cattle, and poultry wastes) generated composts with different odor characteristics due to the presence (or absence) of added inoculum. Thus, the addition of an inoculum composed of *S. cerevisiae*, *B. subtilis*, and *R. palustris* to the composting process was efficient in reducing unpleasant odors of the three composts, and the soil odor was predominant when the compost was originated with inoculum addition in the two tested seasons (i.e., summer and winter). Without inoculum addition, the predominant odors were similar to peat for swine compost, ammonia for cattle compost, and manure for poultry compost, regardless of the tested season. Overall, the composting process with appropriate inoculum and improved management can help in the correct disposal of slaughterhouse wastes by transforming organic matter into composts, which can have economic and environmental value as a conditioner and/or fertilizer for degraded soils.

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Author contributions

M.J. Batista-Barwinski: Conceptualization, Methodology, Investigation, Supervision, Writing – original draft. N. Butzke-Souza: Methodology, Investigation, Validation, Writing – original draft. R. Radetski-Silva: Methodology, Investigation. F. Tiegs: Methodology, Investigation. R. Laçoli: Methodology, Investigation. G.A. Venturieri: Conceptualization, Methodology, Validation, Investigation, Supervision. P.R.M. Miller: Conceptualization, Methodology, Validation, Investigation, Supervision. J.O. Branco: Methodology, Resources, Validation, Data curation. R. Ariente-Neto: Methodology, Investigation, Writing – original draft. C.M. Radetski: Writing – review & editing, Supervision.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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