Effect of Calcium Peroxide on the Food Waste Composting Process

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Abstract:
Aerobic composting acknowledged as a crucial technology in the management of food waste, offers a potential approach to sustainable production practices by producing top-notch organic fertilizers and soil conditioners. Nevertheless, the natural process of composting contributes to environmental pollution by releasing carbon dioxide (CO2) and methane (CH4) into the atmosphere. This study examines the effectiveness of adding calcium peroxide to the composting process to improve the availability of oxygen, reduce CO2 emissions, and enhance the quality of the final products. The study involved conducting experimental trials using different doses of calcium peroxide (5%, 10%, 15%, and 20%) to evaluate its effect on reducing CO2 levels. The results demonstrate a substantial decrease in CO2 emissions, where concentrations of 20% lead to a reduction of 36.82% while in 5%, 10%, and 15% the reductions were 19.15%, 26.36%, and 36.32%, respectively. In addition, the inclusion of calcium peroxide raises the pH of food waste samples and introduces calcium ions (Ca2+) into the end product. The results emphasize the significance of dealing with carbon emissions in composting procedures to adhere to Sustainable Development Goals 12 (responsible consumption and production) and 13 (climate action), thus progressing towards more sustainable waste management techniques.

Keywords: Food waste, composting, calcium peroxide, carbon emission.

Introduction
The term “food waste” refers to any edible product that is meant for human consumption and could be thrown out, misplaced, spoiled, or left uneaten at various times throughout the process of food distribution. The production, processing, distribution, retail, or consumption stages are all potential locations where this may be generated. Approximately one-third of the world’s food production intended for human consumption is wasted, resulting in approximately 1.3 billion tonnes of waste per year (Gustafsson et al., 2013). This scenario of food wastage will continue to upscale due to rising patterns of worldwide population expansion and urbanization (Srivastava et al., 2015). Meanwhile, the composting process...
which involves the transformation of carbon, including processes like carbonation and methanogenesis, leads to inevitable carbon loss. This loss results in secondary pollution and compromises the quality of compost. The primary culprits for carbon loss are emissions of carbonaceous gases, specifically carbon dioxide (CO₂) and methane (CH₄), which accounted for 92.3% (CO₂) and 0.56% (CH₄) of total carbon loss from food waste (Ye et al., 2023). Notably, methane has a much higher greenhouse potential, being 25 times more impactful than carbon dioxide. Carbon loss has emerged as a significant challenge hindering the advancement of composting. It is imperative to expedite the development of efficient technology for managing carbon loss during composting.

One promising avenue involves calcium peroxide a chemical substance represented by the molecular formula CaO₂. It is classified as a peroxide and appears as a solid material with the peroxide ion, O₂²⁻, present in its chemical composition (Wang et al., 2016). The molecular structure exhibits a diatomic configuration of oxygen atoms connected by a singular covalent bond (O-O). In the past, CaO₂ served as an oxygen-release compound (ORC) that gradually decomposed upon contact with water, hence releasing oxygen (Arienzo, 2000). According to the chemical stoichiometry, the oxygen release potential of Calcium peroxide is 0.2222 grams of O₂ per gram of CaO₂. (Lu et al., 2017)

\[
CaO_2(s) + H_2O(l) \rightarrow 0.5O_2(g) + Ca(OH)_2(aq) \quad (1)
\]

\[
CaO_2(s) + 2H_2O(l) \rightarrow H_2O_2(aq) + Ca(OH)_2(aq) \quad (2)
\]

\[
H_2O_2(aq) + e^- \rightarrow HO_2^-(aq) + O \quad (3)
\]

\[
HO_2^-(aq) + H_2O_2(aq) \rightarrow HO_2^-(aq) + H_2O(l) \quad (4)
\]

\[
HO_2^-(aq) \rightarrow O_2(aq) + H^+(aq) \quad (5)
\]

\[
CO_2(g) + Ca(OH)_2(aq) \rightarrow CaCO_3(s) + H_2O(l) \quad (6)
\]

Furthermore, when CaO₂ reacts with carbon (iv) oxide generated during the decomposition of food waste, a substantial amount of oxygen is liberated. A redox reaction will occur for this, as demonstrated below:

\[
CaO_2(s) + CO_2(g) \rightarrow CaCO_3(s) + 0.5O_2(g) \quad (7)
\]

This additive is a flexible and dependable solid inorganic peroxy compound that can be regarded as a solid manifestation of oxygen (Watts & Dilly, 1996). The released oxygen can enhance the oxidation of pollutants and facilitate their decomposition by aerobic microorganisms in the natural surroundings (Yeh et al., 2003). Thus, CaO₂ has been employed for the mitigation of numerous polluted locations in the United States and other industrialized nations (Zhang et al., 2015). According to Cassidy and Irvine (1999), CaO₂ greatly promoted the growth of microorganisms in arctic soil that was polluted with crude oil. Lu et al. (2017) discovered that the presence of CaO₂ enhanced the process of aerobic bioremediation in a water-saturated silty loam soil polluted with bis-(2-ethylhexyl) phthalate (BEHP). Mosmeri et al. (2018) utilized CaO₂ as an oxygen-releasing substance to create a permeable reactive barrier system (PRBs), which effectively eliminated methyl tert-butyl ether (MTBE) from groundwater.

When water reacts with calcium peroxide, it forms calcium hydroxide. This compound then dissociates in water, leading to the creation of calcium ions (Ca²⁺) and hydroxide ions (OH⁻) (Mohammadi & Dummer, 2011). The calcium ions, possessing a positive charge, readily engage
in a reaction with carbon (IV) oxide to yield calcium carbonate (Muangrat et al., 2010). This compound exists as a solid precipitate, which can be conveniently separated through physical means. The extraction of calcium carbonate is highly important due to its valuable role in various applications. It acts as a beneficial soil amendment by improving the strength and stability of soil and sand. It also helps protect and restore stone and concrete structures, preserve historical stone materials, clean contaminated waste- and groundwater from harmful metals and radioactive elements, and seal geological formations to enhance oil recovery and geological carbon dioxide sequestration (Krajewska, 2018).

The chemical equation for the reaction between calcium hydroxide (Ca(OH)\(_2\)) in an aqueous solution and carbon dioxide (CO\(_2\)) gas can be expressed as:

\[
Ca(OH)\(_2\)(aq) + CO\(_2\)(g) \rightarrow CaCO\(_3\)(s) + H\(_2\)O(l) \\
(8)
\]

The hydroxide ion (OH\(^-\)) possesses a negative charge and exhibits a robust alkaline character. It effectively counteracts the acidic byproducts generated in the course of aerobic biological treatment, resulting in the formation of salt and water as the only products. This process ensures the maintenance of a steady pH level that is conducive to the growth and activity of microorganisms.

\[
H\(_2\)A(aq) + Ca(OH)\(_2\)(aq) \rightarrow CaA(aq) + 2H\(_2\)O(l) \\
(9)
\]

Where; \(H\(_2\)A(aq)\) is the acidic product, \(Ca(OH)\(_2\)(aq)\) is the alkaline calcium hydroxide, \(CaA(aq)\) is the calcium salt, and \(H\(_2\)O(l)\) is the liquid water.

**Material and Method**

To establish an aerobic biological treatment system for food waste co-treated with calcium peroxide, procure the following materials and apparatus: a food waste mixture comprising 1750g of cooked rice, 1050g of cooked noodles, 350g of cooked chicken breast, 700g each of cabbage, celery, apple fruit, and banana, along with 1050g of potato; 1000g of sawdust as a bulking agent with 29% water content; an appropriate quantity of calcium peroxide; 35g (0.5%) of a microorganism inoculant from a reputable supplier; sawdust from local sawmill was used as a mechanism for moisture control to maintain levels below 60% and also decreases the air voids between food waste particles; an aeration tank with an aeration system delivering 0.56 L.kg\(^{-1}\)Dm.min\(^{-1}\); mixing equipment for uniform distribution; temperature and pH control devices; a cover or lid for odor control; monitoring instruments for key parameters; and safety equipment.

**Composting Experimental**

Composting trials were conducted using lab-scale reactors with a working volume of 15 L, as depicted in Figure 1. The control (CK) for composting involved not adding Calcium peroxide (CP). The T1, T2, T3, and T4 treatments were composed of 5%, 10%, 15%, and 20% calcium peroxide (CP) respectively, based on the dry weight of the raw materials. The amounts used were 350g, 700g, 1050g, and 1400g respectively. The experiments were conducted at an aeration rate of 0.56 L.kg\(^{-1}\)Dm.min\(^{-1}\). The duration of the experiment spanned 38 days. Throughout this time frame, the reactors underwent regular turnover to provide an ample oxygen supply. The multi-point sampling technique was utilized to gather samples on days 0, 3, 6, 9, 12, 15, 18, 24, 30, and 38. The fresh samples were held at a temperature of 4 °C to determine the physicochemical properties.
Physiochemical Analysis

Temperature was measured by thermo sensors inserted in the middle of the reactors daily. O₂ was by a syringe and measured using a CY-12C oxygen meter (Hangzhou Jiachang Electronic Technology Co., Ltd), CH₄ and CO₂ were collected using air-tight sampling bags and then measured by gas chromatography (6890-TCD) in the state key laboratory daily until the end of composting.

Data Analysis

The IBM SPSS Statistics 16.0 was carried out for statistical analyses, Microsoft Edge for calculating the raw data, and the Origin 2019 lab was applied for drawing all figures.

Results and Discussion

Physiochemical Parameters

Figure 2 displays the recorded temperatures for the five treatments during composting. They endured mesophilic, thermophilic, and cooling stages in all of the treatments. During the mesophilic stage, the temperature exhibited a favorable trend as a result of the metabolic activity of microbes, which had an ample supply of nutrients to consume. Treatments 1-4 exhibited a higher rate of rise compared to the control treatment, attributed to the addition of CP, which created a medium pH environment in contrast to the low pH levels in the CK treatment. The thermophilic stage, which lasted for more than five days and reached temperatures over 55 °C, met the hygienic criterion as stated by (Bernal et al., 2009). This stage effectively killed pathogens and sped up the decomposition process. Treatments T1, T2, T3, and T4 showed comparatively higher temperatures in the thermophilic range, with T2 exhibiting the highest temperature among all treatments. This might be attributed to two possible factors. Initially, the process of CP decomposition produced a substantial amount of heat and oxygen. Furthermore, CP has the potential to facilitate the breakdown of large molecular compounds, hence promoting microbial degradation (Liu et al., 2019). Starting on day 15, the temperature decreased due to a drop in organic materials. This lack of energy source caused a decrease in the activity of...
microorganisms. On the 20th day, the temperature reached a level that was quite similar to the surrounding temperature. This temperature stayed consistent throughout the remaining composting process, suggesting that the curing stage had begun.

Oxygen Consumption Rate

Microorganisms utilize oxygen in the process of composting. The increased microbial activity during the transition from mesophilic to thermophilic phases led to a higher consumption of oxygen. The process resulted in a decrease in oxygen levels, as depicted in Figure (3a). The CK treatment exhibited a lower oxygen level of 7.9% during the thermophilic stage compared to the other treatments. This can be attributed to the presence of CP in Treatments 1-4, which also underwent decomposition and produced oxygen, as explained in equations 1-5. A negative correlation was seen between the oxygen level and the temperature during the composting process. Specifically, as the temperature ascends from the mesophilic stage to the thermophilic stage, the oxygen level descends. However, during the curing stage, the oxygen level rises to nearly the ambient level. Collectively, the treatments with CP exhibited the highest quantities of oxygen in comparison to the CK treatment, as depicted in Figure (3b).

Figure 2. Temperature Changes in the Composting Process
The release of carbon dioxide (CO$_2$) and methane (CH$_4$) during the process of composting, which are known to be major factors in causing global warming, has received greater focus in recent studies (Chen et al., 2020). The emission of carbon dioxide (CO$_2$) is a result of the enzymatic processes carried out by microorganisms that break down organic matter (OM) (Han et al., 2018). The emissions of methane result from lower levels of oxygen specifically below 10% and in the composting process most oxygen levels were above 10% hence no traces of methane were realized. Based on Figure (4 a), the rates of CO$_2$ emissions increased significantly in all treatments during the initial composting phase. The emission peaks were 10.5% on day 1, 5.499% on day 2, 5.235% on day 3, 4.763% on day 2, and 5.111% on day 2 for the CK, T1, T2, T3, and T4 treatments, respectively. The rise in compost activity is directly related to the higher organic matter content in the compost raw materials, as well as the increased metabolic activity of enzymes and rising temperatures in the compost (Meng et al., 2017).

Notably, the rates of CO$_2$ emissions in the T1, T2, T3, and T4 treatments were initially reduced compared to the CK treatment, potentially because the higher pH levels hindered microbial activity during the initial composting stage. Following that, carbon dioxide emissions progressively decreased until the completion of composting, demonstrating the maturity of the compost. The CO$_2$ accumulation over the composting process showed that CK treatment had a total accumulation of 63.95972028%, whereas the T1, T2, T3, and T4 treatments had accumulations of 51.70951748%, 47.10054371%, 40.72673776%, and 40.40736189% accordingly as depicted on Figure (4 b). Qu et al. (2020) found that the addition of gypsum to composting suppressed CO$_2$ emissions, most likely because gypsum exhibits a high level of carbonation reactivity. The observed reduction in CO$_2$ emission in this study can be ascribed to specific processes delineated in equations (6-9).
Conclusion

Overall, this study highlights the potential of using varying amounts of calcium peroxide (CP) to reduce carbon dioxide emissions in composting processes. Our findings suggest that the inclusion of CP at different concentrations led to significant decreases in carbon dioxide levels in comparison to the control group (CK). More precisely, when 5% CP was used, there was a decrease of 19.15%, and when 10% CP was used, there was a decrease of 26.36%. In addition, higher levels of CP, specifically 15% and 20%, showed even larger reductions, with declines of 36.32% and 36.82% respectively. Also, the utilization of suitable aeration, at a rate of 0.56 L.kg⁻¹Dm⁻¹ min⁻¹, was crucial in ensuring enough oxygen levels during the composting procedure. This aeration technique successfully mitigated the buildup of methane, so matches with sustainable development goals (SDGs) about climate action, including Target 13.3, which highlights the significance of raising knowledge and capability for climate change mitigation and adaptation.

Additionally, the results of this study have substantial ramifications for SDG 12: Responsible Consumption and Production. By employing calcium peroxide and improving aeration procedures, anyone involved in agriculture and waste management can help decrease carbon emissions and enhance the efficient use of resources in production and supply chains.

References


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