

Characterization of composting process and chemical composition of compost from recycling centers in Surabaya City, Indonesia

Karakterisasi proses pengomposan dan komposisi kimia kompos dari pusat daur ulang di Kota Surabaya, Indonesia

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ABSTRACT

Composting serves as a pivotal strategy in waste management, alleviating the burden on final disposal sites while simultaneously providing valuable fertilizer for urban agriculture. This study aims to delineate the intricacies of the composting process and elucidate the characteristics of compost derived from recycling centers/compost houses in Surabaya City, Indonesia. Employing a qualitative descriptive approach, this research scrutinized the composting process by delving into the origins of raw materials, procedural stages, and the chemical composition of the resultant compost. The composting materials encompassed household waste, market refuse, and fall foliage. Notably, composting occurred within an open aerobic system devoid of bio-activators. Chemical analysis revealed: C/N ratio (17.10 - 19.60), C-total (17.65% - 18.10%), N-total (0.95% - 1.12%), P₂O₅ (0.35% - 0.51%), K₂O (0.39% - 0.41%), Cu (1.65 ppm - 2.01 ppm), Pb (2.05 ppm - 3.11 ppm), Cd (0.11 ppm - 0.24 ppm), and Zn (1.02 ppm - 1.14 ppm). Physically, the compost manifested as a dark brown substance, exhibiting a soil-like softness attributable to grinding, with temperatures oscillating between 41.90 to 55.00°C. Visually, the compost appeared mature and primed for utilization based on color and texture criteria; however, indicators such as C/N ratio and temperature suggest an immature state rendering the compost unsuitable for immediate planting. To ensure optimal maturity conducive to plant growth, it is recommended that users store the compost for a minimum of one month before application, thereby fostering its maturation process.

ABSTRAK

Pengomposan berfungsi sebagai strategi penting dalam pengelolaan limbah, mengurangi beban pada tempat pembuangan akhir sekaligus menjadi pupuk berharga dalam pengembangan pertanian perkotaan. Studi ini bertujuan untuk menguraikan kompleksitas proses pengomposan dan menjelaskan karakteristik kompos yang berasal dari pusat daur ulang atau rumah kompos di Surabaya, Indonesia. Dengan menggunakan pendekatan deskriptif kualitatif, penelitian ini mengkaji proses pengomposan dengan menganalisis asal bahan baku, tahapan prosedur, dan komposisi kimia dari kompos yang dihasilkan. Bahan yang dikomposkan meliputi limbah rumah tangga, sisa pasar, dan dedaunan. Secara khusus, pengomposan terjadi dalam sistem aerobik terbuka tanpa bioaktivator. Analisis kimia sebagai berikut: rasio C/N (17.10 - 19.60), C-total (17.65% - 18.10%), N-total (0.95% - 1.12%), P₂O₅ (0.35% - 0.51%), K₂O (0.39% - 0.41%), Cu (1.65 ppm - 2.01 ppm), Pb (2.05 ppm - 3.11 ppm), Cd (0.11 ppm - 0.24 ppm), dan Zn (1.02 ppm - 1.14 ppm). Secara fisik, kompos termanifestasi sebagai substansi cokelat kehitaman dan lembut seperti tanah yang disebabkan oleh penggilingan, dengan suhu yang beresilasi antara 41.9 hingga 55.0 °C. Secara visual, kompos terlihat matang dan siap digunakan berdasarkan kriteria warna dan tekstur, namun berdasarkan indikator C/N rasio dan suhu menunjukkan kompos belum matang dan belum siap digunakan langsung ke tanaman. Untuk memastikan kematangan optimal yang mendukung pertumbuhan tanaman, disarankan agar pengguna menyimpan kompos selama setidaknya satu bulan sebelum digunakan ke tanaman, sehingga mempercepat proses kematangan.

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INTRODUCTION

Market waste, household waste, and leaves from tree pruning are urban wastes, the quantity of which continues to increase. Urban organic solid waste has significant potential for conversion into solid and liquid organic fertilizers, offering a solution to reduce waste in landfills (Molano et al., 2021; Taddese & Balcha, 2022). The sustainable management of urban solid waste is crucial in managing South Asia's growing garbage creation, which is expected to double by 2050 to 661 million tonnes per year (Roy et al., 2021). Urban organic waste consists of waste from urban forests, market waste, food waste, and household waste (Haryanta et al., 2022). The proportion of organic waste in household waste increased during the COVID-19 pandemic (Phuong et al., 2021). Material flow analysis is used to monitor the transformation of waste, including sewage sludge, garden waste, and organic solid waste, into resource recovery in biogas, solid fuel, black soldier fly larvae, and compost. Variations in opportunities, the potential for resource recovery, and urban environmental sanitation should be considered when implementing sustainable waste management systems (Ddiba et al., 2022). Integrated urban organic waste management, which includes collection by household waste recycling groups (Poletto et al., 2016) waste processing, and use of food waste for compost production, as well as compost for urban food production, is regarded as a positive socioecological change for the reclamation and circulation of urban waste management (Yates & Gutberlet, 2011). Empowering environmentally conscious communities will reduce the amount of waste in landfills (Larasati et al., 2023; Trihadiningrum et al., 2017). Communities are willing to pay more for household waste processing to avoid health-related issues caused by waste accumulation (Tassie & Endalew, 2020).

Processing waste from traditional markets can have beneficial effects, such as generating bioenergy, reducing the need for inorganic fertilizers, and minimizing contaminant volumes in the environment. Most market waste is still conventionally processed, either composted or directly disposed of in landfills without a composting process. A composting model for market waste that uses cassava waste, banana stems, and corn husks as bulking agents for vegetable and fruit waste can produce high-quality compost (Akumah et al., 2023). This presents challenges and opportunities for biomass technology in energy generation (Phuong et al., 2021). Solid waste generated at North Keputran Market consists of vegetable waste (biodegradable), plastic, paper, wood, and bamboo. The average daily waste generation volume is 13.34 tons or 43.73 m³, into compost at the Wonorejo recycling center (Erynata et al., 2022).

Composting is a biological process in which microorganisms break down the polymers in organic waste. Temperature, pH, moisture content, C/N ratio, particle size, nutrient content, and oxygen supply influence the efficiency of the composting process (Sokač et al., 2022). The composting process for urban organic waste is the best strategy for improving soil properties, reducing waste disposal in landfills, and recycling nitrogen and other nutrients, especially micronutrients in urban waste to make them biologically available for plants. The addition of EM4 solution accelerates the decomposition process of market organic waste and affects the physicochemical properties of the compost. Composting of market organic waste can be carried out on a large scale to produce affordable organic fertilizers for soil enrichment (Bakari et al., 2016).

The composting method combines market waste, yard waste, and cow rumen to produce quality compost (Dewilda et al., 2019). The composting process with excessive stirring and aeration produces quality compost in a shorter time (Raharjo et al., 2021). The composting process will be more effective if the raw materials are small because the wider surface area allows more contact with decomposing microorganisms. The composting method of cutting the material into small pieces and stirring the biomass requires a lot of equipment and energy, so it is unsuitable for use in the composting process with large volumes of waste (Haryanta et al., 2017). Composting at the Wonorejo recycling center is conducted by blending market waste with branch waste and then allowing the composting process to proceed naturally. Market waste is dismantled on-site and mixed with dry leaf waste. In this composting cell, the waste pile is regularly turned every 2-3 days to ensure thorough mixing of the compost. The last stage involves the separation of compost from non-biodegradable waste using a filter (Erynata et al., 2022).

Research on composting of market waste, household waste, and garden waste has been extensively conducted. Haviz et al (2022) focused on the composition and generation rate of waste in traditional markets. The study examined waste samples from different markets, analyzing their composition, generation rate, and density, without exploring the details of the composting process. In their study, Jara-Samaniego et al (2017) conducted field-scale research where they used a combination of market waste, tree pruning waste, and ornamental palm plants as compost enhancers. Larasati et al (2023) conducted a survey to identify key stakeholders and community behaviors in managing household waste in Surabaya City. Roy et al (2021) studied the composting process of market waste, particularly food waste, considering institutional, economic, social, and biophysical aspects. The study focused on waste separation, improving the quality of compost in the market, and increasing the income of farmers who used compost. In a study conducted by Yangoritha (2023), the main objective was on market waste composting and the use of *Trichoderma harzianum* as a bioactivator. This particular fungus has proven to be highly effective in aiding the decomposition of raw materials. This study used a qualitative descriptive method and was conducted at two recycling centers (PDU) located in Jambangan and Wonorejo. No specific treatments were applied during the study. The researcher closely monitored and carefully documented each stage of the composting process. Several measurements were conducted to ensure the safety and appropriateness of the resulting compost for public use. The study aimed to characterize the composting process of market waste mixed with pruning waste, determine the nutrient content of the compost fertilizer produced, assess heavy metal content in the compost, and recommend the use of recycling center compost products for urban farming activities in Surabaya.

MATERIALS & METHODS

The study was conducted at two recycling centers, specifically the Jambangan and Wonorejo recycling centers, located in Surabaya. The coordinates for the Jambangan recycling center are 7.320° S and 112.720° E, while the Wonorejo recycling center is located at 7.310° S and 112.790° E. The selection was performed because the Jambangan recycling center is the biggest in West Surabaya, while the Wonorejo recycling center is the largest in East Surabaya. Composting at the Jambangan recycling center involves the collection of household waste, which is carefully separated from its inorganic components. This waste is then combined with organic waste from tree pruning. However, at PDU Wonorejo, the composting process involves combining vegetable waste from the Keputran market with waste from tree pruning. The map in Figure 1 shows the geographical positions of both research locations in Surabaya.

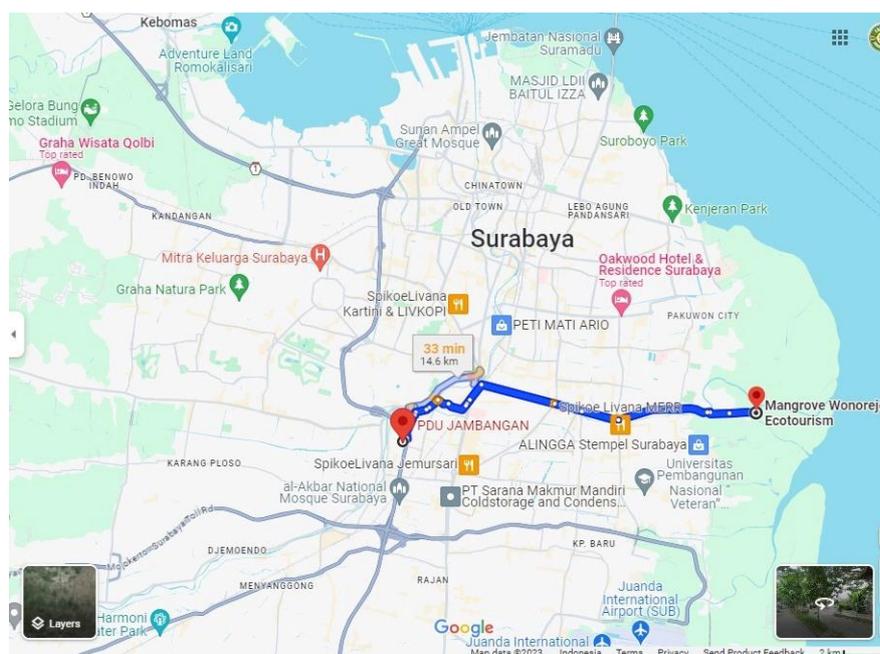


Figure 1. Map of Jambangan and Wonorejo recycling center (west of Mangrove) on Surabaya city map.

Source: Google Maps

The composting process commenced with the threshing of tree-trimming waste, followed by shredding it using a machine for smaller branches. Wet waste, including kitchen waste or waste from households and markets, was then prepared. These materials were mixed together, with the ratio and amount depending on the availability of materials, marking the starting point of the process (week 0). Over the course of the following weeks, the biomass mixture underwent periodic stirring and shifting. In the first week (week I), the mixture was stirred and shifted while being watered if it became dry. This process was repeated in the second (week II), third (week III), and fourth (week IV) weeks. After four weeks, the compost was ready for harvesting in the fifth week (week V). This involved grinding and sieving the biomass, resulting in filtered compost ready for distribution to the community. Any remaining uncomposed material was disposed of in the landfill. The composting stages at the Jambangan and Wonorejo recycling centers are illustrated in Figure 2. This study used a qualitative descriptive approach to thoroughly examine and understand phenomena within their specific context. Data was collected directly from the natural setting using the researcher's key instruments. This study used field research to investigate the composting process at the Surabaya recycling center, aiming to gather up-to-date information on relevant issues.

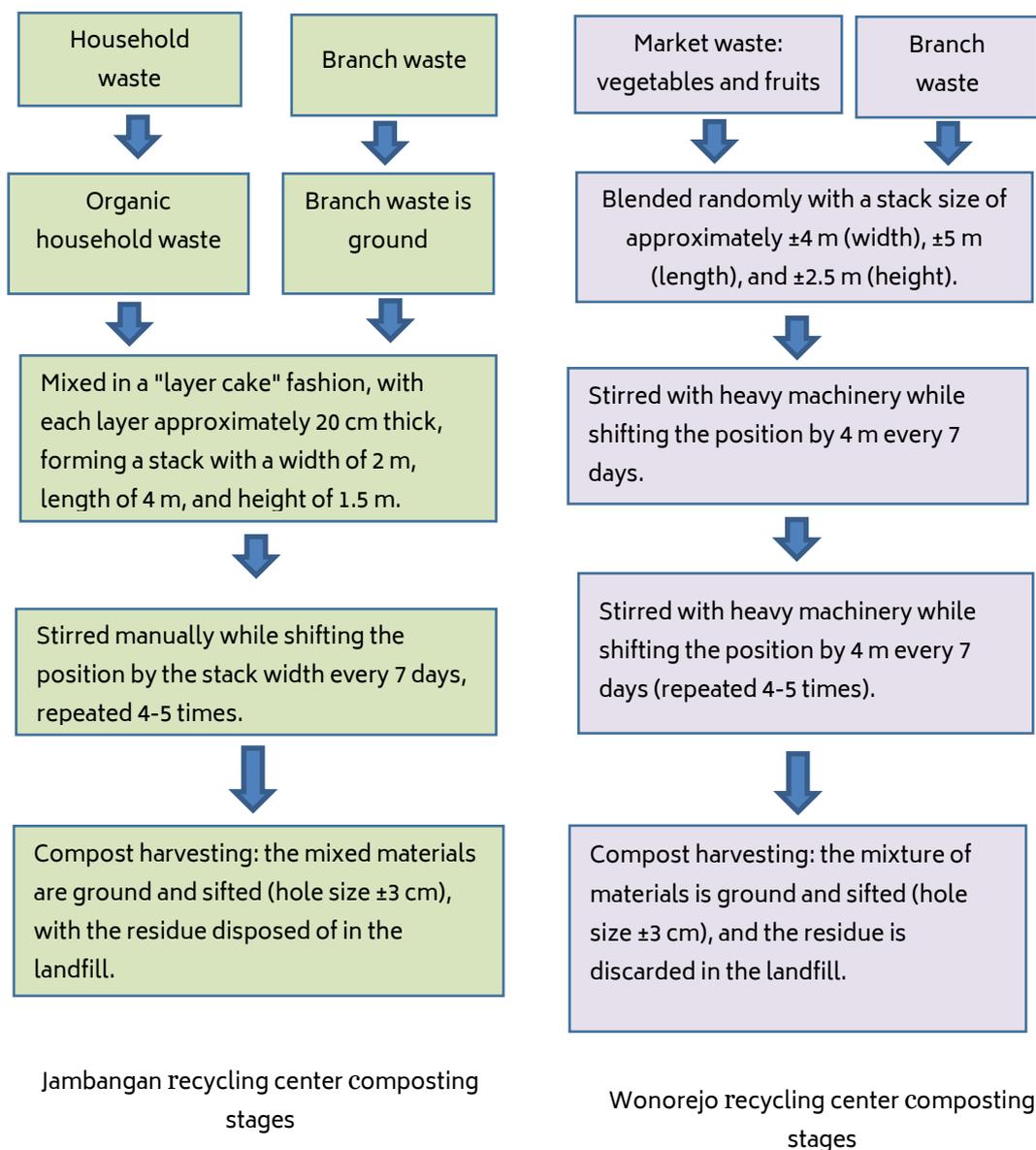


Figure 2. Composting process diagram at Jambangan and Wonorejo recycling centers

The composting process in Surabaya for urban organic waste is primarily carried out in open spaces. This involves stacking the biomass, adding moisture, and periodically stirring it. Aerobic composting is a suitable method for temporary storage locations (TSL) because it is easy to operate and does not produce strong odors (Afifah et al., 2022). Yuriandala et al. (2019) have shown that it effectively reduces urban waste generation.

Variables

Physicochemical characteristics of biomass during composting

Physical and chemical factors, including temperature, pH, particle size, moisture content, aeration, and C/N ratio, are crucial in regulating decomposition (Yanqoritha, 2023). During incubation, variables observed include changes in raw materials, color, smells, temperature, and pH.

Analysis of nutrient content in compost

The analysis of nutrient content in compost produced from the Wonorejo composting house includes the total organic matter determined by the weight loss during drying until it turns into ash, and total organic carbon (TOC), calculated by multiplying the total organic value by a factor of 0.58. Total nitrogen is measured using the Kjeldahl method on dried samples. The content of macro and micronutrients is analyzed using spectrophotometric and Atomic Absorption Spectrophotometric (AAS) methods (Tiwow et al., 2019).

RESULTS & DISCUSSION

The composting raw materials of a mixture of tree branch waste and household waste at the Jambangan recycling center, while the mixture includes tree branch waste and Keputran market waste at the Wonorejo recycling center. The composting process involves several stages: preparing the raw materials, which provides for shredding tree branch waste, mixing the raw materials, and stirring the mixture multiple times (3-4 times) at intervals of 7-10 days, while adding water if the conditions are dry. The compost is harvested by grinding and sieving to separate non-compostable materials for disposal at the final disposal site. The open-air composting process with periodic stirring accelerates the composting process and produces high-quality compost (Raharjo et al., 2021).



Figure 3. The displays the initial stack of raw materials on day 0 of the organic waste composting process at the Surabaya recycling center.

Changes in biomass material structure

The composting process changes the structure of materials, especially waste from tree pruning, which originally was sturdy and not easily broken, turning into easily crumbled fragments at the end of the composting process. After removing branches and wilted/dried leaves, waste from tree pruning is ground with a cutting machine at the Jambangan recycling center. Separating household waste, mainly plastic, cardboard, glass bottles, and metal, is done. The remaining, largely organic waste is combined with trimming debris. The first structure change is minor because composting is not as strong and rigid.

Waste from tree pruning is not ground but only separated from wooden branches, then directly piled with market waste, with a random ratio and position depending on what enters first at the Wonorejo recycling center. The material structure at the beginning of the composting process corresponds to its original state, with leaves that are still strong or relatively hard materials. Mixing of materials occurs during the composting process while shifting their positions and simultaneously stirring with heavy equipment. The change in structure for waste from tree pruning becomes soft and crumbly, while market waste, originally containing water, becomes soft. An illustration of the structural changes in the material mixture during the composting process is presented in Table 1.

Table 1. Data on changes in biomass material structure during the urban waste composting process at the Surabaya recycling center.

Stages of the composting process	Wonorejo recycling center	Jambangan recycling center
Fresh waste material (from place of origin)	Strong like the original material	Strong like the original material
When mixed/combined between composting materials	Strong like the original material	Strong like the original material
One week of incubation	Compressible, solid biomass	Dense biomass, compressed
Two weeks of incubation	Dense	Dense
Three weeks of incubation	Dense	Dense
Four weeks of incubation	A bit crumbly	A bit crumbly
At Harvest	Crumb	Crumb
Compost products ready to be distributed to consumers	Crumb	Crumb

Table 2. Data on changes in the smell of biomass material during the urban waste composting process at the Surabaya recycling center

Stages of the composting process	Wonorejo recycling center	Jambangan recycling center
Fresh waste material (from place of origin)	Smells mildly like the smell of real ingredients when fresh	Smells lightly like real material
When mixed/combined between composted materials	Smells mildly like the smell of real ingredients when fresh	Smells lightly like real material
One week of incubation	Smells unpleasant toward rotten	Smells unpleasant to rotten
Two weeks of incubation	Smells unpleasant toward rotten	Smells unpleasant to rotten
Three weeks of incubation	Smells strong toward rotten	Smells strong toward rotten
Four weeks of incubation	Smells strong toward rotten	Smells strong toward rotten
At harvest time	No smell at all	Smells unpleasant to rotten
Compost products ready to be distributed to consumers	No smell at all	Smells bad

Changes in the smell of biomass material

The composting process at Jambangan and Wonorejo recycling centers doesn't involve the addition of microbes for treatment. The composting process occurs naturally, depending on the existence of microbes in the environment. Throughout the composting process, microbes break down biomass materials, gradually transforming complex chemical compounds into simpler ones. Some intermediate products or compounds produced take the form of gases with unpleasant smells released into the environment, and in some cases, the biomass mixture may emit smoke. During the beginning stages of composting tree pruning waste, there is minimal odor, whereas household or market waste releases a strong odor. The composition and amount of gases responsible for producing unpleasant odors vary depending on the raw material being decomposed. Protein-rich materials often release gases that can result in unpleasant smells. Both market waste and household waste consist of a variety of materials that are rich in proteins and sugars, including vegetable waste, fruits, and animal waste. Table 2 shows the smells of the material mixture throughout the composting process.

Changes in material color

Color variations can be found in tree pruning waste and market garbage when they are still fresh. The color is determined by the pigment concentration of the substance, which normally looks green due to chlorophyll and turns yellowish as chlorophyll decomposes or converts into other pigments. Browning occurs when fruits and vegetables containing sugars or carbohydrates change from their original color to brown. When materials are converted into inorganic compounds, only charcoal/ashes remain, which appear dark brown or black. At the Jambangan recycling center, the material is already dark because tree pruning waste has been there for a long time, has dried, and is being composted. Household waste has also been separated from inorganic materials and composted after at least one night, contributing to the dark color. The color of the material undergoes minimal change from the beginning to the end of the composting process. At the Wonorejo recycling center, the composting process begins with fresh waste, resulting in a variety of colors that eventually turn dark brown. Table 3 shows the changes in the color of the material mixture during the composting process.

Table 3. Data on change in the color of biomass material during the urban waste composting process at the Surabaya recycling center

Stages of the composting process	Wonorejo recycling center	Jambangan recycling center
Fresh waste material (from place of origin)	Like the original material from the origin	Green
When mixed/combined between composted materials	Like the original color from the origin	Light brown
One week of incubation	Yellowish-brown	Light brown
Two weeks of incubation	Yellowish-brown	Brown
Three weeks of incubation	Brown	Brown
Four weeks of incubation	Brown	Brown
At harvest	Blackish brown	Black
Compost products ready to be distributed to consumers	Blackish brown	Black

Changes in material size

During the composting process, the water content decreases, causing the material to shrink and decrease in size. The structural change in the material from strong to fragmented and easily broken causes the material to be chopped into smaller or smaller pieces as a result of the mixing throughout the composting process. At the Jambangan recycling center, tree pruning waste is purposefully ground using a cutting machine before being combined with house waste for composting. During compost harvesting, the material is processed to make the previously fractured structure finer. It is

then sieved to separate the organic compost material from the non-compostable residue. The size of the material cannot be used as an indicator of the maturity level of the compost. Finely sized compost material facilitates specific applications, especially for cultivating plants in pots or polybags. However, for land application, coarser material is more effective in improving the physical properties of the soil. Table 4 shows the material mixture's size changes during the composting process.

Table 4. Data on changes in size of biomass materials during the composting process of urban waste at the Surabaya recycling center

Stages of the composting process	Wonorejo recycling center	Jambangan recycling center (before being chopped)
Fresh waste material (from place of origin)	Like real ingredients from the origin	<10mm
When mixed/combined between composted materials	Smaller after being chopped	<10mm
One week of incubation	Shrink	10-5mm
Two weeks of incubation	Shrink	10-5mm
Three weeks of incubation	Shrinks and starts to dry out	5-2mm
Four weeks of incubation	Shrinks and starts to dry out	5-2mm
At harvest	Dry and smoky	<2mm
Compost products ready to be distributed to consumers	Dry and smoky	<2mm

Table 5. Temperature (°C) data for biomass materials during the composting process of urban waste at the Surabaya recycling center.

Stages of the composting process	Wonorejo recycling center	Jambangan recycling center
Fresh waste material (from place of origin)	42.4	30.1
When mixed/combined between composted materials	50.5	28.3
One week of incubation	48.8	45.8
Two weeks of incubation	51.0	53.8
Three weeks of incubation	47.0	61.2
Four weeks of incubation	65.1	59.0
At harvest	61.3	44.5
Compost products ready to be distributed to consumers	55.0	41.9

Changes in material temperature

Composting is when organic materials decompose by microorganisms and potentially generate heat. The increase in temperature serves as an indicator of microbial decomposition. During the composting process in the two waste recycling centers, there is a general rise in the temperature of the biomass mixture. The temperature decreases when the compost is harvested but still remains relatively elevated, albeit not reaching the levels of the surrounding ambient temperature. Table 5 shows the changes in temperature within the material mixture during the composting process. The activity of thermophilic bacteria, which produce heat, increases and reaches its peak around 10 to 20 days into the composting process before gradually decreasing (Khalil & Hassouna, 2013). Reported (Zakarya et al., 2018) changes in pH and temperature values during the composting process, with pH values ranging from 8 to 10 and temperatures between 20-50°C.

Changes in pH material

The microbial decomposition of biomass during the composting process leads to the breakdown of chemical compounds into simpler forms. The presence of intermediate products or compounds within the biomass can affect the biomass's pH, indicating that the composting process is still in progress. Table 6 shows the pH changes in the material mixture throughout the composting process.

Table 6. pH data on biomass materials during the composting process of urban waste at the Surabaya recycling center

Stages of the composting process	Wonorejo recycling center	Jambangan recycling center
Fresh waste material (from place of origin)	6.8	7.1
When mixed/combined between composted materials	6.0	7.5
One week of incubation	7.0	6.0
Two weeks of incubation	7.5	6.1
Three weeks of incubation	6.0	6.8
Four weeks of incubation	7.5	6.5
At harvest	6.0	7.5
Compost products ready to be distributed to consumers	7.0	7.8

Based on the pH values observed after composting, the process has proceeded effectively and achieved stability. According to (El-Mrini et al., 2021), a pH level close to neutral indicates a successful and mature composting process. This stands in contrast to the findings (Lalremruati & Devi, 2021), who noted that composting of vegetable waste, kitchen scraps, and plant materials (such as wheat straw) typically commences with a lower pH, ranging from 4.5 to 6.8, owing to the high carbon-to-nitrogen (C/N) ratio of the raw materials.

Nutrient content and heavy metal analysis of compost

The analysis data of nutrient content in compost fertilizers harvested from Jambangan recycling center and Wonorejo recycling center are presented in Table 7. Composts from both PDUs contain varying levels of the analyzed nutrients.

Table 7. Nutrient content and heavy metal data of compost from urban waste at the Surabaya recycling center.

Nutrients/heavy metals	Wonorejo recycling center	Jambangan recycling center
C/N ratio	19.60	17.10
C-total (%)	17.65	18.01
N-total (%)	0.95	1.12
P ₂ O ₅ (%)	0.35	0.51
K ₂ O (%)	0.39	0.41
Cu (ppm)	2.01	1.65
Pb (ppm)	3.11	2.05
CD (ppm)	0.24	0.11
Zn (ppm)	1.02	1.14

The nutrient content, particularly N, P, and K, is relatively lower compared to the findings (Yuriandala et al., 2020), who reported higher levels of phosphorus (1.55%), potassium (1.45%), and a C/N ratio of 14.03% in compost from food scraps and vegetable waste. The C/N ratio of the compost harvested in the Jambangan recycling center is lower than Wonorejo, indicating the greater maturity in Jambangan, though both are still not fully mature. In Jambangan, manual mixing and turning of biomass are more than in Wonorejo; heavy machinery is simply used for shifting. Achieving mature and stable compost through active aerobic composting with thorough mixing typically takes 13 weeks (90 days) (Kutsanedzie et al.,

2015). Suggest a minimum of 54 days (Lamourou et al., 2023). Alternatively, propose that compost maturity can be accelerated to just 30 days by adding a bioactivator with a C/N ratio indicator of < 17 to the biomass (Priyambada & Wardana, 2018). The compost produced by both recycling centers meets the standards for compost from domestic organic waste specified in SNI 19-7030-2004 regarding nutrient content and heavy metal concentrations. The composition of raw waste materials and the intensity of mixing during composting affect the maturity and quality of the compost (Hapsoh & Yusuf, 2015). Urban organic waste composting is a suitable waste management approach while promoting vegetable cultivation for food security (Tibu et al., 2019). In the Jambangan recycling center, household waste primarily consists of food waste, which decomposes more rapidly, resulting in a lower C/N ratio and higher nitrogen content. Biomass that decomposes easily will quickly reduce the C/N ratio and increase nitrogen content during composting (Mukai & Oyanagi, 2019).

CONCLUSIONS

In conclusion, the information provided underscores the intricate process of composting at recycling centers in Surabaya City, Indonesia. This process entails a series of steps, including organic waste preparation, blending of raw materials, and maintenance over several weeks. The resultant compost exhibits diverse chemical compositions, with nutrient concentrations crucial for plant growth. It is imperative to acknowledge that this composting process yields positive implications for urban waste management and holds potential for enhancing environmental sustainability. Nonetheless, it is essential to recognize certain limitations, such as the lack of standardized protocols in raw material blending, and the need for further research to enhance composting efficiency and quality. Addressing these challenges necessitates initiatives to raise public awareness regarding the significance of composting and to fortify waste recycling infrastructure at the local level.

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