Journal of Applied and Natural Science
17(2), 671- 676 (2025)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Windrow composting: a viable option for the management and conversion of various agro- industrial organic wastes in Ethiopia

Gezahegn Degefe*
Department of Biology, College of Natural Sciences, Debre Berhan University, Ethiopia
Chrotaw Ayele
Department of Biology, College of Natural Sciences, Dilla University, Ethiopia
Fekadu Shimekit
Bio and Emerging Technology Institute, Addis Ababa, Ethiopia

*Corresponding author. E-mail: gezdeg60@gmail.com

Article Info
https://doi.org/10.31018/jans.v17i2.6310
Received: October 29, 2025
Revised: May 15, 2025
Accepted: May 22, 2025

How to Cite

Degefe, G. *et al.* (2025). Windrow composting: a viable option for the management and conversion of various agro- industrial organic wastes in Ethiopia. *Journal of Applied and Natural Science*, 17(2), 671- 676. https://doi.org/10.31018/jans.v17i2.6310

Abstract

Windrow composting is a biotechnological process where microorganisms decompose and stabilize solid organic wastes under aerobic conditions, creating stable and odorless compost. This study investigates the composting of four frequently discarded municipal and industrial wastes (brewery sludge and solid waste from potato chips factory) around Debre Berhan city and Tulefa town, Ethiopia, examining the change in key physicochemical properties. Experimental wastes were blended with powdered cow dung in a 3:1 ratio and composted in four triangular-shaped piles using the windrow technique under shade. The original physicochemical characteristics of all wastes and the resulting final compost underwent analysis for temperature change, volume reduction, pH, total Kjeldhal nitrogen(TKN), total potassium(TK), total phosphorous(TP), total organic carbon (TOC), and carbon to nitrogen ratio (C:N). All treatments (T_1 = brewery sludge + cow dung, T_2 = solid waste from potato chips factory + cow dung) demonstrated significant volume reduction, ranging from 60% to 70%. The final pH of the compost in all treatments shifted towards neutral (7-7.4). Additionally, all treatments achieved thermophilic temperatures within 15-28 days. The thermophilic phase persisted for 15 to 35 days across treatments, followed by a cooling phase that occurred between 49 and 77 days later. The cessation of further temperature rise was observed between 77 and 99 days. Across all windrows, significant changes were observed in key parameters such as TKN, TK.TP, TOC, and C:N ratio. These findings suggest that windrow composting is a viable alternative for effectively reducing substantial quantities of solid organic waste from residential areas and agro-processing industries, while also producing organic soil amendments that support sustainable agriculture.

Keywords: Compost, Cooling stage, Thermophilic temperature, Windrow composting

INTRODUCTION

In Ethiopia, inadequate waste management practices create significant sanitation challenges. To address these issues effectively, a variety of technological and administrative solutions tailored to the country's socio-economic context are necessary. It is important to understand that no single waste management approach can resolve all issues within a service area. Therefore, municipalities and industries should consider alternatives to conventional methods like landfill disposal. These alternatives should be low-tech, cost-effective, labor-intensive, and environmentally friendly, encompassing household, industrial, and municipal levels. Biological waste management systems, such as windrow composting, are viable options within this range (Sayara, 2020).

Windrow composting is a straightforward process that can be adapted to various scales, from individual households to entire communities and large municipalities. It effectively stabilizes and decomposes organic waste from diverse sources. Composting is the aerobic (oxygen-requiring) decomposition of organic materials by microorganisms to produce a sufficiently stable and nuisance-free product called compost under controlled conditions (Awasthi *et al.*, 2019). Having origins in ancient civilizations, composting is a technology with enduring relevance, utilized today across a spectrum of scales, from individual households to expansive commercial enterprises. Its history stretches back to Ro-

man and biblical times (Alemayehu and Gicha, 2021).
Beyond managing and stabilizing solid waste, windrow composting also produces nutrient-rich organic biofertilizers, enhancing plant health and supporting healthier ecosystems (Sayara *et al*., 2020; Alemayehu and Gicha, 2021). It is widely recognized as a sustainable method in waste management and agriculture (Zhao *et al*., 2023). Compost can significantly improve soil properties, such as enhancing moisture retention, suppressing soil-borne diseases, and gradually releasing nutrients for plant uptake (Shah *et al*., 2019). Furthermore, composting is crucial for reducing waste by diverting organic materials from landfills, which helps minimize negative environmental impacts (Hashim *et al*., 2022).
Ethiopia's agro-based industrial sectors, particularly the food and beverage industries, are experiencing significant growth. However, the waste generated by these industries presents substantial environmental challenges (Milkiyas and Timar, 2019). These industries often produce large quantities of waste with minimal or no treatment, leading to considerable environmental impact due to the discharge of untreated or inadequately treated effluents and waste into local water bodies and soil (Oljira *et al*., 2018). While windrow composting is widely used globally to manage various industrial and municipal solid waste types, it is not yet well-known within Ethiopia's agro-processing industries.
As industrialization, especially agro-industrialization, increases nationwide, there is a growing need for effective, marketable, and environmentally sound waste management systems. It is time for Ethiopian agro-industries to consider adopting biological waste treatment methods such as windrow composting. The present study explores biological solid waste management, with a particular focus on windrow composting, as a viable solution to the current waste management challenges faced by agro-processing industries in Ethiopia. It also highlights the potential of windrow composting to produce valuable soil conditioners.

MATERIALS AND METHODS

Waste collection, processing and pile design

Solid waste from a potato chips factory and sludge from a brewery were obtained from the Sun Chips factory in Tulefa, Ethiopia, and the Habesha Brewery factory in Debre Birhan, Ethiopia. The sludge from the Habesha Brewery factory and the solid waste from the Sun Chips factory were sent to a composting site in Deneba town, situated in the North Shewa zone of Ethiopia. At Deneba composting sites, non-biodegradable materials were manually sorted and subsequently discarded. All experimental wastes were mixed with powdered cow dung in a 3:1 ratio. Cow dung enhances the nutrient quality of the final product, acts as a starter material for composting, facilitates the decomposition of cellulosic plant material, and increases the biological activity of the waste (Muthukumaravel *et al*., 2008).
Two composting piles were prepared under shade using the windrow composting technique. Each pile, shaped in a triangular form, measured approximately 2.5 meters in width and 1.5 meters in height. The piles were manually turned using a pitchfork every three days to ensure proper aeration (Viaene *et al*., 2016). Dry grass clippings were used to cover the piles to insulate them and minimize water loss from the top. The initial moisture content of the mixtures was adjusted to 50- 60%. As the composting process neared completion, moisture levels were adjusted to ensure proper curing and maturation of the compost. Excess moisture was avoided during the curing phase to prevent leaching of nutrients and compaction of the compost.
The composting piles were designated as follows: T1 = brewery sludge + cow dung, T2 = solid waste from potato chips factory + cow dung. Samples were collected from each pile for physicochemical analysis at the beginning and end of the composting period. During sample collection, each windrow was thoroughly mixed with a fork. Subsamples were taken from three evenly spaced locations on each side of the windrow and at all depths of each pile. Samples from each test windrow were replicated three times for every tested waste and finished compost. The volume (height) of the windrows was measured at the initial and final days (after 77 days) of composting.

Physico-chemical analysis

The original physicochemical characteristics of all experimental wastes and the resulting final compost after 150 days of composting underwent analysis for various physical and chemical parameters, including temperature change, volume reduction, pH, total Kjeldahl nitrogen (TKN), potassium (K), phosphorus (P), total organic carbon (TOC), and carbon-to-nitrogen ratio (C: N). The chemical analysis was conducted at the laboratory JIJE Laboglass PLC in Addis Ababa. Temperature changes were recorded at the initiation of the piles and every three days thereafter until maturity using a thermometer probe inserted 30 cm deep. Readings from three sites per pile were equilibrated for 5 minutes and averaged.
pH levels were determined using a digital pH meter (Model ORION 230A) on a 1:10 suspension of compost/waste to distilled water. Volume reduction was calculated by comparing the initial and final pile sizes after 100 days of composting, with reduction representing the difference between these volumes. Total organic carbon (TOC) was estimated by combustion methods, followed by the detection of released carbon dioxide (CO_2) (Nelson and Sommer,1982). While total Kjeldahl nitrogen was assessed using the standard Kjeldahl method. Kjeldahl digestion followed colorimet-

ric methods(Bremner and Mulvaney, 1982). Total potassium and phosphorous levels were determined by Acid digestion followed by flame photometry(Tadesse *et al*., 1991). The C:N ratio was calculated from the measured values of carbon and nitrogen.

RESULTS

In the present study, both treatments (T_1 and T_2) effectively reached thermophilic temperatures exceeding 45° C (Carl et al., 2019) within a span of 15 to 21 days (Table 1). As the process progressed, temperatures steadily climbed, peaking at values between 63°C and 65°C across the composting piles. This thermophilic phase persisted for 15 to 35 days in both treatments. Following this period, a cooling phase (<30°C) (Palaniveloo et al., 2020) occurred, lasting from days 49 to 57 in both composting piles. Temperature fluctuations ceased in both treatment groups after 77 to 90 days (Table 1).

Both treatments exhibited a significant volume reduction throughout the composting process, ranging from 60% to 70%. Notably, the most substantial reduction occurred during the thermophilic stage, indicating rapid decomposition during this critical period. The color of the composting materials varied during the process but ultimately attained a dark brown hue at maturity. The final pH of both compost heaps ranged from 7 to 7.4, indicating a change of 27.3% to 32.1% from the initial pH values (Table 2).

The change in total nitrogen from the initial day of composting in windrows T_1 and T_2, ranged from 50% to 58.7%. The total nitrogen content of compost from both piles followed the order $T_1 > T_{2,}$ consistent with the pattern observed in the original substrates. Like to nitrogen, the final potassium and phosphorus content reflected the initial substrate pattern, with T_1 having the highest and T2 relatively the lowest (Table 3). Both windrows experienced a reduction in total organic carbon (TOC) content, ranging from 41.2 % to 43.25 %. Additionally, both windrows demonstrated a decrease in the carbon-to-nitrogen (C: N) ratio, ranging from 69 % to 74.18% (Table 3)

DISCUSSION

Temperature plays a critical role in the quality of the composting process (Finore *et al*., 2023). In this study, we observed slight temperature variations in both windrows. Notably, both windrows entered the thermophilic phase (temperatures exceeding 45°C) within 15 to 22 days, maintaining this elevated temperature for a duration of 28 to 37 days, indicative of the active composting phase. Similar findings were reported by Raze et al. (2017) and Moubarecka et al. (2023) in composting municipal and organic food waste. These high temperatures are essential for eliminating weed seeds and pathogens in the compost (Sakarika *et al*., 2019). After 49 to 77 days, the composting materials reached a temperature plateau of less than 30°C in both windrows and temperature fluctuations ceased between 70 and 100 days, signifying the maturation of the compost (Khan *et al*., 2009).

The final pH values of the composts in this study align with the commonly reported range for mature compost, which is 7 to 8 (Dominguez *et al*., 2019). However, it is important to note that some studies have identified slightly broader ranges, such as 7.1 to 8.6 for composting fruit and vegetable waste and 7 to 9 for composting market waste with additives (Tibu *et al*., 2019). Generally, pH can indicate compost maturity, with mature compost tending toward a neutral pH. Therefore, the pH values recorded in all windrows of this study fall within the acceptable range for mature compost (Chaher *et al*., 2020). Significant volume reductions were observed in both treatments, ranging from 60% to 70%. This finding is consistent with other studies that have reported substantial volume reductions across various waste types (Ayilara *et al*., 2020; Cuil *et al*., 2023). Collectively, these results highlight the significant potential of composting for waste volume reduction, offering an effective strategy for waste management.

Table 1. Temperature (°C) variation in composting piles after the treatments given

Treatment	Thermophilic temperature attained	Thermophilic temperature persist	Cooling phase starts	Compost maturity (cessation in temperature rise)
T_1	2nd week	2nd- 4th week	7th week	After 11 week
T_2	3rd week	3rd -6th week	8th week	After 13th week

T_1 = brewery sludge + cow dung, T_2 = solid waste from potato chips factory + cow dung

Table 2. Initial and final pH value of the piles after the treatments given

Treatment		T_1	T_2
pH value	Initial	5. 6±0.05	5.5±0.05
	final	7.4 ±0.07	7.00 ±0.05
	% of change	32.1	27.3

T_1 = brewery sludge + cow dung, T_2 = solid waste from potato chips factory + cow dung

Table 3. Percentage change between initial and final nutrient levels after the treatments given

Nutrients	Time	Experimental substrates	
		T_1	T_2
TKN	Initial	2.3 ±0.003	1.9 ±0.003
	Final	3. 65 ±0.01	2. 85±0.2
	% of change	58.7	50
TK	Initial	0.8 ±0.01	0.5 ±0.003
	Final	1.2 ±0.003	0.7 ±0.003
	% of change	50	40
TP	Initial	0.6 ±0.003	0.4 ±0.01
	Final	0.85 ±0.003	0. 65 ±0.003
	% of change	41.6	41.6
TOC	Initial	39.3±0.3	34±0.6
	Final	22.3±0.3	20 ±0.3
	% of change	43 .25	41.2
C:N	Initial	22.17	42.6
	Final	7.4	11
	% of change	69	74.18

Variations in total nitrogen among the final composts of this study likely reflect differences in the starting materials. Interestingly, the final nitrogen content order mirrored the order of initial nitrogen levels (Table 3). The observed general increase in total nitrogen across all windrows may be attributed to dry mass loss as carbon dioxide during decomposition (Soumare *et al*., 2002; Zorpas *et al*., 2003) and potential nitrogen fixation by bacteria in later stages of composting (Huang *et al*., 2004). Supporting evidence comes from similar studies, which reported a nitrogen increase in composted food and green wastes (Azim *et al*., 2018). This study unveiled a steady increase in potassium levels across all composted waste types (Table 3). This coincides with the findings of other studies, which also noted a rise in potassium content in composted food waste (Zakarya *et al*., 2023). Consistent with potassium patterns, phosphorus levels in this investigation increased across all windrows. This aligns with the findings in the composting of agricultural wastes (Shiyu *et al*., 2023).

All composts showed a reduction in TOC (Table 3), likely due to microbial conversion of carbon to CO2 during decomposition. The findings of this study are consistent with those of Yu *et al*. (2019), who investigated composting stubborn carbonaceous matter mixed with biochar. This study observed a significant decline in the C: N ratio across all windrows(Table 3). This observation is consistent with the characteristic of mature compost, which typically has a C: N ratio below 15. As the decrease in C: N ratio is commonly used as an indicator of compost maturity, the values from this study suggest relative stability. Consequently, all composted substrates fell within standard acceptable limits (Lalremrutil *et al*., 2023).

Conclusion

Despite composting being globally recognized as an effective method for managing municipal and industrial solid organic wastes, its adoption for industrial waste management in Ethiopia remains limited. The present study highlights that composting can significantly reduce solid organic wastes from various agro-processing industries in Ethiopia. Physico-chemical analysis of the final compost product revealed substantial changes from the initial substrate. Considerable changes were observed in key parameters such as TKN, TK.TP, TOC, and the C: N ratio. All treatments resulted in a substantial volume reduction, between 60% and 70%. The final pH of the compost in each treatment shifted towards a neutral range, from 7 to 7.4. These findings demonstrate that composting addresses waste management challenges and produces a valuable biofertilizer resource for agricultural applications. This biofertilizer has the potential to supplement synthetic fertilizers, which pose a significant challenge for Ethiopian farmers.

Conflict of interest

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Bio and Emerging Institute for its financial support and to Debre Berhan University for its overall assistance throughout the course of this research.

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