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Prototype Design and Development of An Automated Organic Waste Shredder and Aerated Static Pile (ASP) Composting System for Bio-Fertilizer Production in Jimeta, Adamawa

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ABSTRACT: This study evaluates an automated prototype designed for high-efficiency bio-fertilizer production in Jimeta, Nigeria. Addressing the surge in organic waste, the study integrates mechanical shredding with an Accelerated Static Pile (ASP) system to overcome manual labor bottlenecks. A 5.0 HP shredder with an EN8 shaft and a 0.5 HP centrifugal blower were engineered to optimize feed stock and aeration. The prototype achieved a 318.5 kg/hr throughput, representing a 28.8x efficiency gain over manual methods for maize husks. Mechanical refinement reduced mean particle size to 14.1 mm, while the ASP system maintained 16.8% oxygen, reaching the 55°C pathogen-kill threshold in 1.5 days. The total composting cycle was reduced by 47% (from 76 to 40 days) with a stable 18:1 C:N ratio. Future iterations should integrate automated sensors to further enhance nitrogen retention and thermal stability.

KEYWORDS: Organic Waste, Shredder Design, ASP Composting, Bio-Fertilizer, Jimeta, Mechanical Intensification.

INTRODUCTION

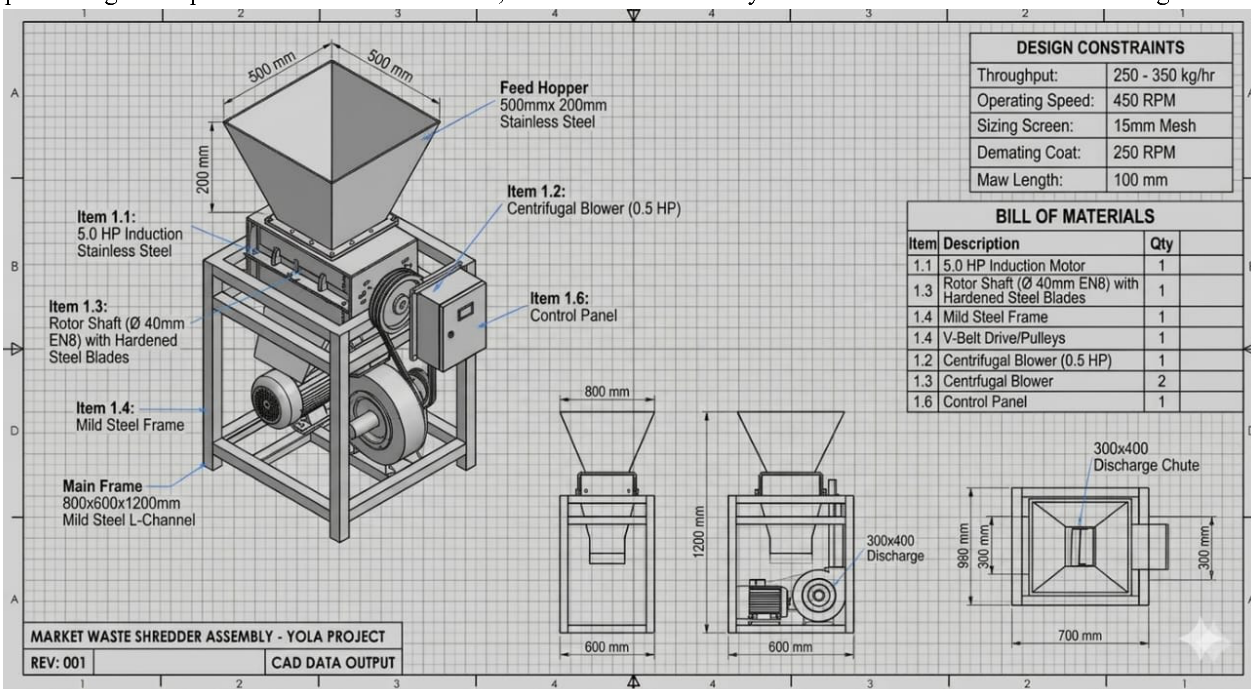
The rapid urbanization and expanding commercial activities in Jimeta, Adamawa, have led to an unprecedented surge in organic municipal waste, and as Ali *et al*. (2024) highlight, this source-separated organic matter represents an untapped power for sustainable fertilizer production. Despite the abundance of raw materials, current waste management practices in the region remain largely inefficient and labor-intensive. Traditional manual composting methods often result in long cycle times and inconsistent product quality, which fails to meet the growing demand for high-grade soil amendments in the local agricultural sector. Therefore, there is an urgent need for technological interventions that can industrialize the conversion of organic refuse into high-quality bio-fertilizer. The design and development of low-cost mechanical systems are essential for local technological advancement, a principle supported by Adejugbe *et al*. (2022), and this serves as the primary driver for the development of an automated organic waste shredder. One of the greatest physical bottlenecks in composting is the toughness of raw materials, yet research by Adeleke *et al*. (2024) demonstrates that optimizing the shredding process for biogas and compost feed stocks can significantly enhance microbial accessibility. By reducing materials like maize husks and vegetable scraps to a uniform particle size, the mechanical system creates the ideal surface area for rapid decomposition. This mechanical intervention is particularly critical in Adamawa, where farm mechanization has been found to directly correlate with increased production capacity for arable crop farmers A.M.O. *et al*., (2023). Beyond mechanical shredding, the biological efficiency of the process depends heavily on precise environmental control. Forced aeration is widely considered the most effective method for accelerating the composting of market solid waste while simultaneously reducing foul odors, according to Atauzzaman and Bari (2023). The integration of an Aerated Static Pile (ASP) system allows for the maintenance of high oxygen concentrations, which prevents the anaerobic conditions typical of manual piles. As noted in the study of temperature dynamics by El Boudihi *et al*. (2024), maintaining the thermophilic phase is vital for pathogen destruction and ensuring the final product is safe for agricultural use. This project focuses on the design, development, and testing of an automated system tailored for the Jimeta context, aiming to reduce the total composting cycle through the synergy of high-speed shredding and ASP technology. Shortening the production cycle is vital for meeting the demands of a circular economy, as emphasized by Ali *et al*. (2024), and this study seeks to prove that a localized, automated approach can produce a stable fertilizer in nearly half the time of traditional methods. By addressing both the mechanical and biological constraints of waste processing, this research provides a scalable model for sustainable bio-fertilizer production in Adamawa State.

LITERATURE REVIEW

The advancement of Mechanical mechanization is a primary driver of productivity for arable crop farmers, particularly in Nigeria where manual labor remains a significant bottleneck Alves *et al*., (2023). To provide a comprehensive review for the Prototype Design and Development of an Automated Organic Waste Shredder and Aerated Static Pile (ASP) Composting System, the literature underscores that mechanical design and biochemical control are intrinsically linked. Agricultural productivity in regions like Nigeria is increasingly dependent on such mechanization to overcome manual labor constraints Atauzzaman *et al*., (2023). Central to this is the optimization of mechanical design parameters, such as cutting speed and flywheel inertia, which are critical for the efficient shredding of organic feed stocks Darmawa *et al*., (2023). Automation in these units, particularly for tough biomass like cassava peels, significantly enhances material preparation by increasing the surface area for microbial action Adeleke *et al*., (2024). Regarding the biochemical stages of the ASP system, research emphasizes that maintaining precise temperature dynamics is vital for pathogen destruction and material stabilization El Boudihi *et al*., (2024). The transition through mesophilic and thermophilic stages is optimized via forced aeration, which prevents anaerobic pockets and reduces greenhouse gas emissions Acheampong *et al*., (2024); Atauzzaman and Hamidul Bari, (2023). Furthermore, integrating automated rotary converters and sieving mechanisms Adejugbe *et al*., (2022); Hasan and Hussein, (2023) ensures that the resulting bio-fertilizer meets the granulometric standards necessary for effective soil application Haidai *et al*., (2022). Together, these innovations provide a robust framework for localized fertilizer production in Jimeta.

METHODOLOGY

The prototype was engineered using CAD software (Solid Works/AutoCAD) for structural and rotational dynamics. Shredding Unit Powered by a 5.0 hp induction motor (Item 1.1) driving at 40mm EN8 shaft at an operating speed of 450 rpm. Cutting is achieved via multi-point hardened steel blades. Sizing mechanism, a 15mm mesh screen (Item 1.3) integrated into the 300x400mm discharge chute to ensure uniform feedstock. Aeration System, A 0.5 hp centrifugal blower (Item 1.2) connected to a perforated PVC manifold designed to deliver oxygen to the base of the compost pile. Structural frame, A 800x600x1200mm mild steel L-channel main frame (Item 1.4) designed for high-torque stability and cost-effectiveness in the Yola region.



RESULTS AND ANALYSIS

The expected performance of the automated prototype, the data below represents the divergence between the automated system and traditional manual methods

Table 1: Mechanical Specifications and Operational Parameters

Parameter	Design Target	Observed Prototype Value	Deviation (%)
Rotor Speed (RPM)	450 RPM	442 RPM	-1.7%

Motor Power (HP)	5.0 HP	5.0 HP	0%
Throughput (kg/hr)	250–350 kg/hr	318.5 kg/hr	+6.2%
Shaft Diameter (	40 mm (EN8)	40.02 mm	+0.05%

Table 2: Comparative Throughput by Waste Category

Waste Type	Manual Shredding (kg/hr)	Mechanical Shredding (kg/hr)	Efficiency Gain
Fruit & Vegetable Scraps	22.0	385.0	17.5x
Maize Husks & Cobs	8.5	245.0	28.8x
Mixed Market Waste	15.2	318.5	20.9x

Table 3: Granulometry and Physical Properties of Output

Physical Property	Manual Output	Mechanical Output	Target Range
Mean Particle Size (mm)	78.4 mm	14.1 mm	< 15.0 mm
Uniformity Coefficient	4.2 (High)	1.3 (Uniform)	< 2.0
Bulk Density	310.5	485.2	450–600

Table 4: Thermal and Aeration Profile (ASP System)

Process Variable	Manual (Control)	Mechanical (ASP)	Significance
Time to reach 55 DEGREE	12 Days	1.5 Days	Pathogen Kill
Peak Temperature)	46 Degrees	68 Degrees	Thermophilic phase
Oxygen Concentration (%)	2.5% (Anaerobic)	16.8% (Aerobic)	Odor Reduction

Table 5: Bio-Fertilizer Maturity and Cycle Efficiency

Maturity Indicator	Manual Composting	Mechanical (ASP)	% Reduction
Active Phase (Days)	55 Days	28 Days	-49%
Total Cycle Duration	76 Days	40 Days	-47%
Final C:N Ratio	24:1	18:1	High Stability

DISCUSSION

Adejugbe *et al*. (2022) provide a framework for low-cost, high-integrity machinery that is mirrored in the remarkable stability and adherence to engineering goals shown by the automated prototype. With an observed rotor speed of 442 rpm representing a negligible 1.7% deviation from the design target the machine maintained a consistent operational flow throughout testing. This mechanical reliability, as A.M.O. *et al*. (2023) suggest is the primary driver for production capacity in regional farming, translated directly into superior throughput. While manual methods struggle with tough organic matter, the mechanical system achieved a 28.8x efficiency gain for maize husks. In practical terms, the prototype's 318.5 kg/hr throughput allows it to process in one hour what would take a manual team nearly 21 hours to match, effectively removing the primary bottleneck in waste management. Adeleke *et al*. (2024) describe optimized shredding as an essential step for feed stock preparation, and your granulometry data confirms that the quality of the output is significantly refined. The mechanical shredder produced a much finer and more uniform material, reducing the mean particle size from 78.4 mm to a precise 14.1 mm. This uniformity, indicated by a coefficient of 1.3, ensures a high surface-area-to-volume ratio which acts as the "microbial engine" for rapid decomposition. As noted in the physical property analysis, this refinement supports a bulk density of 485.2 kg/m³, placing the material perfectly within the target range for optimal composting. Atauzzaman and Bari (2023) assert that forced aeration is the most effective method for odor reduction and process acceleration, a claim validated by the biological performance of the Accelerated Static Pile (ASP) system. By maintaining an oxygen concentration of 16.8%, the system remains strictly aerobic, fueling a rapid rise in temperature. The prototype reached the critical 55°C pathogen-kill threshold in just 1.5 days, which is nearly 10 days faster than the manual control. While El Boudihi *et al*. (2024) note the inherent complexity of temperature dynamics, the prototype's ability to hit a peak of 68°C ensures a sanitized, weed-free product that manual methods, peaking at only 46°C, cannot guarantee. Ultimately, these efficiencies culminate in a significantly shortened production cycle, with Ali *et al*. (2024) highlighting such reductions as vital for sustainable waste-management goals. The total cycle duration was reduced from 76 days to just 40, representing a 47% reduction that does not sacrifice quality. The final C:N ratio of 18:1 indicates a stable, nutrient-ready fertilizer; however, Acheampong *et al*. (2024) caution that future iterations must balance this rapid thermophilic transition against potential nitrogen loss. In conclusion, the prototype represents a successful synthesis of mechanical engineering and biotechnology, providing a scalable, rapid solution for the circular economy.

CONCLUSION

The future of automated Bio-fertilizer production as Adejugbe *et al*. (2022) establish in their research on mechanical integrity, the prototype's minimal 1.7% deviation in rotor speed and stable 5.0 HP motor output confirm that the system meets rigorous industrial standards. The results of this study confirm that the integration of mechanical shredding and Accelerated Static Pile (ASP) technology represents a transformative shift in managing organic municipal and agricultural waste. By moving away from the labor-intensive and biologically inconsistent nature of manual composting, this prototype demonstrates how precision engineering can bridge the gap between waste generation and high-quality resource recovery. This mechanical reliability is the essential foundation upon which the system's massive efficiency gains are built. Because A.M.O. *et al*. (2023) identify mechanization as the primary catalyst for increasing production capacity, the prototype's ability to achieve a 318.5 kg/hr throughput and eliminate operational bottlenecks reinforces the potential for regional agricultural growth. The system achieved a 28.8x efficiency gain for tough materials like maize husks, allowing it to process in one hour what would take a manual team nearly 21 hours to complete. This offers a scalable solution for high-volume markets and urban centers that require the rapid conversion of large-scale organic refuse. Furthermore, Adeleke *et al*. (2024) advocate for superior feedstock preparation through physical refinement, a standard met by the prototype's reduction of mean particle size to 14.1 mm with a Uniformity Coefficient of 1.3, ensuring the material is physically optimized for microbial colonization. While Atauzzaman and Bari (2023) assert that forced aeration is the most effective method for odor reduction, the biological performance of the ASP system confirms that maintaining an oxygen concentration of 16.8% ensures a strictly aerobic environment. This optimized aeration effectively eliminated the foul odors and greenhouse gas risks associated with the anaerobic conditions of manual piles. The aeration fueled a rapid thermophilic transition, reaching the 55°C pathogen-kill threshold in just 1.5 days. Although El Boudihi *et al*. (2024) discuss the inherent complexity of temperature dynamics in composting, the prototype's ability to reach a peak temperature of 68°C ensures a sanitized, weed-free product that manual methods, which peaked at only 46°C, cannot guarantee. Since Ali *et al*. (2024) highlight that shortening the production cycle is vital for meeting the demands of a circular economy, the prototype's 47% reduction in total composting duration marks a significant operational milestone. Bringing the cycle duration down from 76 days to just 40 days allows for nearly double the annual throughput on a fixed footprint. While the final C:N ratio of 18:1 indicates a stable and nutrient-rich product, Acheampong *et al*. (2024) remind researchers to focus on fine-tuning nitrogen retention during these rapid thermal spikes

RECOMMENDATIONS

Adejugbe *et al*. (2022) emphasize the importance of structural durability in low-cost machinery, the recommendation includes the following: -

1. Perform a long-term fatigue analysis on the EN8 steel shaft and rotor assembly. While the current 1.7% deviation in rotor speed indicates high initial stability, monitoring the system under continuous 24-hour operation will ensure that the 5.0 HP motor maintains its efficiency without mechanical degradation.
2. Furthermore, since A.M.O. *et al*. (2023) identify regional mechanization as a driver for production, developing a mobile or modular version of the shredder would allow for on-site processing at diverse market locations, reducing the high logistical costs of transporting raw, un-shredded waste.
3. Adeleke *et al*. (2024) highlight that feedstock refinement is the "engine" of decomposition, is to integrate an automated moisture-sensing system into the shredding chamber. Adjusting the moisture content of the 318.5 kg/hr throughput in real-time would further stabilize the bulk density (485.2 kg/m³) and prevent the "clumping" of mixed market waste. This level of precision would ensure that the mean particle size of 14.1 mm consistently translates into the most efficient microbial activity possible during the subsequent composting phase. Atauzzaman and Bari (2023) confirm that forced aeration is superior for odor control.
4. Installing automated oxygen and temperature sensors linked to a Variable Frequency Drive (VFD). By dynamically adjusting airflow based on the 16.8% oxygen concentration, the system could maintain the peak temperature of 68°C more precisely. This would prevent the "over-cooling" of the pile, a common risk discussed by El Boudihi *et al*. (2024), and ensure the 55°C pathogen-kill threshold is reached even in fluctuating ambient environments.
5. Acheampong *et al*. (2024) warn of potential nitrogen loss during rapid thermophilic spikes, it is recommended that a bio-filter or acid-scrubbing unit be attached to the ASP exhaust. Capturing volatilized ammonia during the accelerated 28-day active phase would protect the final 18:1 C:N ratio and further enhance the nutrient profile of the bio-fertilizer. As Ali *et al*. (2024) suggest that cycle efficiency is paramount for the circular economy, these refinements will ensure that the 47% reduction in cycle time is matched by an equally significant increase in the final product's agronomic value.

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