Elinvo (Electronics, Informatics, and Vocational Education) ISSN 2580-6424 (printed) | ISSN 2477-2399 (online)
Vol 10, No. 1, 2025, pp. 30-43

Solar-Powered Organic Leaves Waste Shredder Machine with IoT-Based Monitoring Integration

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Article Info

Article history:
Received January 11, 2025
Revised May 4, 2025
Accepted June 24, 2025

Keywords:
IoT; organic waste; shredder machine; solar panel

Abstract

Organic waste management relying on conventional non-renewable energy, which produces significant carbon emissions, poses challenges to environmental pollution. A shift to sustainable waste management practices, prioritizing renewable energy sources and reducing greenhouse gas emissions is needed. This study aims to design and develop a prototype of an organic waste shredder powered by solar panels, integrating IoT technology to address the environmental impact of traditional shredding methods. The solar-powered shredder is portable and addresses challenges in processing organic waste, especially dry leaves, while promoting renewable energy use in composting. The portable machine operates with a 30-watt, 12-volt DC motor, achieving a maximum speed of 3500 RPM, and features a Blynk-based monitoring system for real-time control and data analysis. Key sensors demonstrate low error rates, including the INA219 and load cell. The shredder processes various leaf types, with production capacities of 23.96 kg/hour for grape leaves, 20.18 kg/hour for ketapang leaves, 19.93 kg/hour for cherry leaves, and 21.6 kg/hour for mango leaves, achieving 93.09% and 95.17%. The portable power station fully charges in 15 hours and provides up to 18 hours of continuous power. The Blynk application monitors and controls the system within a 9-meter range before disconnection. By integrating solar energy and IoT technology, this device offers a sustainable alternative to traditional shredding methods, reducing carbon emissions and promoting environmentally friendly waste management practices.

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INTRODUCTION

Agriculture is a fundamental pillar for any food security and relies heavily on the quality and continued progress in this sector. Modernizing agricultural practices is one solution to maximize yields despite limited resources. Because as the population increases, the potency availability of arable land continues to shrink [1], [2]. Planting, caring for, and harvesting crops must be optimized to use minimal resources efficiently. In the era of technological advancement, the focus has shifted towards more sustainable and environmentally conscious methods [3], [4]. Increasing agricultural resilience is crucial for adapting to climate change and ensuring food security for future generations. By adopting climate-smart agricultural practices, such as improved resource management and sustainable technologies, we can reduce the environmental impact while enhancing productivity, especially in regions facing challenges like shrinking arable land and climate-induced risks [5]. The growth of lush plants, producing organic rubbish like dry leaves, comes from various trees, whether in gardens, forests, or even from the trees around settlements. The many dry leaves scattered around make it potential for organic wastes that can be utilized as organic compost fertilizer.

Organic agricultural waste is free from toxic and pathogenic toxins and has the potential to regenerate and become compost. Organic agricultural waste should be processed into compost, and parts of plants, such as dry leaves, must be chopped first to expedite decomposition to prevent environmental problems. Other studies have also proposed that bio-agricultural waste, such as citrus and olives, can be recycled into fertilizers that support soil improvement and garlic crops [6]. It indicates that all generated by-products can be effectively utilized in the agricultural sector, with various transformation methods that align with environmental, economic, and agricultural sustainability principles. Another study discussed using palm oil waste as a substrate for mushroom cultivation to increase the added value of biomass. The experiment showed that palm oil biomass can be recycled into edible mushroom substrates, animal feed, and compost [7]. The decentralized production concept presents opportunities for adaptation and challenges in scaling up to underdeveloped and disadvantaged regions. This approach can assist in recycling agricultural waste, thereby benefiting the natural environment.

In recent decades, waste processing has advanced by adopting industrial and plantation techniques, emphasizing energy sustainability as the key to achieving a cleaner environment. One of the world's issues is the increasing production of waste, which is estimated to surge annually by 2050 [8]. Adopting technology, particularly indirect sorting methods like sensor-based sorting (SBS), has advanced significantly, driven by computer hardware and software improvements [9], [10]. Integrating various physical principles, particularly spectroscopy, and using faster actuators has significantly enhanced performance. Waste management prevents the release of harmful impacts to the environment [11], [12], [13]. It can help reduce environmental damage and maintain ecological balance. It presents an opportunity to reuse materials through composting. Then, a horizontal-type organic waste shredding machine using a diesel engine was designed and constructed [14]. After that, a dynamic facility location model incorporating mobile production units is proposed for waste recycling applications. The multi-period production-site problem involves small recycling units housed in standard containers, allowing them to move from one location to another [15]. Studies in other countries show that applying technology in agriculture tends to help farmers develop green energies and reduce fossil fuel consumption [16]. Other studies also examine organic plant waste for composting and as a potential source of biogas, helping to reduce greenhouse gas emissions [17]. Previous studies show that the achievement is the adoption of technology for agriculture, which supports the promotion of portability and devices that enhance productivity.

The use of sensors, actuators, and power generation have also previously been experimented to support plantation [18], [19], [20], [21]. Other works of social acceptance studies, such as those in particular areas in Egypt, highlight the potential of solar systems in urban sustainability, with a preference for rooftop photovoltaics supported by energy storage despite economic barriers [22]. Similarly, solar dryers in rural Mexico demonstrate using solar energy for agriculture to reduce agricultural waste and promote sustainable development by preserving agricultural products and supporting global supply [23]. Other researchers are also conducting studies on the transition to renewable energy by powering local tomato farms using offshore renewable energy along Romania's Black Sea coast [24]. State aid schemes support energy investments, especially in agriculture. Solar energy tends to be produced intermittently, influenced by weather and seasons. It impacts the installation in an area with different seasonal variations. With proper energy storage, excessive energy can be stored and utilized at different times according to the user's needs [25], [26]. Using renewable energy sources in the form of solar photovoltaics, combined with energy storage in the form of batteries, offers a solution for providing an independent electricity supply for agricultural equipment.

Based on previous research, fertilizer management is a method of recycling organic waste that benefits the environment. Its impact can be further enhanced if combined with environmentally friendly energy sources. This study presents a solar-powered organic waste shredder supported by IoT with an integrated monitoring system. The main points of this work in the article can be summarized as follows:

1. Development of a portable, solar-powered organic waste shredder prototype that can be easily moved from one location to another, addressing challenges in organic waste processing, specifically dry leaves.

2. Integration of IoT technology for enhanced monitoring, control of the shredding process, and energy savings.
3. Promoting renewable energy use in leaf composting contributes to sustainable waste management and reduces reliance on non-renewable energy sources.

This paper is structured as follows: Section 2 presents the materials and methods. Section 3 describes the results and discussion of this study, while conclusions are presented in Section 4.

METHODS

Compost Fertilizer

Compost is an organic fertilizer composed of various natural materials, such as leaves, decayed organic matter, and animal waste. It is created through decomposition or fermentation of these materials, often including remnants from animals, plants, and other organic waste. A study of the composting system, especially for Agricultural Organic Waste (AOW), found that its implementation in nature has potential benefits, including accelerating compost maturation, reducing hazardous substance pollution, reducing greenhouse gas emissions during the composting process, and improving the quality of compost products [27]. It also contains essential mineral nutrients beneficial for plant growth and boosts the soil's organic matter content. Since compost can be made from accessible and inexpensive organic materials, it is an affordable, self-sustainable fertilizer option. This type of organic fertilizer is highly versatile and suitable for various plants, including crops, plantations, and ornamental plants. Other work explores composting using organic waste to improve compost quality [28]. Studies have investigated the use of additives to improve the physical structure and overcome the limitations of compost, one of which is a mix of dry leaves [29]. The mixing method affects the rate and quality of composting when bamboo powder and tea leaves are composted. Another work discussed processing agricultural organic waste (AOW) into compost that contributes to sustainable agricultural development by improving compost quality, reducing greenhouse gas emissions, reducing toxicity, and accelerating compost maturation [27]. Compost, one of which is a mixture of dry leaves, has potential benefits for composting, enriching nutrient content, improving soil structure, and promoting sustainable agricultural practices.

Hardware and Software for Shredder Machine

Automatic shredding machines generally cut larger items into smaller pieces, making the task easier. Unlike the slower and less effective manual method, a good process can speed up composting by quickly shredding waste into finer materials [30]. As machine shredder technology advances to support various human tasks, many types have been developed to meet specific needs.

The tool utilizes Internet of Things (IoT) technology, enabling automatic data transmission and communication between devices without manual intervention. The system is supported by a structured algorithm that guides the hardware to perform specific tasks and integrates a microcontroller to connect the digital components with the physical aspects of the system. The Arduino Integrated Development Environment (IDE) is the primary platform for programming the microcontroller, allowing for code compilation, uploading, and testing using the C/C++ programming language. Additionally, Blynk, an Android-based application, enables remote control and monitoring of microcontroller modules. Blynk provides features like graphical displays and notifications, simplifying programming with its compatible library [31], [32], [33], [34]. The system manages the DC motor and monitors power consumption via a load cell.

On the hardware side, the NodeMCU ESP32 microcontroller features WiFi and Bluetooth capabilities for IoT integration [35], [36], [37]. The BTS7960 Motor Driver allows precise DC motor control in both directions and supports Pulse Width Modulation (PWM) control, accommodating operating voltages from 5.5 to 27.5 VDC [38]. The DC motor converts electrical energy into mechanical energy, making it ideal for high-torque industrial applications. The INA219 sensor assists in monitoring the DC motor's current and voltage through I^2C communication, reducing the need for multiple cables. The equation for the duty cycle is expressed as follows :

$$k = \frac{S_{on}}{(S_{on}+S_{off})} \times 100\% \tag{1}$$

$$V_{out} = \frac{S_{on}}{S_{total}} x\, V_{in} \quad (2)$$

where k is the Duty Cycle duration of the high pulse in one period (%), S_{on} is High Pulse Time, S_{off} is Low Pulse Time, S_{total} is Total signal in one period, V_{out} is Output voltage, and V_{in} is Input voltage. The power required by the motor to perform shredding is given as follows.

$$P_{motor} = T \times \omega \quad (3)$$

$$\omega = \frac{2\pi \times N}{60} \quad (4)$$

where P_{motor} is the motor power (W), T is the torque motor (Nm), ω is the angular velocity (rad/s), and N is motor speed (RPM). The estimation of battery lifetime in a power station can formulated as follows.

$$t_{batt} = \frac{E_{batt} \times \eta_{batt}}{P_{load}} \quad (5)$$

where t_{batt} is battery operation time (hours), E_{batt} is battery capacity (Wh), η_{batt} is battery discharge, P_{load} is power consumption (W).

Additional hardware components include the LM2596, a step-down regulator that can be connected to a 3-A electric load [39]. It has a fixed or adjustable output, can be used with a few external components, and has internal frequency compensation and a fixed oscillator. The load cell sensor measures force by converting pressure into an electrical signal, utilizing a Wheatstone bridge and strain gauges to assess pressure levels. The HX711 module, a 24-bit analog-to-digital converter (ADC) commonly used in digital scales, amplifies the resistance changes in the load cell and translates them into voltage [40].

The tool is powered by solar panels that convert sunlight into electricity, providing an alternative energy source for remote areas without grid access. A portable power station comprising a battery pack, inverter, and Battery Management System (BMS) offers mobile energy. A solar charger controller regulates the direct current (DC) between the solar panels, battery, and load, preventing overcharging and extending battery life. Figure 1 illustrates the general flowchart of a waste shredder machine with IoT-based monitoring.

Organic Waste Shredder Machine

Changes were made to overcome these deficiencies and improve the performance of the previously designed prototype machine. The deficiencies in question were changes to the frame that were considered too many, so they were changed and reduced. In addition, changes were also made to the output hopper, which was initially flat, to be more slanted downwards to make it easier for the shredded results to fall. In addition, wheels were added to the shredder machine to move it. Design waste shredder machine (a) full body and (b) detail components can be seen in Figure 2. Key components include the upper funnel, leaves container, DC motor, knife chopper, shredder frame, hopper, electronic panel box, and mobilization wheels.

Based on the development, the organic waste shredding machine has the following specifications. The shredder machine has a framework measuring 36 cm in length, 36 cm in width, and 33 cm in height. It is equipped with a funnel that measures 25 cm in length, 25 cm in width, and 22 cm in height. The reservoir tank has a diameter of 25 cm and a height of 24 cm. The chopping knife is 220 mm in length, 50 mm in width, and 3 mm thick. The machine is powered by an XD-3420 threaded DC motor rated at 30 watts with a rotational speed of 3500 revolutions per minute. The hopper output measures 17 cm in length and 14 cm in width. Overall, the entire machine has dimensions of 36 cm in length, 36 cm in width, and 87 cm in height.

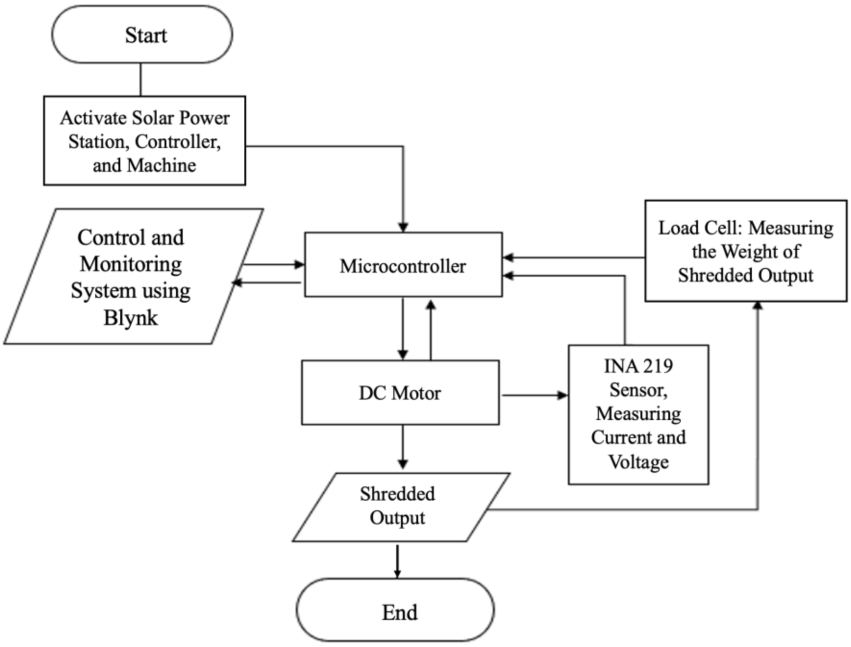
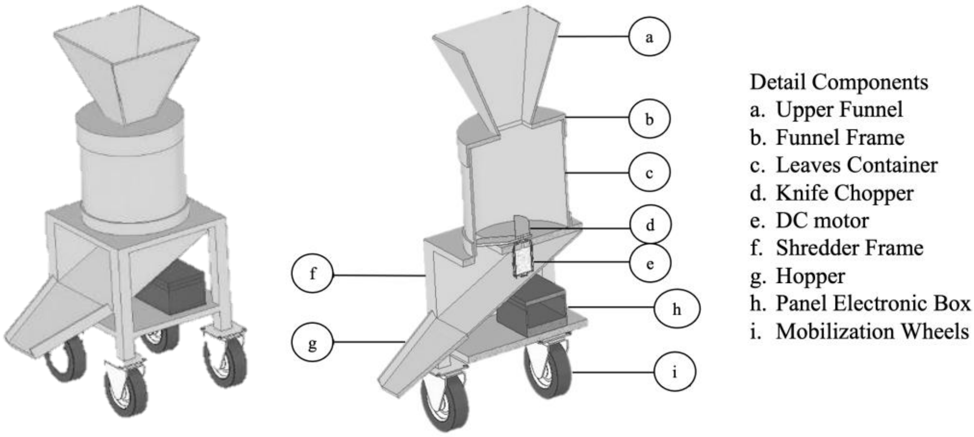


Figure 1. Flowchart Waste Shredder Machine with IoT-Based Monitoring



(a) (b)

Figure 2. Design Waste Shredder Machine (a) Full Body and (b) Detail Components

RESULT AND DISCUSSION

Integration and Operation

The hardware design of the shredder includes a solar-powered energy source to meet outdoor operational requirements. The system features a 540Wh portable power station that powers the microcontroller and other components, with an LM2596 step-down module ensuring appropriate voltage levels. The Blynk application connects to the microcontroller via the internet, allowing for the monitoring and controlling of components such as the DC motor, INA219 sensor, and load cell. The motor driver operates the DC motor, which drives the blades for shredding organic waste, while the INA219 sensor measures current, voltage, and power, relaying this data to the Blynk application. The load cell, in conjunction with the HX711 module, accurately calculates the weight of the shredded material.

The workflow begins when the DC output from the power station connects, powering the microcontroller, which subsequently links to the app. Organic waste is loaded into the machine, and the Blynk activates the DC motor to rotate the chopping blade. The load cell detects the shredded material's weight, while the INA219 sensor measures current, voltage, and power consumption. The microcontroller processes and transmits these data points to the application for real-time monitoring. The control system consists of a microcontroller that governs the ON/OFF function for the DC motor and a load cell sensor in the output hopper to weigh the shredded waste. The wiring diagram, designed using the Fritzing application, details all input and output connections for the system components and specifies assignments for each ESP32 pin. Figure 4 shows the installation of electronic and IoT devices for monitoring. The various structural components:

1. Funnel: A trapezoidal-shaped funnel measuring 25 cm by 22 cm.
2. Tube Container: A 25 cm diameter, 24 cm high tube for holding the shredded leaves.
3. Leg Frame: Made from angle iron with dimensions of 36 cm by 55 cm.
4. Panel Box: A plastic box (22 x 15 x 7.5 cm) to secure the microcontroller.
5. Output Hopper: Crafted from a 1 mm thick iron plate with a hole for the DC motor cable.
6. Scales: An acrylic scale used to measure organic waste before and after shredding.
7. Chopping Blade: A 220 mm by 50 mm dimensions blade, driven by the DC motor for leaf shredding.

The control system manages the shredder machine's operation and collects data for analysis via the IoT platform. It consists of several components:

a. ESP32: A microcontroller connected to sensors and transmitting data to the Blynk platform.
b. INA219 Sensor: Measures the motor's voltage, current, and power consumption.
c. Step-down LM2596: Reduces and delivers power to components as needed.
d. BTS7960 Motor Driver: Controls the speed and rotational direction of the DC motor.
e. ESP32 Expansion Board: Extends the capabilities of the ESP32 module by providing additional connection options and features.

Testing and Calibration

The testing aims to ensure the device operates correctly and can utilize wireless connectivity, such as WiFi, to enable monitoring via an IoT platform like Blynk. This testing involves measuring current and voltage across the load, with monitoring facilitated by technology that relies on an internet connection for data transfer and communication between system components.

In Table 1, it can be seen that the current and voltage sensors used, namely the INA219 sensor module, can be used to perform the process of reading the current and voltage used on a load, which has been compared with the reading results of the measuring instrument in the form of an analog multimeter. The data shows that the INA 219 sensor module has an average reading error of 3.00% for voltage and 2.65% for current. The results with a percentage error of less than 10% have met the requirements, and the sensor is considered suitable for data collection. The average error value from the current test is 2.65%. The values measured by the INA219 sensor are close to those measured by the multimeter, which is generally considered standard.

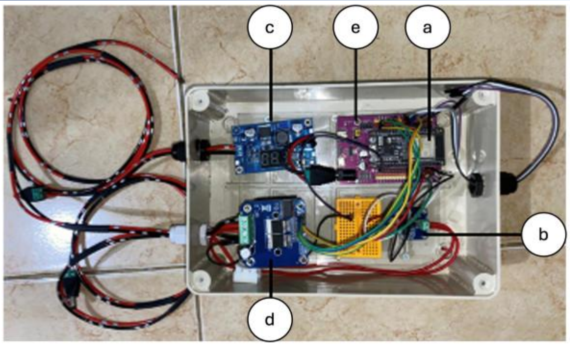


Figure 4. Electronics and IoT Installment for Monitoring

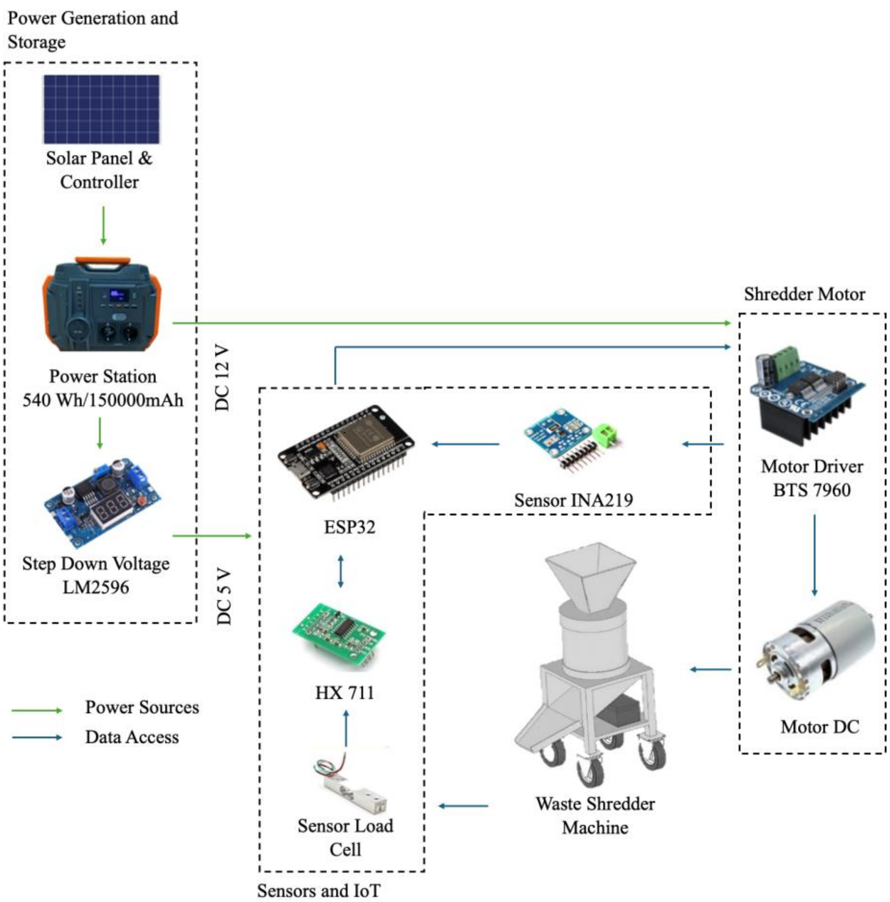


Figure 5. Detail Flowchart Diagram and Related Components

Table 1. INA219 Sensor Test Results

Measurement using sensors		Measurement using a multimeter		Error (%)	
Voltage (V) Sensor	Current (A) Sensor	Voltage (V) Multimeter	Current (A) Multimeter	Voltage	Current
10.73	0.985	10.94	1	1.92%	1.49%
9.55	0.943	9.78	0.96	2.35%	1.75%
8.26	0.824	8.52	0.86	3.05%	4.29%
7.08	0.815	7.33	0.84	3.27%	2.95%
5.83	0.798	6.1	0.82	4.43%	2.77%

ISSN 2580-6424 (printed) | ISSN 2477-2399 (online)

Experiment in Greenhouse

The experiment was conducted at Telkom University, Surabaya Campus. The load cell sensor test is carried out to determine the level of accuracy of the load sensor reading. The percentage of error values that occur in measurements weighing 100 grams, 300 grams, and 500 grams by comparing them with national standard manual scales as a reference for the actual weight. From Table 2, the test data uses a load cell, which shows that the average error generated is 0.23% for the mass before and 0.95% for the mass after being chopped. The data obtained shows a significant variation in error, with the slightest error being 0.00% and the largest error reaching 3.19%. Most measurements have relatively low error values, such as 0.20%, 1.02%, and 2.25%, which indicates that the load Cell can generally provide pretty accurate measurements. However, some measurements, such as a weight of 91 g, have an error of 3.19%. In Figure 5, the green line represents the measurement data using the load cell, while the blue line represents the actual weight measured by the scale. This graph shows how the data from the load cell compares to the scale data. The graph generally shows consistent results between the two types of measurements.

A leaf shredding test was conducted to measure the movement and rotation speed of the DC motor when rotating the shredder blade with a dry leaf load and to determine how the DC motor is in shredding dry leaves, which can be seen from the capacity results and the resulting shredding results. Figure 6 depicts the shredder machine, machine frame, shredding blade, and drive motor. This test used dry grape, ketapang, cherry, and mango leaves. The following is the data from the shredding test and DC motor with PWM 255 settings, as represented in Table 3. Table 4 contains data on the experiment of cutting dry leaves from various types of leaves with different loads. The data includes measurements of leaf weight before and after being chopped, the time required to chop, revolutions per minute (RPM), PWM, and average power measured in watts per minute. The difference between leaf weight before and after being chopped is relatively small, indicating that leaf-cutting does not significantly reduce leaf weight, improving chopping. Leaf weight measured by load cell and scales are almost the same, indicating that the measuring instrument has good accuracy. The power used also increases with the increasing weight of the leaves. While the RPM produced is inversely proportional. When the load increases, the RPM decreases. RPM is measured using a tachometer. Cutting time increases with increasing leaf weight. It can be seen from the time required to cut 100 grams of leaves, which is much shorter than 500 grams.

Table 2. Load Cell Sensor Test Results Before and After Shredding

Mass On Load Cell Sensor (Gram)		Mass On Digital Scales (Gram)		% Error	
Pre-Shred	**Post-Shred**	**Pre-Shred**	**Post-Shred**	**Pre-Shred**	**Post-Shred**
100	92	101	93	0.99%	1.08%
	87	100	89	0.00%	2.25%
	92	101	93	0.99%	1.08%
	91	100	94	0.00%	3.19%
300	284	300	285	0.00%	0.35%
	288	302	290	0.33%	0.69%
	292	301	295	0.33%	1.02%
	286	300	287	0.00%	0.35%
500	480	501	482	0.20%	0.41%
	483	500	486	0.00%	0.62%
	481	500	483	0.00%	0.41%
	491	500	493	0.00%	0.40%

Table 3. Results of Chopping and DC Motor Tests

Dry Leaf Weight (grams)	Types of Dry Leaves	Leaves Before Chopping (grams)		Leaf Counting Results After Chopping (grams)		Time (s)	RPM	Average Power (Watt/minute)
		Load Cell	Measuring	Load Cell	Measuring			
100	Cherry	100	101	92	93	70	2948	12.07
	Mango	100	100	91	94	51	2968	14.87
	Ketapang	100	100	87	89	71	2916	13.65
	Wine	100	101	92	93	88	2821	12.53
300	Cherry	300	301	292	295	169	2863	15.06
	Mango	300	300	286	287	161	2431	21.63
	Ketapang	301	302	288	290	138	2657	19.29
	Wine	300	300	284	285	120	2793	15.58
500	Cherry	500	500	481	483	194	2679	18.87
	Mango	500	500	491	493	201	1912	20.76
	Ketapang	500	500	483	486	211	2591	17.12
	Wine	500	501	480	482	148	2529	16.30

The results of the shredder prototype can be seen from the shredding results and the machine's production capacity. Data collection uses the weight measured by the load cell to determine the tool's overall operating performance. The following is the data on the results of the calculation and capacity in Table 5. The production capacity and results in the 2nd to third tests on each leaf type can be calculated using the same formula. Residue in grams indicates the number of dry leaves not accommodated on the scale because, during the shredding process, the leaves come out of the collection tube, where they are shredded and do not fall directly into the output hopper that goes to the scale. After all, an open part in the output hopper causes the shredded results to be thrown out during the shredding process.

Table 4. Production Capacity of Shredder Machine

Types of Dry Leaves	Input Load Cell (gram)	Output Load Cell (gram)	Residue (gram)	Time (s)	Production (kg /hour)	Result (%)
Cherry	100	92	8	70	4.73	92
	300	292	8	169	6.23	97.33
	500	481	19	193	8.98	96.2
Mango	100	91	9	51	6.41	91
	300	286	14	161	6.40	95.33
	500	491	9	201	8.79	98.21
Ketapang	100	87	13	71	4.42	87
	301	288	13	138	7.51	95.67
	500	483	17	211	8.24	96.6
Wine	100	92	8	88	3.76	92
	300	284	16	120	8.52	94.67
	500	480	20	148	11.67	96

Table 5. Total Machine Capacity Production

Types of Dry Leaves	Production Capacity (kg/hour)	Average Yield (%)	Shredding Time (s)
Cherry	19.94	95.17	432
Mango	21.60	94.84	412
Ketapang	20.18	93.09	420
Wine	23.96	94.23	355

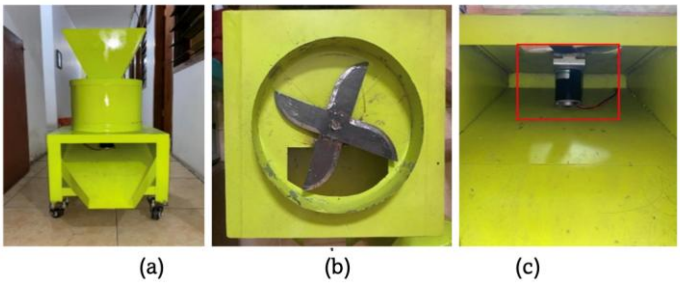


Figure 6. Shredder Machine (a) Machine Frame (b) Shredding Blade (c) Drive Motor

In Table 5, grape leaves have the highest production capacity, while cherry leaves have the lowest production capacity. However, all leaves show a high average yield (%), indicating improved shredding processing. Shredding grape leaves and ketapang leaves achieves different results due to differences in leaf shape characteristics. Grape leaves tend to be thinner and softer, making it easier for the shredding machine to crush them. Ketapang leaves may have a thicker or stronger fiber structure, slightly complicating the shredding process. Grape leaves produce as much as 35 grams (70%) of the total 50 grams chopped into perfect size (1-4 mm), 8 grams (16%) medium size (5-10 mm), and 3 grams (6%) large size (11-20 mm). Ketapang leaves produce as many as 27 grams (54%) chopped into perfect size, 17 grams (34%) medium size, and 5 grams (10%) large size. Both leaves require shredding twice to get the best results at perfect shredded size (1-4 mm). Dry leaves can be cut to the desired size by the shredder, but more than one process is required to get the best results.

Figure 7. Results of the Organic Waste Shredder Machine: (a) Shredded grape leaves, (b) Chopped Ketapang leaves, (c) Chopped Cherry leaves, (d) Shredded mango leaves.

Testing the Blynk application's display results ensures that data sent from hardware (such as INA219 sensors, motor drivers, and load cells) can be displayed correctly in the application. The Internet of Things-based data is presented in two visual outputs: the smartphone application and the console website, which are depicted in Figure 5. Figure 7 represents the result of the organic waste shredder machine: (a) processed grape leaves, (b) cut ketapang leaves, (c) chopped cherry leaves, and (d) shredded mango leaves. After that, Figure 8 shows the results from the stage application blynk, namely blynk Console, accessed via the web (a) and displays the application blynk on a smartphone (b). This visualization demonstrates that the data transmitted from the device's machine to the Blynk platform is both visible and consistent across the web dashboard and the smartphone application. The values displayed on the web dashboard and smartphone application are the same, namely voltage 12.28 V, current 3.1 mA, power 0.03 W, weight 0 g (no load detected), and the switch in the "Off" position (the motor is off).

ISSN 2580-6424 (printed) | ISSN 2477-2399 (online)

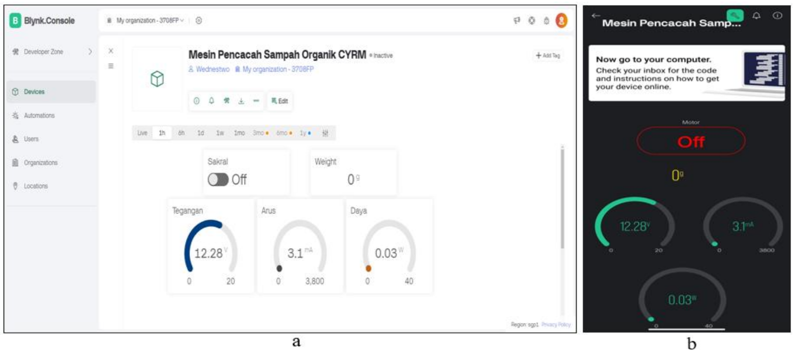


Figure 8. Results Displayed (a) Website Console (b) Blynk Application

Table 6. Power Station Charging Test Results

Time	Light Intensity (W/m²)	Voltage (V)	Current (A)	Solar Panel Power (W)	Battery Capacity (%)
1	523.3	19.34	0.46	8.9	20
2	729.1	19.43	1.54	29.92	23
3	928.7	16.38	2.54	41.61	26
4	968.3	17.25	3.37	58.13	36
5	964.9	17.2	3.78	65.02	44
6	940.1	15.91	4.92	78.28	50
7	967	16.18	3.25	52.59	60
8	881.9	16.57	3.34	55.34	65
9	995.8	17.29	3.29	56.88	65
10	987.9	17.07	2.55	43.53	74
11	915.2	17.67	3.37	59.55	80
12	834.9	16.7	1.8	30.06	86
13	877.9	16.74	2.32	38.84	93
14	965.1	16.64	3.25	54.08	93
15	923.6	19.73	0.71	14.01	99

Table 6 is the measurement result of portable power station charging using 100 wp solar PV. Charging of this portable power station lasts for 3 days with a total charging time of 20 percent to 100 percent, which is 15 hours. The first day lasts from 08.00 to 15.00. The next day lasts from 11.00 to 15.00. Moreover, the last day lasts from 12.00 to 13.00, when the portable power station is 100% charging. The power generated by the solar panel peaks around 11:00 to 13:00 when the light intensity and current are at their highest.

The Blynk application was tested for its data transmission capabilities, revealing that it can successfully send and receive data up to 9 meters. Beyond this distance, specifically at 10 meters, the application becomes unresponsive, resulting in a disconnection. This loss of connectivity is attributed to disruptions in the internet connection. Additionally, the test assessed the strength of the hotspot network or mobile tethering, allowing for an evaluation of optimal connection distances to maintain a stable Blynk connection.

CONCLUSION

This work concerns designing and implementing a solar-powered organic waste shredding machine integrated with IoT technology. With dimensions of 36 cm in length, 36 cm in width, and 87 cm in height, the machine incorporates essential components, including a funnel, cover, container, shredder knives, a DC motor, and wheels. It uses two 220 mm by 50 mm shredder knives powered by a 30-watt DC motor operating at 3500 RPM. Functional testing confirmed that the system operates reliably, with the ESP32 and various sensors exhibiting low error rates of 3.00% for voltage and 2.65% for current readings. The machine's production capacity reaches up to 23.96 kg/hour, with improvement ranging from 93.09% to 95.17%, depending on the leaf type processed. The Blynk application effectively facilitates real-time control and monitoring of the shredder, reinforcing its role in enhancing organic waste processing while utilizing renewable energy sources.

Future improvements could focus on enhancing the machine's shredding capacity, portability, and monitoring capabilities through additional sensors. This innovative approach improves waste management practices and contributes to reducing carbon emissions, supporting a circular ecosystem, and making it a viable solution for environmentally friendly organic waste processing.

ACKNOWLEDGMENT

The authors would like to thank Telkom University, Indonesia, for funding this research activity.

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ISSN 2580-6424 (printed) | ISSN 2477-2399 (online)

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