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Development and Performance Evaluation of Bio Chopper for Agricultural Biomass Processing

Mohammad Afzal Hossain[1*], Md. Moudud Ahmmed[1,2], Md. Anwar Hossen[3], Md. Mofazzel Hossain[4], Faria Rahman[5]

[1]Workshop Machinery and Maintenance Division, Bangladesh Rice Research Institute, Gazipur, Bangladesh
[2]Graduate School of Science and Technology, University of Tsukuba, Tsukuba, Japan
[3]Farm Machinery and Postharvest Technology Division, Bangladesh Rice Research Institute, Gazipur, Bangladesh
[4]Entomology Division, Bangladesh Rice Research Institute, Gazipur, Bangladesh
[5]Agricultural Economics Division, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh
Email: *engr.afzal@yahoo.com

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Abstract

Agricultural biomass residues such as rice straw, weeds, fodder grass, and vegetable residues are generated in huge quantities every year and improper disposal of these materials causes serious environmental pollution and management problems. Efficient biomass size reduction technologies are essential for improving composting, mulching, livestock feeding, and biomass utilization processes. Therefore, the present study was conducted to design, fabricate, and evaluate a low-cost bio chopper for efficient chopping and size reduction of agricultural biomass materials. The machine was developed at the Workshop Machinery and Maintenance (WMM) Division of Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh. The developed bio chopper mainly consisted of a conical feeding hopper, chopping chamber, rotating blade assembly, electric motor, shaft and bearing system, speed regulator, and supporting frame. The machine operated based on impact and shearing action generated by high-speed rotating blades inside the chopping chamber. Performance evaluation of the developed machine was conducted under laboratory conditions using rice straw, weeds, fodder grass, and vegetable residues. The performance parameters included chopping capacity, chopping efficiency, particle size reduction, uncut material percentage, power consumption, and specific energy consumption. The chopping capacity of the machine ranged from 145.2 to 178.5 kg/h, while chopping efficiency varied from 91.4% to 95.1% depending on biomass type and moisture content. The highest chopping capacity and chopping efficiency were observed for fodder grass due to its softer texture and lower cutting resistance. The percentage of uncut biomass materials ranged from 4.9% to 8.6%, whereas average particle size varied from 19.4 mm to 24.5 mm. Power consumption of the machine ranged from 420 W to 445 W and specific energy consumption varied from 2.49 to 2.89 Wh/kg. The developed bio chopper showed satisfactory chopping performance, stable operation, and efficient energy utilization for agricultural biomass processing applications.

Keywords

Bio Chopper, Biomass Management, Chopping Efficiency, Agricultural Residues, Specific Energy Consumption

1. Introduction

Agriculture is one of the major contributors to global biomass generation through the production of crop residues, weeds, grasses, and other agricultural by-products. Every year, enormous quantities of agricultural biomass are generated worldwide from rice, wheat, maize, sugarcane, vegetables, and fodder crops [1]. These biomass materials are considered valuable renewable resources that can be utilized for composting, mulching, livestock feed preparation, bioenergy production, biochar generation, and other sustainable agricultural applications [2]. However, improper management of agricultural residues has become a serious environmental and agricultural problem, particularly in developing countries where residue management technologies are still limited. In many agricultural regions, farmers commonly dispose of crop residues through open-field burning because of labor shortages, lack of machinery, and difficulties associated with biomass handling and transportation [3]. Open burning of agricultural residues causes severe environmental pollution through the emission of greenhouse gases, particulate matter, and toxic pollutants that negatively affect air quality, soil fertility, and human health [4]. In addition, burning leads to substantial nutrient losses from agricultural fields and contributes to climate change through carbon dioxide and methane emissions [5]. Therefore, sustainable biomass management technologies are urgently needed to reduce environmental pollution and improve agricultural sustainability.

Agricultural biomass possesses several physical and mechanical characteristics such as high fiber content, low bulk density, irregular shape, and high moisture variability that create difficulties during handling, storage, transportation, and processing operations [6]. Biomass size reduction is considered one of the most important pre-treatment operations before utilization of agricultural residues. Chopping and shredding operations reduce particle size, increase surface area, improve bulk density, and facilitate easier transportation and storage of biomass materials [7]. Smaller particle sizes also improve composting efficiency, microbial decomposition rate, livestock digestibility, and thermochemical conversion performance during bioenergy production [8].

Biomass chopping machines are widely used for agricultural residue management and feed preparation purposes. Different types of biomass choppers and shredders have been developed using flail, hammer, rotary blade, and flywheel cutting mechanisms [9]. The chopping performance of these machines depends on several factors including blade geometry, cutting speed, feeding mechanism, biomass moisture content, fiber characteristics, and machine power transmission systems [10]. Researchers reported that chopping efficiency and energy consumption are significantly affected by biomass physical properties and machine operational parameters [11]. Several studies have been conducted on biomass chopping and shredding technologies for agricultural applications. Okasha *et al.* [12] developed a crop residue shredder for paddy straw management and reported that chopping efficiency increased with higher blade rotational speed and lower feeding rate. Hassan *et al.* [13] evaluated a fodder chopper and found that moisture content and blade sharpness significantly affected chopping capacity and particle size distribution. Xie *et al.* [14] reported that proper blade arrangement and rotational balance reduced machine vibration and improved chopping uniformity during biomass processing operations. Similarly, Fauzan *et al.* [15] observed that direct shaft coupling systems improved mechanical efficiency and reduced power losses compared to belt-driven chopping systems.

Although different biomass chopping machines are available in developed countries, many existing machines are expensive, structurally complex, and unsuitable for small-scale farmers in developing countries such as Bangladesh. Some conventional machines also suffer from excessive vibration, high power consumption, low chopping uniformity, poor feeding performance, and difficulty in handling fibrous biomass materials such as rice straw and maize stalks [16]. In addition, imported biomass processing machines are often economically unaffordable for marginal farmers and small agro-industries. Therefore, development of low-cost, efficient, and locally adaptable biomass chopping technologies is essential for sustainable agricultural residue management in developing agricultural economies. Bangladesh is an agriculture-based country where rice is cultivated extensively throughout the year. Large quantities of rice straw, weeds, vegetable residues, and other crop by-products are generated annually after harvesting operations [17]. Improper disposal of these residues creates environmental pollution and management difficulties in rural farming systems. Efficient biomass management technologies can help farmers convert agricultural residues into valuable organic resources for composting, livestock feeding, and renewable energy production. Small-scale biomass chopping machines may also reduce labor requirements and improve biomass utilization efficiency at the farm level.

Mechanical chopping of biomass materials not only improves residue management but also enhances the quality of compost and animal feed preparation. Chopped biomass decomposes more rapidly because of increased surface area available for microbial activity [18]. Uniformly chopped fodder materials also improve feed intake and digestibility in livestock production systems [19]. Furthermore, chopped biomass materials are easier to handle during briquetting, pelletization, and biochar production processes. Therefore, efficient chopping technology plays an important role in modern biomass processing systems.

The physical and operational characteristics of chopping machines are influenced by blade material, blade configuration, shaft speed, feeding system, and power transmission mechanism. High-carbon steel blades are widely used in chopping systems because of their superior hardness, wear resistance, and cutting strength [20]. Proper blade arrangement and symmetrical mounting significantly reduce operational vibration and improve machine stability during high-speed rotation. In addition, direct shaft coupling systems reduce mechanical losses and increase transmission efficiency compared to pulley-belt arrangements [21].

Recent studies also emphasized the importance of energy-efficient biomass processing technologies for sustainable agricultural mechanization. Lower specific energy consumption and higher chopping efficiency are considered important indicators of biomass chopping machine performance [22]. Optimization of machine parameters such as blade speed, feeding rate, and moisture content can significantly improve chopping efficiency and reduce energy consumption during biomass processing operations [23]. Therefore, considering the increasing need for sustainable agricultural residue management and efficient biomass utilization technologies, the present study was undertaken to design, fabricate, and evaluate a bio chopper for efficient chopping and size reduction of agricultural biomass materials. The specific objectives of the study were: 1) to design and fabricate a low-cost bio chopper suitable for small-scale agricultural applications, 2) to evaluate the chopping capacity and chopping efficiency of the developed machine under different biomass conditions, 3) to determine particle size reduction performance and percentage of uncut biomass materials, and 4) to analyze power consumption and specific energy consumption during chopping operations.

2. Materials and Methods

The developed bio chopper was designed, fabricated, and evaluated at the Bangladesh Rice Research Institute for efficient chopping and size reduction of agricultural biomass materials such as rice straw, weeds, fodder grass, vegetable residues, maize stover, and crop residues. The machine was developed to facilitate biomass management, compost preparation, mulching, and livestock feeding operations while reducing labor requirement and processing time. The conceptual and structural design of the machine was prepared using SolidWorks software. During the design stage, special consideration was given to operational stability, chopping efficiency, ease of operation, low fabrication cost, reduced vibration, and safe machine handling. The developed bio chopper mainly consisted of a feeding hopper, chopping chamber, rotating blade assembly, shaft and bearing system, electric motor, power transmission unit, speed regulator, electrical switch, supporting frame, and protective cover. The feeding hopper was fabricated in a conical shape using stainless steel sheet to facilitate smooth gravitational movement of biomass materials into the chopping chamber. The conical structure minimized material blockage during operation and improved feeding efficiency. The hopper height was approximately 380 mm with a larger upper opening diameter to allow convenient manual feeding of biomass materials.

The fabrication process of the bio chopper involved several sequential operations including preparation of CAD drawings, cutting of mild steel sheets and angle bars, fabrication of the conical hopper, shaft machining using a lathe machine, blade fabrication and sharpening, frame welding, installation of shaft and bearings, motor assembly, electrical wiring, and final machine alignment. After fabrication, preliminary trial operations were conducted to evaluate blade balance, machine vibration, shaft alignment, and operational safety before final experimental testing. The developed machine operated based on impact and shearing action generated by high-speed rotating blades inside the chopping chamber. During operation, biomass materials were manually fed into the hopper and moved downward into the chopping chamber through gravitational force. The rotating blades fragmented the biomass materials into smaller particles through repeated impact and shearing forces. The chopped materials were discharged downward through the outlet section by centrifugal force and gravity action. The speed regulator enabled adjustment of blade rotational speed to achieve desired chopping performance under different operating conditions (Figure 1).

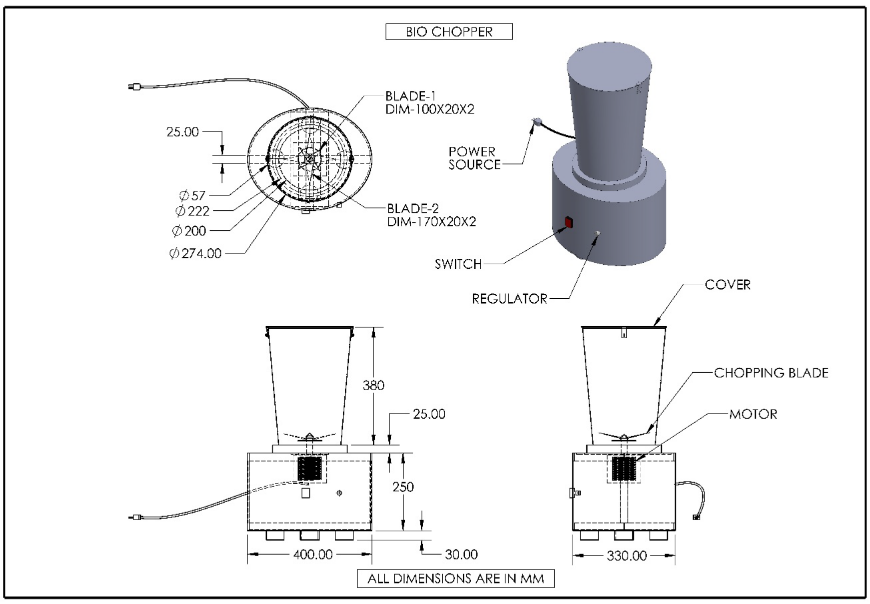

Figure 1. Layout of bio chopper.

The chopping chamber was fabricated using mild steel and stainless steel materials to withstand operational vibration and repeated impact generated during chopping operations. The chopping mechanism consisted of two sets of high-carbon steel blades mounted symmetrically on a centrally aligned rotating shaft. High-carbon steel was selected for blade fabrication because of its superior hardness, wear resistance, and ability to maintain sharp cutting edges during continuous operation. Two different blade dimensions were used in the machine to improve chopping efficiency and biomass fragmentation performance. Blade-1 had dimensions of 100 mm × 20 mm × 2 mm, whereas Blade-2 had dimensions of 170 mm × 20 mm × 2 mm. The blades were sharpened carefully and arranged symmetrically on the shaft to maintain rotational balance and minimize vibration during operation. Proper blade clearance and alignment were maintained during assembly to reduce frictional losses and improve cutting performance. A mild steel shaft was used to transmit rotational motion from the electric motor to the chopping blades. Pillow block bearings were installed to support the shaft and reduce rotational friction during machine operation. Proper shaft alignment was maintained to ensure smooth rotation and minimize excessive vibration and mechanical wear. The machine used a direct shaft coupling system between the electric motor and chopping shaft to reduce power transmission losses and simplify the overall mechanical structure.

A single-phase electric motor was used as the prime mover of the developed bio chopper. The motor was installed inside the lower housing chamber directly beneath the chopping unit. The machine was operated using AC electrical power supply. A speed regulator was incorporated into the electrical system to control blade rotational speed depending on biomass type and moisture content. An electrical on/off switch was also installed to facilitate safe machine operation and emergency shutdown during testing. The supporting frame and motor housing were fabricated using mild steel angle bars and sheet materials to provide sufficient structural rigidity and operational stability. A stainless steel protective cover was installed above the chopping chamber to minimize accidental contact with rotating blades and improve operator safety. The overall dimensions of the developed machine were approximately 400 mm in length and 330 mm in width. The lower housing section had a height of approximately 250 mm with a ground clearance of approximately 30 mm.

The performance evaluation of the developed bio chopper was conducted under laboratory conditions using different agricultural biomass materials. Before each experimental run, biomass samples were cleaned and weighed carefully. The moisture content of biomass materials was also measured because moisture significantly affects chopping efficiency, cutting resistance, and power consumption. A known quantity of biomass was manually fed into the machine, and the total operating time required for chopping was recorded using a digital stopwatch. The chopped biomass materials were collected separately for performance analysis. Figure 2 illustrates the working principle of the developed bio chopper. Biomass materials are fed through the hopper into the chopping chamber where high-speed rotating blades generate impact and shearing action to cut the materials into smaller particles before discharge through the outlet section.

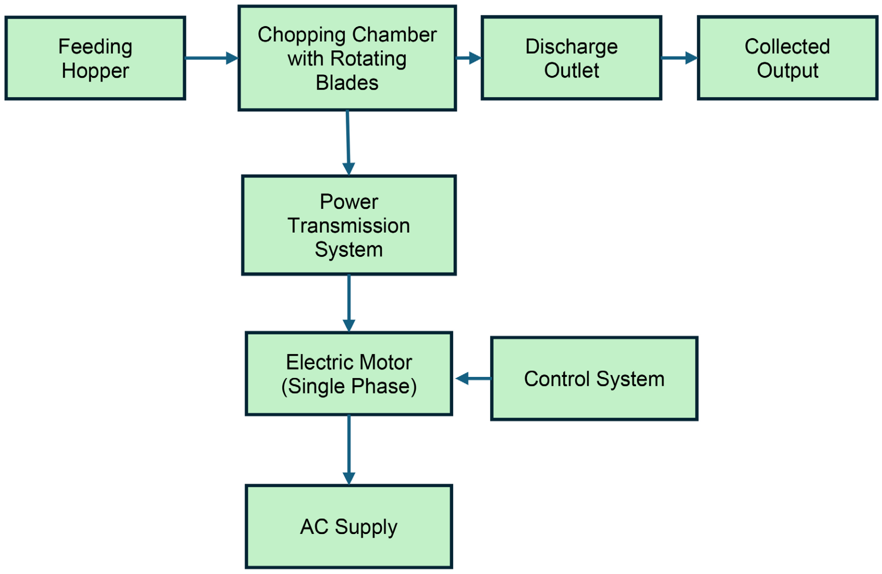

Figure 2. Block diagram of bio chopper.

3. Performance Evaluation of the Developed Bio Chopper

The performance evaluation of the developed bio chopper was conducted under laboratory conditions to determine its operational efficiency, chopping capacity, particle size reduction ability, and energy consumption characteristics. Different types of agricultural biomass materials including rice straw, weeds, fodder grass, and vegetable residues were used during the experimental investigation. Prior to each experimental run, the biomass materials were cleaned to remove foreign materials such as stones, soil particles, and metallic impurities. The moisture content of the biomass samples was measured because moisture significantly affects chopping efficiency, cutting resistance, and power consumption of chopping machines.

During operation, a predetermined quantity of biomass material was manually fed into the hopper at a uniform feeding rate to maintain steady operating conditions. The machine was operated continuously until the complete chopping of the supplied biomass materials was achieved. The operating time required for chopping was measured using a digital stopwatch, while the chopped materials were collected separately for further analysis.

The chopping capacity of the developed bio chopper was determined by calculating the quantity of biomass chopped per unit time. The chopping capacity was calculated using the following equation:

$$C = \frac{W}{T}$$

where,

C = chopping capacity (kg/h),

W = weight of chopped biomass materials (kg), and

T = total operating time (h).

The chopping efficiency of the machine was evaluated based on the proportion of properly chopped biomass materials to the total input biomass. Properly chopped materials were considered as those having acceptable particle lengths suitable for composting, mulching, or animal feeding purposes. The chopping efficiency was determined using the following equation:

$$\eta = \frac{W_c}{W_t} \times 100$$

where,

η = chopping efficiency (%),

W_c = weight of properly chopped biomass (kg), and

W_t = total weight of input biomass (kg).

The average particle size of chopped biomass materials was measured to evaluate the cutting performance and uniformity of the machine. Random samples were collected from the chopped biomass output, and the particle lengths were measured using a digital vernier caliper. The average particle length was calculated from multiple observations. Uniform particle size distribution indicated better chopping performance and improved suitability for biomass management applications.

The percentage of uncut and partially cut biomass materials was also determined to evaluate the cutting effectiveness of the machine. The uncut materials were manually separated from the chopped biomass and weighed separately. The uncut material percentage was calculated using the following equation:

$$U = \frac{W_u}{W_t} \times 100$$

where,

U = uncut material percentage (%),

W_u = weight of uncut biomass materials (kg), and

W_t = total input biomass weight (kg).

The power consumption characteristics of the machine were evaluated during operation. The voltage and current drawn by the electric motor were measured using a digital multimeter. Power consumption was determined using the following equation:

$$P = VI$$

where,

P = power consumption (W),

V = operating voltage (V), and

I = operating current (A).

The specific energy consumption of the bio chopper was also determined to evaluate energy requirement per unit biomass chopping. Specific energy consumption was calculated using the following equation:

$$SEC = \frac{P}{C}$$

where,

SEC = specific energy consumption (Wh·kg·h^{-1}),

P = power consumption (W), and

C = chopping capacity ($kg \cdot h^{-1}$).

Machine vibration and operational stability were visually observed during operation. Excessive vibration, abnormal noise generation, and blade imbalance were monitored to assess machine stability and operational safety. The effectiveness of the speed regulator in controlling chopping performance under different biomass conditions was also evaluated.

The performance tests were conducted under identical operating conditions with three replications for each biomass type to improve experimental reliability and accuracy. The collected experimental data were analyzed statistically using average, standard deviation, and coefficient of variation (CV). The performance results were presented using tables, graphs, and comparative analysis to evaluate the overall operational capability of the developed bio chopper. Table 1 presents the detailed technical specifications of the developed bio chopper including machine dimensions, blade configuration, power transmission system, and construction materials. The specifications indicate that the machine was designed as a compact, efficient, and low-cost biomass chopping system suitable for small-scale agricultural residue management applications.

Table 1. Technical specifications of the developed bio chopper.

Parameters	Specifications
Machine type	Electric bio chopper
Overall length	400 mm
Overall width	330 mm
Total height	Approximately 660 mm
Hopper height	380 mm
Base housing height	250 mm
Ground clearance	30 mm
Hopper type	Conical
Hopper material	Stainless steel
Frame material	Mild steel
Blade material	High-carbon steel
Blade-1 size	100 mm × 20 mm × 2 mm
Blade-2 size	170 mm × 20 mm × 2 mm
Shaft material	Mild steel
Power source	Single-phase electric motor
Transmission system	Direct shaft coupling
Control system	Electrical switch and speed regulator
Operating mechanism	Impact and shearing action
Application	Biomass chopping and size reduction

4. Results and Discussion

4.1. Operational Performance and Quantitative Results

The performance evaluation of the developed bio chopper was conducted using different agricultural biomass materials including rice straw, weeds, fodder grass, and vegetable residues under laboratory conditions. The performance of the machine was evaluated based on chopping capacity, chopping efficiency, particle size reduction, uncut material percentage, power consumption, and specific energy consumption. The observed results indicated that the developed machine was capable of efficiently chopping different types of agricultural biomass materials with satisfactory operational performance (Table 2). The developed bio chopper fabricated for agricultural biomass chopping and size reduction operations. The machine consists of a feeding hopper, chopping chamber, rotating blade assembly, electric motor, and supporting frame designed for efficient biomass processing and stable operation (Figure 3).

Figure 3. Developed bio chopper.

Table 2. Performance evaluation of the developed bio chopper for different biomass materials.

Biomass material	Moisture content (%)	Chopping capacity ($kg \cdot h^{-1}$)	Chopping efficiency (%)	Uncut material (%)	Average particle size (mm)	Power consumption (W)	Specific energy consumption ($Wh \cdot kg^{-1}$)
Rice straw	13.5	145.2	91.4	8.6	24.5	420	2.89
Weeds	18.2	162.8	93.7	6.3	21.8	435	2.67
Fodder grass	22.4	178.5	95.1	4.9	19.4	445	2.49
Vegetable residues	25.1	169.6	94.2	5.8	20.7	438	2.58

The chopping capacity of the machine varied depending on the type and moisture content of biomass materials. Fodder grass showed comparatively higher chopping capacity due to its softer texture and easier cutting characteristics, whereas rice straw exhibited comparatively lower chopping capacity because of its fibrous structure and higher cutting resistance. The developed machine maintained continuous operation without major blockage or excessive vibration during testing.

The highest chopping capacity of 178.5 $kg \cdot h^{-1}$ was observed for fodder grass, whereas the lowest chopping capacity of 145.2 $kg \cdot h^{-1}$ was recorded for rice straw. The higher chopping capacity of fodder grass was mainly attributed to its relatively softer texture and lower cutting resistance compared to fibrous rice straw materials. Similar trends were reported in biomass chopping studies where softer materials required lower cutting force and improved feeding continuity.

The chopping efficiency of the developed machine ranged from 91.4% to 95.1% for different biomass materials. The highest chopping efficiency was observed in fodder grass, while rice straw showed comparatively lower chopping efficiency due to the presence of long fibrous materials that occasionally escaped complete cutting. The overall chopping efficiency obtained from the developed machine indicated satisfactory cutting performance suitable for biomass management and livestock feeding applications. The percentage of uncut biomass materials varied between 4.9% and 8.6%. Rice straw exhibited the highest percentage of uncut materials because of its higher fiber strength and irregular feeding behavior during operation. The lower uncut material percentage obtained in fodder grass and vegetable residues indicated effective blade impact and shearing action. Researchers and stakeholders observed the machine's performance for chopping agricultural biomass and crop residues under operational conditions (**Figure 4**).

Figure 4. Demonstration of the bio chopper machine during operation.

The average particle size of chopped biomass materials ranged from 19.4 mm to 24.5 mm. Smaller particle sizes were observed for fodder grass due to easier fragmentation during blade impact. Uniform particle size distribution is important for improving composting efficiency, biomass decomposition, and animal feed preparation. Power consumption of the developed machine varied from 420 W to 445 W depending on the biomass type. Higher power consumption was observed during chopping of fodder grass and vegetable residues because of increased material flow rate and feeding continuity. However, the developed machine maintained relatively stable power requirements during operation. Specific energy consumption of the machine ranged from 2.49 to 2.89 Wh·kg^{-1}. The lowest specific energy consumption was recorded for fodder grass due to its higher chopping capacity and efficient cutting performance. Lower specific energy consumption indicates better energy utilization efficiency of the developed bio chopper.

4.2. Effect of Moisture Content on Chopping Performance

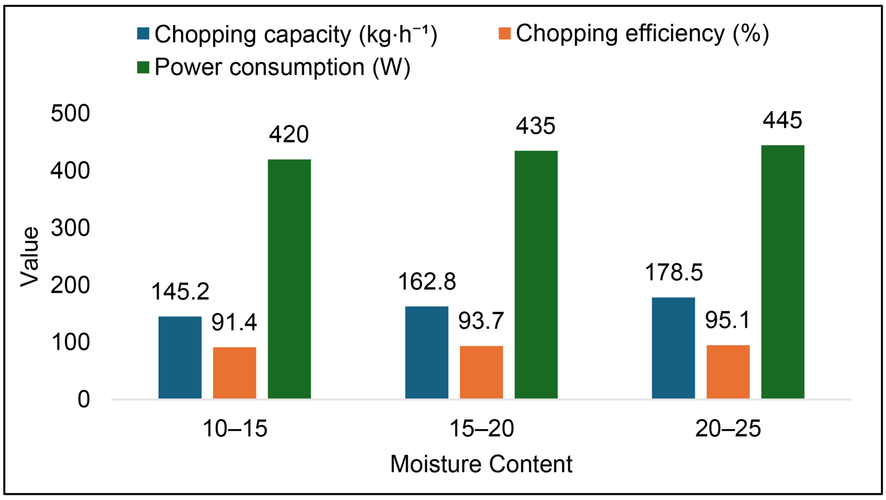

Figure 5. Effect of moisture content on chopping performance.

The results showed that moderate moisture content improved chopping efficiency and chopping capacity due to reduced brittleness and smoother cutting action. However, excessively high moisture content slightly reduced chopping performance because wet biomass materials tended to accumulate around the blade surfaces during operation. **Figure 5** illustrates the relationship between moisture content and chopping capacity of the developed machine. The chopping capacity increased gradually with increasing moisture content up to 22.4%, after which a slight reduction in chopping capacity was observed at higher moisture content levels. Moderate moisture content improved biomass flexibility and cutting performance, resulting in better feeding continuity and higher chopping efficiency. However, excessive moisture slightly reduced machine performance because wet biomass materials tended to adhere to blade surfaces and the chopping chamber. **Figure 4** shows the power consumption of the developed bio chopper during chopping operations. The power requirement varied from 420 W to 445 W depending on the type of biomass materials. The highest power consumption was observed during chopping of fodder grass because of increased feeding continuity and higher chopping throughput. Rice straw required comparatively lower power because of lower feeding rate and chopping capacity. The results indicated stable machine operation with acceptable electrical energy requirement

4.3. Comparative Performance of the Bio Chopper

Figure 6 presents the comparative performance of the developed bio chopper for different agricultural biomass materials based on chopping capacity and chopping efficiency. The chopping capacity ranged from 145.2 to 178.5 kg/h, while chopping efficiency varied between 91.4% and 95.1%. Among the tested materials, fodder grass exhibited the highest chopping capacity and chopping efficiency due to its softer texture, lower fiber strength, and smooth feeding characteristics. In contrast, rice straw showed comparatively lower performance because of its fibrous nature and higher resistance to cutting action. The results also indicated that weeds and vegetable residues produced satisfactory chopping performance with moderate chopping capacity and efficiency values. The comparatively higher chopping efficiency obtained from fodder grass and vegetable residues demonstrated effective impact and shearing action of the chopping blades. Overall, the developed bio chopper showed stable and efficient operational performance for different biomass materials and proved suitable for agricultural biomass management applications such as compost preparation, mulching, and livestock feed processing.

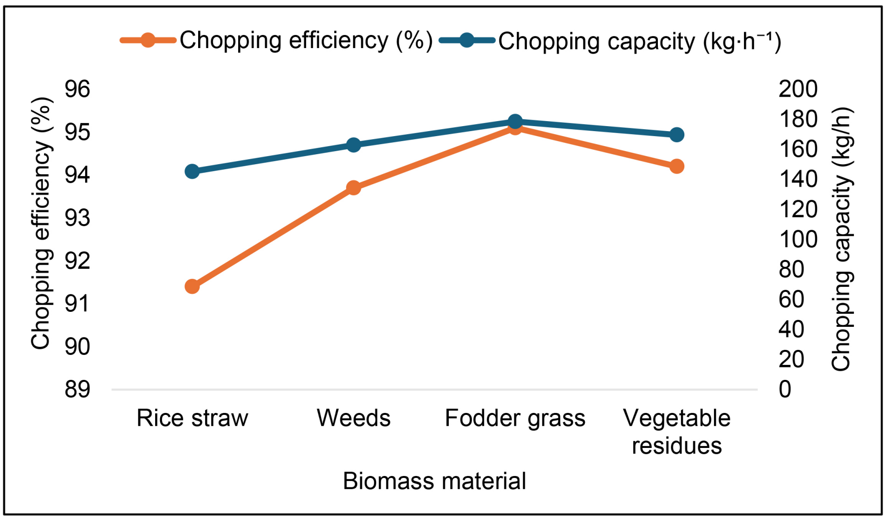

Figure 6. Comparative performance of the bio chopper.

4.4. Specific Energy Consumption and Uncut Material for Different Biomass Materials

Figure 7 presents the specific energy consumption of the developed bio chopper for different biomass materials. The specific energy consumption ranged from 2.49 to 2.89 Wh/kg. Rice straw showed the highest specific energy consumption because of its higher cutting resistance and lower chopping capacity. In contrast, fodder grass exhibited the lowest specific energy consumption due to easier fragmentation and improved chopping performance. Lower specific energy consumption indicates better energy utilization efficiency of the developed machine. pecific Energy Consumption and Uncut Material for Different Biomass Materials. The machine required comparatively more energy to fragment the long and tough rice straw fibers. In contrast, fodder grass exhibited the lowest specific energy consumption due to its softer texture, easier fragmentation, and smoother feeding characteristics inside the chopping chamber. Lower specific energy consumption indicates better energy utilization efficiency and improved operational performance of the developed machine.

The percentage of uncut biomass materials varied from 4.9% to 8.6% depending on biomass type. Rice straw produced the highest percentage of uncut materials because its fibrous nature and irregular feeding behavior occasionally prevented complete cutting by the rotating blades. In contrast, fodder grass showed the lowest uncut material percentage due to its uniform structure and easier cutting characteristics. Lower uncut material percentage indicates better chopping effectiveness and improved cutting performance of the machine.

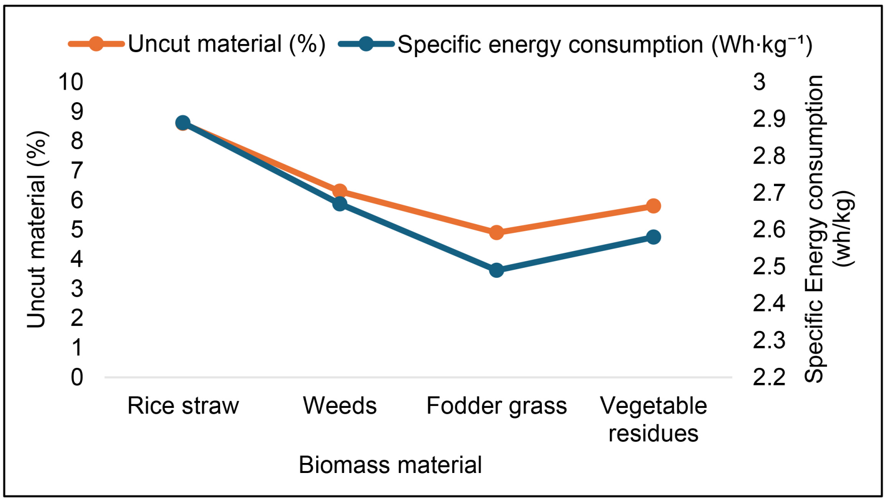

Figure 7. Specific energy consumption and uncut material for different biomass materials.

4.5. Average Particle Size of Chopped Biomass

Figure 8 illustrates the average particle size of chopped biomass materials produced by the developed machine. The average particle size ranged from 19.4 mm to 24.5 mm depending on biomass type. Smaller particle sizes were observed for fodder grass because of its softer structure and efficient fragmentation characteristics. Rice straw produced comparatively larger particles because of incomplete fiber breakage during chopping. Uniform particle size distribution is important for improving composting efficiency and livestock feed quality.

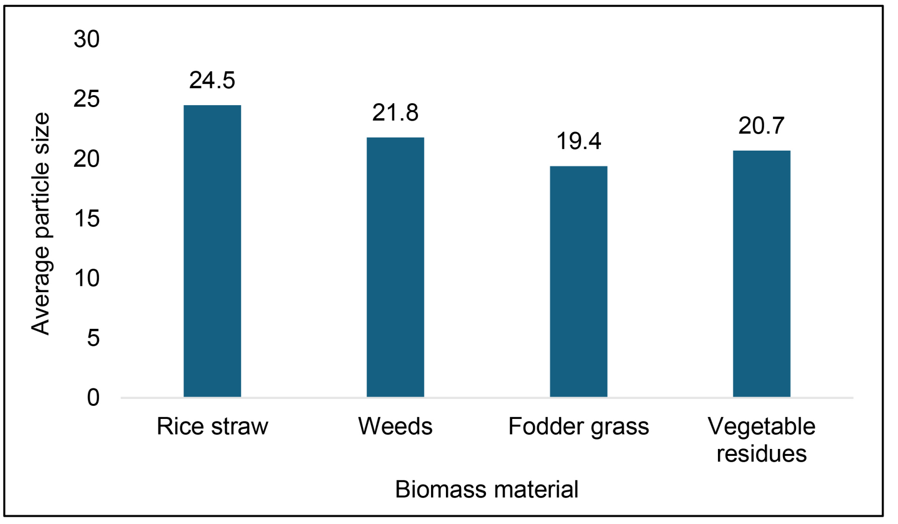

Figure 8. Average particle size of chopped biomass.

5. Discussion

The experimental results demonstrated that the developed bio chopper performed efficiently for chopping different agricultural biomass materials under laboratory conditions. The machine showed satisfactory chopping capacity, chopping efficiency, particle size reduction, and energy utilization performance for rice straw, weeds, fodder grass, and vegetable residues. The operational performance of the machine was significantly influenced by biomass characteristics such as moisture content, fiber strength, texture, and bulk density.

The chopping capacity of the developed machine varied from 145.2 to 178.5 kg/h depending on the biomass type. Among the tested materials, fodder grass produced the highest chopping capacity, whereas rice straw showed the lowest capacity. This variation occurred mainly because fodder grass possesses comparatively softer tissue structure and lower cutting resistance than fibrous rice straw. The softer biomass materials allowed smoother feeding and easier fragmentation inside the chopping chamber, thereby increasing chopping throughput. Similar observations were reported in previous biomass chopping studies where softer biomass materials provided higher feeding continuity and lower cutting resistance during chopping operations.

The chopping efficiency of the developed bio chopper ranged from 91.4% to 95.1%, indicating satisfactory cutting performance of the machine. The highest chopping efficiency was observed for fodder grass due to uniform feeding behavior and effective interaction between the rotating blades and biomass materials. In contrast, rice straw exhibited comparatively lower chopping efficiency because of its long fibrous structure and irregular feeding characteristics. Some rice straw particles escaped complete cutting and produced slightly larger chopped particles. However, the obtained chopping efficiency values indicated that the developed machine was capable of producing acceptable biomass size reduction for composting, mulching, and animal feed preparation applications.

The percentage of uncut biomass materials varied between 4.9% and 8.6%. Rice straw showed the highest uncut material percentage because of its stronger fiber structure and comparatively higher cutting resistance. The lower percentage of uncut materials observed in fodder grass and vegetable residues indicated efficient impact and shearing action generated by the chopping blades. The symmetrical arrangement of blades on the rotating shaft contributed to uniform cutting action and reduced vibration during operation. Proper blade sharpening and alignment also improved cutting effectiveness and reduced incomplete chopping of biomass materials.

The average particle size of chopped biomass materials ranged from 19.4 mm to 24.5 mm. Smaller particle sizes were obtained for fodder grass due to its easier fragmentation characteristics, whereas larger particle sizes were observed for rice straw because of its fibrous structure. Uniform particle size reduction is an important factor for improving biomass decomposition rate, composting efficiency, mulching performance, and digestibility of livestock feed. The developed machine produced comparatively uniform chopped particles suitable for agricultural biomass management applications. Power consumption of the developed bio chopper ranged from 420 W to 445 W during operation. Higher power consumption was observed during chopping of fodder grass and vegetable residues because of increased feeding continuity and higher chopping throughput. However, the overall power requirement of the machine remained relatively stable during operation, indicating proper balance between motor capacity and chopping load. The direct shaft coupling system reduced transmission losses and improved mechanical efficiency compared to conventional belt-driven systems.

The specific energy consumption of the machine varied from 2.49 to 2.89 Wh/kg. Lower specific energy consumption was observed for fodder grass because of its higher chopping capacity and lower cutting resistance. In contrast, rice straw required relatively higher energy consumption because additional cutting force was needed to fragment the fibrous biomass structure. Lower specific energy consumption values indicated efficient utilization of electrical energy during biomass chopping operations. Moisture content significantly affected the operational performance of the developed machine. Moderate moisture content improved chopping efficiency and cutting performance because slightly moist biomass materials were less brittle and easier to fragment. However, excessively high moisture content slightly reduced chopping performance because wet biomass materials tended to adhere to blade surfaces and the chopping chamber. Similar effects of moisture content on biomass cutting performance were reported in previous agricultural residue chopping studies.

The conical hopper design facilitated smooth feeding of biomass materials into the chopping chamber and minimized material blockage during operation. The compact machine structure, symmetrical blade arrangement, and rigid supporting frame significantly reduced vibration and improved operational stability. The incorporation of a speed regulator also provided operational flexibility by allowing adjustment of blade rotational speed according to biomass characteristics and chopping requirements.

The developed bio chopper demonstrated satisfactory technical and operational performance for small-scale agricultural biomass processing applications. The machine showed good chopping efficiency, acceptable energy consumption, stable operation, and effective biomass size reduction performance. Further improvement in blade geometry, automatic feeding systems, and speed control mechanisms may further enhance machine performance, reduce energy consumption, and improve operational durability for commercial-scale biomass processing applications.

6. Recommendations

- The developed bio chopper can be used for efficient chopping of rice straw, weeds, fodder grass, and vegetable residues for composting, mulching, and livestock feed preparation.
- High-carbon steel blades should be used regularly to maintain better cutting efficiency and reduce blade wear during continuous operation.
- Proper blade sharpening and alignment should be maintained to improve chopping performance and reduce the percentage of uncut biomass materials.
- Biomass materials with moderate moisture content should be preferred to achieve higher chopping efficiency and lower power consumption.
- An automatic feeding mechanism may be incorporated in future development to improve feeding continuity and reduce manual labor requirement.
- Variable speed control systems can be added to optimize chopping performance for different biomass types and moisture conditions.
- The machine frame and hopper structure may be strengthened further for long-term commercial operation under heavy loading conditions.
- Safety guards and emergency shutdown systems should be improved to enhance operator safety during field operation.
- Future studies should evaluate the field performance and economic feasibility of the developed bio chopper under commercial farming conditions.
- Further research may focus on reducing specific energy consumption and improving chopping uniformity through optimization of blade geometry and rotational speed.
- Integration of solar power systems may be considered in future versions to reduce dependency on conventional electrical energy and improve environmental sustainability.
- Comparative studies between different blade configurations and cutting mechanisms should be conducted to improve overall machine efficiency.
- The developed machine should be tested with additional agricultural residues such as maize stalk, sugarcane trash, and wheat straw for wider applicability.
- Large-scale field validation and durability testing are recommended before

commercial dissemination of the developed bio chopper.

7. Conclusion

The present study successfully designed, fabricated, and evaluated a bio chopper for efficient chopping and size reduction of agricultural biomass materials such as rice straw, weeds, fodder grass, and vegetable residues. The developed machine demonstrated satisfactory operational performance under laboratory conditions with stable chopping operation, acceptable power consumption, and effective biomass fragmentation capability. The chopping capacity of the machine varied from 145.2 to 178.5 kg/h, while chopping efficiency ranged from 91.4% to 95.1% depending on biomass type and moisture content. Among the tested materials, fodder grass exhibited the highest chopping capacity and chopping efficiency due to its softer structure and lower cutting resistance. Rice straw showed comparatively lower performance because of its fibrous nature and higher resistance to cutting. The percentage of uncut biomass materials remained within an acceptable range of 4.9% to 8.6%, indicating effective impact and shearing action of the chopping blades. The developed bio chopper produced relatively uniform particle sizes suitable for compost preparation, mulching, and livestock feeding applications. The power consumption of the machine ranged from 420 W to 445 W, while specific energy consumption varied from 2.49 to 2.89 Wh/kg, demonstrating efficient utilization of electrical energy during operation. The conical hopper design, symmetrical blade arrangement, and direct shaft coupling system contributed to smooth feeding performance, reduced vibration, and stable machine operation. The machine structure was compact, simple, and easy to operate, making it suitable for small- and medium-scale agricultural biomass processing applications. Overall, the developed bio chopper proved to be an efficient and economical biomass chopping machine capable of improving agricultural residue management and reducing labor requirements. Further improvement in blade design, feeding mechanism, and automation systems may further enhance machine performance and commercial applicability in modern agricultural biomass processing systems.

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Disclosure of Conflict of Interest

The authors declare no conflict of interest in this work. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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