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RESEARCH COMMUNICATION

Power requirement analysis for efficient harvesting of finger millet

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Abstract

Finger millet is a hardy, tufted annual grass that produces tillers and can grow up to 170 cm tall, featuring upright, slender stems that root at the lower nodes. Lack of appropriate machinery is one of the barriers to increasing the production and productivity of the finger millet crop. Determining power requirements for harvesting finger millet is crucial for designing an efficient, cost-effective harvesting machine. This study analyzes key factors influencing power consumption, including crop characteristics, harvesting methods and machine parameters. Laboratory experiments and theoretical calculations were conducted to assess parameters such as cutting force, material resistance and energy input required for effective harvesting. Developing a harvester for finger millet requires integrating cutting, conveying and windrowing functions. During harvesting, the finger millet crop is subjected to shearing action; hence, the cutting force for harvesting finger millet is determined using a cutter bar test rig. This study focuses on determining the power requirements necessary for optimal machine performance. Based on an analysis of cutting force and the quantity of material handled, the total power requirement was calculated to be 6.78 horse power (hp). The findings provide valuable insights for developing energy-efficient harvesting machinery, ultimately enhancing productivity and reducing labor dependency in finger millet harvesting.

Keywords: cutting force; finger millet; harvesting; power; productivity

Introduction

Finger millet (*Eleusine coracana*) is a vital cereal crop widely cultivated in Asia and Africa due to its high nutritional value, drought resistance and adaptability to diverse agro-climatic conditions (1, 2). Despite its importance, finger millet harvesting remains labor-intensive, often relying on manual methods that are time-consuming, physically demanding and inefficient. These traditional methods contribute to significant post-harvest losses and increased labor costs, underscoring the need for mechanization to improve productivity and efficiency in finger millet cultivation (3).

Mechanized harvesting of finger millet involves three primary operations: cutting, conveying and windrowing. Each of these processes requires optimized power input to ensure smooth operation, minimize grain loss and improve efficiency. The power requirement of a harvesting system is primarily influenced by factors such as cutting force, crop density, moisture content and the volume of material handled (4). Proper estimation of these power needs is essential for designing an energy-efficient harvester that meets the specific requirements of finger millet harvesting (5).

Several studies have examined power requirements for harvesting various cereal crops, highlighting the importance of cutting force and material flow dynamics in determining the overall machine efficiency (6, 7). For instance, researchers investigated the power requirements for cutting various cereal crops and found that parameters such as stem hardness, blade sharpness and cutting speed significantly affect the energy demand (8). Similar principles apply to finger millet harvesting, where optimizing the cutting unit, conveying mechanism and windrowing system can improve machine efficiency and reduce energy consumption.

This study aims to analyze power requirements for harvesting finger millet by evaluating interactions between crop characteristics and machine components. The research focuses on determining the required power input for cutting, conveying and windrowing operations, providing essential data for developing an efficient and cost-effective harvester. The findings will serve as a valuable resource for engineers and farmers seeking to implement mechanized solutions for finger millet cultivation.

Materials and Methods

Determining the power requirements for harvesting finger millet is essential for designing an efficient harvester. The process involves three key operations: cutting, conveying and windrowing, each requiring an optimized power input for smooth functionality. Factors such as cutting force, crop density, moisture content and the volume of material handled influence the overall power requirement.

Cutter bar test rig

A cutter bar test rig was designed to measure the force required to cut the finger millet stem. The rig comprises a main frame that supports the power transmission system, cutter bar assembly and a digital load measurement setup. A three-phase induction motor, connected to a variable-speed drive, supplies power to the system. The cutter bar assembly includes a standard reciprocating cutter bar, a knife guard and a knife clip. During operation, the finger millet crop is manually fed into the cutter bar assembly. The cutting force is recorded using a digital load measurement system comprising a load cell and a load indicator. The components of the cutter bar test rig is shown in Fig. 1.

Power required for harvesting

The power required for harvesting finger millet was estimated by measuring the cutting force at the optimized cutting speed (9). This power was then calculated using the following detailed expression:

$$P_1 = \frac{2\pi NT}{60} \quad \text{(Eqn. 1)}$$

where:

P1 = power required for harvesting finger millet (hp)

N = velocity of cutter bar, strokes per minute

T = torque, Nm

Power required for conveying, windrowing and collecting

The power needed for conveying, windrowing and collecting the crop was determined by evaluating the amount of material processed. Additionally, the conveyor belt's self-weight was considered in the calculations.

Power required for conveying and windrowing finger millet stalks using a conveyor belt is determined using the following expression

$$P_2 = \frac{WV}{75} \times \text{Factor of safety} \quad \text{(Eqn. 2)}$$

where:

W = total load on the conveyor (kg)

V = velocity of cutter bar (m/s)

Power required for driving the screw conveyor for the collection of earhead is given by the following expression

$$P_3 = \frac{q_m\,(L\lambda + h)}{102} \quad \text{(Eqn. 3)}$$

Where:

qm = material feed rate (kg s^{-1})

L = total length of the conveyor (m)

λ = material resistance coefficient (1.2 to 4.2)

h = effective elevation at which material is conveyed (m)

Total power required for designing the finger millet harvester

Total power required (P) = Power required for harvesting (P_1) + Power required for conveying, windrowing and collecting (P_2+ P_3) (Eqn. 4)

Results

Cutting force

The cutting force was calculated as 36.79 N at a cutting speed of 1.55 m s^{-1}, corresponding to the maximum stem diameter and minimum cutting force, which is optimal for harvesting finger millet.

Determination of power required for harvesting

The power required for harvesting depends on multiple factors, such as crop characteristics, machine design and operational parameters. Cutting force plays a crucial role in determining the energy required for effective crop severance, which varies with stem thickness, moisture content and cutting speed. The power required for effective cutting of the stalk and earhead requires two cutting units. Hence, the power needed for upper and lower cutting unit was calculated to be 6.6 hp. The detailed calculation of the power required for cutting units is elaborated in the supplementary file.

Power required for conveying, windrowing and collecting

Power is required for conveying and windrowing operations, which depend on the quantity of material handled and the mechanical efficiency of the system. The self-weight of components, such as the conveyor belt, also contributes to the overall power demand (10-13).

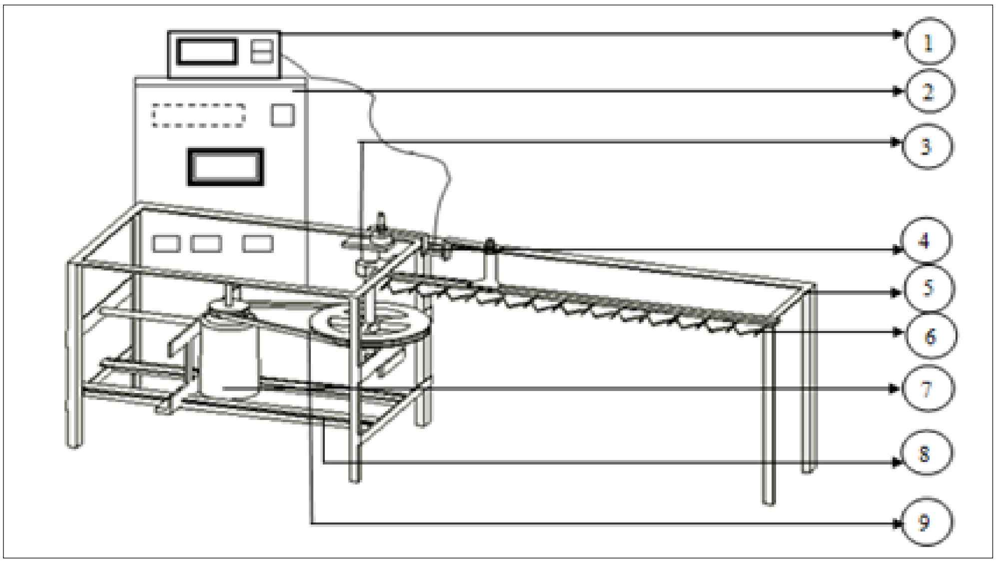

Fig. 1. Components of test rig.

1. Load indicator, 2. Variable speed drive, 3. Slider crank mechanism, 4. Load cell, 5. Main frame, 6. Cutter bar assembly, 7. Electric motor, 8. Provision for horizontal adjustment of motor, 9. Power transmission assembly.

Hence, the total power required for harvesting finger millet, obtained by combining the power required for cutting and the power required for conveying, windrowing and collecting, was found to be 6.78 hp. The detailed calculation is elaborated in supplementary file

Discussion

The total power required for harvesting finger millet was determined by summing the power needed for cutting, conveying, windrowing and collecting. The findings indicate that the overall power requirement for an efficient harvesting operation was 6.78 hp. This value was obtained through a detailed analysis of cutting force, measured using a cutter bar test rig and power consumption in material-handling systems, including the conveyor belt mechanism. The cutting unit's efficiency played a significant role in minimizing energy loss, as optimized cutting speed and a sharp blade design reduced cutting resistance (4).

Furthermore, the power demand for conveying and windrowing operations was influenced by the quantity of material processed and the self-weight of the conveyor system. Previous studies on mechanized harvesting have shown that factors such as crop density, moisture content and material flow dynamics significantly impact energy consumption (6). The results of this study align with similar research on power estimation for small-grain crop harvesters, where power requirements typically range from 5 to 7 hp, depending on machine design and operational conditions (5).

The calculated power of 6.78 hp provides a valuable reference for the development of energy-efficient finger millet harvesters. By optimizing the machine's structural design and transmission system, further reductions in power consumption can be achieved. These findings contribute to ongoing research on sustainable mechanization, ensuring that harvesting machinery operates at maximum efficiency while minimizing fuel costs and environmental impact.

Conclusion

The findings indicate that optimizing the cutting mechanism, conveyor system and windrowing process can significantly reduce the harvester's overall power consumption. Efficient blade design, proper material-handling techniques and an optimized drive system contribute to reducing energy losses and improving performance. The obtained power requirement of 6.78 hp serves as a crucial reference for designing an energy-efficient and cost-effective harvester tailored for finger millet cultivation.

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Authors' contribution

NN and SB contributed to the conception, design of this research article. RK and PV contributed to the drafting of the article. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflicts of interest to declare.

Ethical issues: None

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