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Advancements in shrubs cutting machinery for woody perennial crops: A review

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Abstract

The cultivation of woody perennial crops such as henna (*Lawsonia inermis*), Indian jujube (*Ziziphus mauritiana*), Indian gooseberry (*Emblica officinalis*), mesquite (*Prosopis cineraria*), and Salvadora (*Salvadora oleoides*) provides a promising, sustainable alternative to overcome these challenges. This paper focuses on the development and introduction of advanced shrub-cutting machines specifically designed to meet the unique requirements of woodies and similar applications. This research seeks to address the shortcomings of existing machines by incorporating innovative design features that improve both the operational efficiency and economic feasibility of shrub cutting processes. In particular, cutting mechanisms, ergonomic tool designs, and the optimization of cutting speeds could significantly enhance the efficiency of the harvesting process, thereby reducing the dependence on manual labor and improving overall productivity in these arid and semi-arid regions. In addition, traditional brush cutters also suffer from significant operational drawbacks, including poor maneuverability and limited cutting efficiency, which further highlights the need for design improvements. By advancing these machines, it will be possible to reduce labor costs, improve the precision of cutting operations, and ultimately increase the productivity and sustainability of shrub management and related agricultural activities.

Keywords: Cutting mechanism, woody plant cutting, hard stem cut, shrubs cutting

Introduction

Arid and semi-arid regions, which are defined by their low and unpredictable rainfall, extreme temperatures, and generally poor soil conditions, present considerable difficulties for agricultural development and productivity. In such areas, traditional farming methods often fall short due to the harsh environmental factors. However, the cultivation of woody perennial crops provides a promising, sustainable alternative to overcome these challenges. These resilient crops are well-suited to thrive in difficult climates and offer numerous ecological and economic benefits, making them an important part of sustainable farming practices. This paper delves into the cultivation of key woody perennial crops such as henna (*Lawsonia inermis*), Indian jujube (*Ziziphus mauritiana*), Indian gooseberry (*Emblica officinalis*), Indian mesquite (*Prosopis cineraria*), and Salvadora (*Salvadora oleoides*). These species play a vital role in the agricultural systems of India's arid zones, where they contribute to both local economies and ecological stability [1, 2, 3].

Despite the valuable role these crops play, their harvesting and processing remain inefficient due to traditional, labor-intensive methods. The inherent structure of these woody plants complicates harvesting, leading to a time-consuming and physically demanding process. To address this issue, there is a pressing need for technological advancements in agricultural tools and machinery. Innovations in cutting mechanisms, ergonomic tool designs, and the optimization of cutting speeds could significantly enhance the efficiency

of harvesting, thereby reducing the dependence on manual labor and improving overall productivity in these arid regions. By integrating modern technology into the cultivation and harvesting of these crops, we can better support sustainable agriculture in challenging environments.

Cutting mechanism

There is a wide variety of grass-cutting machines available in the market; however, these machines are generally unsuitable for cutting thick shrubs. As a result, these shrubs must be removed manually or with the assistance of specialized equipment, such as brush cutters. While the rack-pack type of brush cutter is commonly used, it exhibits several inherent limitations. These drawbacks can be mitigated through the development of a shrub-cutting machine mounted on a wheeled frame, which offers improved operational efficiency [4].

Although research specifically targeting the cutting of woody stems remains limited, existing studies on shrub-cutting methods highlight the critical importance of certain parameters. Key factors such as cutting tool angles, operational speeds, and the interplay between these variables significantly impact cutting efficiency [5, 6]. In particular, the geometric design of cutting tools, including blade and sliding-cutting angles, plays a decisive role in determining the force required for cutting and the overall energy consumption [7]. These elements are essential in optimizing the performance of cutting tools, particularly when used in demanding environmental conditions [8].

The cutting mechanisms for woody perennial crops, including henna (*Lawsonia inermis*), Indian jujube (*Ziziphus mauritiana*), Indian gooseberry (*Emblica officinalis*), Indian mesquite (*Prosopis cineraria*), and Salvadora (*Salvadora oleoides*), vary considerably based on their distinct physical properties and harvesting requirements. Henna is typically harvested manually using tools such as sickles or shears, with the cutting force largely dependent on the stem's diameter and moisture content. Indian jujube, due to its thorny nature, necessitates the use of mechanical pruners or manual shears. Indian gooseberry is also harvested manually with pruning shears, although mechanical harvesters are under development to improve efficiency. Indian mesquite, a highly drought-tolerant species, is harvested using manual tools such as axes and saws, while large-scale operations employ mechanical harvesters. Salvadora is similarly harvested manually using sickles and shears. These cutting mechanisms are crucial for enhancing the efficiency of the harvesting process and ensuring the economic sustainability of these crops in arid and semi-arid regions [3, 9, 10, 11, 12].

An additional challenge in designing cutting tools for these crops arises from the variability in cutting properties, which fluctuate with the moisture content of the plant at different stages of harvesting. This variability necessitates the development of specialized machinery capable of adapting to these changing conditions, underscoring the need for tailored cutting solutions. Moreover, the relationship between cutting speed and the energy required for efficient cutting is complex and warrants further investigation to optimize harvesting processes [3].

Recent technological advancements indicate that shifting from conventional stabber blades to rotary saw blades, along with increasing the cutter's rotational speed (RPM), could significantly enhance cutting efficiency. These modifications aim to address previous design shortcomings, such as frictional losses, while improving overall performance. Validation of these improvements through rigorous field testing and laboratory evaluations will be

crucial in confirming their efficacy [4].

A promising innovation in cutting tool design involves the use of fixed cutting devices, such as circular saws or discs with fixed teeth. These designs have demonstrated higher cutting efficiency compared to pivoting blades, as they require less energy to achieve similar cutting capacities, thereby improving performance with the same power input. However, tools equipped with saw teeth demand frequent sharpening, as contact with rocks or soil can cause rapid dulling. Various prototypes and operational circular-saw heads have been tested, particularly in Quebec, with favorable results, highlighting their potential for large-scale shrub-cutting operations [13, 14].



Fig 1: Portable mechanical brush-cutter

The impact of cutting speed on cutting force is illustrated in Figure 2. Specifically, as the cutting speed increases, there is a corresponding rise in the cutting force necessary to complete the operation. The higher speeds demand greater energy input to overcome the resistance of the material being cut, thereby increasing the workload on the cutting mechanism. Understanding this relationship is crucial for optimizing cutting tool performance and efficiency in various applications [8].

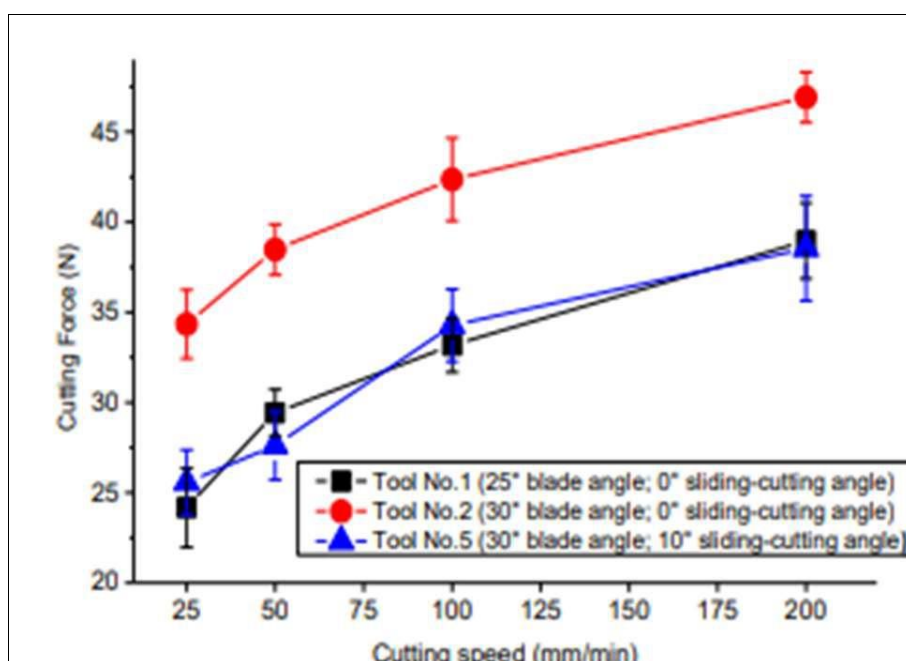


Fig 2: Effect of cutting speed on cutting force

The influence of the sliding-cutting angle on cutting force is depicted in Figure 3b. The sliding cutting is more effective in reducing cutting force compared to straight cutting.

This reduction in force is particularly noticeable when using specific blade angles. The figure 3a also illustrates how the average cutting force varies with different blade angles of the cutting tool. The average cutting force increases as the blade angle becomes larger. It is evident that smaller blade angles significantly reduce the cutting force required to sever the stem, making them more efficient for cutting operations. This finding highlights the importance of optimizing blade geometry to minimize energy expenditure

and improve cutting efficiency [8].

The design and development of specialized harvesters for henna remain largely under-researched, with limited information available in this domain. Traditionally, henna stems are harvested using basic tools such as a heavy, sharp-edged curved sickle, and gloves are worn to protect workers from the impact during cutting. Some large-scale farmers in the Pali district have experimented with mechanical harvesters in an attempt to reduce labor costs. However, these efforts were largely unsuccessful, as the vibration from the harvester's cutter bar caused the leaves to fall off during the process, leading to inefficiencies [15, 16, 17].

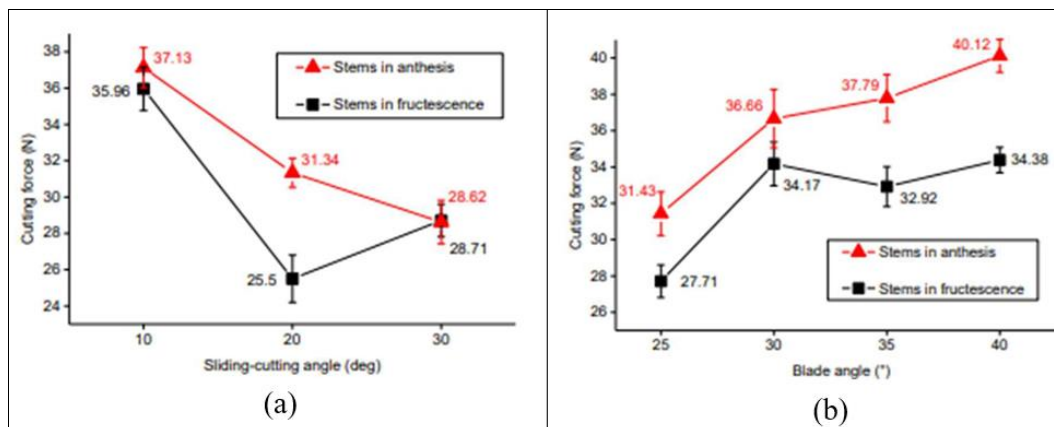


Fig 3: Effect of cutting tool geometric parameters on cutting force: (a) effect of sliding-cutting; (b) effect of sliding-cutting effect of blade angle

Table 1: Physical Parameters Affecting Cutting Force Requirement for Henna Stems

Age of plant (years)	Moisture content of woody material of stem, (% wb)	Size of stem (mm)	Cutting force required (kg)
1	48.5	5 - 10	15 – 50
2	44.3	10 - 12.5	65 - 80
10	42.2	10 – 14.5	60 – 95
25	26.2	12.5 – 22	60 – 175

The table above illustrates the physical parameters affecting the cutting force required for henna stems at various stages of plant maturity. These parameters include moisture content, stem size, and the age of the plant, all of which significantly influence the cutting force [18].

Despite the importance of understanding the power demands involved in harvesting henna, research in this area is scarce. While extensive studies have been conducted on other woody crops such as kenaf and mulberry, there is a lack of similar research specific to henna harvesting. Studies on other crops indicate that rotational speed plays a critical role in mechanical properties like equivalent stress, critical frequency, and vibration amplitude of cutting tools, particularly circular saw blades. For example, Dauda *et al.* (2015) investigated the impact of cutting speeds on the cutting force and power requirements for kenaf stem harvesting. Their findings showed that basic cutting strength increases proportionally with cutting speed, while cutting torque inversely correlates with moisture content [19].

In the case of henna, the harvesting process becomes more complex as the plant matures. Upon reaching maturity, henna stems become highly woody, making manual harvesting with a heavy, curved sickle labor-intensive and inefficient. This method demands considerable physical effort, contributing to worker fatigue and low productivity.

Furthermore, studies have demonstrated that the cutting strength of henna stems is highest when moisture content is at 30%. The cutting strength decreases if the moisture content rises or falls outside of this optimal range, underscoring the importance of considering moisture levels during harvesting operations [3].

Given the challenges posed by stem diameter, moisture content, and plant age, a deeper understanding of these variables and their influence on cutting strength is essential for developing more efficient harvesting technologies. Mechanical solutions that can address these factors will be crucial in improving the efficiency of henna harvesting, reducing labor demands, and enhancing overall productivity [20, 21].

Problems

The harvesting of woody plants, particularly henna, using traditional sickles is an extremely labor-intensive process that significantly raises the cost of cultivation for farmers. Workers are required to frequently shift between standing and squatting positions to cut the henna crop, a physically taxing activity that elevates heart rates and increases energy expenditure, leading to rapid fatigue. Furthermore, this method subjects workers to various musculoskeletal pains, particularly in the shoulder (affecting muscles like the

supraspinatus and deltoid), wrist (involving the extensor pollicis brevis), and forearm (targeting muscles such as the extensor digitorum and extensor carpi radialis brevis). Injuries to both hands are also common during harvesting operations when using sickles, making the process both hazardous and inefficient.

Despite the physical challenges and inefficiencies associated with manual harvesting, the global trade in henna leaves—whether powdered or whole—remains significant, with an estimated annual volume of at least 9,000 tons. During the harvesting process, branches with leaves are cut as close to the ground as possible and then left to dry for 3-4 days. The manual harvesting of henna requires two simultaneous tasks: holding the stem with one hand and cutting it with the sickle in the other. This dual-action process is not only laborious and inefficient but also time-consuming, adding to the drudgery of the task.

The introduction of mechanization—whether partial or complete—into the henna harvesting process would be a transformative step. By reducing the reliance on manual labor, mechanization could alleviate much of the physical strain associated with traditional methods, thus providing greater ease of operation. This, in turn, would lower labor costs, increase efficiency, and potentially encourage more farmers to expand their cultivation of henna. Automating or enhancing the harvesting process with mechanical tools would contribute to the overall growth of the henna industry by making it more economically viable, allowing farmers to increase production and profitability while improving working conditions for laborers [3].

Conclusion

In conclusion, the development and introduction of advanced shrub-cutting machinery specifically designed to meet the unique requirements of woody plants and similar applications are crucial. This research seeks to address the shortcomings of existing machines by incorporating innovative design features that improve both the operational efficiency and economic feasibility of shrub-cutting processes. By enhancing these machines, the goal is to facilitate more effective management of shrub overgrowth, while also boosting productivity, particularly in the harvesting of crops like oilseeds.

Currently, grass-cutting machines available in the market are inadequate for dealing with thick shrubs, forcing farmers to rely on manual labor or specialized equipment like brush cutters. However, these alternatives are often inefficient, labor-intensive, and costly. Traditional brush cutters also suffer from significant operational drawbacks, including poor maneuverability and limited cutting efficiency, which further highlights the need for design improvements. By advancing these machines, it will be possible to reduce labor costs, improve the precision of cutting operations, and ultimately increase the productivity and sustainability of shrub management and related agricultural activities.

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