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Studies on Betterutilization of Jute (*Corchorus olitorius*) Plants Harvested for Seeds in South India-Development of a Novelmethod and Machine: Part-I

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ABSTRACT

Background: No study has been conducted on how to utilize or minimize the agro-waste produced from the jute seed crop of dryland farming in the areas of Bapatla, Palnadu and Guntur districts of Andhra Pradesh state until now. This agro-waste is essentially a wasted natural fibre resource. This fibrous plant's processing waste is huge in terms of quantity. It is a mix of broken hurd, cut pieces of fibre and crushed seedpods of a post-vegetative jute plant. It will be a great advantage to the farmer community if fibre is managed to be separated prior to seed extraction. This is only possible if the fibre source (the main stem) and the seed source (the branches) are separated. Based on this, the current study aimed to: (i) extract and test fibre for quality and (ii) develop a novel method and an ergonomic machine tofacilitate feasible fibre extraction without damaging seedpods.

Methods: In the present study, fibre has been extracted in small qualities from post-vegetative phase jute plants and tested according to Bureau of Indian standards (IS 7032 (1986) and IS 271 (2003)) to assess the fibre quality. Engineering design approach has been followed to develop the novel machine for the separation of the source of the fibre and source of seeds.

Result: Results showed that usable fibres for the textile industrycould be extracted from post-vegetative jute plants and that the separation of the sources of fibre and seed could be facilitated with the use of developed machinery and methodology.

Key words: Jute fibre, Jute seeds, Post-vegetative phase, Source of fibre, Source of seed.

INTRODUCTION

Jute fibers are used in yarns, twine, ropes, hessian cloth, burlap, gunny bags, sanitary napkins, carpet backing cloth, shopping bags, home furnishings, decorative items, floor and wall coverings, soil savers, handicrafts, bouquets, reinforcement in polymer composites, canvas, webbing, blankets, gift articles and felt (Comfort Afi Agbaku *et al*., 2020; G. Basua *et al*., 2009; Md. Siddiqur Rahman, 2010). Due to different growth and harvesting methods, seeds and fibres from jute plants have been gathered independently for decades. Jute seed use is limited. Jute seeds are passed on for fibre crop harvesting. Jute mills batch using jute seed oil (Indian Jute Industries' Research Association, 2020).

Wetlands produce the best jute fiber. These plants grow a 7-12 ft main stem in 120 days. In the vegetative phase, plants are cut at the root and processed for high-quality fibers (Asaduz and Abdullah, 1998; Kundu *et al*., 1959; Rostom *et al*., 2015). Pre-vegetative fibre extraction is not advised for fibre quality. After 120-180 days in wetlands, seeds will ripen on major stem branches. Macrophominaphaseolina, which causes jute anthracnose, stem and root rotting (Goid) and seed discolouration, prevents this on wetlands. Long-term agro-climatic changes may damage ripening seeds and diminish seed yield. (Ghosh, 1983; Mollah *et al*., 2017; Mandal, 2001; Sarkar and Gawande, 2016; Sarkar *et al*., 2016).

Drylands produce more and better seeds from jute than swamps. Wetland seed cultivation's limitations have been eliminated by dryland farming. Eastern India (West Bengal, Odisha and Bihar) makes fiber from jute seeds produced from southern India (Andhra Pradesh and Karnataka) as they aresuperior in quality. Good seeds increase jute fibre crop yields by 15-20% (Sarkar and Satpathy, 2016; Sarkar *et al*., 2016).

Recent dryland jute seed farming involves several steps including planting JRO-524 seeds during the monsoon season, weeding, sizing, adding nutrients, topping (cutting the vertical stem at 4.5-6 feet), cutting plants at the base after 140-150 days (once the seeds have ripened), sun-drying the plants and extracting the seeds using combine harvesters. During the seed extraction process, the main stem, which is the source of fiber, is crushed and becomes unusable. Fig 1 illustrates the waste generated during seed

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extraction. Burning this waste (approximately 2-3 tons per acre) can have detrimental effects on the environment.

In this study, the quality of jute fiber obtained from jute seed crops was extracted and tested. The results were promising and a modified process, along with a novel machine, was proposed to facilitate the separation of seeds from the fiber source.

MATERIALS AND METHODS

The present research was conducted during the kharif seasons of 2019-20 and 2020-21. For the extraction of fiber, 400 main stems (free from branches) were randomly selected from different dryland jute seed farming areas. A method of simple water retting, a biological process, was employed to extract the fiber. As Ryszard *et al.* (2006) research revealed that adding nitrogen-based nutrients (5% urea ($CO(NH_2)_2$ to water retting accelerates decomposition, mixed biological-chemical retting has also been adopted. The BIS system IS 7032 (1986) was used to evaluate water-retted fibres at Indian Jute Indusries Research Association (IJIRA), Kolkata. This test used six physical criteria of post-vegetative phase jute fibre *i.e.*, fineness, bundle strength, bulk density, flaws, color and root content, to evaluate one grade amongst TD1, TD2,...TD8 grades. Mixed biological-chemical retting resulted fibres were graded at the Indian Council of Agricultural Research - National Institute of Natural Fibre Engineering and Technology (ICAR-NINFET), Kolkata, in accordance with a revised BIS system 271 (2003) for grading.

During the 2021-22 session, a novel methodology and machine were developed through an engineering design approach, based on the geometric properties of the jute plant and the feasibility of separating the source of seed and the source of fiber, which were subsequently presented.

RESULTS AND DISCUSSION

Table 1 presents the grading results of jute fibres, showcasing their commercial grades based on the IS:7032-1986 and IS:271-2003 standards. Fibres isolated from post-vegetative phase main stems, subjected to biological and combined biological-chemical treatments, were classified as TD-6+8% and TD5+87% grades, respectively. The grade difference was primarily attributed to the additional retting with urea liquor, which led to a reduction in hemicellulose and lignin content in the fibres (Saha *et al*., 2017). Similarly, Emmanuel Oduwaye *et al*. (2017) conducted a study on kenaf stems retted with different concentrations of urea liquor and analyzed the characteristics of the resulting fibres. The research demonstrated that urea liquors enhanced the retting process due to their higher enzyme activity, resulting in fibres with superior mechanical properties. However, their study did not evaluate the impact of kenaf plant age or fibre quality. In the case of post-vegetative phase Sunnhempfibres, urea treatment outperformed compost culture and the control in terms of mechanical properties and retting period (Vanishree *et al*., 2019). These findings align with the current research, indicating that urea treatment uniformly enhances the fibres' quality in various plant types during the post-vegetative phase. However, further research is needed to substantiate this claim, as it contrasts with the findings of Dhanalaxmi *et al*. (2013) regarding Mesta plants. Comparisons with the research conducted by Banik *et al*. (2007) also reveal the superiority of mixed biological and chemical treatment as a retting strategy for jute fibre extraction, regardless of the plant phase (vegetative or post-vegetative).

The primary objective of this study was to determine the viability of jute seed crops in terms of yielding fibres beneficial to the textile industry. Table 1 provides unequivocal evidence that jute seed crops can produce commercial-grade fibres (TD5 to TD6) suitable for hessian and sack production. The secondary goal of the research, as presented in Table 2, highlights the advantages of jute seed crop fibre extraction without compromising seed production. Regardless of the type of dryland farming, the collection of 30,000 to 50,000 plants per acre resulted in satisfactory seed yields. Each jute plant, with a length of 4-6 ft, can yield 8-15 g of jute fibre without affecting seed production. Therefore, economically viable fibre extraction could lead to an additional production of 4-5 quintals of fibre per acre, providing a significant advantage for farmers. Moreover, the separation of branches containing seeds from the main stems, which are intended for fibre extraction, can reduce agricultural waste by 30 to 50%. However, the current manual method of separating branches from main stems in large quantities is impractical. There are no suitable reports addressing this type of separation, underscoring the urgent

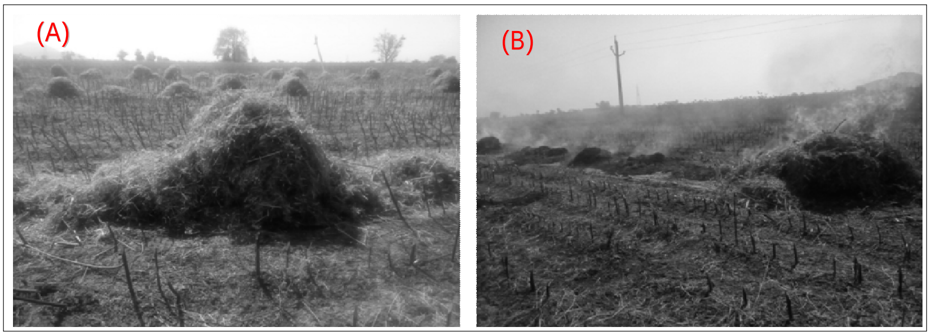

Fig 1: (A); Piles of reject of jute seeds' crop and (B); Burning of the reject for field clearance.

need for innovative and cost-effective equipment to streamline this labor-intensive process and enable the efficient separation of fibres and seeds from jute plants harvested for their seeds.

Considering the industrial applications of post-vegetative phase fibres obtained through dryland farming, it is evident that harvesting both fibres and seeds would be beneficial for farmers. However, the manual separation of branches from main stems poses significant challenges on a large scale due to the inherent labor-intensive nature of the process. This issue becomes apparent when examining the geometric characteristics of the jute plant, as presented in Table 3. The manual separation requires bending along the length of the main stem (approximately 5 ft) to detach the branches.

Table 1: Result summary of testing of post-vegetative phase jute fibres.

Test parameters	IS 7032 (1986) (IJIRA, Kolkata)	IS 271 (2003) (ICAR-NINFET, Kolkata)
Bundle strength (g/tex)	15.73	17.8
Defects (%)	18.09	>2
Root content	21.95	5
Colour (%)	14.4	Fairly good
Fineness (tex)	3.27	2.9
Bulk density (g/cc)	0.478	Medium bodied
Grade	8% higher than TD 6	TD5 + 87% higher

Table 2: Advantages of harvesting fibre from jute seeds' crop.

Major benefits	Quality or quantity
Average amount of fibre per single jute plant (g)	13
Average length of fibre (cm)	150
Quality of fibre	TD5 to TD6
Average fibre quantity per acre (ton)	0.440
Agro-waste reduction per acre	40-50%

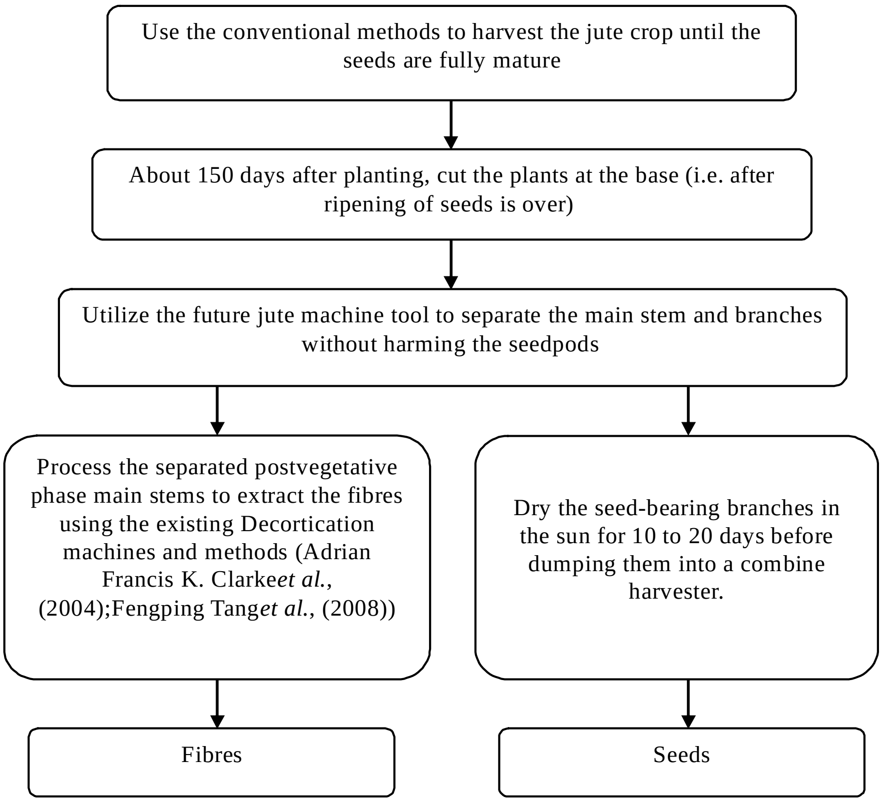

Fig 2: Developed methodology for facilitation of extraction of both seeds and fibres from jute seeds crop.

Consequently, a new machine has been developed, as depicted in Fig 2 and Fig 3 and minor modifications have been made to the dryland farming procedure, as illustrated in Fig 4.

Fig 2 provides a practical approach for separating fibres and seeds from jute crops harvested for seed. The harvesting process outlined above remains intact for obtaining high-quality dryland jute seeds. Once the seeds have fully matured, the main stems and branches need to be separated using the proposed technique. This involves growing or harvesting jute seeds, removing weeds, nurturing jute plants with appropriate fertilizers, trimming the main stalks when they reach 3 to 5 feet and allowing the plants to mature until the seeds ripen. In the next step, the primary stems of the plants are cut at the base in the early morning of winter to prevent seed loss. The revolutionary machine is then employed to separate the main stems from the branches without causing damage to the seeds. The machine is designed to cut branches growing in 360-degree directions from top to bottom. Following the base trimming, the chopped branches are sun-dried for 10-15 days on a tarp. Once dried, the branches are processed for seed extraction using a combine harvester. For optimal seed quality, the branches should be sufficiently dry to enable effective extraction by the combine harvester, which requires less power compared to processing the entire plant.

Considering the auxiliary features listed in Table 3, particularly the radial distance between the main stem and the nearest matured seedpod (10-15 cm) and the relatively straight main stems, it is evident that a machine is required to separate the branches along the main stem without damaging the seedpods. This analysis of the problem statement, coupled with a review of relevant literature presented in Table 4, indicates a lack of existing methods or machine tools for effectively separating the seeds from the fibre source during seed extraction. However, the analysis suggests various factors to consider for the development of a machine tool, including stripping and cutting techniques

Table 3: Ancillary characters of jute plants grown for pure seed purpose.

Characters	Mean value
Plant height (m)	1.5-2.0
Number of branches per plant	8-30
Radial distance between main stem and nearest matured seedpod (cm)	10-15

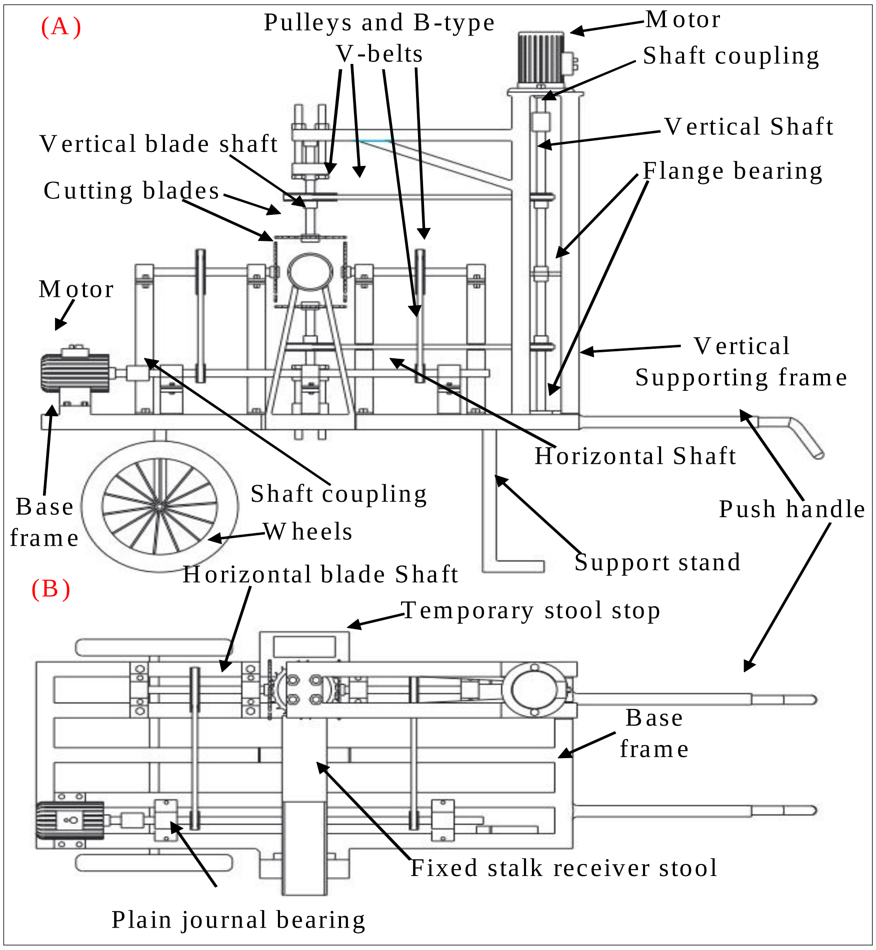

Fig 3: Front and top view of the novel machine.

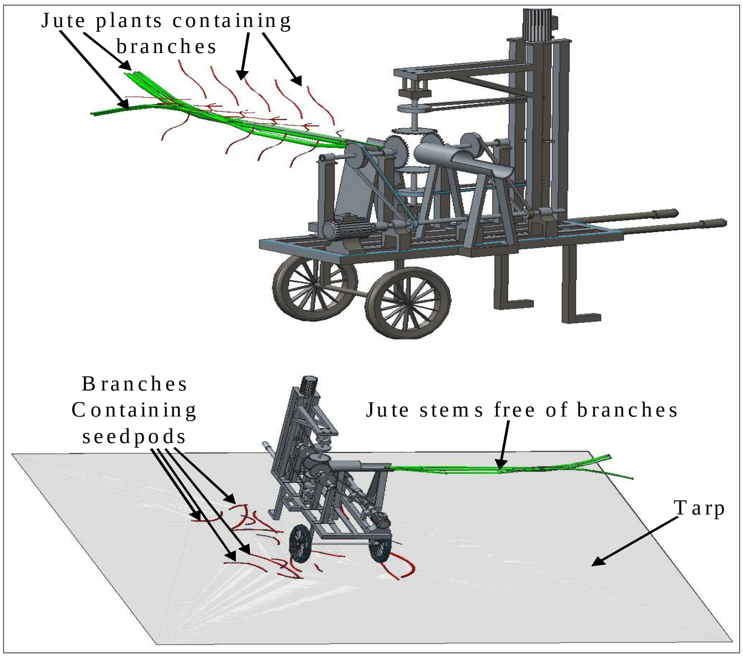

Fig 4: Jute plants insertion, cutting branches and tarp using CAD.

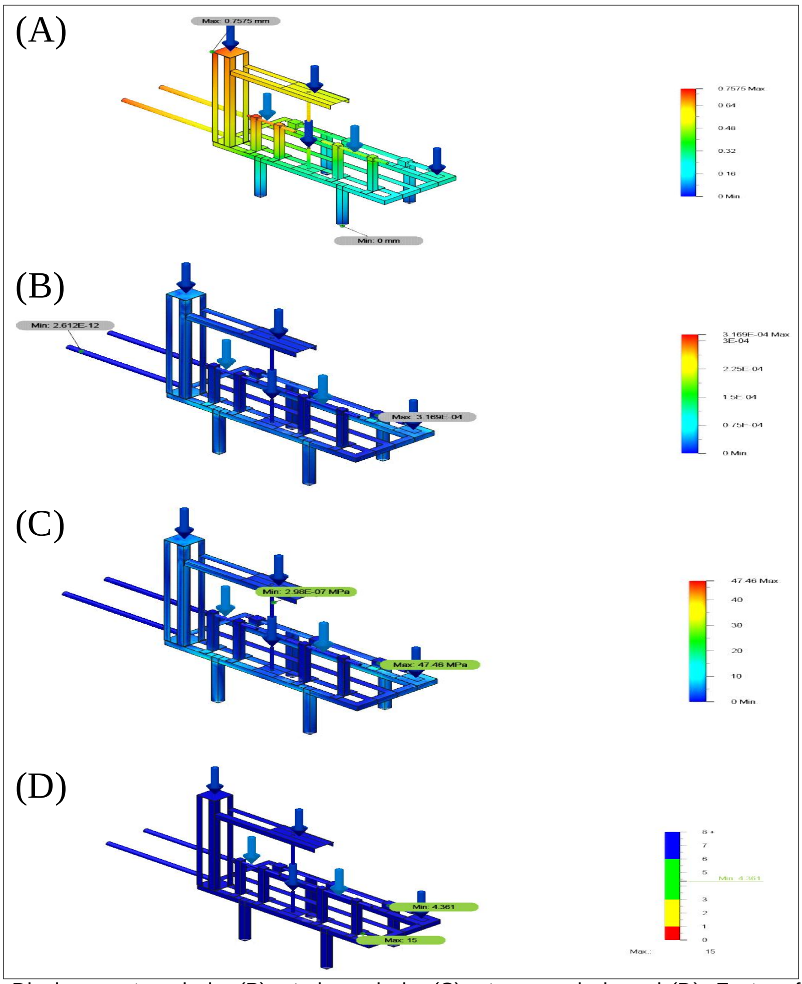

Fig 5: (A); Displacement analysis, (B); strain analysis, (C); stress analysis and (D); Factor of safety.

Table 4: Literature review of related bast fibre processing and machinery.

Title of the invention/discovery	Aim of the invention	Remarks
Process of treating or retting and curing hemp, flax, perini, jute, or other fibrous material (Cromer, 1921), Extraction of hemp fibres (Sung *et al.*, 2006), Enzymatic preparation of plant fibres (Sung *et al.*, 2009)	To extract fibre using various retting technique	Seeds will get mortified. Not suitable
Harvesting and processing green fibrous plant stalks (Mierisch, 1997)	To extract fibre using rupturing technique	Entire plant gets crushed. Not suitable
Jute batch hulling machine (Man, 2013)	To separate the fibrous body from soaked stalks of jute plants	Propulsion rollers rotating in opposite directions, will crush and cut the seedpods and branches, due to its design. In addition to these seeds gets mortified
Combine harvester (Gullickson and Mcneill, 1969)	Grain or seed extraction from different crops like wheat, pigeon peas, black gram etc by crushing technique	Source of fibre will be crushed
A device for extracting both seed and fibre from flax fibrous plants (Barraquet *et al.*, 1987)	Seed and fibre extraction using ginning, torn off, crushing techniques	Best suitable for plants whose fruit bodies are at the top. Not suitable for jute plants having seeds
A hand push jute cutting machine (Man, 2014)	To Cut jute plants at the base with circular blade	Not suitable for separation of branches containing seeds from main stem
Automatic high speed jute ribboning machine (Ghosh, 2010)	To separate the fibres from the stem at an early stage (*i.e.*, in vegetative phase)	Not suitable for jute plant containing seeds
A heavy and expensive machine for processing (Mingzhai, 2010)	To strip of strip of jute and hemp fibre a feeding mechanism, a nipper mechanism, a carding mechanism, a pulling and separating mechanism, a stripping mechanism and a cleaning mechanism	There is no discussion on stripping or separation by any other technique of extraneous material was mentioned
Easy jute processing system (Xiao, *et al.*, 2015)	To extract and comb fibre through a feeding and discharge station, a carding device and a conveying device	Neither the extraction unit nor combing unit, fits to separate seeds from main stem
Felling and seed picking integrated machine for jute (Shifen, 2015)	The self-propelled jute harvesting machine is designed to cut jute plants containing seeds at the root using a cutting wheel. After cutting, the machine picks up the cut plants, transports them, separates the ear and straw, strips the seeds and finally piles the straws	The mentioned machine is suitable for hemp plants with seeds growing at the tip, but not for jute plants with seedpods spreading along branches in all directions along the main stem. It is not designed for branch separation in jute plants
Power ribboneror improved retting of Jute and Mesta Plants (Shambhu *et al.*, 2018), Machinery for extraction and traditional spinning of plant fibres (Das *et al.*, 2010), Kenaf decorticator (Makanjuola *et al.*, 2019) and Jute fibre extraction machine and powered jute fibre extraction machine (Karim *et al.*, 2021)	To extract bast fibre using various mechanical processes	Neither designed nor eventually performs branch separation from main stems of jute plants. Doesn't fit to be an appropriate machine for main stem and branches separation

Table 4: Continue....

Table 4: Continue...

A hemp peeling and scraping machine (Chen *et al*., 2008)	To extract fibre	Neither designed nor eventually performs branch separation from main stems of jute plants. However, the feeding direction importance is highlighted in the report
Peeling machine of hibiscus cannabinus and jute (Xiaodan, 2015)	To extract fibre	Not suitable for jute plant containing seeds. However, picking of jute has been discussed
A Fully automatic hibiscus cannabinus branch and leaf removing device (Qinghuangdao Runchang Tech Development Co Ltd., 2017)	To remove the leaves and branches by entangling and stripping	Jute and Hibiscus cannabinus plants exhibit contrasting seed distribution patterns, with jute seeds growing along and away from the main stems, while Hibiscus cannabinus seeds are primarily located at the tip of the plant
A portable power tool for cutting the branches of standing trees (Sakuji, 1983)	To cut lower branches from standing trees, without injuring a body surface of the tree	It is impractical to manually cut a large number of jute plants containing seedpods (ranging from 30,000 to 50,000)

Table 5: Results summary of analysis.

Name	Minimum	Maximum
Deflection (mm)	0	0.7575
Stress (MPa)	-	47.46
Factor of safety	4.361	15

for branch separation, seedpod picking, direction of feeding and plant handling. The development of the machine tool requires further investigation and research.

To conduct static analysis, the CAD model of the machine was imported into the Fusion 360 program. The material qualities, size and performance of the components were determined based on the availability of market parts such as bearings, pulleys, motors and cutting blades. The frame, which holds all the components together, underwent loading analysis as a single unit, considering the weights of the remaining components (300N). The frame was constructed using Steel AISI 1008-91 HR, possessing specific characteristics such as density, tensile strength, yield strength, elastic modulus and Poisson's ratio. Fig 5 presents the analysis results, including displacement, strain, stress and factor of safety. Table 5 provides an overview of the outcomes, indicating that the suggested frame design can withstand all static stresses without failure, ensuring a promising level of safety. However, there is room for improvement in terms of material selection and mass reduction, which requires a more comprehensive analysis. The subsequent phase of the study will focus on the detailed design of each component and outline the manufacturing process of the machine.

CONCLUSION

For decades, jute fibres and seeds were farmed separately. This study investigated why jute seed crop fibre is not removed and its potential. This study incorporates the newest jute findings. It was also detailed why a new machine tool is needed and how it will fit into the existing process to harvest seeds and fibre from a single crop without affecting seed quality. The suggested approach and machine tools will preserve most of the natural fiber source of jute seed crop. The following information can efficiently separate fibre and seed and design a new machine tool:

(A) Separate fibre and seed sources after seed maturity before sun-drying to maintain seed quality.
(B) "Stripping" and "cutting" machines may separate seed and fibre sources.
(C) The main stem's radial distance from the seedpods can discover the machine's components.
(D) Future machine tools may process sleeping plants or root-cut jute plants since upright trees cannot be processed directly.

Conflict of interest: None.

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