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Design, Development, and Performance Evaluation of a Power-Operated Jute Fiber Extraction Machine

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Abstract: Jute is the golden fiber of Bangladesh, but its production is declining due to the involvement of higher production and processing costs, where a major portion of the cost is needed for fiber extraction. Labor unavailability and increasing labor cost have led to higher jute fiber production cost. To address these issues, this study looks at the development of a power-operated and cost-effective fiber extraction machine aiming at reducing the production cost. The study was conducted at the Rangpur regional office premises of Practical Action in Bangladesh, and the developed machine was branded as "Aashkol", which had the following major parts: a feeding tray, a primary extraction roller, a secondary extraction roller, grabbing rollers, fiber collection stand, base frame, protection cover, and a spring-loaded tray under the primary extraction roller. The Aashkol can extract green ribbon from the jute stem, but jute sticks were broken down into smaller pieces (3–6 cm). The performance evaluation of the machine was conducted using different types of jute (Deshi, Kenaf, and Tossa) and compared with another jute extraction machine (KP model, introduced by Karupannya Rangpur Ltd.). The Aashkol-based extraction and improved retting systems were also evaluated and compared with traditional jute extraction systems. The jute stem input capacity (4.99 t h^{-1}) of the Aashkol was 47.6% higher than the KP model (3.38 t h^{-1}). Compared with the traditional system, across jute types, the Aashkol produced a 9% higher fiber yield and saved 46% retting time. Overall, the Aashkol reduced 90% of the labor requirement and saved 11.6 USD t^{-1} in jute fiber extraction and retting than the traditional method.

Keywords: jute fiber; extraction machine; retting; Aashkol; mechanization; sustainability

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1. Introduction

Jute is one of the natural fibers whose utilization has been proposed broadly due to its eco-friendly properties [1]. With a vegetable origin, jute is a glossy natural bast fiber that contains cellulose fibrils and nonfibrous ground constituents such as lignin and hemicelluloses. Vegetable fibers are biodegradable, annually renewable, and not carcinogenic, which means they are more eco-friendly and healthier than other fibers. Jute shows numerous inherent benefits such as having luster, high tensile strength, moderate heat and fire resistance, and long staple lengths [2]. Jute is called the golden fiber of Bangladesh; it is an internationally traded commodity and is one of the most popular cash crops to Bangladeshi farmers. Jute covers about 3.58% of the total cropped area in Bangladesh [3] and is mainly cultivated from around mid-March to the months of July and August. The total demand for jute goods in the international market is around 0.75 Mt [4].

In 2016–2017, the total production of jute in Bangladesh was 8,247,000 bales from 738,056.68 hectares of land [5].

The major use of jute in Bangladesh is to obtain fiber for textile materials and also for making ropes, mattresses, bags, and diversified handicrafts. Jute fiber and jute sticks are largely used for different domestic purposes such as cooking fuel and fencing of homestead areas [6,7]. To increase the commercial and diversified use of jute fiber, maintaining good production practices and suitable retting processes are essential.

The fiber in its original state is usually tightly bound in the stems of plants, and it is needed to separate the fiber from the woody stem and gummy substances that bind them together. Fiber separation has to be carried out with much care to obtain the best yield and quality of fiber. This fiber could be extracted by the traditional retting method in Bangladesh. The traditional jute retting is a biological process in which fibers are extracted by decomposing the plants through the joint action of water and aquatic microorganisms (bacteria: *Clostridium* sp.); for farmers involved in jute cultivation in Bangladesh, the majority of them use the traditional method of retting, which is a very time-consuming approach. The retting process, along with some other factors, can influence the quality of the fiber, such as strength, color, luster, and texture [8].

In recent years, jute production in Bangladesh is competitively high, but farmers are facing massive problems in jute retting due to water and labor scarcity, resulting in obtaining low fiber quality [9]. It was found that the maximum production cost (16.9–20%) involved in jute production is fiber extraction [6,7]. Therefore, finding an alternate jute fiber extraction system is urgent, namely a system that requires less labor and water and can ensure the quality of fiber. For minimizing the problems of the jute retting process, the farmers are now more interested in the ribbon retting process.

Ribbon retting is an alternative method of jute fiber retting based on a mechanical pretreatment of plant stalks that allows for reducing the requirement of water, the length of retting time, and the level of environmental pollution to almost one-fourth in comparison to the traditional method, which processes the whole plant [9]. Ribbon retting can be done either manually or mechanically; however, the manual ribbon retting process requires more labor to disintegrate the fiber from the stem and to form the fiber in the process [10]. Therefore, for obtaining quality jute fiber, a low-cost ribbon retting technique is essential, and in this way farmers could produce high-quality jute fiber [9]. The improved technology involves the mechanical extraction of ribbon from jute stems immediately after harvest with the help of a machine, followed by retting of the ribbon in water.

The National Institute of Research on Jute and Allied Fiber Technology (NIRJAFT) developed a power ribboner for the extraction of ribbon from jute, mesta, and kenaf plants [11]. The machine can strip green ribbon from the harvested stem/canes without breaking the inner woody stick into pieces, and an improved method of vertical steeping of ribbons in low volume of water with less space has also been developed to obtain fiber of improved quality in lesser time. The power ribboner can extract about 150–200 kg h^{-1} green biomass with unbroken sticks, depending upon plant age, plant diameter, number of plants fed at a time, and the skill and experience of the operator [11].

Another jute extraction machine, i.e., a power decorticator, was developed by the Central Research Institute for Jute and Allied Fibers (CRIJAF) to strike the stems by rotating blades and to remove the green ribbon by breaking the stick into pieces [12]. A kenaf decorticator driven by a 2000 rpm diesel engine power unit with 9.48 kW maximum power was also developed [13,14], and it also breaks the stem. Karupannya Rangpur Ltd. imported a jute fiber extraction machine, and the company developed a process of retting and extracting fiber of jute in Rangpur [15]. Problems of less capacity and frequent logging were found during the use of the extraction machine, and these types of extraction machines were not available to the farmers. Thus, in this study, a power-operated jute fiber extraction machine called the Aashkol is redesigned and developed locally in Bangladesh, and the technical performance of this machine is evaluated. This is the first jute fiber extraction machine development and performance evaluation in Bangladesh. In this manuscript, we explain the details of how this machine is redesigned and developed, and how its performance evaluation compares with the KP model imported from China.

2. Materials and Methods

2.1. Development of the Aashkol

A power-operated jute fiber extraction machine imported by Karupannaya Rangpur Ltd. (KP model, Figure 1) from Zhengzhou Shuliy Machinery Company Ltd., China, was redesigned in Rangpur, Bangladesh, in order to improve the extraction process and increase its efficiency. The fiber extraction capacity of the KP model was 2–3 t h^{-1} for fresh jute stem input. The technical parameters of the extraction model are shown in Table 1. The KP model operates with a 5.5 kW electric motor or 10 hp diesel engine.

Figure 1. Pictorial view of the jute fiber extraction machine of the KP model.

Table 1. Technical parameters of the jute fiber extraction machine of the KP model.

Feeding System	Direct Feeding
Dimension	1.5 × 1.4 × 1.05 m
Weight	255 kg
Motor	5.5 kW electric motor; 10 hp diesel engine
Capacity	2–3 t h^{-1} for fresh jute fiber extraction

The redesign of the jute extraction machine was branded with the name "Aashkol". The brand name came from two Bengali words, i.e., "aash" meaning fiber and "kol" meaning machine. The schematic diagram of the Aashkol was drawn with Solidworks Software (in Figure 2a), and a schematic diagram of the different parts of the modified jute fiber extraction machine (Aashkol) is shown in Figure 2b.

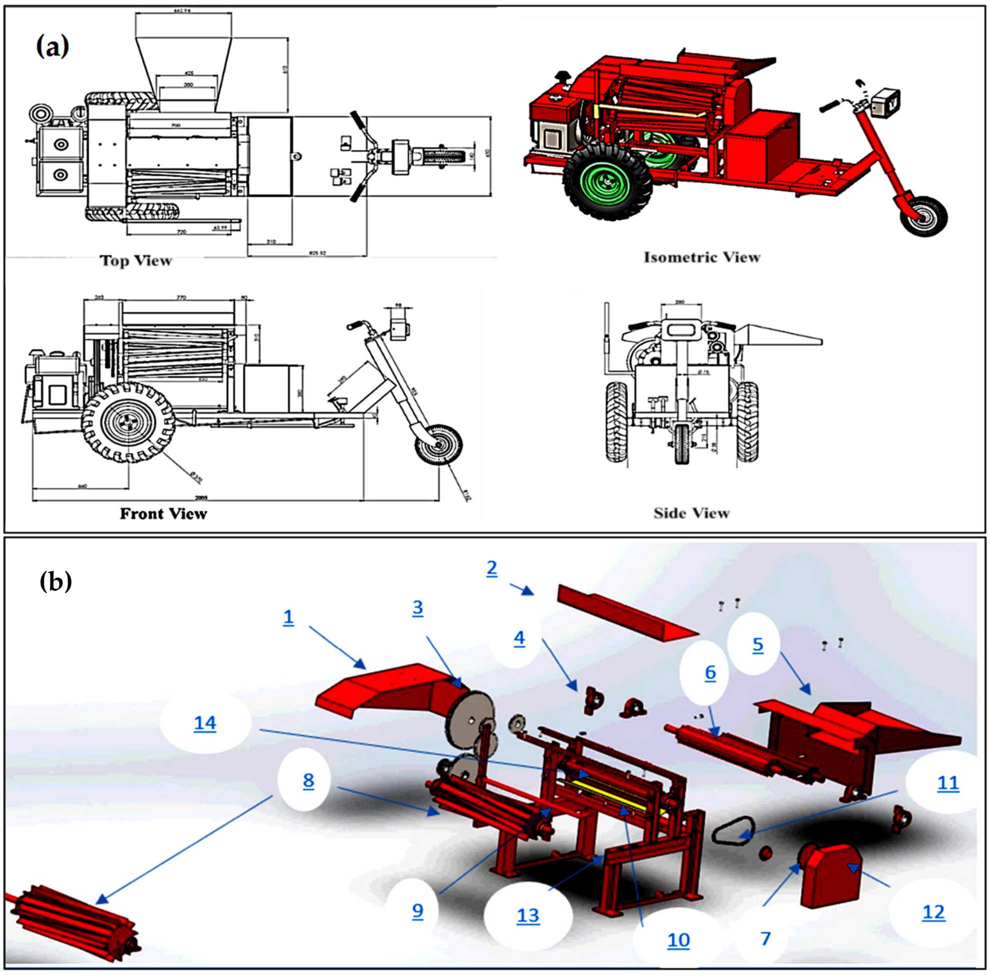

Figure 2. (**a**) A schematic diagram of modified jute fiber extraction machine (Aashkol). (**b**) Different parts of the modified jute fiber extraction machine (Aashkol): 1. Protection cover (Right side); 2. Upper protection cover; 3. Sprocket (dual groove); 4. UCP bearing; 5. Feeding tray; 6. Grabbing roller (small pressing roller); 7. Sprocket (single groove); 8. Secondary extraction roller (big beater roller); 9. Fiber collection stand/rake; 10. Spring-loaded tray; 11. Chain; 12. Protection cover (left side); 13. Base frame; 14. Primary extraction roller (medium beater roller).

The working principle of the developed Aashkol machine was to separate the fiber (green ribbon/barks) from the harvested stem and then retting it in a small amount of water. The green bark/ribbon peeled off from the whole jute plants can be conveniently retted in much less volume of water to maintain the high quality of fiber compared to the conventional method. The machine can extract ribbons in full length from the stick, while the jute sticks were broken down into smaller pieces (3–6 cm on average). The variation in plant diameter was taken care of by adjusting the clearance between two grabbing rollers and the spring-loaded adjustment tray, which were provided beneath the primary extraction roller. The clearance was primarily maintained according to the average diameter of 5–10 plants. The modified extraction machine was fabricated as per the design and drawing at a local engineering workshop in Saidpur, Nilphamari, Bangladesh. The front and top pictorial views of the different components of the Aashkol are shown in Figures 3 and 4.

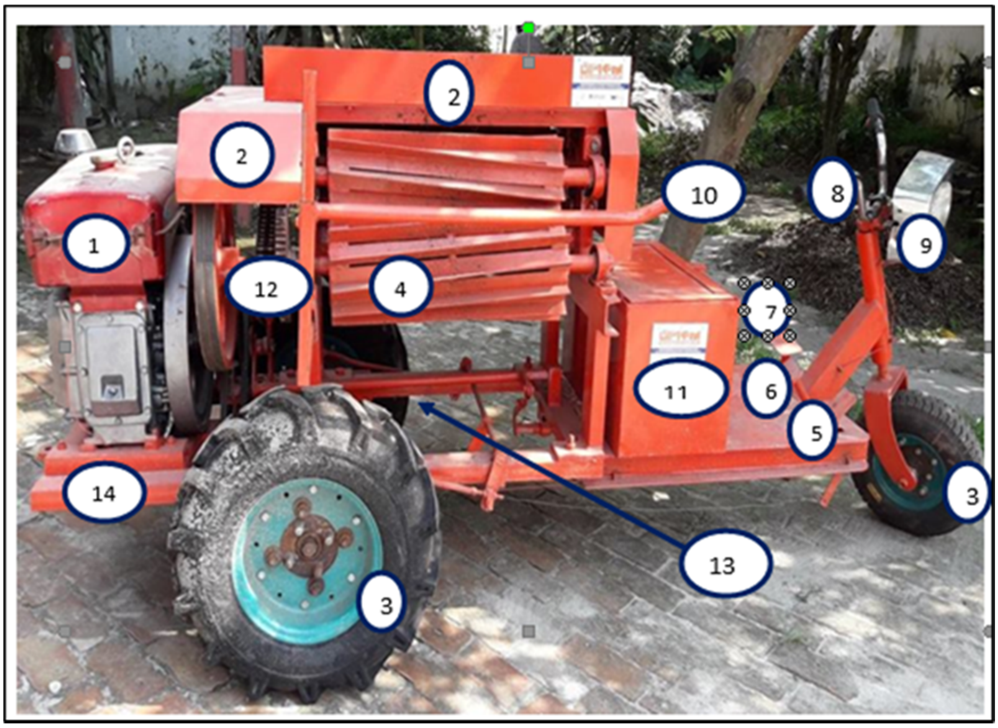

Figure 3. Different components of Aashkol are shown in the pictorial view from the side. 1. Engine; 2. Protection cover; 3. Wheels (two types); 4. Extraction roller; 5. Throttle lever/accelerator; 6. Brake; 7. Main clutch; 8. Handle; 9. Head light; 10. Fiber collection stand; 11. Seat cum toolbox; 12. Sprocket; 13. Differential gearbox; 14. Base frame.

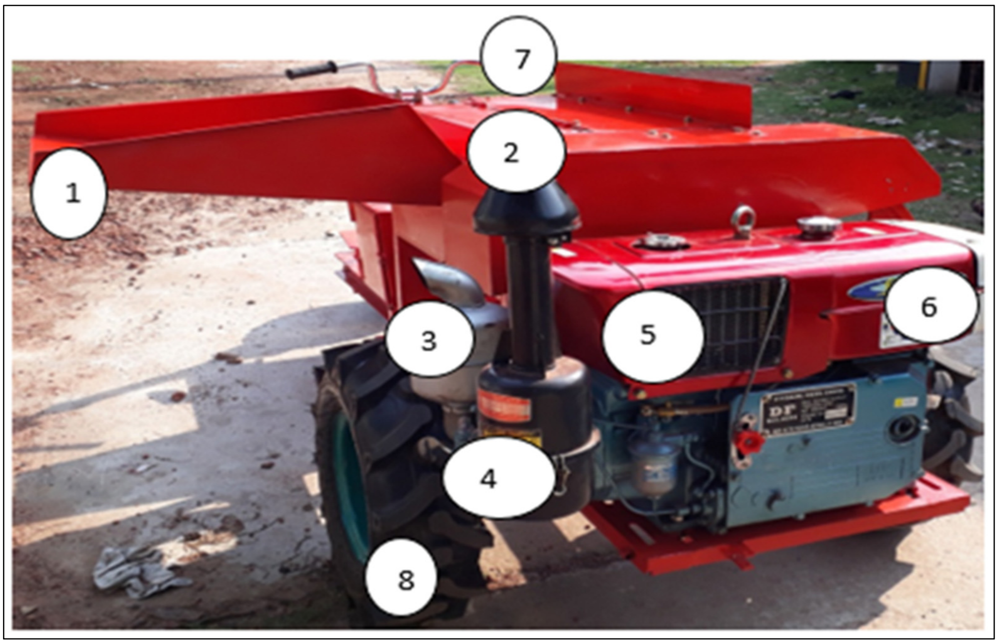

Figure 4. Different components of the Aashkol are shown in the pictorial view from the back. 1. Feeding tray; 2. Protection cover; 3. Silencer; 4. Air cleaner; 5. Coolant tank; 6. Fuel tank; 7. Handle, 8. Wheel.

2.2. Description of Important Parts of the Aashkol

Feeding tray: A feeding tray was designed to feed the green jute stick with fiber. The dimension of the feeding tray was 610 × 663 × 165 mm. A schematic view of the feeding tray is shown in Figure 5.

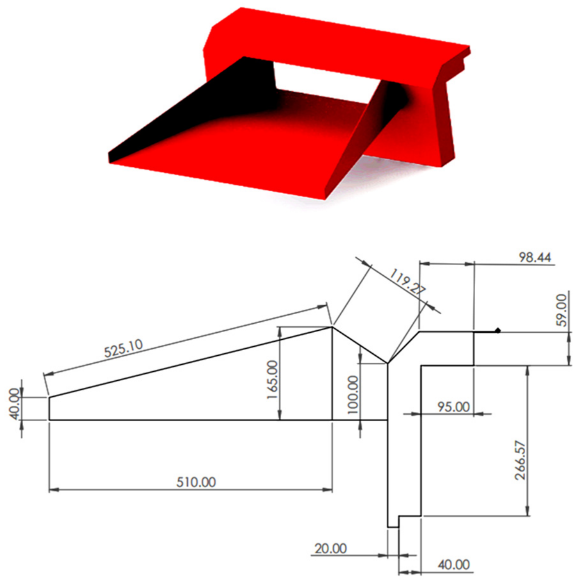

Figure 5. Isometric view of the feeding tray of the Aashkol.

Primary and secondary extraction roller: A primary extraction roller with a 650 mm length and 40 mm diameter was used. There were four external blockades in the primary extraction roller, which was made by a mild-steel (MS) angle bar with a 30 mm height (Figure 6a). This roller is used to loosen the broken jute sticks inside the ribbon, and it performs the primary extraction of jute sticks inside the ribbon to ensure complete separation of ribbon as well as jute sticks in the next step. Two secondary extraction rollers (650 mm in length and 114 mm in diameter in size) and eight crossbars that were 38 mm in height were used (Figure 6b). The function of these two rollers is to complete the separation of the broken jute sticks and ribbon after the primary separation conducted by the primary extraction roller.

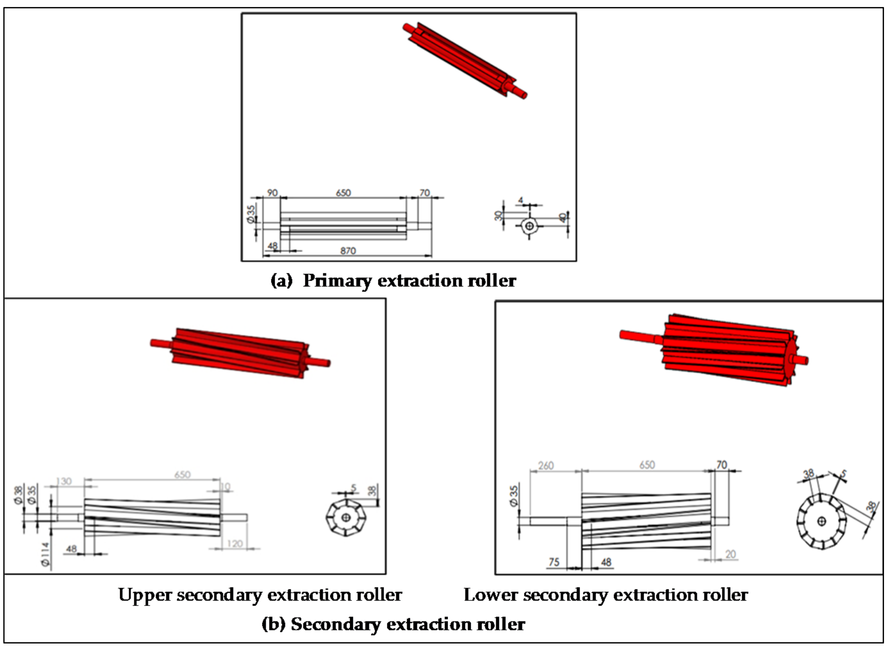

Figure 6. Schematic views of primary and secondary extraction rollers of the Aashkol.

Grabbing rollers: Two grabbing rollers with the same working dimension of 650 mm in length and 88 mm in diameter were used (Figure 7). There were eight external blockades in the grabbing roller made by an MS rod with a 10 mm diameter and 650 mm length.

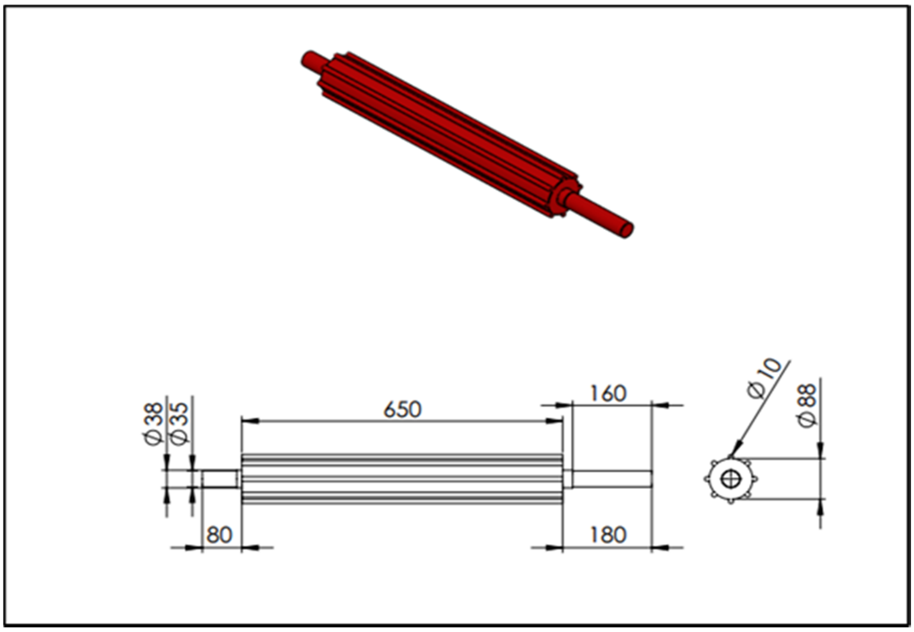

Figure 7. Schematic views of the grabbing rollers of the Aashkol.

Fiber collection stand: A fiber collection stand was used on the outlet side of the Aashkol. It has a setting that allows for adjusting the height and distance of the stand from the extraction rollers.

Base frame: This is the main load-bearing part of the machine. To facilitate easy transportation, three wheels were attached to this frame. This frame was made by an MS angle bar. A toolbox was in-built with this frame as a driving seat during transportation. The size of the base frame was 2285 mm × 650 mm × 758 mm. A schematic view of the base frame of the Aashkol is shown in Figure 8.

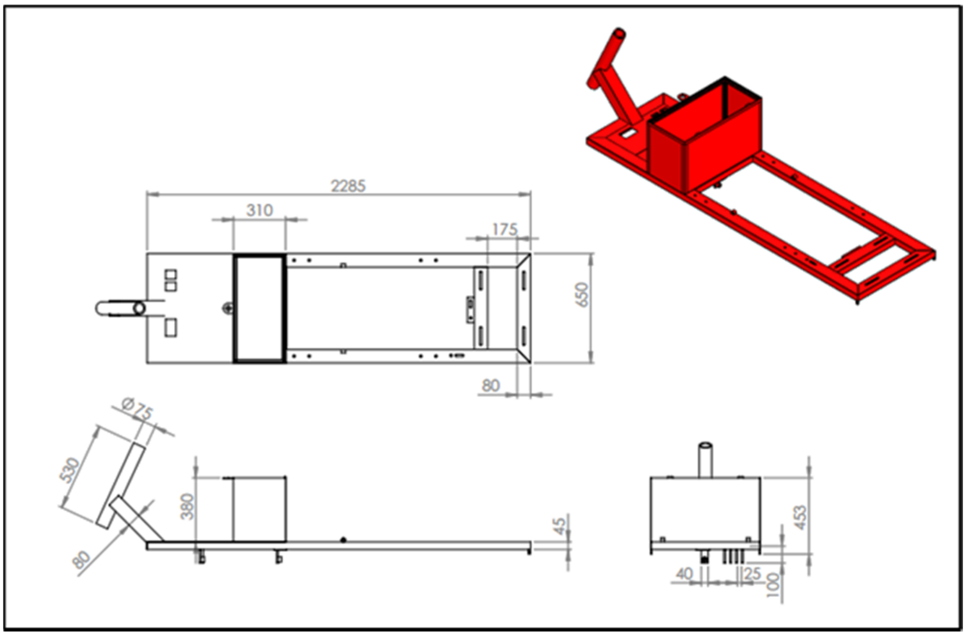

Figure 8. Schematic view of the base frame of Aashkol.

Protection cover: Whole moving parts of the jute extraction machine were covered with protective covers. The protection covers were made by MS sheets and attached with nuts and bolts. This may help prevent accidents, ensuring the safety of the operators. For the protection cover of the upper part of the machine, the broken jute sticks were thrown only in the forward direction. This helps with collecting the separated broken jute sticks easily from the front side of the machine during extraction.

Throttle lever/accelerator: The modified Aashkol was assembled on the base frame and coupled with a diesel engine. During the transportation of the Aashkol, the speed of the machine was controlled with an accelerator. This is a pedal-operated device that can be controlled with the right foot of the operator.

Brake: During the transportation of the Aashkol, the forward speed of the machine can be controlled with the brake. This is a pedal-operated device that can be controlled also with the right foot of the operator.

Main clutch: The power of the engine was transferred to the transport wheel, and this was controlled by the main clutch. The main clutch was operated with the left foot of the operator.

Power transmission system: The power of the engine was transmitted to both the extraction machine and the wheel. The power transmission system of the modified Aashkol is presented in Figure 9.

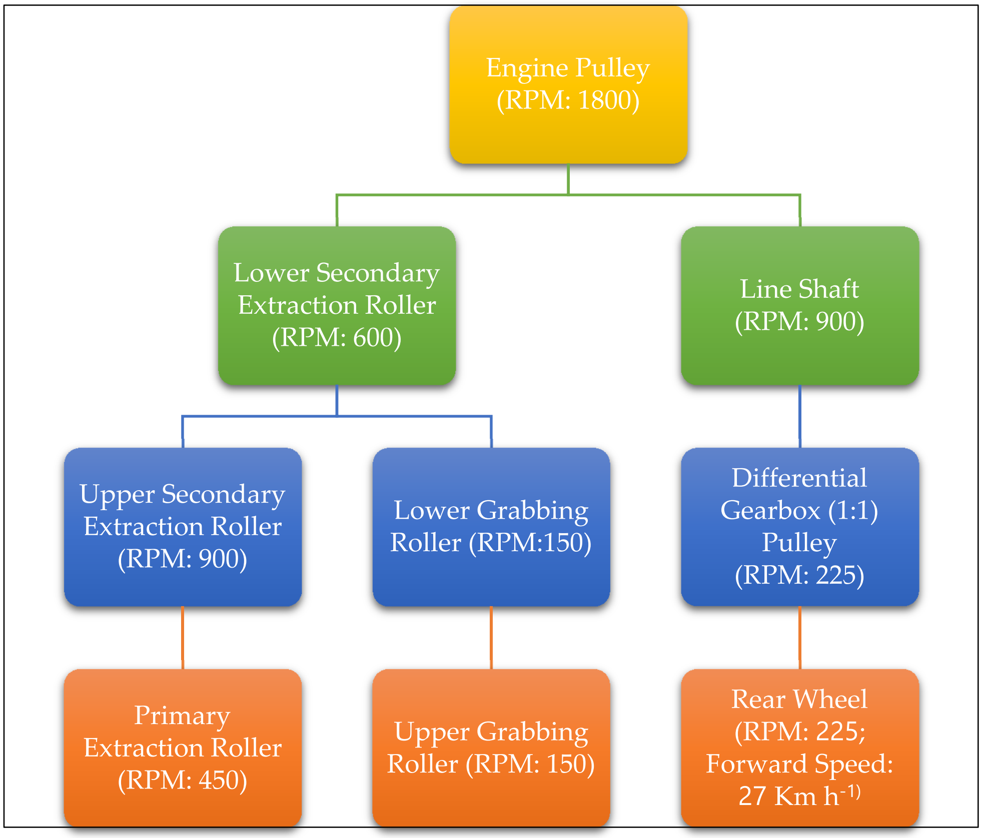

Figure 9. The power transmission system of the modified Aashkol.

Spring-loaded tray: There was a spring-loaded tray (650 mm length × 205 mm diameter) under the primary extraction roller for adjusting or keeping jute plants of different diameters as they pass through the grabbing roller after the breakdown of jute sticks. It helps the primary roller to strike every plant for primary extraction. A schematic view of the spring-loaded tray of the Aashkol is shown in Figure 10.

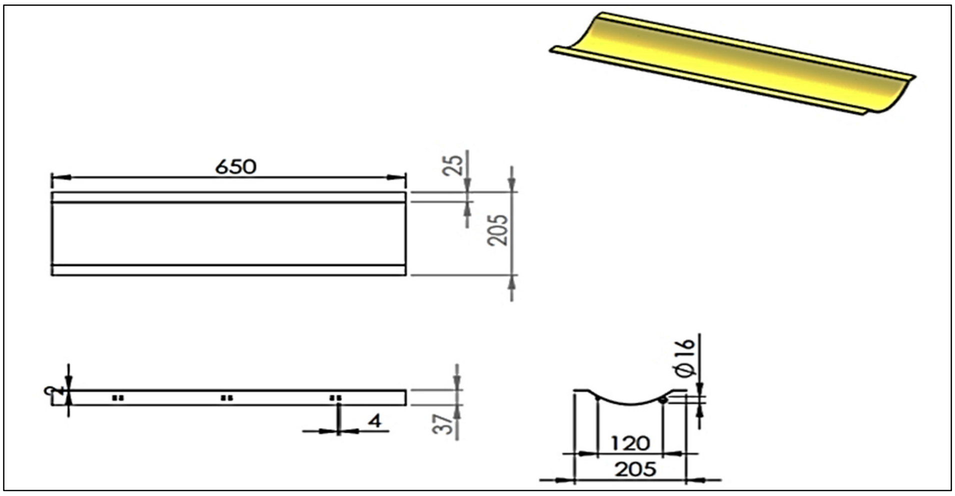

Figure 10. Schematic view of the spring-loaded tray of the Aashkol.

2.3. Modifications for the Aashkol Compared to the KP Model

To improve the performance of jute fiber extraction, a number of modifications were made to the design of the KP model in order to develop the Aashkol. The major modifications in the Aashkol compared to the original KP model are shown in Table 2.

Table 2. Modifications for the Aashkol compared to the KP model.

Sl. No.	Parameters	KP Model	Aashkol
01	Engine power	10 hp	16 hp
02	Power transmission systems	One way	Differential
03	Accelerator	None	Pedal operated
04	Main clutch	None	Incorporated
05	Head light	None	Incorporated
06	Operator's seat cum toolbox	None	Incorporated
07	Front wheel	None	Incorporated
08	Primary and secondary extraction rollers	3 mm thick angle; 6 mm bush pipe	>4 mm thick angle; 6 mm bush pipe
09	Grabbing roller	Made with MS rod	Made with MS shaft
10	Fiber collection stand	Fixed	Adjustable
11	Feeding tray	Length of 300 mm	Length of 762 mm
12	Rear wheels	Tire size of 4-00-8	Tire size of 6-00-12

2.4. Fiber Extraction Mechanism of the Modified Machine (Aashkol)

The Aashkol has a feeding tray where the jute stem is fed into the machine. The stem passes through the grabbing rollers and fiber extraction rollers, which break the jute sticks into smaller pieces (3–6 cm in length), decorticate the ribbon from the sticks, and push out the fiber, after which the fiber is finally received into a fiber collection stand or rake. The fiber is separated from the stem mechanically. The extraction rollers that break the jute stem are of different sizes and types: the grabbing roller is a small pressing roller; the primary extraction roller is a medium-sized beater roller; and the secondary extraction roller is a large beater roller. The first set of pressing rollers (the small set) grips and pull the jute stem or green plants into the beating or extraction chamber of the machine, which was designed to ease the breaking of the jute stems. The medium beater or extraction roller, which is in the middle of the chamber, has a longer blade to separate the broken jute sticks primarily from the ribbon or fiber. The jute stem then gets to the final stage that has the large set of beater rollers (secondary extraction roller), which are responsible for the proper and final decortication of the stem. The three sets of rollers are connected to a set of gear meshed together and chain sprockets. Jute fiber extraction by the developed Aashkol is shown in Figure 11.

Figure 11. Jute fiber extraction by the developed Aashkol.

2.5. Stress, Displacement, and Strain of the Three Types of Rollers in the Aashkol

The effect of the force acting on the three types of rollers (grabbing roller, primary extraction roller, and secondary extraction roller) was analyzed using computer-aided design (CAD) or computer-aided engineering (CAE) tools (SolidWorks Simulation). This was performed through a simulation where a 200 N static force application was assumed for the analysis of the effect on the three types of rollers, and we examined the scenario (pattern) of stress, yield strength, displacement, and strain due to the exerted force. The material properties of the three types of rollers were AISI 1020 steel material. In all cases, the stresses were reduced according to the Huber–Mises–Hencky hypothesis, and displacement was determined [16].

2.6. Performance Evaluation of the Machine

The developed Aashkol was tested as a laboratory test in the Rangpur regional office premises of Practical Action Bangladesh, and we compared its performance with that of the previous KP model. To evaluate the performance of the Aashkol, a total of 40 machines were distributed in four different districts (Rangpur, Gaibandha, Lalmonirhat, and Kurigram) in the northwest part of Bangladesh. During the jute harvesting time in 2018, ten Aashkols were evaluated in each district.

Three available types of jute (deshi, kenaf, and tossa) were used to evaluate the performance of the machine. Thus, these three types of jute were cultivated at 10 farmers' fields of each district (each field was considered as a replication). The unit plot size of the experimental plots was 40 m $\times$ 50 m. The standard seed rate and fertilizer dose were used in all plots. The sowing date of the experiment was 23 March 2018, and the harvesting date was 2 July 2018. The harvested jute stems were used for the technical evaluation of the developed machine, compared with the KP model.

2.7. Determination of Capacity of the Aashkol and KP Model Machine

A fresh, weighted sample of the jute stem was fed into the machine at different speeds, size ranges, and maturity stages. The time taken to complete the decortications was recorded. The capacity of the machine was calculated by using the formula below [17]:

$$\text{Jute input capacity}\left(\text{kg h}^{-1}\right) = \frac{W_t}{T_t} \quad (1)$$

where W_t is the weight of total jute stem fed in kg, and T_t is the time taken (hour).

The ribbon output capacity of the machine was calculated by using the following Equation (2) [17]:

$$\text{Ribbon output capacity}\left(\text{kg h}^{-1}\right) = \frac{W_r}{T_t} \quad (2)$$

where, W_r is the weight of the ribbon in kg, and T_t is the time taken (hour).

2.8. Evaluation of the Aashkol Extracted Jute Retting and the Traditional Jute Retting

The Aashkol retting system was compared with the traditional retting system, and for this, fibers of three types of jute were extracted using the Aashkol and then retted with a minimum amount of water as prescribed by the Bangladesh Jute Research Institute (BJRI) [18]. In the traditional system, the harvested jute plants are formed into bundles and sun-dried for seven days for shattering the leaves. Then the bundles are steeped into the water (at least 60 to 100 cm water depth), which was loaded with mud and banana tree. After decomposition, the jute fibers are separated manually from the sticks. Fibers are removed from the stalk by the method where single plants are taken and their fibers are taken off [19].

2.9. Fiber Quality Test between Aashkol-Based Retting and the Traditional Retting

To test the fiber quality, the tensile strength of the jute fiber (by investigating its mechanical strength) was tested using the universal testing machine (UTM) method at BCSIR Laboratories, Dhaka, Bangladesh. Jute fiber samples of both the traditional and the Aashkol-based retting processes were collected from trial sites and sent to the laboratory for testing the tensile strength.

2.10. Economic Analysis

The total cost of the Aashkol operations consisted of the fixed cost (FC) and variable cost (VC). Fixed costs included depreciation, interest on investment, shelter, taxes, insurance, and cost of housing, etc. A resource is called a variable resource when its quantity is varied at the start of or during the production period. Variable costs comprise the costs of fuel, lubricant, operator's salary, labor cost, repair, maintenance, and miscellaneous expenses (Supplementary Material Table S1).

2.11. Statistical Analysis

The collected data were checked for homogeneity and normality prior to the analysis of variance (ANOVA) tests. The outputs revealed that the homogeneity and normality of the data are satisfied for running further ANOVA. The data were analyzed using the statistical software Statistix 10 (Source: Statistix 10. 1998. Analytical software. Tallahassee, Fla, USA). Tukey's honestly significant difference (HSD) test and t-test were used at the $p <$ 0.05 level to test the differences between the treatment means.

3. Results

3.1. Strength of Aashkol Rollers

The analytical results such as the stress, strain, displacement, and the factor of safety of three types of roller used in the Aashkol are shown in Figures 12–14. In these figures, red, green, and blue indicate the highest, medium, and lowest magnitudes, respectively. For each of the rollers, it could also be seen that the materials in the red segment could not be thinner or lighter during the fabrication of the rollers. The factor of safety distribution, which was the minimum factor of safety (FOS), was found to be 2. It should be noted that a factor of safety of 1.0 at a location indicates that the material is just starting to yield.

A factor of safety of 2.0 indicates that the design is safe at that location and the material would start yielding if the force was doubled.

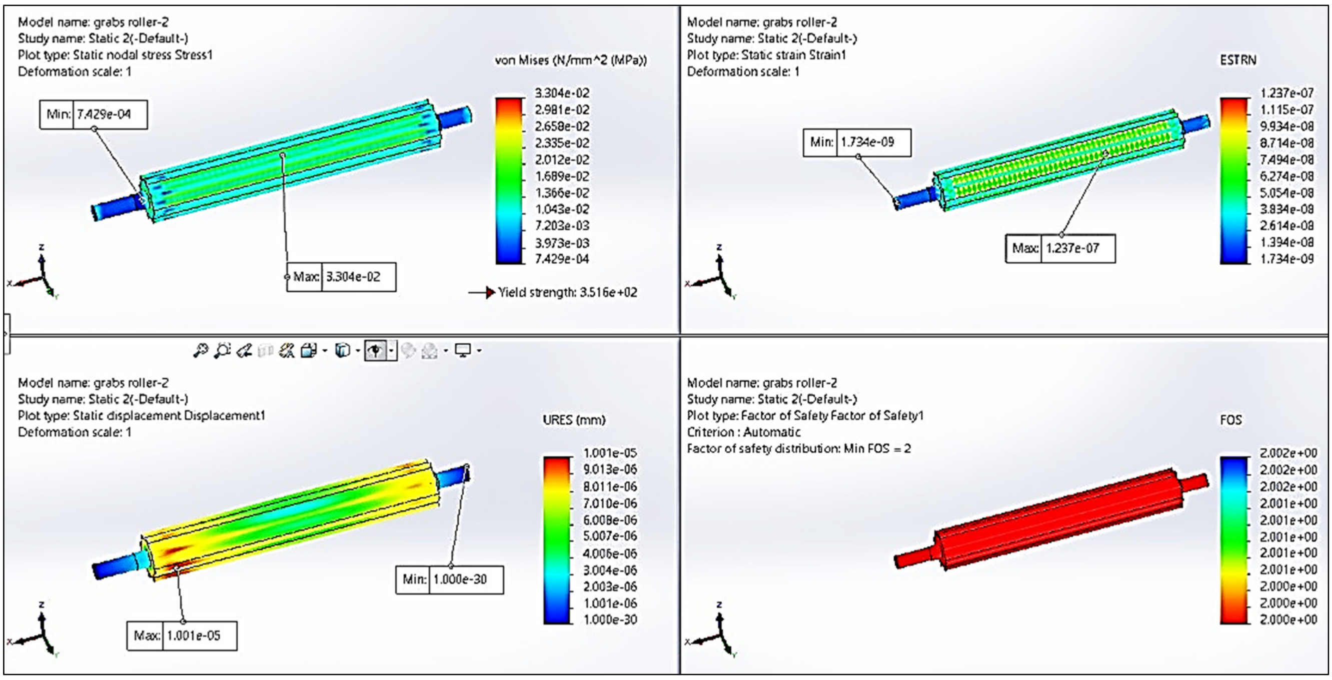

Figure 12. Stress, strain, displacement, and factor of safety of the grabbing roller with a 200 N force considered.

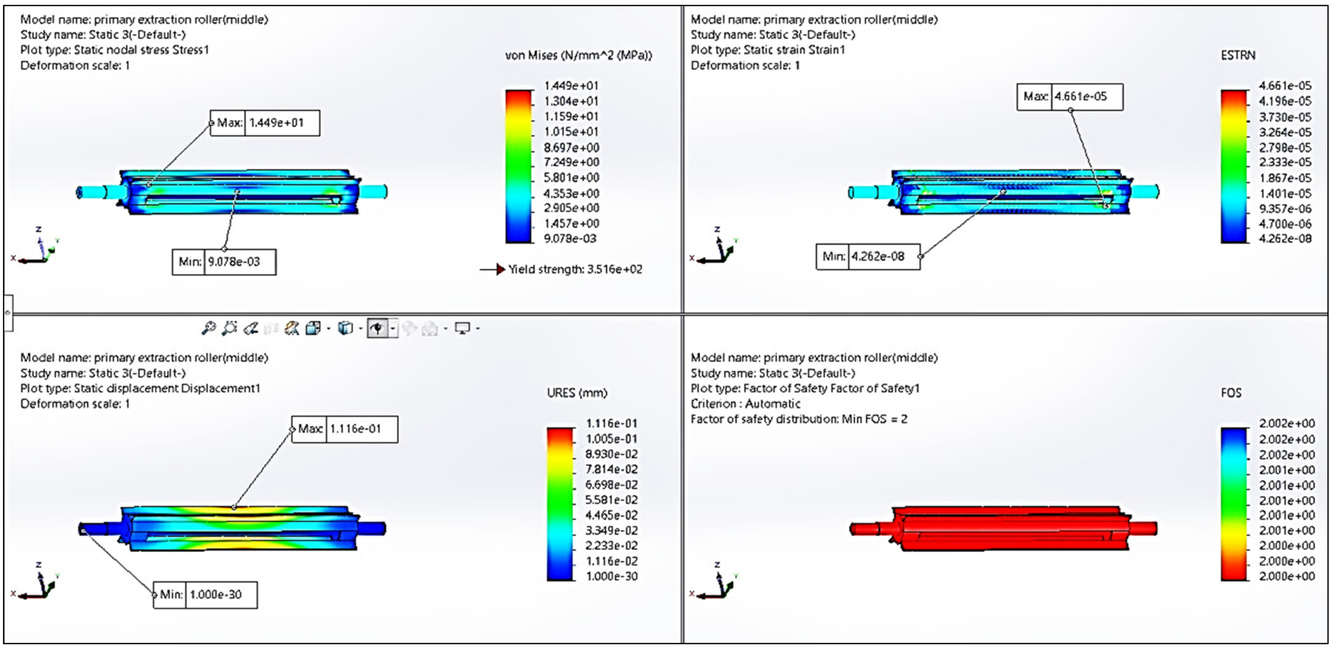

Figure 13. Stress, strain, displacement, and factor of safety of primary extraction roller with a 200 N force considered.

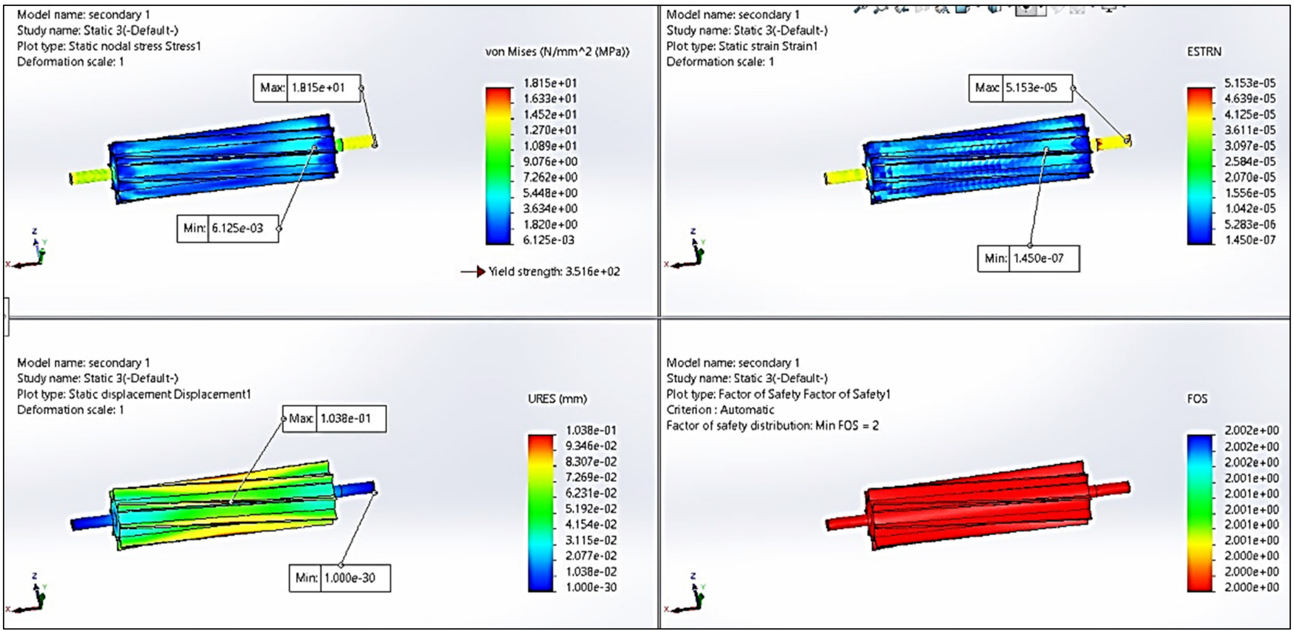

Figure 14. Stress, strain, displacement, and factor of safety of secondary extraction roller with a 200 N force considered.

3.1.1. Strength of Grabbing Rollers

The yield strength of the grabbing rollers was 3.516×10^2 N mm^{-2}, which indicates that when the magnitude of strength is greater than this value, the grabbing rollers would start to deform (Figure 12). In this case, this material was said to start yielding when the von Mises stress reaches the value known as the yield strength (3.516×10^2 N mm^{-2}). It was found that the maximum stress, strain, and displacement were 3.304×10^{-2} N mm^{-2}, 1.237×10^{-7}, and 1.001×10^{-5} mm, respectively, while the minimum stress, strain, and displacement were 7.429×10^{-4} N mm^{-2}, 1.734×10^{-9}, and 1.00×10^{-30} mm, respectively. It was found that in the middle portion of the roller, the highest stress and strain occurred, with these gradually decreasing from the center to left or right side. It was also found that the displacement was highest at the end-point of both sides of the roller and the minimum at the end of the shaft of the roller, which was taken into consideration during the design and fabrication of the roller.

3.1.2. Strength of Primary and Secondary Extraction Rollers

The yield strength of both the primary and secondary extraction rollers was 3.516 $\times 10^2$ N mm^{-2}, and the factor of safety was 2 (Figures 13 and 14). The maximum stress, strain, and displacement of the primary extraction roller was 1.449×10^1 N mm^{-2}, 4.661×10^{-5}, and 1.116×10^{-1} mm, and the minimum were 9.078×10^{-3} N mm^{-2}, 4.262×10^{-8}, and 1.000×10^{-30} mm, respectively (Figure 13).

Similarly, the maximum stress, strain, displacement of secondary extraction roller were 1.815×10^1 N mm^{-2}, 5.153×10^{-5}, and 1.038×10^{-1} mm, and the minimum were 6.125×10^{-3} N mm^{-2}, 1.450×10^{-7}, and 1.000×10^{-30} mm, respectively (Figure 14). The maximum displacement occurred at the center of both the rollers, which was also taken into consideration during the design and fabrication of both the rollers.

3.2. Performance of the Aashkol and KP Model Jute Fiber Extraction Machine on Different Jute Types

Both jute stem input capacity and ribbon output capacity were significantly affected by the jute extraction machine and jute types; however, their interactions were not significant (Table 3). Comparing among jute types, the jute stem input capacity of the Aashkol was 47.63% higher than the KP model. Comparing between the extraction machines, the highest jute stem input capacity was found from the jute type kenaf followed by tossa and deshi jute. The ribbon output capacity followed the same trends of jute stem input capacity, and the Aashkol's capacity was 32.8% higher than the KP model.

Table 3. Performance of the developed Aashkol and KP model jute fiber extraction machine on different jute types (conducted in the workshop at Rangpur).

Parameters	Jute Stem Input Capacity (t h^{-1})	Ribbon Output Capacity (t h^{-1})
Jute fiber extraction machine (FEM)		
Aashkol	4.99 a	1.43 a
KP model	3.38 b	0.96 b
Jute types		
Deshi (D)	3.29 c	0.93 c
Kenaf (K)	5.22 a	1.45 a
Tossa (To)	4.05 b	1.20 b
Analysis of Variance		
FEM	0.001	0.001
Jute types	0.001	0.001
FEM × Jute types	NS	NS

Letters (a, b and c) in the column indicate significantly different at 0.05 level of significance using Tukey honest significance differences test or *t*-test.

3.3. Effect of Jute Fiber Extraction Methods and Jute Types on Jute Fiber Yield, Retting Time, Labor Requirement, and Labor Cost

The retting time was significantly affected by the jute extraction methods and jute types but not their interactions (Table 4). Across jute types, the highest retting time (27.2 days) was required for the traditional methods (whole stem, i.e., steeping into the water and manual retting system), whereas the improved retting system, i.e., extracting the ribbon using the Aashkol, required 46% lower time, compared with the traditional system. Considering the jute types, the highest retting time was required for deshi jute and the lowest retting time was required for kenaf, which was statistically similar with Tossa jute. Dry jute fiber yield varied significantly depending on extraction methods, jute types, and their interactions (Table 4). The highest jute fiber yield was found from the interaction effect of Aashkol-based extraction with kenaf jute followed by kenaf jute extracted with the traditional method. The lowest jute fiber yield was found for deshi jute extracted with the traditional method (Figure 15).

Table 4. Effect of jute extraction methods and jute types on jute fiber yield, retting time, labor requirement, and labor cost.

Parameters	Retting Time (Days)	Dry Fiber Yield (t h^{-1})	Labor Requirement for Extraction and Retting (h ha^{-1})	Labor Cost for Extraction and Retting, (USD t^{-1})	Price of Jute Fiber (USD t^{-1})	Price of Jute Stick (USD t^{-1})
Jute extraction methods (EM)						
Aashkol (A)	14.7 b	3.18 a	126 b	1.30 b	537.96 a	5.90 b
Traditional (Tr)	27.2 a	2.91 b	1276 a	12.93 a	498.92 b	26.15 a
Jute types						
Deshi (D)	21.8 a	2.36 c	729 a	8.68 a	478.26 b	16.68 a
Kenaf (K)	20.2 b	3.70 a	716 ab	5.81 c	582.99 a	15 b
Tossa (T_o)	21.1 ab	3.06 b	657 b	6.8 b	490.86 b	16.39 a
Analysis of Variance						
EM	0.001	0.001	0.001	0.001	0.001	0.001
Jute types	0.02	0.001	0.03	0.001	0.001	0.001
EM × Jute types	NS	0.01	0.01	0.001	0.03	0.001
CV, %	8.30	4.19	12.77	16.11	6.97	2.78

Letters (a, b and c) in the column indicate significantly different at a 0.05 level of significance using Tukey's honest significance differences test or *t*-test.

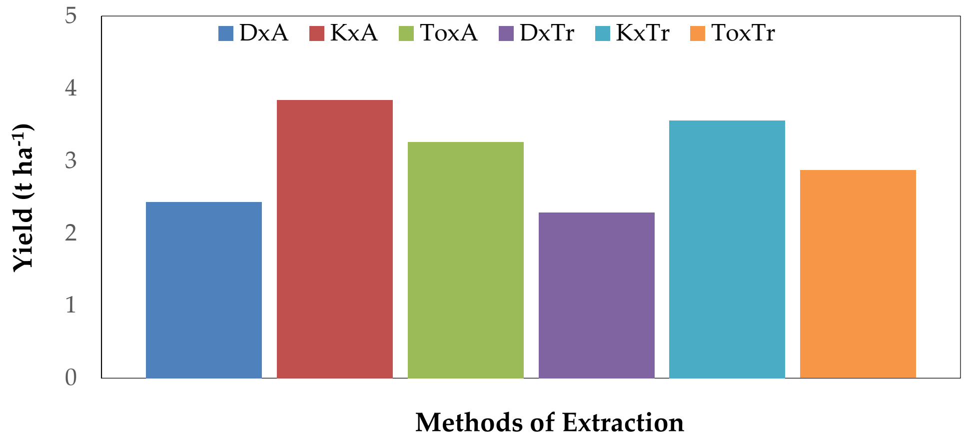

Figure 15. Interaction effect of extraction methods and jute types on fiber yield of jute.

The highest labor requirement (1276 h ha^{-1}) and labor cost for jute fiber extraction and retting were found when using the traditional method. Extraction with Aashkol and retting with an improved method required 90% less labor and labor cost compared with the traditional method. Labor requirement and labor cost also varied with jute variety. Significantly lowest labor requirement (657 h ha^{-1}) was recorded for tossa jute extraction and retting. Deshi and kenaf jute required a similar amount of labor for retting and extraction of fiber. The interaction effect of jute extraction methods and the variety on labor requirements for jute extraction and retting varied significantly (Figure 16). The lowest labor requirement was recorded for using the Aashkol, irrespective of jute variety. The lowest labor requirement was recorded for kenaf jute. The interaction effect of jute extraction methods and the variety on labor costs also varied significantly (Figure 16). The highest labor cost was required in the traditional method with deshi and kenaf jute, and the lowest labor cost was required in the improved method with Aashkol irrespective of jute variety.

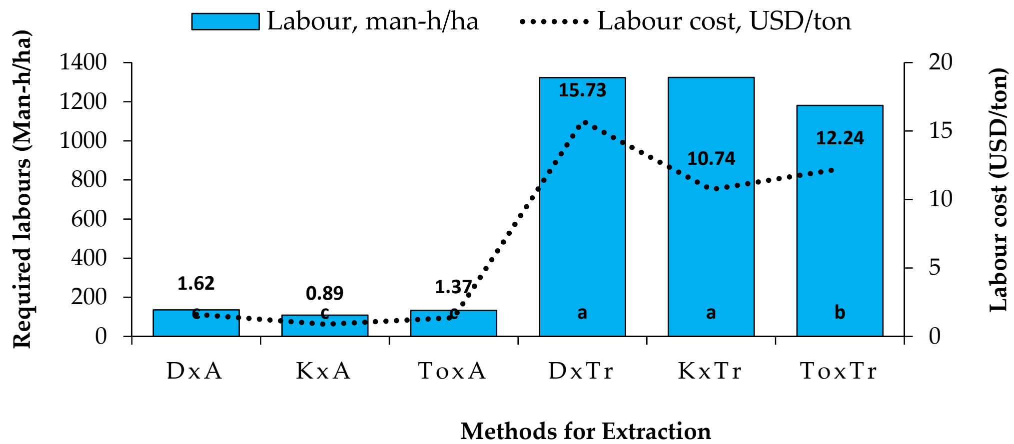

Figure 16. Interaction effect of extraction methods and jute type on labor requirement and labor cost.

The highest price of jute fiber was 537.96 USD t^{-1}, which was found in the improved Aashkol-based processing method. The jute fiber price significantly varied with jute variety. The highest jute fiber price was found in the kenaf variety. Fiber prices of deshi and tossa jute were statistically similar. The highest price of jute stick was found when using the traditional methods. The jute sticks were broken by the Aashkol, which reduced the price. Although the price of whole jute stick produced with the traditional method was higher, it required more time and some extra investment for drying and handling. Jute stick price also varied with jute variety. The highest price of jute stick was found in deshi (16.68 USD t^{-1}) and tossa jute (16.39 USD t^{-1}). The lowest price of jute stick was found in kenaf jute

(15 USD t^{-1}). The interaction effect of jute extraction methods and the variety on jute fiber price significantly varied. The highest jute fiber price was found in the interaction of Kenaf with the improved Aashkol-based extraction method followed by that of Kenaf with the traditional method (Figure 17). The rest interactions were similar. The interaction effect of the jute extraction method and the variety on the price of jute stick varied significantly (Figure 17). The highest jute stick price was found in deshi jute stick produced by the traditional method which was similar with that of tossa jute extracted by the traditional method. The lowest jute stick price was found when using Aashkol in all tested varieties.

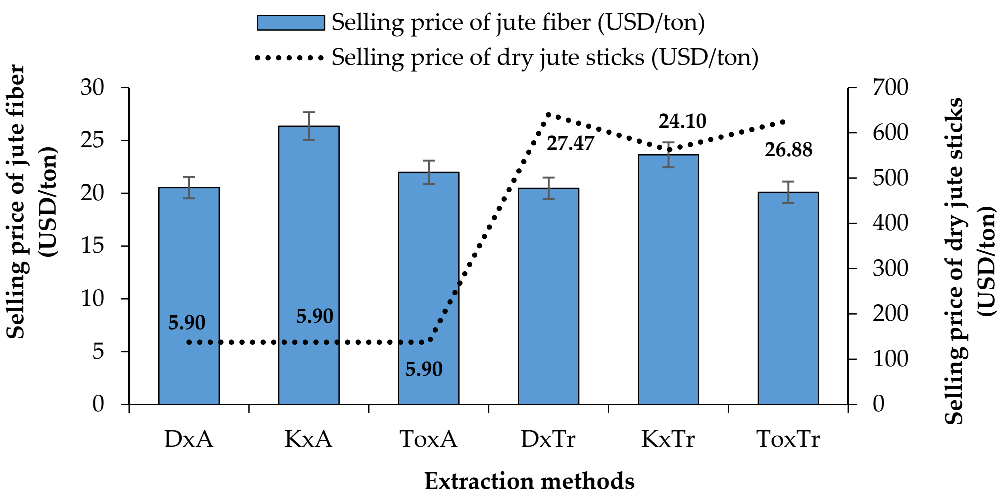

Figure 17. Interaction effect of extraction methods and jute types on selling price of jute fiber and stick.

3.4. Effect of Retting Methods on the Quality of the Jute Fiber

Except for one site (Gaibandha), the tensile strength of fiber was similar for both the improved retting method using the Aashkol-based extraction and the traditional retting method (Figure 18). In Gaibandha, the tensile strength of the traditional method was lower than the improved Aashkol-based method.

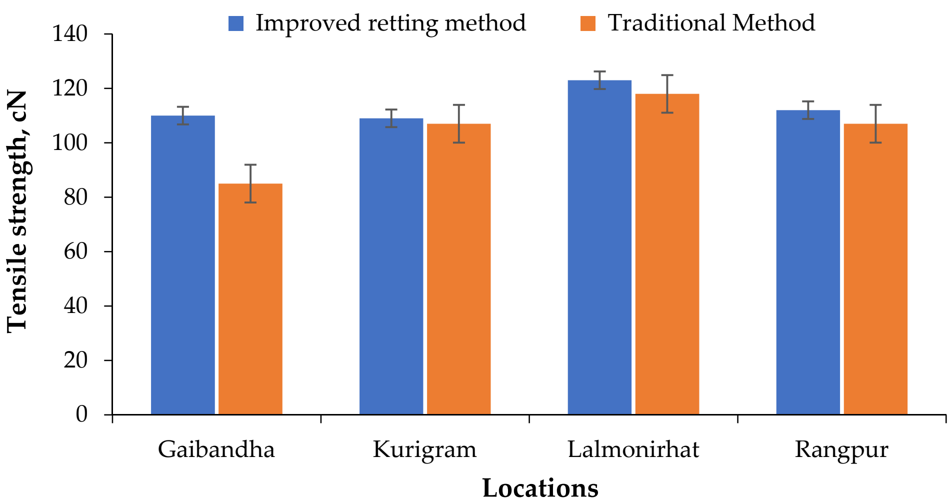

Figure 18. Tensile strength (cN) of jute fiber as influenced by different retting methods in four locations in Bangladesh. Vertical bars indicate the standard errors of the mean.

4. Discussion

4.1. Modified Version Machine (Aashkol) vs. KP Model Machine

In the KP model, the power source was a 10 hp diesel engine, but in the Aashkol a 16 hp diesel engine was used. The spare parts of the engine supplied with the KP model were not available in the local machinery market or machinery dealer points. Moreover, the engine power (10 hp) was insufficient for farmers' expected feeding rate of jute plants.

In the KP machine, power was transferred to the extraction machine only; power was not transmitted to the wheels. In Aashkol, however, a mechanical brake was added for the differential mechanism. The forward speed in the Aashkol was possible due to an attachment of an appropriately sized pulley with the engine flywheel to the line shaft and in the differential shaft. The forward speed of the Aashkol was 27 km h^{-1} for transportation from one field to another field, which became possible with this modification. The warm gearbox of the KP model did not function well, but in the Aashkol the issue was solved.

An accelerator pedal was developed in the footrest of the Aashkol, and this was connected to the engine throttle lever with a cable. The cable was attached with a specially developed tie rod to move the throttle lever up and down, which was developed to control the rpm setting on the operator seat. There was no such rpm control system in the KP machine.

KP machine needed a lot of power to operate, and it difficult to transport. The modification was done to operate the machine easily and to move it easily from one field to another. Regarding the attachment of the two grooves' tension pulley with the lead pipe of the main clutch, it acted as a medium for engaging or disengaging the engine pulley with the differential pulley. There was no headlight in the KP machine; in Aashkol, a headlight was set up in front of the handle. It was separated from the engine head and was placed in front of the handle. Due to the absence of a headlight in the KP machine, it was not possible to operate the machine at night. To address this problem, this modification was done.

In the Aashkol, the operator's seat was separable, which had a 20 cm clearance from the side protection cover. Due to the plug and play system in the operator's seat, safety issues were addressed, and some essential tools could be kept under the seat. The fork used in the Aashkol was ready-made, which was being used in a two-wheel tractor's rear wheel. It was stronger and comparatively safer; thus, wheel setting became easier and safer. In the KP machine, the sprocket attached with the lower secondary extraction roller had double grooves with 15 teeth, and the lower grabbing roller had double grooves with 60 teeth; the chain used for matching these two sprockets was 16 mm in size. In Aashkol, the sprocket attached with the lower secondary extraction roller had double grooves with 13 teeth, and the lower grabbing roller had double grooves with 52 teeth; the chain used for matching these two sprockets was 20 mm in size.

In the KP model, the chain was being dismantled or worn out when overfed. To address this problem, the chain strength was increased in the Aashkol. In the KP machine, it sometimes caused hammering injury in jute ribbons and deteriorated the fiber's tensile strength. Thus, the primary and secondary rollers were improved. The rollers were made with a pipe of 6 mm thickness; the pipe and barriers were made with a 50 $\times$ 50 mm angle bar with 4 mm thickness, which reduced hammering injury.

When greater diameter jute plants were passing through the gap between two grabbing rollers, some jute sticks were not being fully broken as well as separated from the ribbon in the KP model due to the deformed rod's diameter. The grabbing rollers could not exert uniform pressure on all jute plants; some unseparated broken jute sticks were found. In the Aashkol, a 10 mm diameter MS solid shaft was used, and an I-hole was made for setting the UCP bearing as well as the grabbing roller with the base frame for precision setting (increasing or decreasing the clearance), which was not possible in the KP model. Thus, the clearance maintained between the two grabbing rollers can be done accordingly, and a complete breakdown of jute sticks with complete separation could be possible.

According to plant height, the fiber collection stand had to be adjusted from time to time. In the case of the KP developed machine, it was a fixed type, but the stand was made adjustable in the Aashkol. The size of the feeding tray in the Aashkol was bigger than the KP model, which reduced the risk.

The rear wheels in the imported KP machine were the same as the rear wheels of battery-operated, three-wheeler easy bikes (tire size: 4-00-8), which were not skid-free.

In the Aashkol, the wheels of a two-wheel tractor (tire size: 6-00-12) were used as rear wheels. Thus, the longevity of the wheel was increased, reducing chances of puncture, and comparatively less slip/skid was found during movement from one field to another.

4.2. Traditional Retting vs. Improved Ribbon Retting

The traditional retting method requires a large volume of water. The ratio of green plant and water required is 1:20 [20], whereas the ribbon retting method required less quantity of water. The ratio of green ribbon and water required is 1:5 [20]. The traditional method is suited for areas with plenty of water. Due to the shortage of water in the harvesting period, farmers use muddy water and a small canal with insufficient water for the traditional retting of green jute. Several problems are associated with the traditional jute retting method such as environmental pollution, fish cultivation, bad quality fiber, and long time required, etc. Therefore, the traditional retting process of jute is not feasible in water-scarce areas [9]. On the other hand, the ribbon retting method is best suited for water-scarce areas. In the traditional method, retting is completed within 18–21 days under conventional whole plant retting or stem retting [20,21]. On the other hand, in the ribbon retting process, the retting was completed within 7–9 days [20]. Ribbon retting reduces the time of traditional retting by 4–5 days as well as reduces the requirement of water [21,22]. Total fiber production in the traditional method was comparatively lower than ribbon retting because a longer retting duration encourages over retting, resulting in less fiber recovery from the top portion of the plants. After all, a substantial portion of fibers is lost during retting and washing [20]. Ribbon retting is a particular method of retting that allows for a reduced requirement of water to one-fourth based on a mechanical pretreatment of plant stalks and the length of retting time [9].

Highly skilled laborers are not needed to carry out the conventional stem retting and fiber extraction, but labor cost (12.93 USD t^{-1}) is comparatively higher than improved retting. To carry out the retting method, highly skilled laborers are needed, especially for the extraction of green ribbons using an extraction machine. Labor cost in improved retting (1.30 USD t^{-1}) is comparatively lower than in the conventional retting method. In the traditional method, often dark color fiber is produced, but the fiber produced with the ribbon retting method is of golden yellowish in color with very good luster as well as an improved quality of fiber [21].

In the traditional method, fiber has to be extracted after the retting of whole jute plants through a "jak" process, and the defoliated jute bundles have to be transported to the nearby retting places to be immersed in clean or stagnant water according to the availability in natural retting water bodies, e.g., road-side ditches, rivers with locally available jak materials such as weeds, water hyacinth, etc. Most of the jute retting farmers use mud/soil and banana logs and leaves as jak materials for the immersion of jute bundles. On the other hand, in the ribbon retting method, the green ribbon has to be extracted using a jute extraction machine, and fiber is produced through an improved retting process of the ribbon only [17,23]. Moreover, only the ribbon has to be immersed, and there is no hazard in using such kind of jak materials for ribbon retting. Very poor strength of fiber is produced in the traditional system; farmers obtain a low price for their fiber in the market because of lower fiber quality, and most of the fiber produced by this method is unsuitable for the production of high valued diversified products [23]. In the traditional retting process, the volume of water, water quality, and water temperature cannot be controlled; therefore, coarse, dazed, and weak fibers are produced due to under- and overretting in this process, whereas for incomplete submergence, extremely low valued croppy fibers are produced [9].

5. Conclusions

The developed jute extraction machine, which we named Aashkol, performed better than the imported KP model. The fiber extraction capacity of the Aashkol was 48% higher than that of the KP model. The Aashkol can be fabricated in a local engineering workshop.

This machine helps the farmers to adopt the extraction of fiber using the improved Aashkol-based extraction and retting method, which produced a 9% higher yield than the traditional retting method. The improved Aashkol-based retting system reduced the time required for the traditional retting system by 50%. The Aashkol-based retting system increased the dry fiber yield, and this machine also reduced the labor requirement and labor cost by 90% compared to the traditional method. The Aashkol-based fiber extraction and improved retting system can also improve the jute fiber quality, which would be reflected in a higher jute fiber price. This can be a popular technology that can be used in the jute retting period for the areas where scarcity of water is found.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agriengineering3020027/s1, Table S1. Economic analysis of the Aashkol-based jute fiber retting.

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