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Fabrication of Modern Reeling Machine and Its Impact on Quality and Quantity Raw Silk Production in the Field Level

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ABSTRACT

The reeling machines and technologies commonly utilized in Bangladesh are inadequate for producing quality and quantity raw silk. Therefore, there was an urgent need to replace the current reeling machines and technologies to enhance the quality and volume of raw silk production. Considering these factors, this experiment was carried out, leading to the development of an improved modern reeling machine at BSRTI. The raw silk generated by this machine outperformed the silk produced by conventional multi-end reeling machines in both quality and quantity. This experiment was conducted to enhance the quality of raw silk while reducing reeling costs by developing a modern reeling machine. This experiment was undertaken to improve the quality of raw silk and to minimize the reeling cost by fabricating a modern reeling machine. The result of this study revealed that the fabricated modern reeling machine showed the highest reelability% 69.72 with the lowest renditta 9.83 compared to the multi-end reeling machine with reelability% 65.94 and renditta 11.24. A significant difference was also recorded for that the average size (d), size deviation, maximum size deviation, wending breaks, tenacity (g/d), elongation %, and cohesion between fabricated modern reeling machine and multi-end reeling machine. Considering the reeling performances and raw silk quality, the fabricated modern reeling machine showed better performance compared to the multi-end reeling machine.

1. Introduction

Production cost minimization of raw silk is the key objective of sericulture. The production quality and quantity of raw silk differ based on various reeling machines, equipment, cocoon quality, and the skill level of reelers. In Bangladesh, approximately 75% of raw silk is generated using a traditional basic reeling machine known as "Katghai," which yields a coarse type of raw silk with a denier of 35 and significant variation.

The other qualities like evenness, neatness, winding break, etc are also very poor. The appropriate choice of reeling machines, supporting equipment, and reeling techniques is crucial for producing high-quality raw silk.

Considering the present condition of reeling facilities and cocoon quality across different rearing seasons in Bangladesh, it is crucial to adopt suitable reeling technologies and improve traditional reeling machines to increase both the quality and quantity of raw silk production. As a result, this project has been proposed to promote the adoption and adaptation of modern reeling equipment and technologies that focus on improving raw silk quality while lowering expenses. In Bangladesh, cocoon reeling is conducted using kathghai and cottage reeling machines without any quality control measures. Consequently, the silk produced by the reeler is unsuitable for use as a warp in fabric weaving. Despite advancements in methods and reeling techniques, many reelers continue to use traditional reeling practices. Utilizing cottage machines and traditional charka/kathghai for cocoon reeling will not guarantee the production of high-quality silk. Several researchers also reported that the performance of silk reeling and the quality of raw silk production mainly depends on cocoon quality, reeling device and process of reeling, reeler skills and quality control [4, 6-9].

In Bangladesh cocoon reeling is practiced with kathghai and cottage reeling machines without controlling the quality. As a result, the silk produced by the reeler cannot be used as a warp in fabric weaving. Despite the development of improved methods and reeling techniques most of the reelers are still following traditional reeling methods. Reeling cocoons in cottage machines and traditional charka/kathghai will not ensure quality silk production. The performance of silk reeling and quality raw silk production mainly depends

on cocoon quality, reeling device and process of reeling, reeler skills, and quality control [4, 6-9].

The quality of raw silk produced in the cottage basin was better than that of silk produced from the katghai/charkha/thai reeling machine, but yet it could not meet the standards of international grade. Reported that in India, raw silk produced in cottage and domestic basins was better than the silk of charkha production, but this raw silk could not meet the standard of the international market.

The multi-end reeling machine is an advanced apparatus utilized in India and China for reeling bivoltine cocoons, aimed at achieving higher quality raw silk production. In contrast, Bangladesh's climatic conditions favor multivoltine cocoon production, which tends to result in lower yields, reduced productivity, and significant variations in cocoon sizes that affect both reeling efficiency and the quality of silk. The Bangladesh Sericulture Research and Training Institute (BSRTI) has designed a modern reeling machine equipped with a re-reeling unit to address these challenges. Traditionally, the end casting of cocoon filaments during the reeling process is done by hand; however, the new machine features a Z-bow mechanism for casting. This Z-bow facilitates the timely casting of new filaments and simplifies filament size control, making it suitable for producing high-quality raw silk from commercially available hybrid or bivoltine cocoons.

2. Materials and methods

Design and Fabrication of modern reeling machine:

The design and drawing of a contemporary reeling machine were completed initially. Based on this design, one reeling machine was constructed. Once the fabrication was done, the reeling machine underwent performance testing in the laboratory. After achieving satisfactory results, two additional reeling machines were produced for field use. Out of the three reeling machines, one is being utilized in the BSRTI laboratory, while the other two have been distributed to reelers in the field for demonstration and commercial reeling.

This contemporary reeling machine includes several features: a steam supply unit has been introduced, which is a novel concept. The steam unit operates at 20 kg to both boil silk cocoons and assist with reeling. It incorporates a dual drive system that allows for both manual and powered operation, with low fuel consumption, proper tension control of the filament, and one to two-reelers per basin to optimize production efficiency. The structural framework of the reeling machine is constructed from mild iron angle and steel, contributing to its smooth operation. Additionally, a re-reeling unit has been integrated into the main frame to facilitate easy re-reeling during the reeling process at the same operational cost.

Reeling basin: The reeling basin is made of aluminum with an optimum dimension of 70 x 35 x10 cm, accommodating with eight reeling ends. The basin has been set in the machine with removable facilities so that it can easily be removed as and when needed. The reelers may sit or stand during reeling in front of the basin.

Side brushing chamber: A small side brushing chamber is built by the side of reeling basin for brushing the dropped cocoon.

Jetteboute: Jetteboute is made of high-density plastic with brass hollow pins for long durability and provides efficient mechanisms. It is located at a height of 12-18 cm above the reeling water level. An endless spring wire drives Jetteboute to rotate easily at high speed.

Porcelain buttons: Porcelain buttons with appropriate holes are used in the machine and fixed to the steel clip holders, which are 8 cm in height from the jetteboute rail with 2.0 gm weight each.

Croissure pulley: A tavellette' type of croissure is maintained through croissure pulleys to facilitate smoother thread movement during reeling and also to maintain an appropriate tension level. Its weight is 18 gm each. The distance between the top and bottom croissant pulley is about 12-13 cm and the first pulley to porcelain buttons is about 8 cm at the height of 4 cm above the buttons.

Traverse mechanism: A planetary traverse system has been incorporated for suitable distribution of thread on the reel with cam and gear arrangements.

Reel: High quality small aluminum rell with a smooth surface has been used. The circumference of the reels is 65 cm.

Steam chamber: The reeling machine has been cooperated with a steam heating system for boiling cocoon and basin water. High-quality steam chamber included for boiling reeling water. A safety valve, pressure meter, a steam control valve are attached to the machine.

Chula: A gas cylinder facilitated Chula has been used for boiling water**.** The Chula has the option for a heat control switch, which is used to control the required temperature for cocoon boiling for reeling.

Method of Performance Evaluation:

Comparative reeling performance: This study was conducted both in a laboratory setting and, in the field to evaluate the reeling efficiency of commercially available cocoons. A Fabricated Modern Reeling Machine (FMRM) was set up at the BSRTI laboratory, along with two machines installed in the homes of reelers located in the Bholahat area of Nowabgonj district. The reeler households were designated as FMRM Reeler-1 and FMRM Reeler-2, respectively, and were treated as separate replications. Simultaneously, the reeling process was carried out at the BSRTI lab using a conventional Multi-End Reeling Machine (MERM) with the same commercial cocoons, which served as the control group and is referred to as MERM (control). The reeling performance was assessed during three different commercial rearing seasons: Augrahani, Chaita, and Jaistha, denoted as S1, S2, and S3, respectively.

Data Collection: Data was collected throughout the entire reeling period. To evaluate the performance of the newly developed modern reeling machine, both cocoon characteristics and comparative reeling performance were considered.

Cocoon characteristics: Single cocoon weight (SCW), single shell weight (SSW), raw silk recovery percentage, reelability percentage, filament length (FL), non-breakable filament (NBFL), single filament denier (SFD) were evaluated.

Single cocoon weight (gm): An average weight of 80 single cocoons was weighted, and the mean value is recorded as follows:

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Single shell weight (gm): An average of 80 single shell has been weighted and mean value is recorded.

Shell ratio percentage (SR%):

$$\text{SR \%} = \frac{Average\ weight\ of\ single\ shell}{verage\ weight\ of\ single\ cocoon} \times 100 \quad (1)$$

Reelability (%):

$$\text{Reelability \%} = \frac{No\ of\ cocoons\ reeled}{No\ of\ total\ casting} \times 100 \quad (2)$$

Filament length (m): 20 cocoons has been taken randomly from each replication and dried in a dryer. Then cocoons has been reeled with an individual cocoon reeling machine and average filament length has been recorded.

Non-breakable filament length (m):

$$\text{NBFL} = \frac{Reelability\ \%}{100} \times \text{Filament length} \quad (3)$$

Single filament denier (d): The denier of the filament may be defined as the weight in grams of 9000 meter filament.

$$\text{Denier} = \frac{Weight\ in\ gm\ of\ filament\ length}{Total\ weight\ of\ filament\ in\ meter} \times 9000 \quad (4)$$

For comparative reeling performance: Renditta, Reeling wastage %, Raw silk %, Raw silk production/8hrs (kg), Average quality of cocoon used/day (kg), Average quantity of cocoons used/day/basin (kg) was recorded.

Raw silk (%):

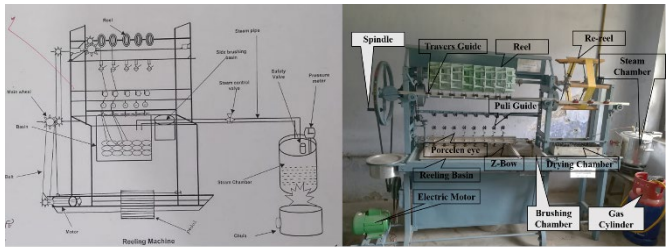
$$\text{Raw silk \%} = \frac{Weight\ of\ raw\ silk\ obtained}{Weight\ of\ fresh\ cocoon\ used} \times 100 \quad (5)$$

Renditta:
Renditta may be defined as the number of kgs of cocoons producing one kg of raw silk.

Quality characteristics of silk reeled on the modern reeling machine and multi-end reeling machine: Average size deviation, size deviation, maximum size deviation, winding breaks, tenacity (g/den), Elongation, and cohesion all the parameters were determined according to standard procedure [3, 9]. The raw silk produced from the study has been tested for different quality parameters as per the standard method.

The main objective of this project was the replacement of conventional reeling machines and reeling technologies. So, a modern reeling machine has been fabricated having a dual operating system with re-reeling and steam chamber facility shown in Fig. 1.

Comparative reeling performance has been done with a developed modern reeling machine to evaluate its performance. Two reelers in Bholahat, Chapai Nowabgang district have been selected to execute this experiment. The experimental performance has been compared with the laboratory performance of existing multi-end reeling as a control. The raw silk produced from the study has been tested for different quality parameters as per standard method.



Sketch Diagram Final Product

Figure 1. Fabricated Modern Reeling Machine.

3. Result and discussion

3.1 Cocoon Characteristics: The data on cocoon characteristics are given in the Table 1.

Table 1. Average Cocoon Characteristics of different seasons.

Parameters		SCW (g)	SSW (g)	SR %	FL (m)	NBFL (m)	SCFD	DFC %
Location	Season							
BSRTI lab, Rajshahi	S_1	1.86	0.33	18.76	650	450	3.41	7.11
	S_2	1.63	0.32	18.67	630	435	3.42	8.23
	S_3	1.53	0.35	17.66	600	420	2.99	8.91
Mean ± SD		1.67 (±)	0.38 (±)	18.37 (±)	627 (±)	435 (±)	3.27 (±)	8.08 (±)

Note: SCW= Single cocoon weight, SSW=single shell weight, SR=raw silk recovery %, FL= filament length, NBFL= non-breakable filament, SCFD= single cocoon filament denier, DFC= Defective cocoon percentage, g= gram, m=meter, S_1=Season 1 , S_2= Season2, S_3= Season3.

The data presented in Table 1 indicates that at the BSRTI lab, the mean weights for a single cocoon and single shell were 1.67 g and 0.38 g, respectively, with a shell ratio of 18.37%. The mean filament length was recorded at 627 m, while the non-breakable filament length was 435 m. The single cocoon filament denier was measured at 3.27. Additionally, the percentage of defective cocoons was found to be 8.08% of the total number of cocoons assessed.

Among the three seasons studied, the best average performance was observed in the Augrahani S1 season, where the average single cocoon weight was 1.86 g, the shell ratio was 18.76%, the filament length was 650 m, and the non-breakable filament length was 450 m.

3.2 Comparative reeling performance:

This study was conducted in both laboratory and field settings to evaluate the reeling efficiency of commercial cocoons. A modern reeling machine was installed at the BSRTI laboratory, while two additional machines were set up in the homes of reelers in the Bholahat Nowabgong district, identified as Reeler 1 and Reeler 2. These locations were treated as replications of the study. The reeling process took place simultaneously at the BSRTI Laboratory using an existing multi-end reeling machine that handled the same type of commercial cocoons, which served as the control group. The evaluation of reeling performance was carried out over three different commercial rearing seasons.

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Table 2. Comparative reeling performances of the modern reeling machine and multi-end reeling machine

Location	Types of Reeling Machine	Seasons	Renditta	Raw silk recovery (%)	Reelability (%)	Waste (%) on raw silk weight	Raw silk production/8 hrs/8ends (kg)	Avg. quantity of cocoons used/day/basin (kg)
BSRTI lab, Rajshahi	FMRC	S_1	9.09	35.4	70.60	21.25	1.5	5.13
		S_2	9.40	35.47	70.55	21.50	1.4	4.70
		S_3	11	32	68	22.6	1.1	5.2
		Mean ± SD	9.83 (±)1.02	34.29 (±)1.90	69.72 (±)1.49	21.78 (±)0.72	1.33 (±)0.20	5.01 (±)0.27
	MERM (control)	S_1	10.24	33.23	68.12	22.57	1.0	3.68
		S_2	10.50	33.64	65.59	23.10	0.98	4.03
		S_3	13	33.23	64.1	22.4	0.97	4
		Mean ± SD	11.24 (±)1.52	33.37 (±)0.24	65.94 (±)2.03	22.69 (±)0.36	0.98 (±)0.20	3.90 (±)0.19
Field Level (Bholahat)	Reeler-1 (FMRM)	S_1	9.38	34.00	70.50	22.00	1.40	5.07
		S_2	9.60	34.43	69.33	22.50	1.35	5.02
		S_3	12	33	66	23.2	1.2	5.03
		Mean ± SD	10.33 (±)1.45	33.81 (±)0.73	88.61 (±)2.33	22.56 (±)0.60	1.32 (±)0.10	5.04 (±)0.02
	Reeler-2 (FMRM)	S_1	9.32	34.21	70.00	22.27	1.38	5.05
		S_2	9.78	34.63	68.78.	22.90	1.20	4.96
		S_2	11.5	32.55	65	23.3	1.1	4.93
		Mean ± SD	10.2 (±)1.15	33.79 (±)1.10	67.93 (±)2.60	22.82 (±)0.52	1.23 (±)0.14	4.98 (±)0.06

Note: FMRM= Fabricated Modern Reeling Machine, MERM= Multi End Reeling Machine, Reeler-1, and Reeler-2 (Two reeling machine in reelers house in the field level, Bholahat); S_1= Augrahani season, S_2= Chaita season, S_3= Jasta Season.

Table 2 presents the reeling performance of cocoons using both the Modern Reeling Machine and the Multi-end Reeling Machine. The reeling results showed that, at the laboratory level, the mean renditta, raw silk recovery percentage, reliability percentage, and waste percentage for the Modern Reeling Machine were 9.83, 34.29%, 69.72%, and 21.78%, respectively. In contrast, the Multi-end Reeling Machine yielded results of 11.24, 33.37%, 65.94%, and 22.69%, respectively. These results varied across different seasons due to the quality of the cocoons.

At the field level, the performance of the Modern Reeling Machine was as follows: renditta, raw silk recovery percentage, reliability percentage, and waste percentage were 10.33, 33.81%, 88.61%, and 22.56%, respectively. In the case of Farmer 2, the results were 10.02, 33.79%, 67.93%, and 22.82%, respectively which were similar to the findings of another researcher [12]. Here, renditta is defined as the number of kilograms of cocoons required to produce one kilogram of raw silk.

In the context of the Modern Reeling Machine, all reeling parameters, except for raw silk production (per 8 hours across 8 ends) and the average quantity of cocoons used per day per basin, showed significant differences compared to the Fabricated Modern Reeling Machine across all rearing seasons.

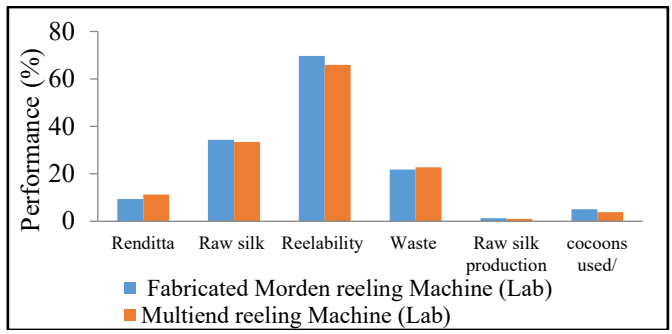

Figure 2. Comparative reeling performance of modern and multi-end reeling machine in laboratory level.

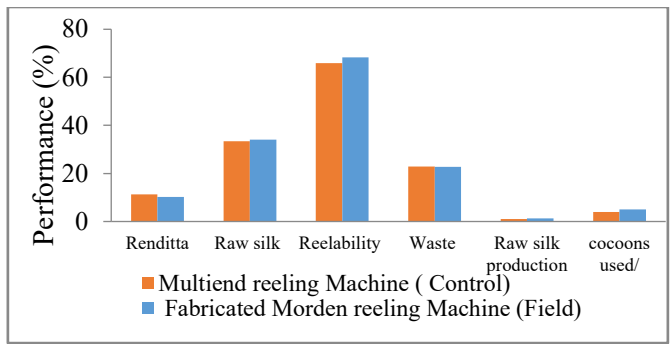

Figure 3. Comparative reeling performance of modern and multi-end reeling machine (control) in field level.

Table 2 indicates that the modern reeling machine demonstrated better reeling performance compared to the multi-end reeling machine. Other researchs also reported the same findings [2, 8].

In the current study, variations in reelability percentage were observed across different locations and within seasons. This observation is consistent with another researcher who suggested that the observed variations in silkworm cocoon characteristics may be attributed to several key processes [4]. Specifically, they pointed to the techniques involved in drying the cocoons, the methods of cooking the silk fibers to

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facilitate extraction, and the various reeling techniques employed to ensure optimal quality. These factors collectively influence the overall quality and properties of the silk produced, highlighting the importance of each stage in the silk production process.

According to the data presented, the mean production of raw silk from multivoltine cocoons over an 8-hour reeling period was approximately 1.334 kg for the modern reeling machine, compared to 0.980 kg for the multi-end reeling machine. Furthermore, several researchers also reported raw silk yields of 1.14 kg and 1.00 kg, respectively, from multivoltine hybrid cocoons using improved multi-end reeling machines, which supports the current findings [4, 5].

Overall, the reeling performance of multivoltine cocoons on the BSRTI fabricated modern reeling machine was found to be more satisfactory than that of the existing multi-end reeling machine.

Characteristics of silk reeled on modern reeling machine and multi-end reeling machine:

Average size deviation, size deviation, maximum size deviation, winding breaks, tenacity (g/den), Elongation, and cohesion were evaluated as silk characteristics.

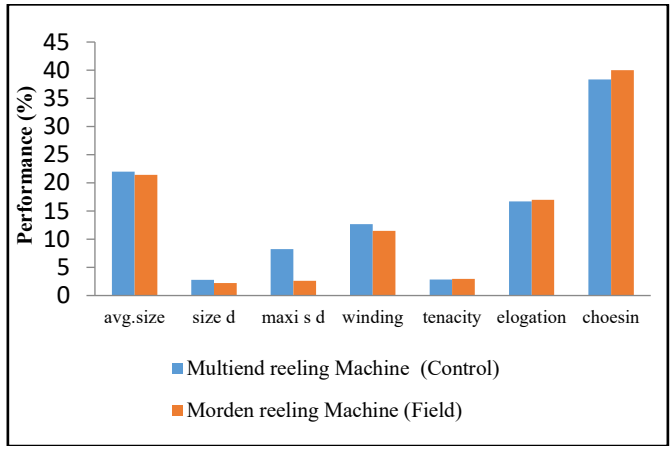

Figure 4. Comparative quality characteristics of modern reeling machine (Control) and multiend reeling machine (Field)

Table 3. Comparative quality characteristics of silk reeled on fabricated modern reeling machine (FMRM) and multi-end reeling machine (MERM).

Location	Types of Reeling Machine	Seasons	Avg. size (d)	size deviation	Maximum size deviation	Winding breaks/40 skeins	Tencity (g/d)	Elongation	cohesion
BSRTI lab, Rajshahi	FMRM	S_1	21.44	1.95	2.36	05	3.45	18.51	45
		S_2	20.70	1.98	2.56	06	3.08	18.52	44
		S_3	21.43	1.9	2.96	10	2.9	17.2	43
		Mean ± SD	21.19 (±)0.24	1.94 (±)0.04	2.63 (±)0.31	7 (±)2.64	3.03 (±)0.11	18.08 (±)0.76	44 (±)1
	MERM	S_1	22.98	2.81	3.87	16	2.91	16.90	39
		S_2	21.50	2.70	2.80	15	2.80	16.78	38
		S_3	21.49	2.8	3.12	16	2.75	16.4	38
		Mean ± SD	21.99 (±).85	2.77 (±)0.06	8.25 (±)0.55	12.67 (±)4.86	2.82 (±)0.08	16.69 (±)0.26	38.33 (±)0.57
Field Level (Bholahat)	Reeler-1 (FMRM)	S_1	21.50	2.50	2.65	07	3.05	17.40	43
		S_2	20.75	2.27	2.9	08	3.26	17.4	43.66
		S_3	22.1	1.63	2.38	16	2.7	16	40
		Mean ± SD	21.45 (±)0.67	2.13 (±)0.45	2.64 (±)0.26	10.33 (±)4.93	3.00 (±)0.28	16.93 (±)0.80	42.44 (±)2.11
	Reeler-2 (FMRM)	S_1	21.34	2.45	2.55	10	3.05	17.20	41
		S_2	20.9	2.48	2.91	12	2.93	16.17	37.66
		S_3	22.1	1.9	2.38	16	2.7	16	35.67
		Mean ± SD	21.44 (±)0.61	2.28 (±)0.33	2.61 (±)0.27	12.67 (±)3.05	2.89 (±)0.18	16.46 (±)0.64	38.11 (±)2.69

Note: FMRM= Fabricated Modern Reeling Machine, MERM= Multi End Reeling Machine, Reeler-1, and Reeler-2 (Two reeling machine in reelers house in the field level, Bholahat); S_1= Augrahani season, S_2= Chaita season, S_3= Jasta Season.

Table 3 presents the quality characteristics of reeled silk produced by a modern reeling machine and a multi-end reeling machine. The data indicates that the mean size (denier) and size deviation were 21.19 and 1.94 for the modern reeling machine, while the multi-end reeling machine showed mean values of 21.99 and 2.77, respectively. This suggests that the operator effectively maintained all 08 ends with the required number of cocoons during the reeling process with the multi-end reeling machine.

Additionally, the mean tenacity and elongation percentage for the modern reeling machine were recorded at 3.03 g/d and 18.08%, whereas the corresponding values for the multi-end reeling machine were 2.77 g/d and 16.69%. The results clearly indicate that the denier, size deviation, tenacity, and elongation percentage of raw silk reeled on the modern reeling machine were superior compared to those produced by the multi-end reeling machine.

Furthermore, in the modern reeling machine, the field-level performance metrics included: average size deviation, size deviation, maximum size deviation, winding breaks, tenacity (g/den), elongation, and cohesion recorded for reeler-1 were 21.45, 2.13, 2.64, 10.33, 3.00, 16.93, and 42.44, respectively. For reeler-2, the values were 21.44, 2.28, 2.61, 12.67, 2.89,

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16.46, and 38.11, respectively, which were supported by the other findings [13-15].

4. Conclusion

The results from both laboratory and field studies indicate that the raw silk yield was significantly improved with the use of the FRMC (Fabricated Reeling Machine for Cocoon). The highest raw silk recovery rate recorded was 34.29%, with a reelability of 69.72% for the FRMC, compared to the MERC (Modern Electronic Reeling Machine). Additionally, the FRMC exhibited the lowest waste percentage at 21.78%.

Key quality characteristics of raw silk, such as tenacity, elongation, and cohesion, were notably enhanced with the FRMC compared to the MERM (Modern Electric Reeling Machine).

From this discussion, it can be concluded that the BSRTI (Bangladesh Sericulture Research and Training Institute) has developed a modern, improved reeling machine suitable for commercial use and producing high-quality raw silk throughout all seasons in Bangladesh.

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Ethical Approval

The work submitted is original to the field and has not been published in any other format or language. The results are reported honestly and straightforwardly without any fabrication, falsification, or improper manipulation of data, including images. The authors have collected, selected, and processed data according to discipline-specific guidelines.

Consent of Participants

The authors have obtained individual consent to publish their data prior to submitting this paper to the journal.

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Author Contributions

All authors contributed to the initial concept and design of the study. The principal author, Md. Abdul Alim was responsible for the experimental setup, data collection, data review, data processing, and material preparation. Co-author Dr. Md. Shakhawat Hossain contributed to data analysis and data interpretation. Both the main author and the co-author were involved in writing, correcting, and proofreading the manuscript.