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INVESTIGATING THE EFFICIENCY OF THE HONEYCOMB PROFILED COCOONING DEVICE FOR ENHANCED CONSTRUCTION AND QUALITY OF MUGA (*ANTHERAEA ASSAMENSIS*) SILKWORM COCOONS

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ABSTRACT

Cocooning is a critical phase in sericulture, profoundly impacting the quality and quantity of silk production. In this study, we investigated the efficacy of honeycomb-inspired mountages, comparing to traditional jail based mounting techniques in constructing muga silkworm cocoons. Guided by larval dimensions, the structural dimensions of each cell in the mountages were optimised to house single muga silkworms and resulting cocooning behaviour were studied. Preliminary trials employing honeycomb profiled mountages demonstrated visually and physically improved cocoons over traditional setups. However, challenges in harvesting technology prompted modifications, transitioning the material used to construct used, from laminate to tin/aluminum sheets and finally to adopting fiber-reinforced polymer (FRP) sheets, which provided comparable cocooning efficiency to traditional methods. FRP honeycomb mountages not only exhibited a substantial 7-9% enhancement in reeling performance but also offered advantages such as efficient space utilization, durability, heat resistance, and streamlined processing by eliminating intermediate harvesting. Thus, in this study, we developed and constructed a novel honeycomb-profiled mountage aimed at creating uniform cavity dimensions to improve the likelihood of obtaining consistently high-quality cocoons.

Keywords: Muga Sericulture, Cocooning, *Honeycomb-inspired mountages, Fiber-reinforced polymer (FRP), Reeling performance*

Introduction

The Muga silkworm, an exceptional semi-domesticated sericigenous insect native to the North Eastern region of India, particularly Assam, is renowned for its unique silk production (Tikedar *et al*., 2013). The cultivation of Muga silk, known as the Muga culture, employs semi-domesticated practices. The process involves indoor cocoon construction and grainage operations, while outdoor rearing of silkworms occurs on host plants. Once the silkworms finish their feeding cycle (which lasts for five instars) and completely mature, they begin the process of spinning their cocoons through the aid of mountages. Mountaging operations are critical aspect of sericulture as it provides the environment necessary for the silkworms to complete their life cycle by undergoing metamorphosis and create their silk cocoons. Once the silkworms have completed cocoon formation and the pupal stage is finished, the cocoons are ready for harvesting. The cocoons are carefully removed from the mountages without damaging the silk fibers. Proper care and management during the mountaging process can significantly impact the quality and quantity of silk produced.

Mountages that are typically used in muga culture are either trays, frames, or surfaces made from materials like bamboo, wood, plastic or bunch of leaves (Jali in local terms as shown in the Figure 1). These substrates provide the silkworms with a suitable environment to spin their cocoons. Depending on available resources, farmers employ various locally sourced materials to craft mountages. In muga culture, rearers prefer, jali (bunch of leaves) as shown in the figure below for allowing the cocoon formation. Sometimes these semi-dried tree leaves with twigs are enclosed in a nylon net to avoid the loss of worms due to its escape behavior.

The material used, the finishing of the mountages, the available space within the mountage cavities for worm spinning, and the prevailing environmental conditions collectively determine the quality of the resulting cocoons. The absence of proper mounting technology can lead to the formation of defective cocoons, which in turn adversely affects reeling performance and the overall quality of the silk produced. Furthermore, this can result in lower prices fetched for the cocoons. Even when silkworm larvae are healthy, significant losses can occur due to defective cocooning, stemming from factors such as inadequate mountages, poor mountage quality, time constraints, lack of space, insufficient care in mounting, and improper environmental management. Thus, they certainly play a pivotal role in ensuring good cocoon production.

Muga silk is highly prized for its unique golden color, natural shine, and durability. The overall quality of Muga cocoons in Assam varies based on combination of many factors but when those, pertaining to cocoon construction are considered it can be iterated that the quantity of silk obtained from a cocoon (silk yield), is an important quality factor (Manjunath *et al.*, 2020). Good quality (well-formed and consistent-sized) cocoons produce good amount of silk besides aiding efficient silk extraction procedures. The cleanliness and lack of impurities in the cocoon contribute to the quality of the silk fibers obtained during processing. Thus, proper hygiene and rearing practices help ensure that cocoons are free from debris and contaminants.

Fig. 1 : Jali Mountaging methods widely practiced in Muga culture

Even though, Jali mounting is presumed good for muga cocoon construction they have their own share of disadvantages. It is voluminous in size, necessitates significant storage space, lacks suitable Jali leaves, and is often not reusable. Previous literature has documented various attempts to develop suitable mountage devices for Muga silkworms. While different types of mountages have been experimented with, they have achieved better cocooning percentages. However, the recovery percentage seems to plateau around 50% (Kumar *et al.*, 2017). Though the quality of cocoons and the quantity of raw silk produced are genetically influenced, there can be a possibility to moderately influence through improved management techniques and practices wherein proper mounting technology and adequate spacing provided to the larvae significantly contribute to superior cocoon formation.

This was also highlighted by Cheng *et al.* (2018) which likely focuses on studying the mechanical properties and construction of mulberry silkworm cocoons produced in confined environment. It was evident from their study that the cocoons produced in smaller boxes exhibited greater compactness and had reduced flossy silk on their outer surfaces, in contrast to cocoons obtained from larger boxes. Similarly, our hypothesis lies with the point that, the larger and irregular the space within the mountage cavities, the more could be the silk wasted in the form of floss (due to more search involved by the worms to find an anchor for beginning the cocoon construction). Thus a more confined and optimized cavity dimension could lead to uniformity in the cocoon production. Therefore, in this work we tried to design and fabricate a novel mountage type in the form of honeycomb profile that can possibly provide a cavity of uniform dimensions so that the probability of obtaining uniform and good quality cocoons can be enhanced.

Materials and Methods

Cocooning is a crucial stage in the process of sericulture, as it directly impacts the quality and quantity of silk that can be harvested. The term "better cocoon construction" suggests an improvement in the quality, strength, and structure of the cocoons that silkworms create during the cocooning process. Therefore, to envisage the efficacy of new mounting conditions the following methods were followed;

Rearing of Silkworms

Rearing of silkworms were carried out on Som plantations at Institute farms and upon reaching the final stage of maturity and completion of the feeding cycle, the matured muga silkworms were delicately harvested from their host plants. The larval dimensions were recorded in terms of length & width and documented. These dimensions hold the key to determine an optimal cell size dimension that can comfortably accommodate the silkworms and facilitate their intricate task of cocoon construction.

Fabrication of Honeycomb mountages

Upon recording the silkworm dimensions, the requisite cell dimensions were optimised and a pilot prototype of Honeycomb mountage with approximately 50 worms' capacity made of laminate sheets was fabricated (Figure 2). The harvested matured silkworms were allowed to spin cocoons in these mountages and their behavioral responses to the confined environment were vigilantly observed throughout the mounting and spinning stages. Simultaneously, matured worms were subjected to the traditional jali setup, where branches of jali leaves were enclosed in nylon nets for cocooning. The resulting cocoons from both techniques were harvested and compared visually and physically as shown in the Figure 3.

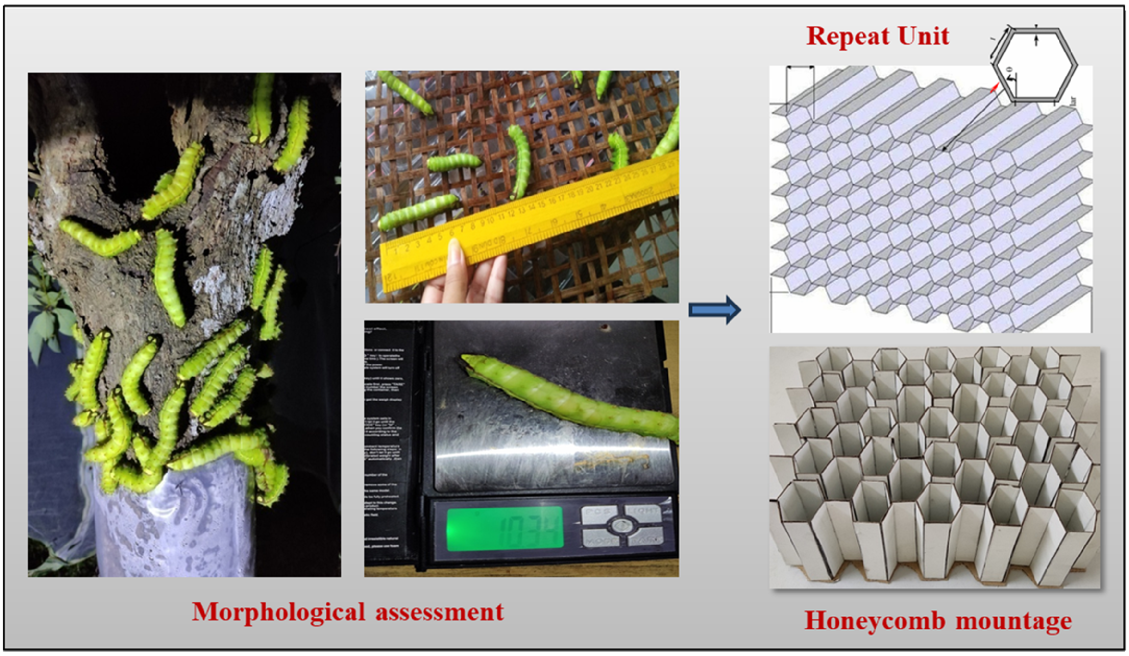


Fig. 2 : Dimensional optimization of Honeycomb mountages

Fig. 3 : Comparative mounting and resultant cocoons from Honeycomb mountages and traditional jali

Assessment of cocoon characters and reeling performance

Assessing cocooning efficiency involves quantifying the production of viable cocoons while disregarding any defective ones or those lacking worms. To ascertain the quality of cocoons, various physical characteristics such as weight and dimensions are meticulously examined prior to advancing to the reeling stage. In the subsequent step of single cocoon reeling, each cocoon's filament length and denier are carefully measured. The reeling performance in mass reeling were thoroughly assessed through reelability and raw recovery percentage.

Result and Discussions

Initial trials on Honeycomb profiled mountages

In our initial trials with honeycomb mountage set up, the silkworms were highly mobile and tend to come out of the cell more often. In order to avoid the wandering of silkworms, the top and bottom face of the honeycomb set-up were covered with net due to which almost all the worms that stayed in the cell spun the cocoons successfully. The cocooning performance of honeycomb mountages were simultaneously compared with traditional Jali methods bamboo box type mountages. Around 90-95% of cocooning performance indicates that a significant majority of silkworms were able to successfully spin the cocoons whereas the box type mountage and Traditional Jali method demonstrated around cocooning efficiency was around 85-88% (However, it is noteworthy to mention that the number of worms were more in the case traditional methods). This improvement could be directly attributed to optimal environmental conditions for cocoon spinning like humidity, temperature, and lighting that encourage the silkworms to produce silk with consistency. The resultant cocoons harvested from all the three techniques were taken to study their cocoon parameters and quality assessment that involved comparative assessment of cocoon weight, reelabilit, raw silk recovery, filament length & denier (linear mass density of fibers) [Figure 4].

- Upon visual inspection the cocoons obtained from the honeycomb mountage exhibited improved uniformity in shape, size, girth and weight compared to those from the traditional jali setup. Furthermore, the cocoons from the honeycomb structure were cleaner, free from debris, and devoid of leaf imprints.
- Reliability % (Reelability) measures the percentage of successful and consistent reeling of silk from a cocoon. Honeycomb cocoons demonstrated highest reelability at 52.57%, followed by Jali at 47.27%, and Bamboo at 46.35%.
- Recovery % refers to the percentage of silk that can be successfully recovered from cocoon shell vide reeling. Honeycomb has a recovery rate of 49.8%, Jali at 45.2%, and Bamboo at 46.4%. Honeycomb appears to be the most reliable in this regard.
- Similarly, cocoons from Honeycomb mountages yielded longest filament at 519.86 meters, followed by Jali at 473.12 meters, and Bamboo at 448.99 meters. And on the contrary, Honeycomb cocoons has the lowest denier at 4.91, followed by Bamboo at 5.04, and Jali at 5.44.

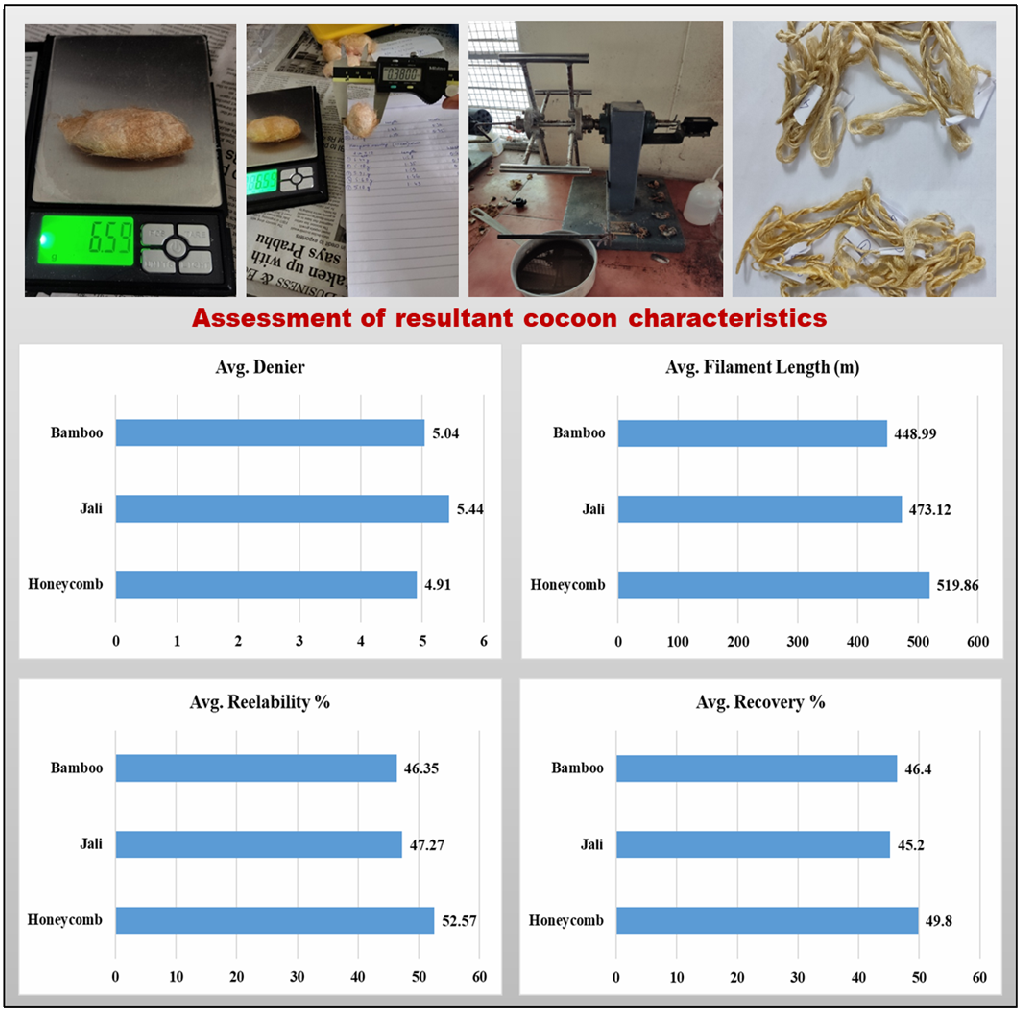


Fig. 4 : Assessment of cocoon characteristics from initial trials

A series of t-tests based on the averages of 10 trials were conducted to statistically analyze the data and determine whether the cocoons harvested from Honeycomb mountage are significantly different from those of Jali and Bamboo mountages and the separate analysis for each parameter are listed the Table 1 below :

Table 1: Statistical analysis between Jali vs Honeycomb cocoons

#	COCOON PARAMETER	F-STATISTIC	P-VALUE	INTERPRETATION (ALPHA = 0.05)
1	Avg. Cocoon weight	0.853	0.411	No statistically significant difference
2	Avg. Filament length	3.007	0.049	There is statistically significant difference
3	Avg. Denier	-1.491	0.199	There is no statistically significant difference
4	Avg. Reelability %	3.069	0.046	There is statistically significant difference
5	Avg. Recovery%	0.086	0.086	Might be statistically significant difference

While Honeycomb mountages demonstrated significant advantages during cocoon spinning and in their resultant cocoon characteristics, a drawback emerged during the harvesting phase. As we know, cocoon harvesting involves carefully removing the cocoons from the mountages.

Fig. 5: Constraints in harvesting cocoons individually

In the Honeycomb-profiled mountage (figure above), each cell typically houses a single cocoon. During the harvesting phase, each individual cocoon needs to be extracted separately (Figure 5). This process involves opening each cell, gently removing the cocoon, and ensuring that minimal damage occurs to both the cocoon and the silk threads within it. Without any specialized equipment, this meticulous and individualized approach can significantly increase the time required for harvesting.

Re-modification (orientation) in Honeycomb mountage set-up

To address the challenges associated with the previous method, a straightforward solution involving a change in the direction of using the mountage. Instead of individually placing single silkworms into separate mountage cells (similar to a honeycomb structure), a continuous sheet of mountage material was fabricated and this time the silkworms were placed horizontally within the mountage unlike the previous method where the silkworms were singularly mounted vertically. The sheets when placed one over the other, form a structure resembling the honeycomb profile as shown in the Figure 6.

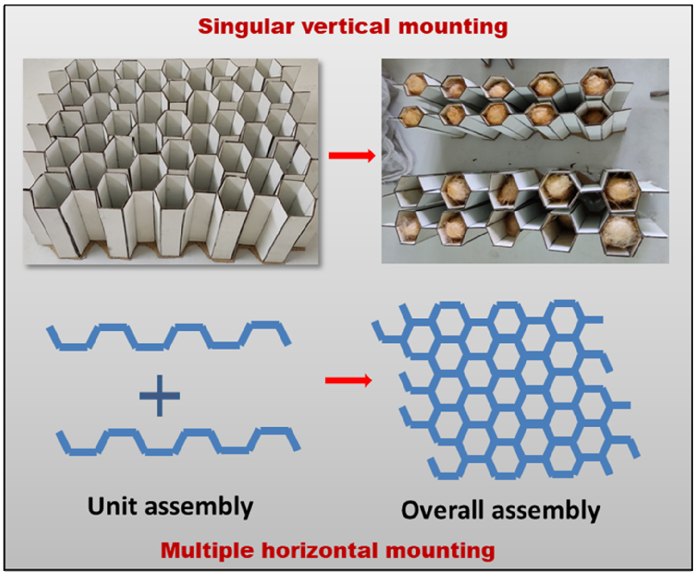


Fig. 6: Vertical mounting to Horizontal mounting approach

This design made it easier to manage multiple silkworms simultaneously and the change in orientation could facilitate in easier access to the silkworms and a potentially more efficient layout. Overall, this modification aimed to streamline the process of cocoon harvesting by simplifying the way silkworms were mounted and managed. It reduced the need for individually handling each silkworm in separate cells, potentially saving time and labor. The honeycomb structure formed by layering the mountage sheets provided an organized and efficient way to accommodate the silkworms during their cocoon-spinning phase.

The initial approach of constructing mountages from laminated materials was found to be problematic due to the extensive labor and time required for fabrication. The intricate construction of these mountages involved multiple laborious operations, making it impractical for efficient cocoon harvesting. In response to the limitations of the laminate-based approach, efforts were made to identify alternative materials that could serve the same purpose more effectively. One such approach involved experimenting with metal sheets, specifically tin/aluminum by cutting and shaping into the desired pattern due to their versatility and ease of fabrication. The dimensions of each sheet were made into 1.5ft x 2ft (LxW) which could easily accommodate 40-50 worms per sheet. The newly created mountages were utilized in cocoon construction trials, following a procedure similar to the one described earlier along with certain modification in mounting and harvesting operations which are illustrated in the Figure 7.

Fig. 7 : Horizontal mounting and harvesting of cocoons on Honeycomb profiled sheets

The construction process of these mountages was expected to be less labor-intensive and more time-efficient compared to the previous laminate-based method. The newly introduced flat sheet mountages, designed with a honeycomb profile, were subjected to trials over the course of four seasons to evaluate their effectiveness in facilitating cocoon construction and harvesting. The figure likely illustrates the outcomes of these trials, showcasing the quality and quantity of the harvested cocoons, which would be critical in assessing the success of the new approach.

Re-modification (material) in Honeycomb mountage set-up

The utilization of aluminum sheets in a honeycomb configuration can optimize the cocooning process for silkworms, offering stability and protection during cocoon formation. However, drawbacks such as the material's weight and cost were notable considerations, particularly for large-scale sericulture. Consequently, the quest for a newer and more cost-effective material for constructing The use of FRP sheets in a honeycomb profile for silkworm cocoon construction could be a promising innovation, offering organized cocoon production. Depending on the scale, budget, and resources available, this cocooning setup may be a valuable investment for maximizing silk production quality. The process of assembling these sheets, layer by layer, culminated in the creation of the honeycomb profile structure, a visual representation of which can be found in the Figure 8.

Fig. 8: Layer-by-layer stacking of FRP sheets to arrive at the Honeycomb structure

Subsequently, these honeycomb mountages, constructed from Fiber Reinforced Plastic (FRP), were employed in cocooning trials as detailed in the Figure 9 below.

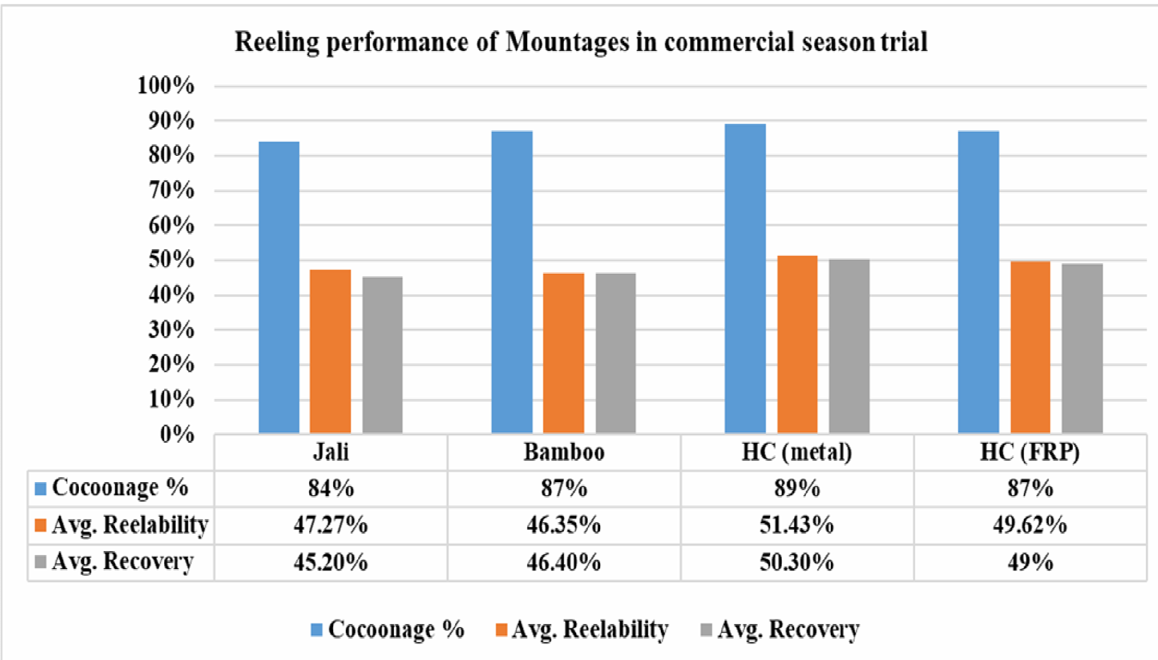
Fig. 9: Mounting of silkworms and subsequent cocooning in FRB based Honeycomb structure

Following the completion of the mounting and cocooning operations, the resultant cocoons were harvested as shown in the Figure 10.

Fig. 10: Harvesting of cocoons from FRP based honeycomb mountage

Assessment of cocoon characteristics

Following this stage, an extensive and thorough quality assessment was undertaken with an objective to meticulously scrutinize and draw comparisons between the various quality attributes of the cocoon viz., cocoonage percentage, mean filament length, average reelability, and average recovery% of different mountage techniques (Jali, Bamboo, HC (metal), and HC (FRP) as depicted in the Figure 11.



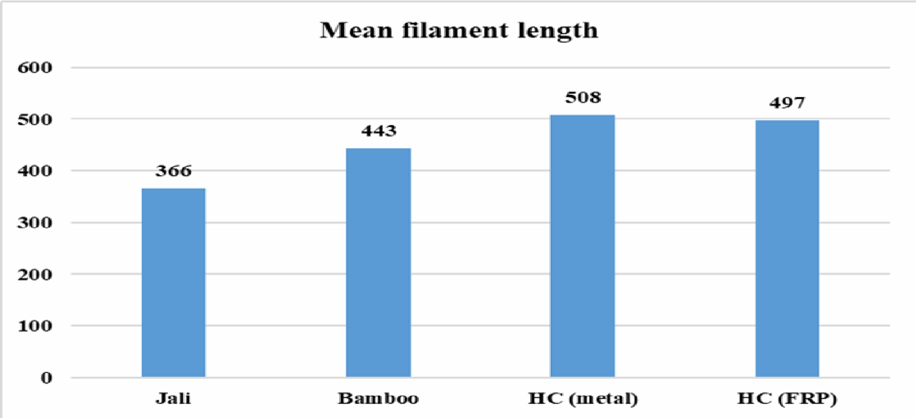


Fig. 11: Quality assessment of cocoons in commercial season

Honeycomb Mountages exhibit the comparatively higher cocoonage performance followed closely by Bamboo and Jali, while still good, but has a slightly lower cocoonage rate. The same trend was observed in the case of Average Filament length. Bamboo also demonstrates commendable performance across these parameters, with high cocoonage percentages and competitive average recovery. The average reelability and raw silk recovery % of cocoons harvested from Honeycomb mountages was nearing 50% while, Jali and Bamboo exhibited slightly lower reelability rates comparatively. Overall, while HC (metal) stands out as the preferred choice for cocoon formation and silk filament extraction, Bamboo also presents itself as a viable option. Therefore, on a larger scale, the choice between these two methods would depend on various factors, including cost, practicality, and specific production goals.

Summary & Conclusions

Cocooning is a pivotal stage in sericulture, influencing silk quantity and quality. During this stage, silkworms spin protective cocoons, transforming from larvae to pupae. "Better cocoon construction" implies enhancing cocoon quality, strength, and structure. In this project and attempt was made to design and fabricate a novel mountage type in the form of Honeycomb structure aimed to improve cocoon quality and cocooning efficiency in muga cocoons.

Upon arriving at the required dimensions of the honeycomb mountage cells (through morphological assessment), pilot prototypes of honeycomb mountages were made from laminate sheets and were used to conduct trials to assess their efficacy in cocoon construction. The outcome of these trials resulted in higher cocooning efficiency (90-95%) compared to traditional setups (85-88%) resulting in cleaner, uniform cocoons with superior reliability and silk recovery. However, a challenge emerged during cocoon harvesting which turned out to be time-consuming and labor-intensive.

To address the harvesting challenge, a modification involved changing the orientation of silkworm placement and subsequent changes in constructional materials. The resulting cocooning trials demonstrated improved cocoon construction and reeling performance in the cocoons besides easing the mounting and harvesting operations. The overall comparison of cocooning trials utilizing FRP-made honeycomb mountages revealed that they achieved creditable cocooning efficiency, which was on par with conventional methods. Additionally, the resulting cocoons displayed a notable improvement of approximately 7-9% in their reeling performance compared to their counterparts from traditional methods (Jali & Box-type mountages). This approach is particularly beneficial for commercial crop and reeling cocoon production. However, factors like material weight and cost should be carefully considered when implementing this technology on a larger scale thus requiring a thorough validation through large scale field trials.

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