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## Article

# Impact of Seasonal Variations on Filament Length and Non-Broken Filament Length in Relation to Silk Reeling Performance

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**Abstract:** Mulberry silk production in West Bengal and north-eastern India, primarily involving bivoltine and multi-bi hybrid silkworm varieties, is a cornerstone of the sericulture industry. However, seasonal climatic variations, characterized by elevated temperatures and humidity, significantly affect cocoon quality, posing challenges for silk reeling efficiency and productivity. This study examines the influence of seasonal variations on the quality and reeling performance of bivoltine and multi-bi hybrid silk cocoons in these regions. Key parameters, including filament length (FL), non-broken filament length (NBFL), and shell ratio, were analysed over five seasons. Results indicate a marked decline in cocoon quality during unfavourable seasons (June–July, August–September), with bivoltine cocoons exhibiting greater sensitivity through reductions in FL, NBFL, and reeliability compared to the more resilient multi-bi hybrids. These seasonal impacts undermine reeling efficiency and silk yarn quality. The findings emphasize the importance of adaptive rearing practices and technological innovations, such as multi-end reeling machines with enhanced speed and evenness control, to bolster productivity and address climatic challenges. This research provides critical insights for improving the sustainability and economic viability of sericulture in West Bengal and north-eastern India.

**Keywords:** Silk Reeling; Production; Bivoltine cocoon; Multi-bi cocoon; Filament length;

## Introduction

Sericulture is an agro-based industry that involves the rearing of silkworms for the production of raw silk, which is the yarn obtained from cocoons spun by certain species of insects. The major activities of sericulture include food-plant cultivation to feed the silkworms, which spin silk cocoons, and reeling the cocoons to unwind the silk filament for value-added benefits. Like all other crops, seasonal factors play a pivotal role in determining the productivity and quality of raw silk. Weather conditions in different seasons impact sericulture (silk production) by affecting the growth and development of mulberry plants, the primary food source for silkworms. Fluctuations in temperature, precipitation patterns, and extreme weather events can lead to reduced silk production, lower-quality cocoons, and increased pest and disease outbreaks. Since silkworms are cold-blooded animals, they are highly sensitive to temperature changes and require specific climatic conditions for optimal silk production (Rahmatulla, 2012). Optimal conditions for silkworm rearing include temperatures between 23–28°C and relative humidity of 70–80%, ensuring high cocoon yield and superior filament quality. However, extreme heat and excessive humidity during summers and monsoons adversely affect cocoon production, leading to thinner shells, irregular shapes, and reduced filament lengths, ultimately compromising reeling efficiency (Rahmatulla, 2012).

In India, different states have distinct crop schedules based on their climatic suitability. For this study considering the oldest sericulture state that is West Bengal, particularly the Murshidabad region, where silk production is documented to have started as early as the 13th century. In West Bengal, sericulture districts cultivate up to seven crops annually, with five being major crops (Sericulture West Bengal, [seriwb.gov.in](http://seriwb.gov.in)). The state experiences a transitional climate, ranging from tropical wet-dry conditions in the south to humid subtropical conditions in the north. To maintain silk quality and production, the introduction of more resilient and high-yielding silkworm breeds has been implemented. Traditional Nistari breeds have been enhanced through hybridization, leading to the development of better-performing multi  $\times$  multi hybrids such as N  $\times$  MCon4 and MCon1  $\times$  MCon4, as well as bivoltine hybrids like Sk6  $\times$  Sk7 and BHP DH. Further advancements have led to multi-bi cross hybrids such as N  $\times$  SK6  $\times$  SK7 and MCon4  $\times$  BCon4, which combine the high silk quality of bivoltine strains with the resilience of multivoltine varieties, ensuring better adaptability to fluctuating environmental conditions (Dayananda, 2012). According to the 2023–24 State Government report, Nistari (multivoltine), Sk6  $\times$  Sk7 (bivoltine), and N  $\times$  SK6  $\times$  SK7 (crossbreed) are the most popular breeds among farmers due to their superior performance. These technological and biological advancements have led to better-quality cocoons and increased silk production (Chakraborty, 2020).

Regarding the reeling sector, West Bengal's sericulture remains decentralized but is transitioning from traditional reeling methods, such as Katghai and Ghosh Basin, to modern technologies like Multi-End Reeling Machines (MRM) and Automatic Reeling Machines (ARM). In 2023–24, twelve MRMs were established, along with one ARM in Malda and Murshidabad districts. This displays the interest of people in the adaptation of new technology. These innovations have enhanced efficiency, uniformity, and productivity while reducing manual inconsistencies (Alim, 2016). However, these new technologies require substantial investment and high-quality raw materials to ensure profitable and efficient production.

Assessing the suitability and understanding variations of locally produced mulberry cocoons for advanced machines has become imperative. MRM units require high-quality cocoons, and their efficiency is influenced by several factors, including operator skill level, the number of ends per thread, raw material characteristics, and machine maintenance (D. Chattopadhyay, 2018). Filament length, non-broken filament length (NBFL), and single-fiber denier are critical parameters that directly impact reeling speed, production efficiency, and yarn uniformity. Studies suggest that maintaining minimum reeling speeds of 100 m/min for MRMs and 200 m/min for ARMs is crucial for economic viability (International Sericulture Research Institute, 2017; Ramesh et al., 2019).

Research indicates that the NBFL for popular crossbreed hybrid, bivoltine, and Nistari cocoons ranges between 450–800 m, 350–900 m, and 250–450 m, respectively (Silk Board Research Report, 2022). Given the direct correlation between NBFL and reeling speed, optimizing cocoon characteristics is essential for maximizing the efficiency of MRM units.

This study aims to comprehensively assess the filament length, NBFL, and single filament denier of locally produced mulberry cocoons and cocoons procured from other states to evaluate their suitability for MRM reeling. By optimizing reeling parameters such as winding speed, the number of cocoons per end, basin water temperature, and croissure length, this research seeks to enhance productivity and reduce silk production costs. Ultimately, this study intends to address the technological and biological challenges facing the sericulture sector, thereby supporting its sustainable growth in West Bengal. So in terms of raw material Filament length and NBFL becomes important characteristics to determine the speed of Reeling machine and its production as well as evenness of the yarn. Optimizing these parameters is essential for improving the profitability of MRM units and reducing the cost of silk production (D. Chattopadhyay, 2018).

## Material and Method

A sample of 1 kg of cocoons was procured for each popular bivoltine and Multi  $\times$  Bi hybrid across five major seasons in West Bengal and the north-eastern region of India. The single cocoon

weight, single shell weight, and shell ratio were measured. These samples were further analysed using the standard single cocoon reeling analysis to determine filament length, non-broken filament length, reeliability, renditta, and silk recovery.

$$\text{Shell ratio (\%)} = \frac{\text{shell weight of 50 cocoons}}{\text{weight of 50 cocoons}} \times 100$$

#### Drying of Cocoons:

The cocoons were stifled and dried using a hot air dryer following a standard procedure. The drying process began at 115°C for 1 hour, with the temperature gradually reduced by 15°C each hour, following the profile: 115°C → 100°C → 85°C → 70°C → 55°C. After reaching 55°C, the cocoons were allowed to cool for 30 minutes before being removed from the chamber.

#### Cocoon Sorting and Preparation for Reeling Analysis

The cocoons were sorted to identify defective ones in the lot. A random sample of 200 cocoons was selected for single cocoon reeling analysis, while another 300 cocoons were chosen for evaluating other reeling parameters.

#### Cocoon Cooking Process

The selected cocoons were cooked using a two-pan cooking mechanism based on the low-high-low temperature principle. The process lasted 8–12 minutes, ensuring the optimal cooking of the cocoons. The cocoons were brushed in the same pan at the same temperature to group the filament ends for reeling.

#### Single Cocoon Reeling Analysis

Cooked cocoons were reeled individually using an *éprouvette* until the filament end. The total filament length and the number of breaks were recorded. For this analysis, the average of 5 cocoons was used.

The calculations were as follows:

$$NBFL = \frac{\text{total length of filament}}{1 + \text{number of breaks}}$$

$$\text{Denier} = \frac{\text{weight in gms}}{\text{total length of filament}} \times 9000$$

#### Reeling analysis

A sample of 300 cocoons was reeled by a skilled reeler using a multi-end reeling machine operating at a speed of 100 meters per minute. The reeling basin temperature was maintained at 40–45°C, with a croissure length of 8 cm. Eight cocoons per end were used, with two ends being reeled simultaneously. The number of castings and carryovers was recorded for further calculations of reeling efficiency and performance.

#### Statistical analysis:

Based on 200 readings for FL and NBFL, the mean, median, mode, standard deviation, and skewness have been calculated in Excel using standard formulas

## Result and Discussion

Data was collected from 200 bivoltine and multi-bi hybrid cocoons for each season across two years from the north-eastern region of India. The grouped frequency distributions for FL and NBFL are analysed to understand their behaviour across seasons. These parameters are critical indicators of cocoon quality, as they influence silk yield, reeling efficiency, and the overall economic feasibility of silk production. The shell ratio, filament length, and NBFL variations between favourable and unfavourable seasons reveal the sensitivity of cocoon quality to environmental factors. (D. Chattopadhyay, 2018)

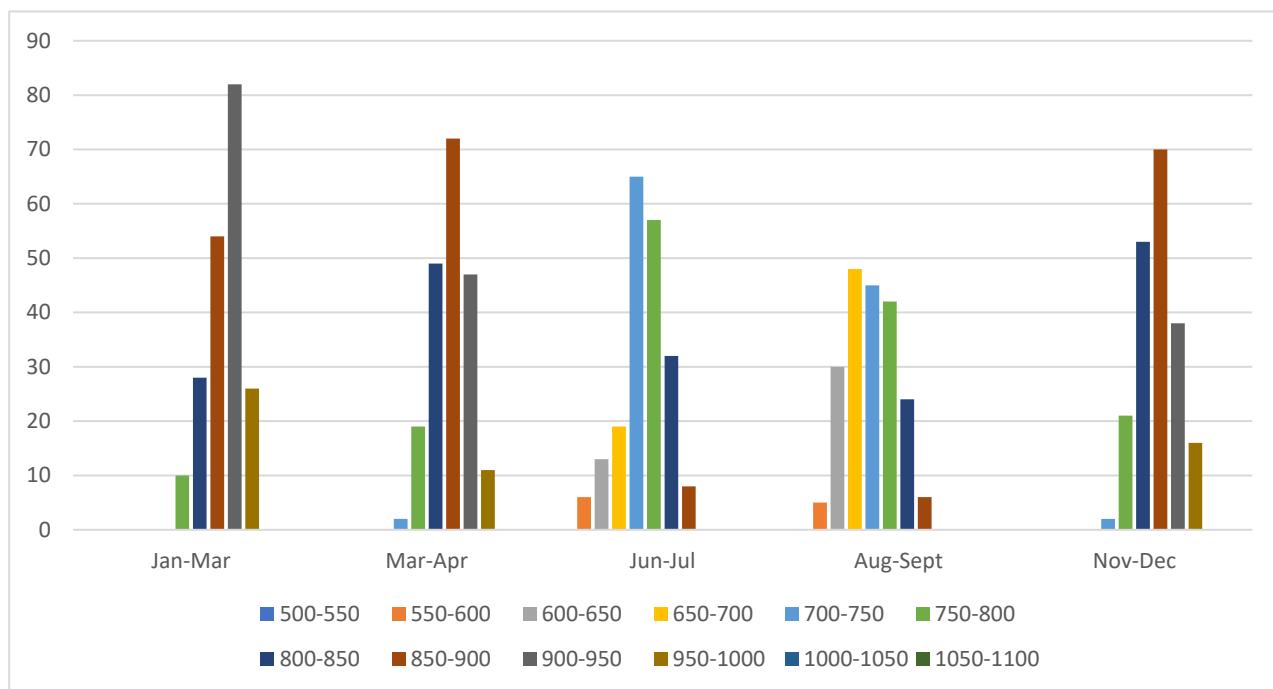
#### Shell Ratio and Filament Length Analysis

The shell ratio, defined as the ratio of shell weight to green cocoon weight, is an essential parameter for estimating raw silk content in cocoons. A higher shell ratio indicates a greater silk yield relative to the size of the pupa. This ratio is consistently higher in bivoltine cocoons during favourable

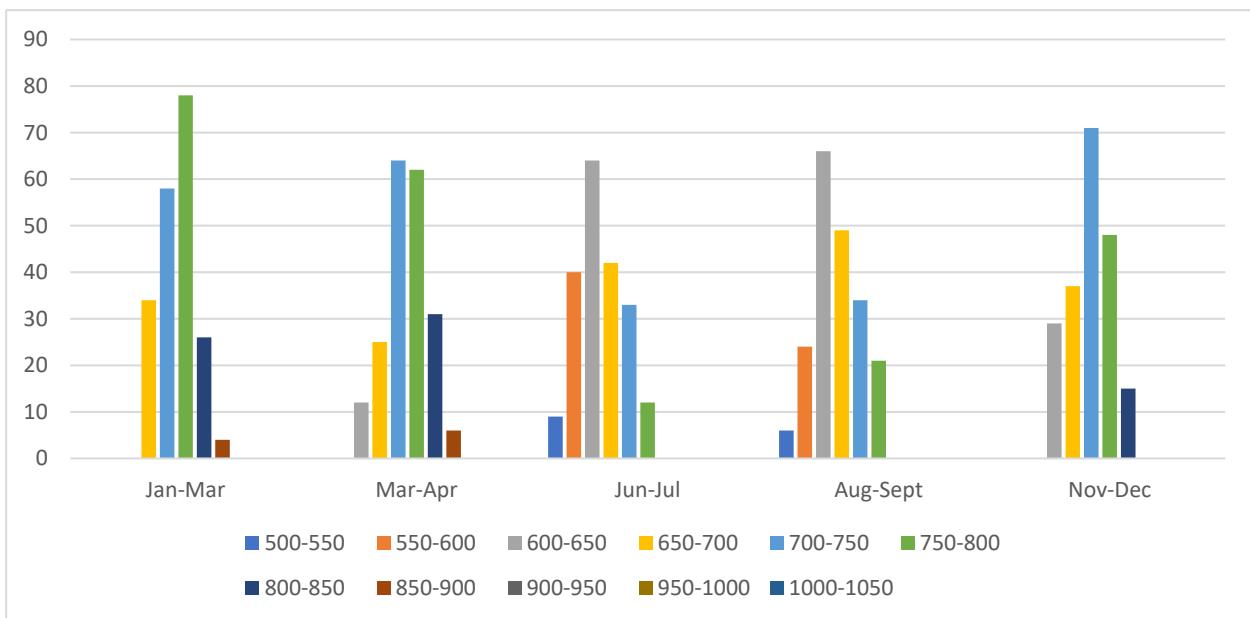
seasons, highlighting their superior raw silk potential. However, it decreases significantly during unfavourable seasons due to stress-induced reduction in silk deposition.

Filament length (FL) in bivoltine cocoons ranges from **750 to 1000 meters** during favourable seasons such as January–March, March–April, and November–December. The mean FL for these seasons is **897 m, 869 m, and 867 m**, respectively, with the highest frequencies observed in the ranges **900–950 m (82 cocoons), 850–900 m (72 cocoons), and 850–900 m (70 cocoons)**. In contrast, during unfavourable seasons such as June–July and August–September, the FL decreases and shifts to a range of **550–900 meters**, with mean values of **746 m and 721 m**, and the highest frequencies in the ranges **700–750 m (65 cocoons) and 650–700 m (48 cocoons)**.

For multi-bi hybrids, FL ranges between **650 and 900 meters** during favourable seasons, with mean values of **752 m, 748 m, and 721 m**, with the highest frequencies observed in the ranges **750–800 m (78 cocoons), 700–750 m (64 cocoons), and 700–750 m (71 cocoons)**. In unfavourable seasons, the FL reduces to a range of **500–800 meters**, with mean values of **647 m and 661 m**, and the highest frequencies in the ranges **600–650 m (64 cocoons) and 600–650 m (60 cocoons)**. These observations indicate that while multi-bi hybrids are less sensitive to seasonal changes compared to bivoltine cocoons, they also experience a decline in filament quality during unfavourable periods.



**Figure 1.** Filament length distribution of bivoltine cocoons in different seasons.



**Figure 2.** Filament length distribution of multi-bi hybrid cocoons in different seasons.

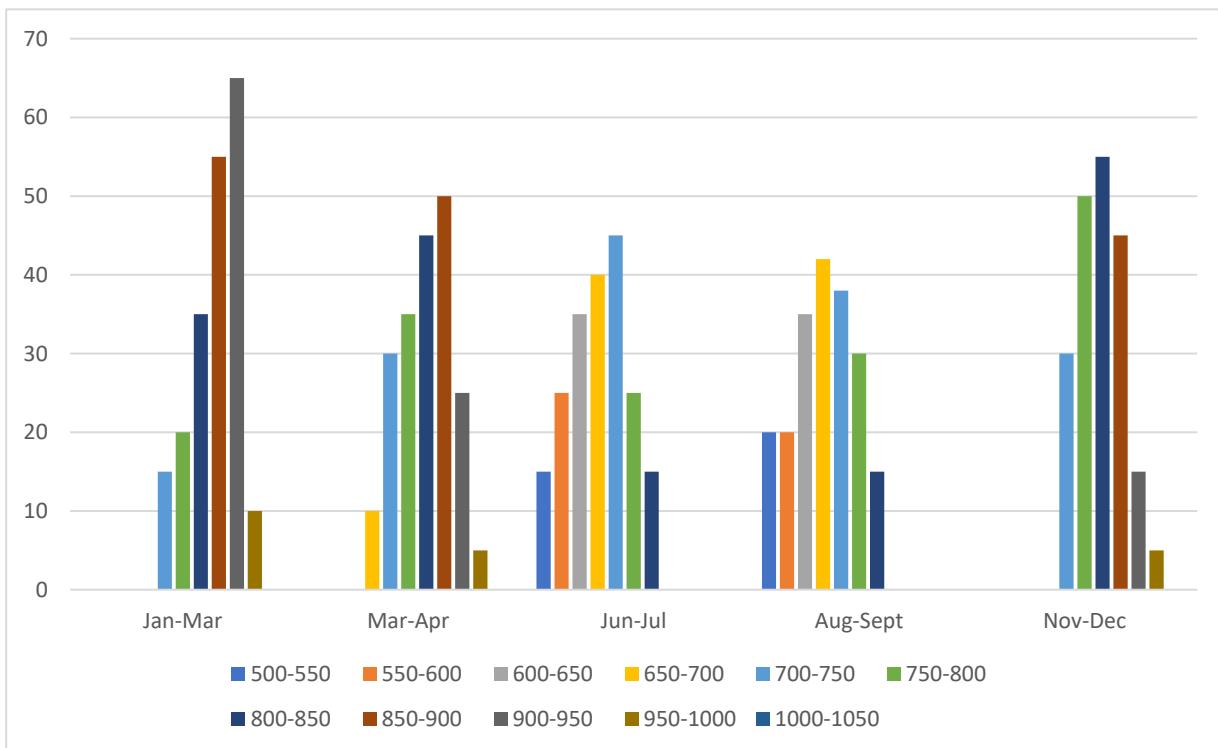
#### Non-Broken Filament Length (NBFL) Analysis

Non-broken filament length (NBFL) is another crucial parameter, as it directly affects reeling efficiency and silk quality. In favourable seasons, NBFL for bivoltine cocoons ranges between **700 and 1000 meters**, with mean values of **866 m, 823 m, and 820 m**, and mode values of **908 m, 858 m, and 817 m**. During unfavourable seasons, the NBFL decreases significantly, ranging between **500 and 850 meters**, with mean values of **678 m and 677 m**, and mode values of **626 m and 636 m**. This reduction highlights the challenges of maintaining quality if raw silk yarn and productivity during unfavourable climatic conditions.

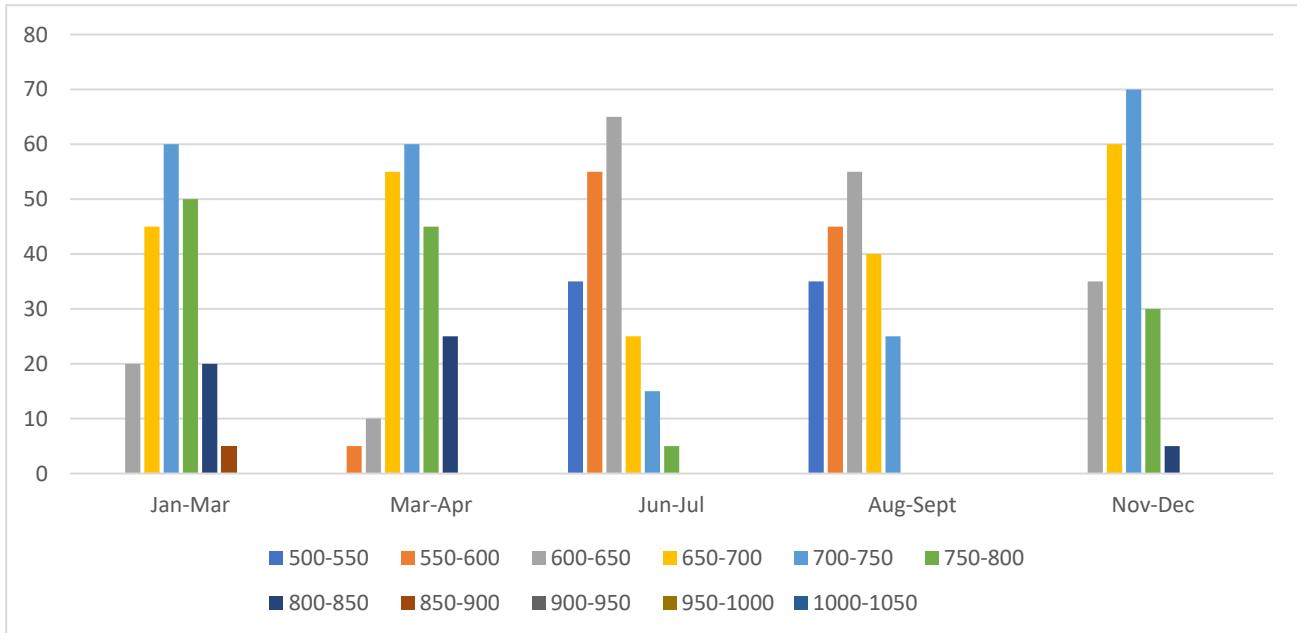
Similarly, for multi-bi hybrids, NBFL during favourable seasons ranges between **600 and 900 meters**, with mean values of **730 m, 726 m, and 703 m**, and mode values of **730 m, 713 m, and 710 m**. In unfavourable seasons, the NBFL drops to a range of **500–800 meters**, with mean values of **611 m and 619 m**, and mode values of **610 m and 620 m**. These results show that while multi-bi hybrids exhibit better stability compared to bivoltine cocoons, they are not entirely immune to environmental stress.

#### Impact of Seasonal Variations

Seasonal changes have a pronounced effect on cocoon quality, particularly for bivoltine silkworms, which are more delicate and sensitive to environmental fluctuations. The shell ratio, filament length, and NBFL all decrease during unfavourable seasons, resulting in poorer reeling performance. Reelability, defined as the percentage of reelable cocoons out of 100, drops from **80% in favourable seasons to 60% in unfavourable seasons** for bivoltine cocoons. Multi-bi hybrids show a smaller decline, with reelability decreasing from **76% to 68%**. Raw silk recovery follows a similar trend, remaining above **80% in favourable seasons** but dropping below **60% in unfavourable periods** for both types.



**Figure 3.** NBFL distribution of bivoltine cocoons in different seasons.



**Figure 4.** NBFL distribution of multi-bi hybrid cocoons in different seasons .

### Statistical Analysis

Based on data obtained from single cocoon reeling analysis, key statistical measures, including the mean, median, mode, standard deviation (SD), and skewness, were computed for filament length (FL) and non-broken filament length (NBFL). These statistical parameters provide insights into the variability and distribution of filament characteristics among different silkworm cocoon types.

The results of these calculations are summarized in Tables 1 and 2 for bivoltine silkworm cocoons, while Tables 3 and 4 present the same parameters for multi-bi hybrid silkworm cocoons.

Additionally, the cocoon characteristics, assessed prior to the reeling analysis, are displayed in Tables 5 and 6.

A detailed examination of skewness, a measure of asymmetry in data distribution, reveals notable patterns. For bivoltine cocoons, skewness values are predominantly negative in all seasons except for the November–December period, suggesting a tendency towards shorter filament lengths. This indicates that, under most conditions, the filament length distribution is skewed towards lower values. Conversely, multi-bi hybrid cocoons exhibit mostly positive skewness, except in the January–March and March–April periods, where skewness values are near zero, suggesting a more symmetrical distribution of filament lengths in these seasons.

These observed trends indicate that unfavorable environmental conditions disproportionately affect bivoltine cocoons, reducing their quality and filament characteristics to levels comparable to those of multi-bi hybrid cocoons. This suggests that bivoltine varieties may be more sensitive to seasonal variations, whereas multi-bi hybrids demonstrate a relatively stable performance across different seasons.

The findings highlight the importance of season-specific management strategies to mitigate the impact of environmental factors on filament characteristics, particularly for bivoltine silkworms, to ensure optimal cocoon quality and reeling efficiency.

**Table 1.** Bivoltine-Filament length.

	Jan-Mar	Mar-Apr	Jun-Jul	Aug-Sept	Nov-Dec
<b>Mean</b>	897	869	746	721	867
<b>Median</b>	905	871	748	719	823
<b>Mode</b>	917	874	743	693	857
<b>SD</b>	52.08	53.75	65.99	71.05	56.15
<b>Skewness</b>	-0.48	-0.10	-0.10	0.10	2.38

**Table 2.** Bivoltine-Non Broken filament length.

	Jan-Mar	Mar-Apr	Jun-Jul	Aug-Sept	Nov-Dec
<b>Mean</b>	866	823	678	677	820
<b>Median</b>	877	828	681	680	818
<b>Mode</b>	908	858	710	682	817
<b>SD</b>	66.04	74.12	82.88	70.96	58.09
<b>Skewness</b>	-0.50	-0.21	-0.14	-0.12	0.09

**Table 3.** Multi x Bi Hybrid-Filament length.

	Jan-Mar	Mar-Apr	Jun-Jul	Aug-Sept	Nov-Dec
<b>Mean</b>	752	748	647	661	721
<b>Median</b>	755	749	640	654	696
<b>Mode</b>	764	748	626	636	730
<b>SD</b>	49.20	58.07	63.35	58.52	56.96
<b>Skewness</b>	-0.19	-0.05	0.32	0.35	1.31

**Table 4.** Multi x Bi Hybrid-Non broken filament length.

	Jan-Mar	Mar-Apr	Jun-Jul	Aug-Sept	Nov-Dec
<b>Mean</b>	730	726	611	619	703
<b>Median</b>	729	725	608	618	654

<b>Mode</b>	730	713	610	620	710
<b>SD</b>	61.03	59.67	62.24	49.85	51.17
<b>Skewness</b>	0.04	0.06	0.17	0.03	2.83

**Table 5.** Bivoltine cocoon characteristics.

	<b>Jan-Mar</b>	<b>Mar-Apr</b>	<b>Jun-Jul</b>	<b>Aug-Sept</b>	<b>Nov-Dec</b>
<b>Single cocoon weight</b>	1.92	1.94	1.60	1.52	2.11
<b>Single shell weight</b>	0.37	0.36	0.26	0.23	0.41
<b>SR%</b>	19.36	18.35	16.02	15.45	19.52
<b>Denier</b>	2.13	2.19	1.95	1.89	2.22

**Table 6.** Multi Bi hybrid cocoon characterises.

	<b>Jan-Mar</b>	<b>Mar-Apr</b>	<b>Jun-Jul</b>	<b>Aug-Sept</b>	<b>Nov-Dec</b>
<b>Single cocoon weight</b>	1.79	1.72	1.51	1.46	1.84
<b>Single shell weight</b>	0.29	0.27	0.21	0.20	0.32
<b>SR%</b>	16.40	15.92	13.68	13.56	17.13
<b>Denier</b>	1.98	1.87	1.92	1.85	2.11

NBFL is a crucial parameter for determining the optimal reeling machine speed, directly influencing production rates while maintaining the desired silk yarn quality. For instance, in producing 20–22 denier silk yarn, the reeling process typically requires 10 cocoons per end. Maintaining consistent feeding of these cocoons is critical to achieving uniform quality and high efficiency. Skilled reeling workers play an essential role in managing this process, as their ability to sustain consistent feeding directly correlates with reeling performance.

The relationship between NBFL, feeding rate, and reeling speed is mathematically expressed as:

$$\text{Reeling Speed} = \frac{\text{NBFL} \times \text{No.of feeding ends (pcs/min/man)}}{\text{Average No.of cocoons per yarn end} \times \text{Number of reels handled by reeler}}$$

Performance data for bivoltine hybrids (Sk6 x Sk7) and multi-bi hybrids (NxSk6 x Sk7) across different seasons highlight the influence of NBFL on reeling speed:

**Table 7.** Reeling Speed with respect to NBFL.

<b>Speed (MPM) N=10</b>	<b>Jan-Mar</b>	<b>Mar-Apr</b>	<b>Jun-Jul</b>	<b>Aug-Sept</b>	<b>Nov-Dec</b>
Sk6 x Sk7	104	99	81	81	98
NxSk6xSk7	88	87	73	74	84
<b>Speed (MPM) N=08</b>	<b>Jan-Mar</b>	<b>Mar-Apr</b>	<b>Jun-Jul</b>	<b>Aug-Sept</b>	<b>Nov-Dec</b>
Sk6 x Sk7	130	123	102	102	123
NxSk6xSk7	110	109	92	93	105

According to the *Reeling and Testing Manual* by Yong-Woo Lee, a skilled reeling worker can consistently feed 12–14 cocoon ends per minute, which serves as a benchmark for reeling speed calculations under standard conditions. This benchmark enables reeling units to optimize their operations for both bivoltine and multi-bi hybrid cocoons.

## Conclusion

NBFL is the most important quality characteristic of reeling cocoons, as it helps predict the achievable production speed. The NBFL value depends on the breed of the silkworm—bivoltine silkworms have a higher filament length (FL), resulting in higher NBFL if the number of breaks is minimal. In contrast, the multi-bi hybrid has a lower NBFL.

Seasons with temperatures below 30°C and relative humidity (RH) around 70% or lower are favorable for silkworm health. Temperatures above this threshold start to negatively impact silkworm health and silk gland function, leading to higher mortality, reduced FL, and lower crystallinity. High humidity during spinning also affects silk quality.

A lower NBFL means more frequent breaks, requiring additional feedings within the same period. For bivoltine cocoons, the highest frequency range for NBFL is above 800 meters during January–February and November–December. This indicates that during favorable seasons, a reeler can achieve an approximate production speed of 100 meters per minute (mpm), whereas in unfavorable seasons, it may drop to around 80 mpm, leading to a 20% production loss due to raw material quality.

For multi-bi hybrids, production is lower in the January–February, March–April, and November–December crops, while in the remaining two seasons, the NBFL value is almost at par. This allows reelers to select raw materials based on price and demand.

This alignment ensures consistent silk quality and efficiency, even under variable seasonal conditions. The adoption of such optimized reeling practices is vital for sustaining the competitiveness of the silk reeling industry in the northeastern region.

**Conflicts of Interest:** No potential conflict of interest was reported by the authors.

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