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Storage duration of bivoltine Silkworm (*Bombyx mori* L.) hybrid cocoons: its effect on reeling performance and cocoon characteristics

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Abstract

This investigation explored the reeling performance of bivoltine hybrid cocoons as affected by different storage duration and it was conducted at the Sericulture Research and Development Institute, Don Mariano Marcos Memorial State University, Sapilang, Bacnotan, La Union, Philippines from January 2019 to December 2020. The different storage durations which served as the treatments were as follows: T₀ – non storage, T₁ – 1 mo., T₂ – 3 mos., T₃ – 5 mos., T₄ – 6 months. Results revealed no significant difference among treatments in terms of cocoon characters. The reeling percentage showed no significant difference among treatments whereas in terms of raw silk percentage, T₀ recorded the highest with 27.90%. As to renditta, T₂ recorded the highest (13kg) but comparable to all other treatments except for T₀. Reeling waste percentage recorded highest from T₁ (53.30) but comparable with T₀ (50.50%). The performance of silkworm hybrid cocoons on raw silk quality showed that all treatments were comparable in terms of unevenness. The profitability analysis showed that unstored cocoons (T₀) produced the highest raw silk yield, gross income and ROI.

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Introduction

Sericulture is the art of silk production which encompasses different unique processes of mulberry cultivation, rearing of silkworms for the production of cocoons, unwinding of the silk filaments of cocoons through suitable techniques to form a composite thread fit for weaving. The main product is silk which is considered the “queen of textiles” which spells luxury, elegance, class and comfort. It is an industry which is a prospective earning sector capable of creating an employment as well as alleviating poverty especially in the rural areas.

Silkworms are reared for the sole purpose of obtaining cocoons which serve as raw material for producing raw silk. It was discovered in an ancient kingdom of China when Queen Xi - Ling, wife of Emperor Huang-Di who was said to have ruled China in about 3000 BC found that the cocoons of the silkworm could be softened in hot water and the continuous silk filaments could be drawn there to produce well united and strong threads of uniform thickness for the manufacturer of beautiful and durable silk fabrics.

Silk has been the highly valued textile fiber over the countries in the world. The quality of cocoons is one of the contributing factors to the raw silk quality. Moreover, the quality of cocoons depends upon the quality of mulberry leaf and type of rearing condition and rearing method (Ramesh *et al.*, 2005).

A cocoon is a silky web spun around the larvae of many insects. When a silkworm has eaten enough, it constructs a cocoon which turns into a pupa. After many days, a fully formed adult silkworm moth emerges, through a split-soaked opening in the bottom of a cocoon. It serves as the raw material used for reeling raw silk. It is, in fact, a protective shell made up of a continuous and long protein rich silk filament spun by the mature silkworm prior to pupation for self-protection from adverse climate factors and natural enemies.

Storage of cocoon is one of the important concerns in silk processing particularly when the stifled cocoon

has to be stored for a very long period. Before storing the cocoons, it is necessary to dry it in order to kill the pupa to avoid moth emergence so that the continuous filament is preserved in the cocoon shell. After the process of drying the cocoons, it can be stored for a long period of time before reeling them (FAO, 1987).

The cocoons are dried completely so that when they are cooked, the fiber is released neatly to help increase reeling efficiency. Dried cocoons shall be stored in containers with humidity below 70% and able to prevent damages from insects and rats (Reddy and Gowda, 2007).

Long period storage tends to deteriorate cocoon quality which is also affected by the storage conditions. Sufficient care should be paid to the condition for bad and unsatisfactory storage that may result in the development of molds or damaged caused by rats. To maintain quality of cocoons and adequate supply of fresh air, low humidity (not over 70% RH), and of no longer than three months in tropical areas (ESCAP, 1992).

In building the cocoon storage room, the following should be considered: air space for ventilation must be provided at the bottom of the storage room, to prevent moisture coming from underground (Yon-Woo Lee, 2018).

In order to produce a better reeling performance and superior grade raw silk of our commercial silkworm hybrid cocoons, high quality raw silk consistently is attributed to better quality cocoons. Cocoons were hot air dried to the optimum level using a temperature of 115°C to 55°C for five hours, cooking of cocoons uniformly to the required level at 95°C water for three (3) minutes in the case of bivoltine hybrid cocoons using conveyor cooking machine are all considered to produce high quality raw silk (Naik and Somashekar, 2008).

Since sericulture helps in poverty alleviation, small-scale farming groups are attracted towards sericulture. Cocoon quality parameters play an important role in the quality of the raw silk reeled.

The cocoon parameters are defined by a large number of categories, some of which are important for the parent cocoons race maintenance and some are for cocoon reeling. The technological parameters of the cocoons are significantly important, since they determine the quality, quantity and efficiency of reeling process (Gowda and Reddy, 2007).

One essential factor to consider for higher silk productivity is cocoon storage. Hence, this investigation highlights the different storage durations and their effect to the quality of raw silk as material for silk fabric production.

Generally, this investigation aimed to evaluate the performance of bivoltine silkworm hybrid (DMMMSU 408) cocoons as affected by storage duration. Specifically, it sought answers to the following objectives: to evaluate the cocoon characters such as filament length (m) and filament size (denier); to determine the reeling performance as reelability (%), raw silk yield (%), reeling waste (%), and renditta (kg); to evaluate the raw silk quality in terms of unevenness (%), and yarn number (denier); and to analyze the profitability of raw silk in terms of net income and return of investment (ROI).

Materials and methods

Research design

This study was conducted at the Filature of Sericulture Research and Development Institute, Don Mariano Marcos Memorial State University, Bacnotan, La Union from January 2, 2019 to June 30, 2020. The experimental design utilized was Complete Random Design (CRD) and Tukeys' Honest Significant Difference (HSD) Test for the test of significance.

Methods

The production and processing standards in producing 21 denier raw silk were followed. The cocoons were properly assessed, sorted, deflossed, weighed, packed and labelled. Single cocoon reeling was also done to determine the cocoon characters of the samples.

At the end of each duration, sample cocoons were cooked using the conveyor type cooking machine, while individual cocoon was reeled using the open pan method and the epprouvette with an automatic counter to determine the filament length of the individual cocoon.

Silkworm hybrid DMMMSU 408 dried cocoons were filled in fifteen (15) nylon nets with 1000 grams of cocoons each and randomly distributed to five (5) treatments with three (3) replications.

The silkworm hybrid (DMMMSU 408) cocoons were used as experimental materials which were produced by farmer-cooperator from Binalonan, Pangasinan. The sample cocoons were properly cooked, brushed then reeled in a multi-end basin reeling machine. Then the raw silk produced from silkworm hybrid cocoons were re-reeled, laced, skeined, and weighed. Further the raw silk produced was further subjected to sample testing at the Philippine Textile Research Institute (PTRI) of the Department of Science and Technology (DOST), Taguig City, Metro Manila, Philippines.

The following storage duration which served as the treatments were as follows:

- T₀ - No Storage
- T₁ - 1 Month storage duration
- T₂ - 3 Months storage duration
- T₃ - 5 Months storage duration
- T₄ - 6 Months storage duration

During the conduct of the study, proper storage of the cocoons was observed. Daily monitoring and recording of relative humidity inside the storage room were undertaken at 7:00 AM, 11:00 AM and 3:00 PM. The average relative humidity recorded was 54.76%. Good ventilation of storage room was observed to avoid the occurrence of insects and fungus.

The temperature at the commencement of drying is 110-115°C, which is then lowered in stage to 100, 90, 80, & 70°C until the final temperature of 60-55°C is reached.

The duration of drying from fresh cocoon to standard dried condition is 5.5 to 6.0 hours, when the target degree of 39-42 percent drying can be reached (Yongwoo lee, 2018).

Data gathering

The data gathered were as follows:

Cocoon characters

Filament Length: This was taken by dividing the total filament length of reeled silk by the number of cocoon samples reeled using the epprouvette.

Denier/Filament size: This was taken by dividing the weight of reeled silk by the filament length of reeled silk multiplied by 9000.

Reeling performance of cocoons

Reelability Percentage: This was computed by the dividing the number of cocoons reeled plus number of breakage multiplied by 10.

Raw Silk Percentage: This was taken by dividing the weight of raw silk by the weight of cocoons used during reeling multiplied by 100.

Reeling Waste Percentage: This was taken by dividing the weight of silk waste by the weight of cocoons used during reeling multiplied by 100

Renditta: This is the ratio of the quantity of fresh cocoons used in reeling to produce a kilo of raw silk.

Raw silk quality

Unevenness percentage: The variation of one specific property and linear density. This method is concerned with measuring the unevenness of a textile strand.

Yarn Number/ Evenness Test: The object of this test was to determine the degree of evenness of raw silk with in approximately the same length of the sizing skein. Evenness defects are those positions of raw silk threads on an inspection board which show stripes caused by variations on the size of raw silk to such a degree as it is easily noticeable by visual inspection.

Profitability analysis

The inputs in the production of 21 denier raw silk with bivoltine hybrid cocoons as affected by storage duration consist of fixed, variable and overhead costs. The fixed cost was obtained from the depreciation cost of boiler, reeling machine, re-reeling, building,

repair and maintenance of machineries, electricity and water. Variable cost included the total expenses incurred in the production, i.e. material cost, labor cost and factory overhead cost which was obtained by computing 10% of the total material cost and labor cost.

Data analysis

Frequency counts and means were established and one-way ANOVA was used to evaluate the bivoltine silkworm hybrid cocoons (DMMMSU 408) in terms of cocoon characters and reeling performances as affected by storage duration.

The raw silk quality was analyzed at the Philippine Textile Research Institute of the Department of Science and Technology, Taguig City, Metro Manila.

The data gathered in the production were tabulated and analyzed using the cost and return analysis to determine the profitability of raw silk produced by bivoltine silkworm hybrid cocoons (DMMMSU 408) as affected by storage duration.

Results and Discussion

Cocoon characters

Table 1 shows the cocoon characters of the bivoltine hybrid cocoons as affected by storage duration. Result showed no significant difference observed among various treatments. Filament length recorded ranged from 733.27 (T₀) – 774.67m (T₄) while denier size ranged from 2.58 (T₁) – 2.63 (T₀, T₃ & T₄). Analysis of variance revealed that there was no difference among the various treatments on the filament length. The cocoon characters can be improved up to certain extent by providing ideal environmental conditions even during spinning stage of larvae affected with high temperature and relative humidity (Gowda and Reddy, 2007).

Cocoon cooking condition influence the swelling and softening of sericin of cocoon filament layers and crossover points the cocoon shell and hence the agglutination force between the cocoon filament and cocoon shell (Subhas and Somashekar, 2007). The influence of temperature and humidity maintained during cocoon spinning on reeling performance and

quality of raw silk for multivoltine cocoons with temperature of 27°C and 30°C and humidity conditions of 70% and 90% with or without air circulation. The effect of humidity on reeling performance and quality of silk may be attributed to the structural changes in the sericin due to the high humidity conditions during cocoon spinning (Somashakar and Subhas, 2003).

The silkworm breeds developed for tropical conditions remain adapted to both seasonal and local conditions of the area for ensuring stable cocoon production under a high temperature coupled with

other associated biotic/abiotic vagaries (Suresh *et al.*, 2011).

The thickness of silk filament yarn is expressed in terms of denier, the number of grams of weight per 9000 meters (9,846 yards) of length. Silk has good strength, resisting breakage, when subjected to weights of about 4 grams (0.5 ounce) per denier. A silk filament can be stretched about 20% beyond its original length before breaking but does not immediately resume its original length when stretched more than about 2 percent (Rogers, 2022).

Table 1. Cocoon characters of the bivoltine hybrid cocoons as affected by storage duration.

Treatment	Filament length (M)	Denier SIZE (D)
To – NO STORAGE	733.27	2.63
T1 – 1 month	749.50	2.58
T2 – 3 months	733.60	2.59
T3 – 5 months	764.00	2.63
T4 – 6 months	774.67	2.63
level of significance	Ns	ns
CV (%)	2.67	2.61

Reeling performance

Table 2 presents the reeling performance of the bivoltine hybrid cocoons as affected by storage duration. Results revealed that the reelability percentage ranged from 81.19% (T₁)- 88.38% (T₂). Results revealed are not significantly different at 0.05 level in terms of reelability percentage. Galano (2015) revealed that reeling performance of DMMMSU 406 silkworm hybrid cocoons obtained the highest reelability percentage with 85.86%. Reeling performance of cocoons and quality of raw silk are found to be very good in the case of cocoons spun under 27°C and 70% RH with air circulation of about 50cm/s. Temperature during rainy season temperature and humidity maintained during cocoon spinning will influenced the cocoon (sericin) quality, particularly behavior of sericin during cooking. It was the reason why cocoon quality, and reelability from the same race deteriorates (with high humidity) affects the reeling performance and quality of raw silk (Subhas and Somashakar, 2004).

Raw silk percentage result revealed significant difference among treatment means. T₀ (no storage) produced the highest raw silk percentage of 27.90% followed by T₃ (22.83%) which is comparable with T₁ (20.80%) and T₄ (21.07%). The lowest mean observed was 18.77% (T₂). The result implies that the sericin is disaturated as the duration of storage increases. The result also conformed to the result of the study of (Libunao, 1997).

T₂ recorded a renditta of 13.0(kg) but comparable to T₁ (8.67kg), T₄ (11.33kg) and T₃ (10.33 kg). Comparison of means using the Honest Significant Difference (HSD) Test revealed significant differences on the renditta among the various treatments. However, renditta is defined as the amount of cocoon required to produce one kg of silk yarn and a lower renditta indicates better quality of silk yarn.

Reeling waste included frison (brush silk), pellet (pupa cloth) and unreelable cocoons.

T₁ (1 mo.) registered the highest reeling waste percentage with 53.30% but comparable to T₀ (no storage) with 50.50%. The lowest was recorded from T₄ (6 months) with 24.43% but comparable to T₃ (5 months) with 27.73%. This is in consonance with the findings of Libunao (1997), that the reeling performance of the bivoltine cocoons in terms of reelability percentage and percentage of reeling waste, were not affected up to 4months duration of storage. The reeling characteristics of cocoons as influenced by the cocoon quality and cooking temperature in multi-end reeling machines are the single cocoon filament was significantly longer with

normal cocoons cooked at 86±2°C (824.5m), normal cocoon cooked at 90±2°C (759.9m) and it was shorter in uji-pierced cocoons cooked at 90±2°C (362.9m) (Ramesh, 2002).

Cocoons produced using different cropping practices such as organic vam, organic vamri, leisa vamri and conventional method were reeled, the reelability percentage of organic vam has the highest percentage of 93.94%, obtained the lowest renditta of 9.21kgs and lesser reeling waste percentage of 36% (Galano, 2020).

Table 2. Reeling performance of the bivoltine hybrid cocoons as affected by storage duration.

Treatment	Reelability Percentage (%)	Raw silk yield (%)	Renditta (Kg)	Reeling waste percentage (%)
T ₀ - no storage	85.85	27.90 a	8.67 b	50.50 a
T ₁ - 1 month	81.19	20.80 bc	11.67 a	53.30 a
T ₂ - 3 months	88.38	18.77 c	13.00 a	40.90 b
T ₃ - 5 months	83.33	22.83 b	10.33 ab	27.73 c
T ₄ - 6 months	83.33	21.07 bc	11.33 ab	24.43 c
Level of significance	Ns	*	*	*
CV (%)	3.82	6.40	9.39	5.0

All means followed by the same letter in a column are not significantly different at 0.05 level (HSD).

Raw silk quality

Table 3 presents the raw silk quality of the bivoltine (DMMMSU 408) hybrid cocoons as affected by storage duration. Result showed no significant difference among various treatment means on yarn number that ranged from 26.46 (T₁)- 35.64 (T₄). The unevenness percentage result revealed significant difference observed among various treatments. The unevenness registered ranged from 7.02 % (T₃) – 13.70% (T₁). The result implies that the variation in cocoon cooking condition would influenced the process of unwinding of cocoon filament from the shell which in turn has an effect on reeling performance and also on the quality of raw silk. The result also conformed to the result of the study of (Radhalakshmi *et al.*, 2013).

The sericin shell, traditionally referred to as cocoon cooking, affect cocoon reeling and the quality of the raw silk (Ting-Ting Cao, 2014).

In the study conducted by Chattopadhyaya *et al.*, 2023, it was carried out that no significant different was noted for shell weight and filament length after storage. The bivoltine race facilitate production of quality cocoons and if reeled with proper processing parameters can significantly improve the reeling performance and quality of raw silk compared to multi-bivoltine cocoons reeled silk. The cocoon reeling and quality characteristics of raw silk yield from bivoltine hybrid cocoons are significantly better compared to multi-bivoltine crossbred cocoons (Harirag, 2006).

Table 3. Raw silk quality of the sample test of bivoltine hybrid cocoons as affected by storage duration.

Treatment	Unevenness %	Yarn number (Denier)
T ₀ – no storage	12.09	28.56
T ₁ –1month	13.70	26.46
T ₂ –3months	13.09	34.46
T ₃ –5 months	7.02	31.02
T ₄ - 6months	7.05	35.64
Level of Significance	*	Ns
CV %	26.90	26.18

All means followed by the same letter in a column are not significantly different at 0.05 level (HSD).

Profitability analysis

Table 4 shows the profitability analysis of raw silk from bivoltine silkworm hybrid cocoons as affected by storage duration. Unstored cocoons (T₀) produced the highest raw silk yield of 0.846kgs, with a total gross income of ₱3,488.00, highest additional gross income from waste of ₱120.00, net income amounting to ₱1,614.30 and a return on

investment of 86.15%, but registered the lowest break even cost (BEC) of ₱2,225.30. Profitability analysis in the production of 21 denier showed that the higher the raw silk produced, the lower the break - even cost, higher net income will be achieved and higher Return on Investment (ROI) will be attained.

Table 4. Summary table on the profitability analysis of raw silk product from cocoon as affected by storage duration.

Treatment	Raw silk yield (kg)	Gross income (₱)	Add'l gross income from wastes (₱)	Total gross income (₱)	Total production cost (₱)	Net income (₱)	ROI (%)
T ₀ –No Storage	.846	3,368.00	120.00	3,488.00	1,873.70	1,614.30	86.15
T ₂ – 1 month	.623	2,492.00	120.00	2,612.00	1,893.20	718.80	37.96
T ₂ – 3 months	.566	2,264.00	98.40	2,362.40	1,901.95	460.00	24.21
T ₃ – 5 months	.685	2,740.00	66.56	2,806.56	1,886.60	919.96	48.76
T ₄ – 6 months	.632	2,528.00	58.64	2,586.64	1,887.90	698.74	37.01

Conclusion

Based on the results of the study, it was concluded that the different storage durations tested did not significantly affect cocoon characters such as filament length and denier size of DMMMSU 408 silkworm hybrid. In terms of reeling performance of DMMMSU 408 cocoons, there was no significant difference observed among treatment means on reelability percentage. However, all treatments significantly affected raw silk yield, renditta and

reeling waste percentage, with comparable results. The different cocoon storage durations did not affect the raw silk quality in terms of yarn number (Denier) of the bivoltine silkworm hybrid (DMMMSU 408) while its unevenness (%) presented a significant effect. Result of profitability analysis revealed that unstored DMMMSU 408 cocoons obtained higher ROI.

Generally, the cocoons of DMMMSU 408 silkworm hybrid can be stored up to 6 months to attain quality cocoon characters such as filament length and filament size. However, it manifests a higher reeling performance if cocoons are not stored. Hence, to produce higher raw silk yield and increased economic return, cocoons should be processed immediately without storage.

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Declaration of interests

All the authors declare no conflicts of interest.

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