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A Comparative Study of Drying of Muga Cocoons using Convection and Infra-red Heating Method

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ABSTRACT

Background: Muga is an exclusive golden-colored silk produced by the Antheraea Assamensis silkworm species in North-east India. In the silk processing stage, drying of Muga silkworm cocoon is essential to prevent the pupa from emerging from the shell and to preserve the cocoons for a longer period (3-6 months). It is necessary to reduce the potentially harmful high moisture level in the cocoon shell and pupa body to an optimum or safe level of moisture content (6-12%). In India, the natural sun drying method is the most common method to preserve Muga cocoons for a longer period. Considerably losses may occur using the sun-drying method due to various effects such as rodents, insects, rain, microorganisms, excessive temperature, *etc*. To address this issue the study was conducted to improve the quality of Muga silk yield using a comparative study between Convection and IR heating methods for cocoon drying.

Methods: In this study, Muga cocoons were dried properly at optimum temperature (50-100°C) to obtain a safe moisture level for getting quality Muga silk. The drying of the Muga cocoon is processed using convection (1 kw) and Infrared (650 watts) modes of heating for the same duration of time. Muga cocoons were placed in a drying chamber initially at a high temperature (100±5°C) using both convection and Infrared heating methods separately to maintain the moisture content to an optimum level. It took approximately 75 minutes to obtain the temperature 100 from room temperature and every 15 minutes temperature measure was recorded for both methods and compared. The parameters studied were temperature, time, cocoon weight, shell weight, shell ratio and moisture content. These parameters were examined, evaluated and compared for both the Convection and IR heating methods.

Result: The comparative study results indicated that the performance of the studied cocoon parameters namely temperature, cocoon weight, shell weight, shell ratio and moisture content are approximately similar for both convection and IR heating methods. Moisture content was maintained at the optimum range (6-12%) for both the convection and IR methods. The study provided a better performance using the IR heating method as compared to convection heating concerning energy consumption and safety for the same duration of time. Energy consumed by a 1 kW convection heater is 1.25 kWh, whereas energy consumption in a 650-watt IR heater is 0.8125 kWh.

Key words: Antheraea Assamensis Helfer, Convection, Infrared, Muga cocoon, Shell ratio, Shell weight.

INTRODUCTION

Assam has been popular for Muga silk production since ancient times. Muga silkworm, Antheraea Assamensis Helfer is the producer of Muga silk in Assam. The purpose of *Muga* culture is the production of Muga silk fibre or Muga yarn. Among the non-mulberry silks, Muga is the most critical, particularly for two reasons *viz*. its natural color and the exclusivity of the region. The naturally golden-colored strands of Muga silk are recognized worldwide as exclusive silk. From ancient times to date, India has been the only producer of this silk (Padaki *et al*., 2014). The origin of *Muga* culture is in Assam. There is a large number of Muga silk production in Assam. The production of Muga silk comprises several processing stages after harvesting. All the cocoons are dried and used as source material for the production of Muga silk fibre. Drying of cocoons is essential to prevent the pupae from transforming into a moth, which otherwise is killed and comes out of the cocoon by piercing through the shell. Thus, the cocoon shell becomes useless. Cocoons can be stifled either through steam or hot air stifling methods, to kill the pupae (Hendaw, 2017). The main purpose of drying *Muga* silkworm cocoons is to kill pupae and to reduce the potentially harmful moisture content to a safe level, enabling the cocoons to preserve for a longer period under normal temperature and humidity (6-12 months) (Hegazy *et al*., 2006). The major source of moisture is inside the pupa (75-79%) and the remaining moisture is in the cocoon shell (11-12%). To preserve the cocoons for a longer period drying must be done properly to maintain the moisture at an optimum level (approximately 8-12%). Sun drying is the traditional method of drying *Muga* cocoons in Assam. The

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disadvantage of this method is that it cannot control heat, cleanliness and heating time. Therefore, cocoon quality will deteriorate (Wiset *et al*., 2018). This method has a negative effect on the sericin layers of these cocoons and decreases the quality characteristics due to exposing cocoons to ultraviolet and infrared rays, which in turn, increase the total reeling losses of cocoons. It was also indicated that the silk filament loses about 50% of its strength if exposed to ultraviolet rays for 6 hours.

Several methods of artificial drying have been tried to kill the pupae, by spreading cocoons on perforated mats or in a wire box where they are exposed to steam or water for three hours. After that, the cocoons are subjected to drying. but the method most commonly used for pupae-killing and drying cocoons involves blowing heated air at 50 to 102+2°C vertically through a grill on which the cocoons are placed in mesh bags (Hegazy *et al*., 2006). To check the quality of *Muga* cocoons some parameters are checked manually like shell ratio, cocoon weight, shell weight, *etc*.

When fresh cocoons are placed in the drying machine, water in the cocoon shell evaporates rapidly and heat enters the pup through the shell. After the pupa is dead, generally 10 minutes later the pupae's body evaporates very quickly. Cocoon drying continues gradually and when the desired amount of water has evaporated, the speed of drying is reduced relative to the decrease of moisture until drying is completed. The drying temperature impacts the cocoon shell and its resultant raw silk yield. For example, if the temperature exceeds certain limits, sericin degenerates and concurrently efficiency, reelability and raw silk percentage decline. It is advisable to observe the following limits: For hot air drying 115±5°C is recommended in contact with the cocoon. For steam-heat drying 102±2°C is the preferred guideline (Jasur *et al*., 2018). While setting a higher finishing temperature increases drying efficiency, the melting point of sericin declines when the drying rate exceeds 50 percent. The finishing temperature should be reduced gradually from 60°C in hot air drying and 55°C in steam-heat drying (Hussain *et al*., 2011).

Drying cocoons using IR treatment would determine an optimum mode for energy saving and control the technological processes of the drying equipment for producing high-quality and environment-friendly products (Zulpanov *et al*., 2022).

Muga cocoon drying using convection heating and IR heating methods was studied in this paper. Here, a comparative study of convection drying and IR drying methods was carried out. *Muga* cocoons were placed separately in a 1000-watt convection heater chamber and a 650-watt Infrared heater chamber. The temperature of the heating chamber was monitored and controlled to obtain an optimum level of moisture content (8-12%) to properly dry the *Muga* cocoons. Finally, the quality of the dried cocoons was checked manually separately for both convection and Infrared heating methods by checking three parameters: cocoon weight, shell weight, shell ratio and moisture content.

The objective of this work is to study and compare the drying of Muga cocoons used for convection and IR mode of heating at the *Muga* cocoon drying stage for Muga silk production. The study was based on designing, developing and implementing a drying system to provide an automated controlled environment during the processing of *Muga* cocoons. The study would try to emphasize some physical parameters like temperature, cocoon weight, shell weight, shell ratio and moisture content maintaining optimum value during the processing of *Muga* cocoons. It would enhance product quality, processing duration reduction and simplify the process.

MATERIALS AND METHODS

Samples of freshly harvested Muga cocoons were collected from different regions of Assam. The experiment was conducted from November 2022 to February 2023 at the laboratory of the Department of Electrical and Electronics Engineering, Assam Don Bosco University, Guwahati, Assam. Muga cocoon samples were selected from the Katia crop. While conducting the experiment the room temperature of 27°C and relative humidity of 75% were observed inside the room.

The studied drying system consisted of a drying chamber enclosed with three stacks made of netted steel. The mechanical dryer included five main parts: the drying frame, a drying rack, a heating source with a temperature control unit (Energy regulator) and an air-cooling system (processor fan). A 50 × 50 cm^2 heating chamber was designed with plain sheet metal. At the bottom of the chamber, the heater was placed. The main dryer frame was alternately attached to two heating sources (Convection and Infrared). A 1000 W Convection heater and a 650 W Infrared heater were used as heating sources alternately inside the drying chamber and the performance of both was observed. An 8.5-inch and a 10-inch steel netted tray were placed in a stack as shown in Fig 1(a, b and c). An 8 mm steel shaft was attached at the centre of the stacked tray for the continuous shuffling of the Muga cocoons while drying. Two processor fans were attached on two sides of the chamber for uniform cooling of Muga cocoons and air circulation inside the chamber. The system is shown in Fig 1.

The block diagram of the studied system is shown in Fig 2. A 0-100 scale (1000 Watts) energy regulator was used to control the temperature of the heating sources. The heater (Convection or infrared) was installed inside the heating chamber. The air-cooling system consisted of two processor fans (50/60 Hz, 0.08A) installed inside the heating chamber. An industrial thermometer in the range of 0-110°C was installed at the back side of the heating chamber to continuously monitor the temperature during the drying of Muga cocoons.

Since sericin, which binds the two fibroin threads, is also a protein, its physical, mechanical and chemical properties depend on the drying mode and storage conditions of the cocoons. Sericin begins to dissolve in water at a temperature of about 70°C, soluble in acid and base solutions. The correct choice of drying mode for cocoons is explained by the effect of the drying process on sericin properties. Sericin scouring is performed by a thermochemical process known as degumming (Choudhury *et al*., 2016). Analyzing the initial processing of cocoons, the hot air method showed the solubility of sericin in the cocoon shell at 0.97%. However, the fumigation and Infrared methods showed the solubility as 0.85% and 0.75% respectively. Therefore, hot-air treatment had a significant effect on the melting of the sericin in the shell. The fumigation method of anesthetizing the sponge and drying it in the shade retains the properties of the shell well, but the release of chemicals retained in the cocoons during the drying stage would have a negative impact on the health of workers. Complete drying in the shade by anesthetizing a live cocoon sponge under the influence of infrared light ensures good bending, evaporation and good rinsing during the rinsing process due to the well-preserved technological properties of sericin (Gulamov *et al*., 2021).

Experimental procedure

a) Experiment using convection heating and Infra-red heating method

Initially, the experiment was conducted using a convection heater for drying Muga cocoons in four batches. Then the heater was replaced by a 650-watt Infrared heater. In both treatments, each batch contains 10 cocoons. 10 cocoons were placed in the medium tray and bottom tray for drying and the upper tray was used to cover the cocoon to protect them from falling down the tray. Before placing the cocoons in the tray their weight was recorded using a digital balance. When the heater was ON immediately heating chamber door was immediately closed such that no external air could be passed to it. Then the temperature of the closed chamber started to increase and the internal temperature was monitored every 15 minutes using the thermometer.

The heat treatment was stopped as soon as the temperature reached its desired level and the two processor fans inside the dryer were switched on immediately for uniform circulation of air. When the dryer would reach its cooling temperature of approximately 50°C the door would be opened and the dried cocoons would be collected from the trays. For each treatment, the collected cocoons were weighed using a digital balance after and before drying to calculate different cocoon parameters. The energy consumed by the Infrared heater was very much less as compared to the convection heater.

Single cocoon weight is the average weight of the cocoon (Nagadevara, 2004). In the present study, it was calculated by selecting 10 cocoons at random and this sample represents the entire quality of individual replicas. The cocoon weight was measured in grams. Shell weight is the average of the single shell weight (Nagadevara, 2004). Shell is the portion of the cocoon after removing the pupae. The average single shell weight was calculated from 10 shells used for the measurement of cocoon weight. This was also measured in grams. Shell Ratio is the ratio of the

a b c

(a) the drying frame, b) inside the chamber with an IR heater and c) inside the chamber with a convection heater.

Fig 1: Images of the drying chamber.

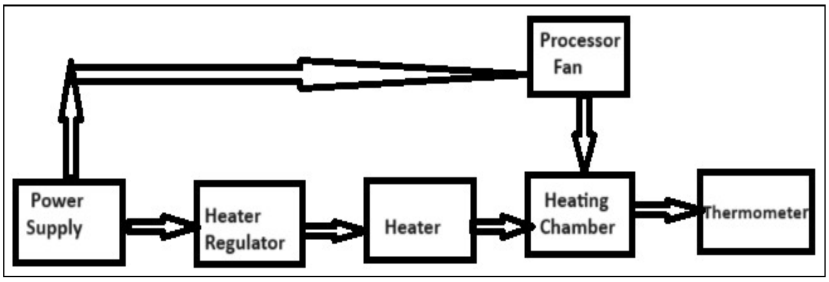

Fig 2: Block diagram of the proposed drying system.

weight of the shell to the weight of the cocoon and it is expressed as a percentage. The quantity of raw silk produced from each cocoon depends on the shell ratio (Nagadevara, 2004).

$$S.R.\% = \frac{\text{Weight of cocoon shell}}{\text{Weight of cocoon}} \times 100$$

The moisture content of the dried Muga cocoons could be calculated using the formula:

$$\%\text{Moisture content} = \frac{w - d}{d} \times 100$$

Where:
w= Initial weight of the cocoon.
d= Dried weight of the cocoon.

b) Energy calculations

Energy of the convection and IR heater can be calculated from the power of the heater. Power is the rate of energy conversion or transfer per unit of time.

Let the energy and power consumed by the be E and P respectively.
Therefore:

$$E = P \times t$$

Where:
T= The period of the heater.

RESULTS AND DISCUSSION

a) Determination of cocoon parameters

i) Effect of temperature

The quality of the muga cocoon was determined using three parameters namely cocoon weight, shell weight and shell ratio. An Average of 10 cocoons were placed inside the drying chamber using two heating methods separately: convection heating and IR heating. For both methods, the temperature was monitored every 15 minutes until it reached 100°C. Fig 3 shows the temperature changes concerning time in both convection and IR heating.

Fig 4 shows the Energy consumed by a 1kwatt convection heater for the period of 1.25 hours is given as = (1 × 1.25) kWh= 1.25 kWh. Similarly, energy consumed by a 650-watt(0.650kW) IR heater for the period of 1.25 hours is given as (0.650 × 1.25) KWh= 0.8125 kWh. Hence, the IR heating method was observed to be a more energy-efficient method for drying Muga cocoons.

ii) Cocoon weight, shell weight and shell ratio

After properly drying the Muga cocoons using convection and IR heating methods, three parameters namely single cocoon weight (SCW), shell weight (SW) and shell ratio (SR) were calculated and compared for two methods. The observations were carried out in four batches, each with 10 cocoons and the average value of each parameter was calculated. The performance of different cocoon parameters was analyzed statistically for both Convection and IR heating methods.

Statistical analysis of Cocoon parameters for the Convection and IR method such as cocoon weight, shell weight, shell ratio and moisture content were shown in Table 1,2,3 and 4 respectively for four batches. It can be observed from all the above tables that the Muga cocoon parameters namely cocoon weight, shell weight, shell ratio and moisture content measured using the convection method and IR heating method were not significantly different. The comparative study provided us with the performance of all these parameters during the drying of Muga cocoons using the convection and IR heating methods. From Table 1,2,3 and 4, it was observed that the standard deviation and SEM for cocoon weight, shell weight, shell ratio and moisture content were minimal in the IR method. The standard deviation for all parameters would be more precise in the IR heating method. It was also observed that SEM was minimum or very close to zero in the IR method for all studied parameters *viz*. cocoon weight, shell weight, shell ratio and moisture content.

The change in shell ratio concerning cocoon weight is shown in Fig 5. Here it can be observed that the highest shell ratio (9.2%) for convection heating is obtained for cocoon weight 1.32 gm and the highest shell ratio (9.5%) for IR heating is obtained for cocoon weight 1.35 gm. The comparative study between IR and Convection heating methods showed no significant difference in the obtained results. The change in shell ratio concerning shell weight is

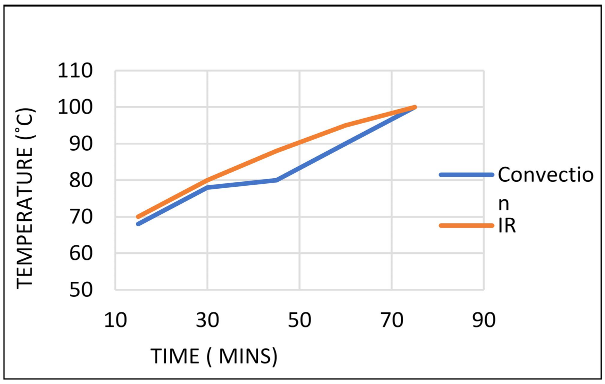

Fig 3: Temperature-T graph for convection and IR.

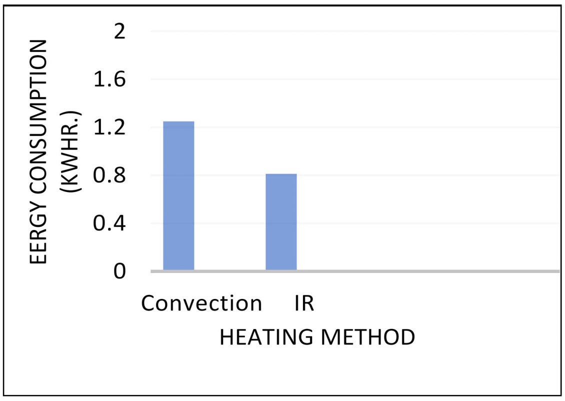

Fig 4: Energy consumption of convection and IR.

shown in Fig 6. As shown in Fig 6 the highest shell ratio for convection heating is 9.5% for shell weight 0.0763 gm and for IR is 9.43% for the same shell weight. In Fig 7 the moisture content changes with cocoon weight in a similar manner for both convection and IR heating methods. It can be observed from the study that the moisture content measured for both methods is within the safe range (6-12%) which enables the cocoons to preserve for a longer period and avoid the loss of cocoons due to other environmental factors.

Table 1: Statistical analysis of cocoon weight for convection and IR method.

Heating method	Batch	Cocoon weight (gm)	Mean (gm)	Standard deviation	Standard error of mean (SEM)
Convection	1	1.01	1.032	0.0172	0.0086
	2	1.029			
	3	1.041			
	4	1.05			
IR	1	1.029	1.037	0.0121	0.0051
	2	1.029			
	3	1.041			
	4	1.05			

Table 2: Statistical analysis of shell weight for convection and IR method.

Heating method	Batch	Shell weight (gm)	Mean (gm)	Standard deviation	Standard error of mean (SEM)
Convection	1	0.092	0.092	0.0009	0.0004
	2	0.09277			
	3	0.0942			
	4	0.0927			
IR	1	0.0927	0.093	0.0007	0.0003
	2	0.0927			
	3	0.0942			
	4	0.0927			

Table 3: Statistical analysis of shell ratio for convection and IR method.

Heating method	Batch	Shell weight (gm)	Mean (gm)	Standard deviation	Standard error of mean (SEM)
Convection	1	9.175	9.088	0.0627	0.031
	2	9.09			
	3	9.059			
	4	9.03			
IR	1	9.09	9.067	0.0271	0.013
	2	9.08			
	3	9.08			
	4	9.03			

Table 4: Statistical analysis of moisture content for convection and IR method.

Heating method	Batch	Moisture content (%)	Mean (gm)	Standard deviation	Standard error of mean (SEM)
Convection	1	9.98	8.681	0.966	0.482
	2	7.641			
	3	8.752			
	4	8.51			
IR	1	8.24	8.421	0.224	0.112
	2	8.24			
	3	8.696			
	4	8.518			

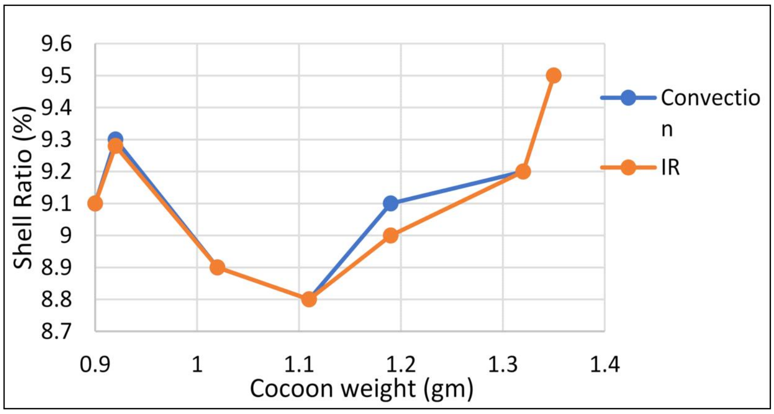

Fig 5: Cocoon weight- Shell ratio graph.

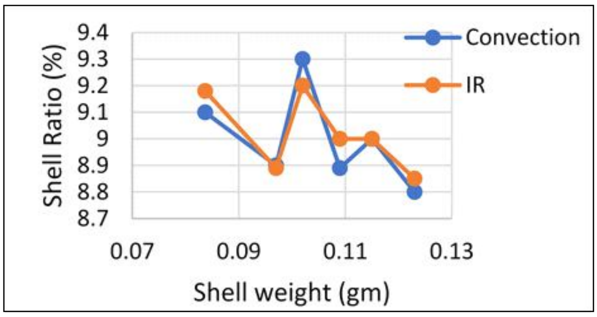

Fig 6: Shell weight-shell ratio graph.

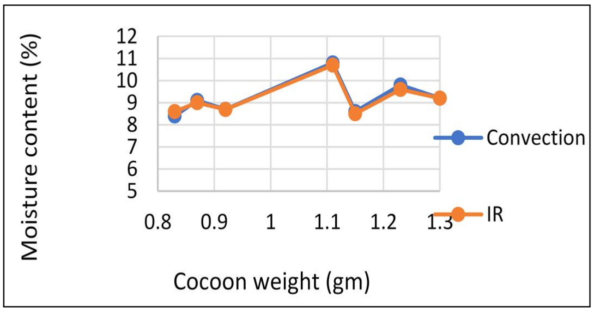

Fig 7: Cocoon wight-moisture content.

It is known that the proper mode of heating method to dry the Muga cocoons depends on the effect of the drying process on the cocoon parameters. The study implied that the performance of the IR heating method would be more efficient than that of the Convection method of the cocoon weight, shell weight, shell ratio and moisture content (Gulamov *et al*., 2021). The IR heating method consumed less power during the drying process as compared to the Convection method.

CONCLUSION

From the experimental results conducted for drying Muga cocoons using convection and IR heating methods can be concluded that Infrared heating will be a bit faster drying method than convection heating. The energy consumed by the IR heating is 0.8125 kWh. and energy consumed by the convection heating is 1. 25 kWh.Therefore it is observed that using an Infrared heater gives more efficient heating at a very low cost compared to convection heating. The Infrared heater generates very clean and low harmful emissions. It provides thermal comfort like heating the floor zone, not the ceiling.IR does not heat the air to circulate the chamber, rather it focuses only to heat the nearby objects.IR heating provides a better alternative to convection heating for drying Muga cocoons in the production of Muga silk. There is no significant difference seen in the study concerning the performance of the studied cocoon parameters, but the IR heating method provides a better alternative method to convection because of less consumption of energy and it provides a safe environment inside the drying chamber as heat generation of IR heater is very less. Due to this, it does not damage the cocoon and the cocoon parameters retain their quality after drying.

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