Influence of cooking and adjustment treatments on reeling and quality characteristics of raw silk

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Received 4 October 2002; revised received 7 March 2003; accepted 22 May 2003

The hot air dried Indian multi-bivoltine cocoons (PM x NB, D2 race) treated at different cooking temperatures, cooking durations and adjustment temperature profiles in pan system of cooking have been found to have significant influence on reeling characteristics, viz. grooving and efficiency, reeling stability, raw silk percentage, raw silk recovery percentage, reeling tension, waste generated during reeling, pedale weight generated and degumming loss percentage of silk waste, and on quality characteristics, viz. neatness, cleanliness, cohesion and degumming loss percentage of raw silk. However, the complete cooking and reeling do not show significant influence on sericin dissolution during cooking and reeling, tenacity and elongation. The study clearly shows that the complete cooking of cocoons in pan system of cooking using five treatment temperatures effectively softens the sericin uniformly in different layers of the cocoon shell compared to single temperature treatment, thus facilitating the improved reeling performance from hot air dried Indian multi-bivoltine cocoons. The cocoon cooked using the retting temperature of 50°C for 1 min, high permeation temperature of 90°C for 2 min, low permeation temperature of 60°C for 1 min followed by the cooking temperature of 93-95°C for 2 min and adjustment temperature of up to 60°C yields better reeling performance and quality of raw silk.

Keywords: Degumming, Multi-bivoltine cocoon, Silk

IPC Code: Int. Cl. D01B 7/00

1 Introduction

Suitable method for releasing the cocoon filaments from the agglutination points (crossover points) between sericin layers has effectively been developed using complete cocoon cooking process. The process of cooking consists of the following stages:

- Retting in which the cocoon shells are moistened with hot water.
- High permeation temperature in which air inside the cocoon is made to expand and expel to create a pressure difference inside the cocoon.
- Low permeation temperature in which the cocoon is suddenly treated with low temperature water so that the cocoon can suck water through its layers.
- Cooking in which water inside the cocoon is made to exit through the cocoon layers so that the inner cocoon layer sericin is softened effectively.

- Adjustment in which the temperature of water is gradually reduced to enable the cocoon to absorb maximum amount of water.

During the above operations, the cocoon shell sericin is softened suitably so that the cocoon filament unwinds smoothly without any break in the reeling process. The cooking treatment is of extreme importance since it decides the quantity of water absorbed into the cocoon (semi-sunken / sunken system of reeling), waste production level, sericin swelling level adjustment and quality of raw silk reeled. Cooking technology was developed with a view to improve quality of raw silk and at the same time to reduce silk waste. A cooking technology involving pretreatment, cooking at 98°C for about 2 min with gentle boil followed by adjustment and finishing was developed. This method improved raw silk percentage and reduced the cleanliness defects of raw silk.

Systematic studies to understand the processes of cocoon cooking were carried out in Japan. In these studies, the improvement in raw silk recovery was focused considering the concept of V-type conveyor cocoon cooking machine, in which the retting, permeation, steam cooking and adjustment
temperatures could be controlled. This helps in setting the parameters for different quality cocoons. A cooking technique employing infrared heating in the cooking part was also discussed\textsuperscript{15,16}. The inner layer cooking is not achieved during permeation treatment, but it is achieved in cooking and adjustment treatments. The available literature clearly confirms that the complete cooking processes improve both the productivity and quality of raw silk.

Nakagawa\textsuperscript{17} developed a cooking technology involving pretreatment, cooking at 98°C for about 2 min with gentle boil followed by adjustment and finishing. This method improved raw silk percentage and reduced the cleanness defects of raw silk. Shimazaki\textsuperscript{18} showed that the quality of raw silk is greatly influenced by cocoon cooking, reeling and allied operations of raw silk production. He observed that the cleanness and neatness characteristics are improved by using suitable cooking temperature profiles. Matsumoto\textsuperscript{19} studied the influence of drying temperatures on raw silk quality, i.e. neatness and cleanness characteristics. Kinoshita \textit{et al.}\textsuperscript{20-22} optimized the cooking methodology using multivariate analysis. They inferred that the raw silk quality characteristics show significant improvement, depending on cooking temperature profiles.

The available literature clearly confirms that complete cooking processes improve the productivity and quality of raw silk. However, the standardization of temperature profile for cooking and adjustment treatment suitable for hot air dried multi-bivoltine cocoons has not been reported so far. Hence, an attempt has been made in the present work to study the influence of cooking temperature, cooking duration and adjustment temperature profiles with constant retting and permeation treatments of hot air dried Indian multi-bivoltine cocoons on reeling and quality characteristics.

\textbf{2 Materials and Methods}

\textbf{2.1 Materials}

Commercially available multi-bivoltine cocoons (PM \(\times\) NB,D\(_2\) race) reared in Karnataka State, India, in June 1998 have been used for the study. Water having 7 pH, 80ppm hardness and 150ppm M-alkalinity was used for the study.

\textbf{2.2 Drying}

The cocoons were dried in batch type hot air drier following the temperature pattern of 130 -120 -110 -100 - 90°C for a period of 5 h. The degree of drying achieved was 36 - 38%.

\textbf{2.3 Retting}

The dried cocoons were taken in a cage and then retted at 50°C for 1 min in first pan of cooking.

\textbf{2.4 Permeation}

The retted cocoons were immediately treated at high permeation temperature of 90°C for 2 min in second pan of cooking followed by treatment at low permeation temperature of 60°C for 1 min in third pan of cooking.

\textbf{2.5 Cooking and Adjustment}

The retted and permeated cocoons were immediately treated at cooking temperature of 93°C, 95°C and 97°C for 2 min and 3 min in second pan of cooking followed by adjustment treatment by pouring cold water in second pan itself. After the cocoons were cooked, they were left in the same bath without steam supply for 1 min. Then small quantity of water was added to the bath for 1 min to decrease the temperature from 93°C to 90°C. The addition of water to the bath was increased gradually so that in a period of 2 min the temperature of water reduces to 80°C, 70°C and 60°C. The cocoons were kept at the same temperature for 1 min and then removed from the cooking bath for brushing. The total period of adjustment was thus 4 min and the cooking was carried in a pan system of cooking. The details of cooking temperature and duration are given in Table 1.

\begin{table}[h!]
\centering
\begin{tabular}{|l|l|}
\hline
\textbf{Particular} & \textbf{Treatment temperatures (durations)} \\
\hline
Retting & 50°C (1 min) \\
High permeation & 90°C (2 min) \\
Low permeation & 60°C (1 min) \\
Cooking and adjustment & 93°C (2min) and 93°C to 60°C in 4min \\
& 93°C (2min) and 93°C to 70°C in 4min \\
& 93°C (2min) and 93°C to 80°C in 4min \\
& 95°C (2min) and 95°C to 60°C in 4min \\
& 95°C (2min) and 95°C to 70°C in 4min \\
& 95°C (2min) and 95°C to 80°C in 4min \\
& 97°C (2min) and 97°C to 60°C in 4min \\
& 97°C (2min) and 97°C to 70°C in 4min \\
& 97°C (2min) and 97°C to 80°C in 4min \\
& 93°C (3min) and 93°C to 60°C in 4min \\
& 93°C (3min) and 93°C to 70°C in 4min \\
& 93°C (3min) and 93°C to 80°C in 4min \\
& 95°C (3min) and 95°C to 60°C in 4min \\
& 95°C (3min) and 95°C to 70°C in 4min \\
& 95°C (3min) and 95°C to 80°C in 4min \\
& 97°C (3min) and 97°C to 60°C in 4min \\
& 97°C (3min) and 97°C to 70°C in 4min \\
& 97°C (3min) and 97°C to 80°C in 4min \\
\hline
\end{tabular}
\end{table}
2.6 Brushing
The cooked cocoons were brushed at 80°C in mechanical brushing unit and then transferred to reeling basin for picking at 45°C.

2.7 Reeling
Three hundred good cocoons were selected for conducting reeling test and the test was conducted as per the procedure followed in cocoon testing houses of Japan. The cooked cocoons were then reeled on 3 ends of multi-end reeling machine, maintaining fixed number of cocoons to a reeling end. The temperature of reeling bath was maintained at 45°C and reeling speed at 120 m/min (ref. 24).

2.8 Quality and Reeling Characteristics
The raw silk after reeling was assessed for quality characteristics. The testing was conducted as per the International Silk Association (ISA) standards. Among the eleven characters used for grading of raw silk, five characters, viz. neatness, cleanliness, tenacity, elongation and cohesion, were determined. The raw silk samples produced were also subjected to degumming loss test. The testing equipments, viz. seriplane tester (Okamoto Kasakusho, Toyo Sangyo Consulting Inc., Japan), tensile tester (Instron Company Ltd, U K) and Duplan cohesion tester (Toyo Sangyo Consulting Inc., Japan), were used for the study.

The quality data, viz. grading end efficiency, average filament length, non-broken filament length, reeling temperature, raw silk percentage, raw silk recovery percentage, waste % on silk weight and pelade weight, were observed while reeling with different combinations of treatments. The sericin dissolved during the process of cooking and reeling was calculated from the weights of shell, silk and other waste produced during reeling.

The quality data, viz. neatness, cleanliness, tenacity, elongation and cohesion characteristics, were observed after treating raw silk reeled with different combinations of treatments. The silk waste obtained during cooking and the raw silk produced were treated with sodium carbonate solution (0.5%) for about 20 min at 92°C and the weight loss was observed. From the difference in weights of the sample, the degumming loss of the silk waste and raw silk was found. The data thus obtained were analysed statistically using SPSS package.

3 Results and Discussion
The analysis of variance results of reeling and quality characteristics of Indian multi-bivoltine cocoons based on cooking and adjustment temperature treatments are shown in Tables 2 and 3. The mean results of the reeling and quality characteristics of the Indian multi-bivoltine cocoons treated with different cooking temperatures and durations are given in the Tables 4 - 7. The mean reeling and quality characteristics results of the cocoons treated with different adjustment temperature profiles are given in Tables 8 and 9.

3.1 Analysis of Variance Results for Reeling Characteristics
The analysis of variance results (Table 2) show that the significant difference exists among cooking temperature, cooking durations and adjustment temperature profiles with regard to reeling characteristics, viz. grouping end efficiency, reelingability, raw silk, raw silk recovery, reeling tension, waste (%) on silk weight, pelade weight, sericin loss and degumming loss (%) of silk waste. From the results, it could be inferred that the cooking and adjustment temperatures are the significant factors which determine the reeling characteristics of Indian multi-bivoltine cocoons.

3.2 Effect of Cooking Treatments on Reeling Characteristics
3.2.1 Groping End Efficiency
The ANOVA results (Table 2) indicate that the grouping end efficiency is significantly influenced (5% level) by cooking temperature and adjustment temperature, whereas cooking duration does not have significant influence. It could be observed from Table 4 that as the cooking temperature increases from 93°C to 95°C, the grouping end efficiency is increased by 6.1%, whereas at boiling temperature the grouping end efficiency is decreased by 5.8%. The CD (critical difference) values at 5% level indicate significant difference between the cooking temperatures of 93°C, 95°C and 97°C with regard to grouping end efficiency, which is attributed to the loose shell structure of the cocoons. The results suggest that the cooking temperature of 95°C is highly suitable for Indian multi-bivoltine cocoons based on grouping end efficiency. The cooking temperature of 97°C gives lower grouping ends efficiency because of the less water penetration in the cocoons due to the entry suction phenomenon.
Table 8 shows that the adjustment temperature significantly influences the grooping end efficiency. It is interesting to note that as the adjustment temperature increases, the grooping end efficiency decreases by 6.3%. This is attributed to the fact that at higher difference in adjustment temperature profiles, more air pressure difference is created and more water permeates inside the cocoons. Thus, at 93-60°C adjustment temperature profile, more grooping end efficiency is observed.

Table 5 shows that as the cooking duration is increased from 2 min to 3 min, the grooping end efficiency.
Table 4—Mean results of reeling characteristics with reference to cooking temperature

<table>
<thead>
<tr>
<th>Cooking temp. °C</th>
<th>Groping end efficiency %</th>
<th>Reelability %</th>
<th>Raw silk %</th>
<th>Raw silk recovery %</th>
<th>Reeling tension g/den</th>
<th>Waste (%) on silk weight</th>
<th>Pelade weight g</th>
<th>Sericin dissolution %</th>
<th>Degumming loss of silk waste %</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>82.89 (6.66)</td>
<td>79.99 (7.97)</td>
<td>12.63 (0.51)</td>
<td>72.38 (3.74)</td>
<td>0.276 (0.0328)</td>
<td>23.69 (2.35)</td>
<td>0.0155 (0.0034)</td>
<td>5.56 (1.01)</td>
<td>31.92 (4.19)</td>
</tr>
<tr>
<td>95</td>
<td>87.94 (4.66)</td>
<td>89.21 (8.51)</td>
<td>13.64 (0.36)</td>
<td>78.15 (3.08)</td>
<td>0.267 (0.0303)</td>
<td>21.85 (2.01)</td>
<td>0.0150 (0.0025)</td>
<td>5.34 (0.984)</td>
<td>31.28 (4.14)</td>
</tr>
<tr>
<td>97</td>
<td>83.11 (6.12)</td>
<td>83.58 (10.21)</td>
<td>13.44 (0.36)</td>
<td>77.01 (3.06)</td>
<td>0.278 (0.0281)</td>
<td>23.15 (1.95)</td>
<td>0.0156 (0.0035)</td>
<td>5.82 (1.26)</td>
<td>26.88 (3.25)</td>
</tr>
<tr>
<td>CD at 5%</td>
<td>4.085 (0.276)</td>
<td>6.287 (0.0150)</td>
<td>2.542 (0.0288)</td>
<td>1.394 (0.0034)</td>
<td>2.35 (0.0034)</td>
<td>5.56 (0.984)</td>
<td>31.92 (4.14)</td>
<td>31.28 (4.14)</td>
<td>26.88 (3.25)</td>
</tr>
</tbody>
</table>

Values in the parentheses are standard deviation values. CD = Critical difference.

Table 5—Mean results of reeling characteristics with reference to cooking duration

<table>
<thead>
<tr>
<th>Cooking duration min</th>
<th>Groping end efficiency %</th>
<th>Reelability %</th>
<th>Raw silk %</th>
<th>Raw silk recovery %</th>
<th>Reeling tension g/den</th>
<th>Waste (%) on silk weight</th>
<th>Pelade weight g</th>
<th>Sericin dissolution %</th>
<th>Degumming loss of silk waste %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>85.96 (5.17)</td>
<td>87.50 (9.13)</td>
<td>13.36 (0.57)</td>
<td>76.51 (3.63)</td>
<td>0.266 (0.0288)</td>
<td>22.96 (2.44)</td>
<td>0.0137 (0.0015)</td>
<td>5.55 (1.25)</td>
<td>30.55 (3.60)</td>
</tr>
<tr>
<td>3</td>
<td>83.33 (6.97)</td>
<td>81.02 (9.04)</td>
<td>13.12 (0.62)</td>
<td>75.18 (4.50)</td>
<td>0.282 (0.0296)</td>
<td>22.83 (3.99)</td>
<td>0.0170 (0.0035)</td>
<td>5.94 (0.923)</td>
<td>29.50 (5.15)</td>
</tr>
<tr>
<td>CD at 5%</td>
<td>3.335 (0.0576)</td>
<td>2.133 (0.036)</td>
<td>0.250 (0.0288)</td>
<td>0.0171 (0.0035)</td>
<td>1.13 (0.0035)</td>
<td>0.652 (0.0015)</td>
<td>2.493 (0.0025)</td>
<td>2.493 (0.0025)</td>
<td>2.493 (0.0025)</td>
</tr>
</tbody>
</table>

Values in the parentheses are standard deviation values.

Table 6—Mean results of quality characteristics with reference to cooking temperature

<table>
<thead>
<tr>
<th>Cooking temp. °C</th>
<th>Neatness %</th>
<th>Cleanness %</th>
<th>Tenacity g/den</th>
<th>Elongation %</th>
<th>Cohesion (strokes)</th>
<th>Degumming loss of silk, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>84.61 (3.56)</td>
<td>90.00 (4.31)</td>
<td>3.787 (0.136)</td>
<td>19.20 (1.31)</td>
<td>77.83 (14.50)</td>
<td>25.28 (1.61)</td>
</tr>
<tr>
<td>95</td>
<td>88.42 (3.59)</td>
<td>93.44 (3.87)</td>
<td>3.801 (0.134)</td>
<td>19.46 (1.05)</td>
<td>88.50 (21.47)</td>
<td>26.77 (1.20)</td>
</tr>
<tr>
<td>97</td>
<td>86.86 (3.46)</td>
<td>90.89 (2.45)</td>
<td>3.772 (0.112)</td>
<td>19.70 (1.09)</td>
<td>88.56 (14.40)</td>
<td>24.94 (1.44)</td>
</tr>
<tr>
<td>CD at 5%</td>
<td>2.756 (0.0976)</td>
<td>2.621 (0.0976)</td>
<td>0.09776 (0.8096)</td>
<td>12.431 (1.035)</td>
<td>25.35 (1.18)</td>
<td>25.97 (1.93)</td>
</tr>
</tbody>
</table>

Values in the parentheses are standard deviation values.

Table 7—Mean results of quality characteristics with reference to cooking duration

<table>
<thead>
<tr>
<th>Cooking duration, min</th>
<th>Neatness %</th>
<th>Cleanness %</th>
<th>Tenacity g/den</th>
<th>Elongation %</th>
<th>Cohesion (strokes)</th>
<th>Degumming loss of silk, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>87.22 (3.78)</td>
<td>92.15 (3.72)</td>
<td>3.791 (0.125)</td>
<td>19.44 (1.06)</td>
<td>90.85 (14.43)</td>
<td>25.35 (1.18)</td>
</tr>
<tr>
<td>3</td>
<td>86.94 (3.83)</td>
<td>90.74 (3.92)</td>
<td>3.783 (0.132)</td>
<td>19.48 (1.26)</td>
<td>79.07 (18.62)</td>
<td>25.97 (1.93)</td>
</tr>
<tr>
<td>CD at 5%</td>
<td>2.250 (0.0798)</td>
<td>2.140 (0.0611)</td>
<td>0.0798 (0.6611)</td>
<td>10.150 (1.845)</td>
<td>25.35 (1.18)</td>
<td>25.97 (1.93)</td>
</tr>
</tbody>
</table>

Values in the parentheses are standard deviation values.
Table 8—Mean results of reeling characteristics with reference to adjustment temperature profiles

<table>
<thead>
<tr>
<th>Adjustment temp. profiles °C</th>
<th>Groping end efficiency</th>
<th>Reelability %</th>
<th>Raw silk %</th>
<th>Raw silk recovery %</th>
<th>Reeling tension g/den</th>
<th>Waste (% on silk)</th>
<th>Pelade weight g</th>
<th>Sericin degumming dissolution %</th>
<th>Degumming loss of silk %</th>
</tr>
</thead>
<tbody>
<tr>
<td>93-80</td>
<td>82.22</td>
<td>(8.95)</td>
<td>(0.64)</td>
<td>(4.84)</td>
<td>(0.0294)</td>
<td>(1.99)</td>
<td>(0.0032)</td>
<td>(1.20)</td>
<td>(0.0294)</td>
</tr>
<tr>
<td>93-70</td>
<td>84.33</td>
<td>(10.57)</td>
<td>(0.54)</td>
<td>(3.83)</td>
<td>(0.0293)</td>
<td>(2.19)</td>
<td>(0.0030)</td>
<td>(1.27)</td>
<td>(0.0293)</td>
</tr>
<tr>
<td>93-60</td>
<td>(4.98)</td>
<td>(8.91)</td>
<td>(0.62)</td>
<td>(3.66)</td>
<td>(0.0320)</td>
<td>(1.72)</td>
<td>(0.0034)</td>
<td>(0.755)</td>
<td>(0.0320)</td>
</tr>
<tr>
<td>CD at 5%</td>
<td>4.085</td>
<td>6.287</td>
<td>0.306</td>
<td>2.542</td>
<td>0.0219</td>
<td>1.394</td>
<td>0.00207</td>
<td>0.798</td>
<td>3.053</td>
</tr>
</tbody>
</table>

Values in the parentheses are standard deviation values.

Table 9—Mean results of quality characteristics with reference to adjustment temperature profiles

<table>
<thead>
<tr>
<th>Adjustment temp. °C</th>
<th>Neatness %</th>
<th>Cleanness %</th>
<th>Tenacity %</th>
<th>Elongation %</th>
<th>Cohesion (strokes)</th>
<th>Degumming loss of silk %</th>
</tr>
</thead>
<tbody>
<tr>
<td>93-80</td>
<td>85.81</td>
<td>90.22</td>
<td>3.786</td>
<td>19.20</td>
<td>81.28</td>
<td>25.06</td>
</tr>
<tr>
<td>(3.83)</td>
<td>(4.22)</td>
<td>(0.132)</td>
<td>(1.15)</td>
<td>(1.19)</td>
<td>(14.77)</td>
<td>(14.77)</td>
</tr>
<tr>
<td>95-70</td>
<td>86.81</td>
<td>91.28</td>
<td>3.762</td>
<td>19.69</td>
<td>85.89</td>
<td>25.83</td>
</tr>
<tr>
<td>(4.19)</td>
<td>(4.08)</td>
<td>(0.140)</td>
<td>(1.20)</td>
<td>(1.20)</td>
<td>(16.06)</td>
<td>(16.06)</td>
</tr>
<tr>
<td>97-60</td>
<td>87.28</td>
<td>92.83</td>
<td>3.839</td>
<td>19.48</td>
<td>87.72</td>
<td>26.09</td>
</tr>
<tr>
<td>(3.47)</td>
<td>(2.85)</td>
<td>(0.132)</td>
<td>(1.12)</td>
<td>(1.12)</td>
<td>(21.44)</td>
<td>(21.44)</td>
</tr>
<tr>
<td>CD at 5%</td>
<td>2.756</td>
<td>2.621</td>
<td>0.09776</td>
<td>0.8096</td>
<td>12.431</td>
<td>1.035</td>
</tr>
</tbody>
</table>

Values in the parentheses are standard deviation values.

efficiency is decreased by 3%. The CD values at 5% indicate no significant difference in groping end efficiency.

3.2.2 Reelability

Table 2 shows that reelability percentage is significantly influenced by cooking temperature at 5% level and cooking duration at 1% level. The adjustment temperature does not show any influence on reelability of multi-bivoltine cocoons. It could be observed from Table 4 that as the cooking temperature increases from 93°C to 95°C, the reelability is increased by 11.5%. It is interesting to note that 6.7% drop in reelability is observed at boiling temperature, which is because at boiling temperature cocoons absorb less water due to the entry suction phenomenon. The cooking temperature of 95°C is observed to be quite suitable for multi-bivoltine cocoons. This indicates that cooking temperature significantly improves the reelability of the cocoons. This is because of the uniform sericin softening due to complete cooking of Indian multi-bivoltine cocoons.

Table 8 shows 6.15% decrease in reelability of the cocoons as the difference in adjustment temperature increases from 13°C to 33°C. This is attributed to the pressure difference created by the adjustment temperature profiles. However, the CD values at 5% do not show any significant difference among the adjustment temperatures with regard to reelability of Indian multi-bivoltine cocoons.

Table 5 shows that the increase in cooking duration from 2 min to 3 min decreases the reelability of cocoons by 8%, which is significantly more as indicated by the CD values at 5% level.

3.2.3 Raw Silk Percentage

Table 2 shows that raw silk yield is significantly influenced by cooking temperature at 1% level and cooking duration at 5% level. The adjustment temperature profiles do not show any significant difference due to shell structure of multi-bivoltine cocoons. This indicates that cooking temperature significantly improves the raw silk yield. Table 4 shows that 95°C cooking temperature gives 13.64% raw silk. It is interesting to note that up to 95°C, the raw silk percentage in Indian multi-bivoltine cocoons
is higher, whereas at boiling temperature the raw silk percentage decreases. This is because due to the thin shell thickness of Indian cocoons, they do not withstand the air pressure created at boiling temperature and result in less permeation of water during cooking. These cocoons break more during reeling and the repeated brushing reduces the raw silk yield. Hence, the cooking temperature of 95°C is suitable for better raw silk yield. The CD values at 5% level indicate that significant difference exists between the cooking temperatures with regard to raw silk percentage. It is further observed that raw silk percentage increases as the cooking temperature increases up to 95°C, but it drops at boiling temperature in case of Indian multi-bivoltine cocoons.

Table 8 shows 1.8% increase in raw silk as the difference in adjustment temperature increases from 93-80°C to 93-60°C, which is attributed to the reduction in difference between adjustment temperature profiles. The CD values at 5% indicate no significant difference between the adjustment temperatures of 93-60°C and 93-70°C but the adjustment temperatures of 93-60°C and 93-80°C show significant difference in raw silk yield.

Table 5 shows that the raw silk percentage improves as the cooking duration increase from 2 min to 3 min, which is significantly more as indicated by the CD values at 5% level. Thus, it is observed that 2 min duration of cooking treatment yields more raw silk percentage because suitable softening of sericin takes place for effective unwinding of filaments from the cocoons.

3.2.5 Raw Silk Recovery

Table 2 shows that raw silk recovery after complete cooking is significantly influenced by the cooking temperatures at 1% level. It is observed that as the cooking temperature increase from 93°C to 95°C, the raw silk recovery increase by 8%, whereas the increase in cooking temperature from 90°C to boiling temperature shows 1.5% reduction in raw silk recovery (Table 4). The CD values at 5% level indicate that significant difference exists for raw silk recovery percentage between the cooking temperatures of 93°C and 95°C, but between cooking temperatures of 95°C and 97°C, no significant difference is observed.

Table 8 shows 1.7% decrease in raw silk recovery as the difference in adjustment temperatures increases from 93-80°C to 93-60°C. This is because when the difference between the adjustment temperatures is large, more quantity of water penetrates inside the cocoons. In cooking process, as the energy available to remove this water is constant, complete removal of water cannot be achieved and hence the water penetration at 93-80°C reduces. At 93-60°C, this water is completely removed in cooking, resulting in maximum penetration of water in adjustment part. The CD values at 5% show no significant difference among the adjustment temperatures profiles of 93-60°C and 93-80°C with regard to raw silk recovery percentage. Table 5 shows that the cooking duration increases the raw silk recovery by 4.2%. The CD values at 5% show significant difference between the permeation durations.

3.2.6 Waste (%) on Silk Weight

Table 2 shows that waste (%) on silk weight is significantly influenced by cooking temperature, cooking duration and adjustment temperature profiles at 1% level. It could be observed that the increase in cooking temperature from 93°C to 95°C decreases the waste (%) on silk weight by 9.6, whereas the increase in cooking temperature from 95°C to boiling temperature increases the waste (%) on silk weight by 5.9 (Table 4). This is because of over softening of sericin in outer layers at boiling temperature. The high permeation temperature of 95°C is observed to be quite suitable for multi-bivoltine cocoons with respect to waste (%) on silk weight. The CD values at 5% level indicate that no significant difference exists between the cooking temperatures of 95°C and 97°C with regard to waste (%) on silk weight.

Table 8 shows 11.9% decrease in waste (%) on silk weight as the difference of adjustment temperature profiles increases from 13°C to 33°C. This is attributed to the non-uniform treatment at higher adjustment temperature due to less water permeation, which, in turn, results in more dropping and repeated
brushing, thereby increasing the waste percentage. However, the CD values at 5% show significant difference between 93-80°C and 93-70°C, but between 93-70°C and 93-60°C no significant difference in waste (%) on silk weight is observed.

Table 5 shows that the waste percentage increases by 0.6 as the cooking duration increases from 2 min to 3 min, which is not significantly more as indicated by the CD values at 5% level.

3.2.7 Pelade Weight
Table 2 shows that the pelade weight is not influenced by cooking and adjustment temperatures and cooking duration. This may be attributed to better reelability of the multi-bivoltine cocoons and uniform softening of sericin during cooking. The CD values at 5% level also indicate no significant difference between the cooking temperatures with regard to pelade weight (Table 4).

3.2.8 Sericin Loss
Cooking and adjustment temperatures and cooking duration do not significantly influence the sericin dissolution during cooking (Table 2). This is due to the fact that sericin dissolution is standardized in the permeation treatment and further significant dissolution does not take place during cooking treatments. The results given in Table 4 show a decreasing trend in sericin dissolution by 4% as the cooking temperature increases from 93°C to 95°C. It is interesting to note that at 97°C, maximum sericin dissolution occurs because of the over softening of sericin in Indian multi-bivoltine cocoons. The CD values at 5% level indicate that significant difference exists between 95°C and 97°C high permeation temperatures with regard to sericin dissolution percentage, whereas between 93°C and 95°C, no significant difference is observed. Hence, the cooking temperature of 95°C is suitable for obtaining less sericin loss from multi-bivoltine cocoons.

3.2.9 Degumming Loss of Silk Waste
Table 2 shows that degumming loss of silk waste is significantly influenced by cooking temperature at 1% level. The other factors do not show significant influence on degumming loss of silk waste. It could be observed that the increase in the cooking temperature from 93°C to boiling reduces the degumming loss of silk waste by 16.4% (Table 4). The CD values at 5% level indicate that significant difference exists between the cooking temperatures of 95°C and 97°C with regard to degumming loss of silk waste percentage. This is because at boiling temperature, more sericin dissolution takes place and hence the waste does not contain much sericin.

Table 8 shows 4.1% decrease in degumming loss of silk waste percentage as the adjustment temperature increases from 93-80°C to 93-60°C, which is attributed to more sericin loss during cooking and hence the waste does not have much sericin during degumming. The CD values at 5% do not show significant difference among the adjustment temperatures with regard to degumming loss of silk waste. Table 5 shows that the cooking duration also decreases the degumming loss of silk waste by 3.6%. The CD values at 5% do not show the significant difference between the cooking durations.

3.3 Analysis of Variance Results for Quality Characteristics
The analysis of variance results (Table 3) show that significant difference exists among cooking temperature, cooking duration and adjustment temperature profiles with regard to quality characteristics, viz. neatness, cleanliness, tenacity, elongation, cohesion and degumming loss of raw silk. From the results, it could be inferred that the cooking and adjustment temperatures are also most significant factors which improve the quality characteristics of Indian multi-bivoltine cocoons. The interaction among cooking temperature, cooking duration and adjustment temperature profiles does not significantly affect the quality characteristics, indicating that this follows the similar trend as performed individually.

3.4 Effect of Cooking Treatment on Quality Characteristics
3.4.1 Neatness
Table 3 shows that cooking temperature significantly influences the neatness of raw silk at 5% level. It could be observed from Table 6 that as the cooking temperature increases from 93°C to 95°C, the neatness of raw silk is increased by 4.5%, whereas at 97°C cooking temperature the neatness is slightly lowered by 1.8%. This is because at higher cooking temperature the over softening of sericin takes place, leading to decrease in binding of fibrils which reduces the neatness of raw silk. The CD values at 5% level indicate significant difference between the cooking temperatures with regard to neatness of raw silk, which is attributed to the softening of sericin during cooking process for multi-bivoltine cocoons. The results suggest that cooking temperature of 95°C is suitable for Indian multi-bivoltine cocoons based on
neatness characteristics of raw silk. The lower and higher cooking temperatures reduce the neatness characteristics due to non-uniform softening of sericin in cooking process. Though the neatness is a racial characteristic to the extent of 80% as described by Shimazaki\textsuperscript{26}, the study shows that proper cooking could improve the neatness characteristic of multivoltine cocoons to some extent.

Table 9 shows that the adjustment temperature profile does not significantly influence the neatness of raw silk. However, the adjustment temperature profile of 93-60°C increases the neatness of raw silk by 1.7%, which is attributed to the fact that at higher adjustment temperature profile, the difference between cooking temperature and adjustment temperature profile reduces and this creates the lower air pressure difference so that the less water permeates inside the cocoons. Table 7 shows that as the permeation duration is increased from 2 min to 3 min, the neatness of raw silk is decreased by 1.4%. The CD values at 5% indicate that no significant difference is observed in neatness of raw silk. This is attributed to water permeation into the cocoons during adjustment part.

3.4.2 Cleanness

Table 3 shows that the cleanness of raw silk is significantly influenced by cooking temperature at 5% level. Cooking duration and adjustment temperature profile do not show any influence on cleanness of raw silk of multivoltine cocoons. It could be observed from Table 6 that as the cooking temperature increase, the cleanness of raw silk also increase by 3.8%. It is interesting to note that the drop in cleanness of raw silk is observed at boiling temperature, which is because at boiling temperature due to entry suction phenomenon the water entry is restricted and this causes sericin softening. The cooking temperature of 95°C is observed to be quite suitable for multivoltine cocoons. The CD values at 5% level indicate that significant difference exists between the cooking temperatures of 93°C and 95°C with regard to cleanness of raw silk of the cocoons. It is observed that there is an increasing trend of cleanness of raw silk as the cooking temperature increases up to 95°C.

Table 9 shows 2.9% increase in cleanness of raw silk as the adjustment temperature profile varies from 93-80°C to 93-60°C, which is attributed to the reduction in temperature difference between cooking temperature and adjustment temperature profile. However, the CD values at 5% did not show any significant difference among the adjustment temperature profiles with regard to cleanness of raw silk.

Table 7 shows that as the cooking duration increases from 2 min to 3 min, the cleanness of raw silk decreases by 1.6%, which is significantly more as indicated by the CD values at 5% level.

3.4.3 Tenacity

The tenacity of raw silk is not influenced by cooking and adjustment temperatures and cooking duration (Table 3). This is because the tenacity of raw silk is quite high compared to other fibres. Table 6 shows that the tenacity of raw silk is above the minimum level of 3.6g/den at all the cooking temperatures used. The CD values at 5% level indicate no significant difference between the cooking temperatures with regard to tenacity of raw silk.

Table 9 shows that adjustment temperature profile does not significantly influence the tenacity of raw silk. Table 7 shows that as the cooking duration increases from 2 min to 3 min, the tenacity of raw silk decreases by 0.2%. The CD values at 5% do not show significant difference in tenacity of raw silk. This is attributed to the uniform softening of sericin during cooking treatments for 2 min, leading to better permeation of water into the cocoon shell.

3.4.4 Elongation

The elongation of raw silk is not influenced by the cooking and adjustment temperatures and cooking duration (Table 3). Tables 6 and 9 show that the elongation is above 19% at all the cooking and adjustment temperature profiles.

Table 7 shows that as the cooking duration increase from 2 min to 3 min, the elongation increase by 0.2%. The CD values at 5% do not show significant difference in elongation with respect to cooking durations. This is attributed to the uniform softening of sericin during complete cooking treatments.

3.4.5 Cohesion

Cohesion of raw silk is significantly influenced by the cooking duration at 5% level (Table 3). It could be observed that as the cooking temperature increases, the cohesion of raw silk also increases by 13.8% (Table 6). The CD values at 5% level indicate that no significant difference exists between the cooking temperatures with regard to cohesion of raw silk.
Table 9 shows 7.9% increase in cohesion of raw silk as the adjustment temperature profile decreases from 93-80°C to 93-60°C. However, the CD values at 5% do not show any significant difference between adjustment temperature profiles with regard to cohesion of raw silk. Table 7 shows that the cooking permeation duration decreases the cohesion of raw silk by 14.9% as the duration is increased from 2 min to 3 min, which is significantly higher as indicated by the CD values at 5% level. This is attributed to the uniform softening of sericin in cocoon shell during 2 min permeation treatment.

3.4.6 Degumming Loss of Silk
The degumming loss of silk is significantly influenced by the cooking temperature at 1% level (Table 3). It could be observed that as the cooking temperature increases from 93°C to 95°C, the degumming loss of silk increases by 5.9%, whereas further increase in cooking temperature from 95°C to boiling decreases the degumming loss of raw silk by 7.3% (Table 6), which is significant at 5% level as indicated by the CD values.

Table 9 shows 4.1% increase in degumming loss of silk as the adjustment temperature profile increases from 93-60°C to 93-80°C, which is attributed to the sericin loss during complete cooking. The CD values at 5% do not show significant difference among the adjustment temperature profiles with regard to degumming loss of silk. Table 7 shows that the cooking duration also increases the degumming loss of silk slightly by 2.4%, which does not show significant difference as indicated by the CD values at 5%.

4 Conclusions
4.1 At the standard retting temperature and duration, high permeation temperature and duration, and low permeation temperature and duration, the cooking temperature and duration and adjustment temperature profiles have significant influence on the following reeling characteristics: groping end efficiency, reelability percentage, raw silk percentage, raw silk recovery percentage, waste (%) on silk weight, and degumming loss percentage of silk waste, whereas reeling tension, pileade weight and sericin dissolution percentage do show much influence on cooking treatments. The cooking temperature of 95°C softens the cocoon shell uniformly. However, the boiling temperature over softens the sericin and entry suction phenomenon reduces the water permeation, resulting in lower reeling performance.

4.2 The adjustment temperature is found to perform well in reeling characteristics in the temperature range of 93-60°C. The adjustment temperature of 93-80°C does not give good results due to improper softening of sericin, which is because of the less difference between the adjustment temperatures. The cooking duration also improves the reeling characteristics due to proper softening of sericin. The study reveals that the cooking temperature of 95°C for 2 min duration followed by adjustment temperature of 93-60°C gives the better reeling results in case of multi-bivoltine cocoons. The study also reveals that the complete cooking of hot air dried multi-bivoltine cocoons yields better silk recovery.

4.3 The cooking temperature of 95°C softens the cocoons shell uniformly and improves the raw silk quality significantly. The adjustment temperature does not show significant influence on quality characteristics because it enables maximum amount of water to permeate into the cocoons during complete cooking of Indian multi-bivoltine cocoons. The cooking duration is found to improve the cohesion characteristics of raw silk due to the proper softening of sericin.

Acknowledgement
The authors express their gratitude to Mr. B P Nair, CSTRI, Bangalore, for performing statistical analysis of the results. The thanks are due to Reeling Section staff of CSTRI, for their cooperation while conducting the study.

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