DEVELOPMENT OF NON-DESTRUCTIVE METHODS FOR QUALITY CONTROL OF SILKBERRY COCOONS

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Abstract. *Non-destructive methods and mathematical models have been developed for determining and monitoring the quality parameters of silkworm cocoons. The proposed methods provide greater accuracy in determining quality parameters such as silkiness, maturity, and cocoon shell thickness, which are the most important for determining the quality parameters of raw silk.*

Keywords: *cocoon, non-destructive statistical method, mathematical model, silkiness, correction factor, shell thickness, maturity.*

The development and implementation of new, effective methods for determining and monitoring the quality of silk cocoons is extremely important, offering significant potential for increasing the profitability of sericulture. Quality control of silk raw materials at all stages of production is essential and mandatory, especially during the initial processing of cocoons.

Therefore, assessing and accepting cocoons based on quality parameters will not only allow the introduction of highly productive silkworm breeds and hybrids into production but will also motivate sericulture producers to significantly improve the quality of their raw materials.

We propose non-destructive methods for monitoring cocoon quality parameters without cutting them, as well as computer programs for calculating cocoon parameters.

Method 1. From a submitted batch of live cocoons, n undeformed cocoons ($10 \le n \le 20$) are selected. Cocoons are selected one by one, their initial length $\ell 0$ along the major axis and average diameter d are measured, and compression is created at both poles of the cocoon using equal mechanical force. The shortest length $\ell 1$ between two indentations at the poles is then measured, and the silkiness of each cocoon is determined using the empirical formula:

$$Sl = \frac{k \cdot d \cdot F}{\ell_0 - \ell_1} \cdot 100\%$$

Where k is a correction factor depending on the cocoon breed; F is a force of a given magnitude; d is the average cocoon diameter; ℓ_0 is the initial length of the cocoon's major axis; ℓ_1 is the smallest distance between two cocoon indentations on the pole side after applying force F.

Then, the silkiness of batches of live cocoons is determined by averaging the silkiness of n cocoons:

$$Sl = \frac{\sum_{i=1}^{n} Sl_i}{n}$$

Method 2. The method for determining the silkiness of cocoons consists of placing cocoons in a cylindrical container and subjecting them to shaking on a vibration stand. Then, to improve accuracy, after stopping the vibration stand to account for the effect of the shell thickness on silkiness, the cocoons are compressed with a load of 10-20 kg (which corresponds to an excess pressure of 3333 - 6666 Pa above atmospheric pressure on the cocoon layer). Height sensors transmit information about the change in the average height of the cocoon layer H-Δh to the computer, and the silkiness of live cocoons is calculated using the empirical formula:

$$Sl = K \cdot (H - \Delta h) + A$$

Where K is the correction coefficient; H is the cocoon layer height after vibration; Δh is the change in cocoon layer height after shell compression;A is the free term;

Method 3. The method for determining silkiness is based on the rigidity of the cocoon shell. It involves taking cocoon samples, placing them in vertical cells, filling the cells with distilled water, and determining their initial volume. The cocoons are then compressed until their volume decreases by 5-10% (within the limits of elastic deformation) of the initial value. The pressure value P at which the volume decreases is recorded, and the silkiness Sh is determined using the mathematical relationship

$$Sl = \kappa \cdot p + в$$

Where k is the proportionality coefficient; b is the absolute term; p is the excess pressure at which the cocoon volume decreases by 5–10%, with the cocoon compression process monitored by projecting the cocoon shadow onto a photosensitive screen.

The proportionality coefficient k, depending on the cocoon species, is determined at the beginning of the live cocoon harvesting season based on the results of calibration using the least-squares method.

Method 4. The method for determining the silkiness of cocoons involves placing the cocoons in a cylindrical container, shaking them on a vibration stand to a specified degree of compaction, and determining the silkiness Sh using the formula:

$$Sl = \kappa \cdot \frac{H_{cp}}{m} \cdot 100\%, \quad k = f\left(\frac{1}{V_{cp}}\right),$$

Where Hcp is the average filling height of the instrument cylinder; m is the mass of cocoons in the instrument cylinder; k is the coefficient for a given silkworm breed.

The K coefficient for any silkworm breed is determined using a calibration curve constructed from measurements of the average volume of a single cocoon and the K coefficient determined for two silkworm breeds with different cocoon sizes [6].

Method 5. To determine silkiness, cocoons of a given batch are placed in a measuring container. Eight to fifteen cocoons of a suitable diameter are stacked on top of each other. A lid with a special support is placed on top of the cocoons. The cocoon layer height H is recorded. To account for the effect of shell thickness on silkiness, the cocoons are compressed with a specific weight P. Height sensors transmit information about the change in cocoon column height Δh to a computer. The computer calculates the silkiness of live cocoons using an empirical formula.

$Sl = K \cdot (P \cdot H / \Delta h)$,

Where P is the weight of the lid and the load, including the support, measured in newtons; H is the initial height of the cocoon layer before compression; Δh is the change in the height of the cocoon column after compression; K is the correction factor, measured in %/N.

Method 6. The developed non-destructive method for determining silkiness is based on the thickness of the cocoon shells. 10-15 cocoons are selected from the submitted batches of live cocoons, the shell thickness and silkiness of each sample are measured. Based on these data, the silkiness of living cocoons is calculated using the empirical formula

$$Sl = k \cdot T + b$$

Where k is the proportionality coefficient; b is the absolute value; T is the cocoon thickness, mm.

Where "Sh" is the silkiness, "T" is the longitudinal thickness of each of the 10-15 cocoon shells, and "k" and "b" are coefficients depending on the cocoon species. The silkiness is then determined using this straight line and inserted into the nomogram.

Method 7. The developed method for determining silkiness by cocoon length without cutting live cocoons is based on determining the silkiness of mature cocoons by their size. To solve this problem, a small sample (10-15 pieces) is selected and the cocoon length of this sample of live cocoons is measured. The computer calculates the silkiness of live cocoons using the empirical formula:

$Sl = a \cdot l + b$

Where "Sl" is the silkiness of the cocoon, in %; " " is the cocoon length, mm;

"a" and "b" are coefficients depending on the cocoon breed.

Method 8. The method for determining the silkiness of live cocoons involves filling the cocoon and determining the silkiness using a mathematical relationship. The cocoon shell is pierced with an injection needle, then the cocoon is placed in a sealed chamber connected to a liquid manometer. Air is pumped through the needle at a pressure of P = 12,000–20,000 Pa for a time of Δt = 3–7 s. The excess pressure ΔP, which depends on the shell thickness, is recorded using a liquid manometer, and the silkiness is determined using the formula:

$Sl = K \cdot P \cdot \Delta t / \Delta P$,

Where Sl is the silk yield, %; P is the pressure at which air enters the cocoon, Pa;

K is a coefficient that depends on the cocoon type and the volume of the working chamber. It is determined by calibration at the beginning of the season and is measured in %/sec.

When accepting cocoons from harvesters, determining the percentage maturity of live cocoons is very important and of great significance.

To improve the accuracy of determining the maturity of live cocoons, we have developed a non-destructive method for determining maturity based on the hardness of the cocoon shell.

Method 9. Cocoons are individually placed vertically in a measuring container of suitable diameter. To measure the shell thickness, the cocoon is compressed with a 0.1 kg weight. The cocoon height is recorded before and after compression, the information is transmitted to a computer, and the maturity of the living cocoons is determined using the empirical formula:

$$Z_з = \frac{\Delta h_з}{\Delta h} \cdot 100\%$$

Where is the change in height of the mature and test cocoons, respectively, after shell compression, in mm.

One of the main parameters of cocoons is their shell thickness.

Method 10. We propose a non-destructive method for determining cocoon shell thickness based on the shell rigidity. This method involves collecting cocoon samples, loading them into a cylindrical measuring container of a suitable diameter in a column, recording the height of the cocoon layer, then compressing the cocoons with a specified weight P (within the elastic deformation limits), and using height sensors to transmit information about the change in cocoon column height Δh to a computer. The computer calculates the thickness of the shell of living cocoons using a mathematical relationship

$$T = \kappa \cdot \frac{p}{\Delta h} + в \quad ,$$

Where k is the proportionality coefficient depending on the cocoon breed; p is the load weight, measured in Newtons; Δh is the change in cocoon column height after compression; b is the term indicating the portion of the ordinate the line intercepts from the ordinate axis.

The proportionality coefficient k, depending on the cocoon breed, is determined at the beginning of the live cocoon harvesting season based on the results of calibration using the least-squares method.

Thus, we have proposed non-destructive methods and mathematical models for determining the quality indicators of cocoons based on the rigidity of their shell such as silkiness, degree of maturity, and the thickness of the cocoon shell, which are the most important in terms of determining the quality indicators of raw silk.

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