

THE RELATIONSHIP BETWEEN THE DEVELOPMENTAL BIOLOGY OF THE MULBERRY SILKWORM AND THE TECHNOLOGICAL QUALITY INDICATORS OF COCOON YARN

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Abstract: The article systematically analyzes the biological development cycle of the mulberry silkworm, consisting of egg, larva, pupa and butterfly stages, and the technological factors of this cycle affecting the quality of the cocoon shell and cocoon thread. The study is based on a comparative-analytical generalization of data from two educational and methodological sources. The five-year development of the worm, four molts, incubation conditions, nutritional status and four stages of the cocoon winding process were evaluated as the main biological and technological factors shaping the quality of the cocoon.

Keywords: mulberry silkworm, *Bombyx mori* L., developmental stages, incubation, mulberry leaf, cocoon wrapping, cocoon shell, granularity, silkiness, cocoon thread, fibroin, sericin, silkiness.

Abstract: V state systematizirovana vzaimosvyaz mejd biologicheskim razvitiem tutovogo silkkopyada i technologicheskimi pokazatelyami kachestva kokona i kokonnoy niti. Na osnove sravnitelno-analiticheskogo obobshcheniya uchebno-metodicheskikh materialov rassmotreny stadii razvitiya *Bombyx mori* L., osobennosti incubatsii, kormleni, linki, obrazovaniya kukolki i vykhoda babochki. Otdelnoe vnimanie udeleno four periods of zavivki cocona, geometrical parameters of cocona, granularity, jyostkosti obolochki, silkiness, razmatyvaemosti, obshchey i nepreryvnoy dline niti, linear plotnosti, chemical composition and physical-mechanical properties of natural silk.

Keywords: tutovy silkworm, *Bombyx mori* L., stages of development, incubation, listya shelkovitsy, zavivka cocona, obolochka cocona, zernistost, shelkonosnost, coconaya nit, fibroin, sericin, razmatyvaemost.

Abstract: The article systematizes the relationship between the developmental biology of the silkworm and technological quality indicators of cocoon and cocoon filament. Using an analytical and comparative approach, the study summarizes data on the egg, larval, pupal and moth stages of *Bombyx mori* L., the five larval instars, molting, incubation, feeding conditions and cocoon spinning. The four periods of cocoon formation are linked with cocoon shell structure, shape, color, geometric dimensions, granularity, hardness, silk content, reelability, total and continuous filament length, linear density, chemical composition and mechanical properties.

Keywords: silkworm, *Bombyx mori* L., developmental stages, incubation, mulberry leaf, cocoon spinning, cocoon shell, granularity, silk content, cocoon filament, fibroin, sericin, reelability.

Main part

In world sericulture practice, improving the quality of raw silk, controlling biological processes in cocoon cultivation, and increasing the efficiency of cocoon spinning are among the



important scientific and practical issues. The final result of mulberry silkworm productivity is inextricably linked not only with the technical regimes in the cocoon spinning workshop, but also with seed revitalization, proper care of the worm according to its young age, ensuring the quality of feed, creating optimal conditions during the cocooning period, and determining the morphological indicators of the cocoon shell. Therefore, it is important to study biological development and technological quality indicators as a single system in sericulture [1,2].

The mulberry silkworm *Bombyx mori* L. belongs to the phylum Arthropoda, class Insecta, order Hemiptera, and its life cycle consists of egg, larva, pupa, and pupa stages. The pupal stage is the main feeding and storage stage before the cocoon is formed, and is usually divided into five years and characterized by four moults. Each moult is considered the age of the worm; during the moult, the worm does not eat leaves, moves little, and is apparently "dormant" [1].

The purpose of this article is to scientifically systematize the developmental stages, nutrition, and cocooning process of the mulberry silkworm in relation to the quality indicators of the cocoon shell and cocoon thread. The main attention was paid to the cause-and-effect relationships between the biological state of the worm, nutrition, cocoon winding periods, shell structure, cocoon geometry, silkiness, spinnability, and the physicochemical properties of the cocoon thread.

The research methodology was based on a comparative-analytical generalization of the data of educational and methodological materials on two topics, linking biological processes with technological results, systematizing the quality indicators of cocoons and cocoon thread, as well as explaining the main criteria used in assessing the shape of cocoons and thread properties. The article does not claim to be the results of experimental measurements; it is considered as an analytical study aimed at creating a theoretical and methodological foundation for further laboratory and production tests based on the available educational and scientific data.

The scientific novelty of the article is that the biological development of the mulberry silkworm and the technological indicators of the cocoon thread were interpreted not separately, but as a single system in the form of a chain of "seed - worm - nutrition - cocooning - cocoon shell - cocoon thread - raw silk". This approach shows that the age stages of the worm, food consumption, incubation regime, cocooning period and shell morphology all have a combined effect on the formation of cocoon quality.

The silkworm egg is biologically the initial stage of the next generation, and is shaped like an egg with compressed sides, slightly concave in the middle and oval in shape. The newly laid egg is initially light yellow, later changing to pink, reddish-brown and grayish-gray. The size of the overwintering egg is approximately 1.5×1.1 mm, and the weight is around 0.5–0.7 mg. The fact that one gram of worm egg contains up to 1200–2000 eggs, and the hatching of eggs in special incubators lasts about 20 days, is important in planning the simultaneous revival and maintenance of worms [1].

The incubation process is a crucial step in obtaining healthy and uniformly developed worms from worm seed. Methods of slowly increasing the temperature or maintaining a certain temperature constant are used for seed revival. In conditions of cool spring or sudden weather changes, a method of gradually increasing the temperature is appropriate. In the constant temperature method, conditions are initially maintained around 13–14 °C, and then the temperature is increased to 24–25 °C. This process allows for the coordination of the emergence of messenger worms and the mass revival of worms [1].

The larval stage creates the biological basis for the quality of the cocoon. At this stage, the body of the worm accumulates the necessary nutrients for subsequent metamorphosis and cocooning. By the fifth instar, morphological characteristics are fully formed: the body of the worm is elongated, cylindrical, slightly flattened on the ventral side, and convex on the shoulder side; the body consists of the head, thorax, and abdomen. The location of the eyes, whiskers,



mouthparts, and silk-separating tube on the head form the anatomical basis for the cocooning process [1].

The feed factor is one of the most important controllable indicators in sericulture. Mulberry silkworms feed mainly on mulberry leaves; the carbon, hydrogen, oxygen, nitrogen and mineral salts contained in the leaves directly affect the metabolism of the worm. The source notes that 1000–1200 kg of mulberry leaves are used for one box of worm seeds, and 15–20 kg of leaves are required to obtain 1 kg of cocoon [1]. Therefore, in increasing cocoon productivity, it is necessary to pay attention not only to the amount of leaves, but also to their age, purity, moisture and nutritional value.

After the worm has had enough food, the process of spinning the cocoon begins. This process is divided into four stages. In the first stage, the worm produces silk, forms a cocoon, and forms a cotton-like cocoon. In the second stage, the thread is spun more densely, but the resulting cocoon is not suitable for spinning. In the third stage, the worm spins the main part of the cocoon; this part makes up 70–85% of the cocoon shell and is the most important for spinning. In the fourth stage, the inner shell is formed, in which the thread is spun thinner and looser [2].

The technological interpretation of the cocooning period shows that the shell suitable for weaving is formed mainly in the third period. The pendulum-like movement of the head of the worm and the spinning of the thread in a semi-octagonal shape ensure a relatively regular arrangement of layers in the cocoon shell. If the temperature, humidity, ventilation, worm maturity and density of the cocoon deviate from the norm during this period, unevenness of the shell, an increase in the amount of lice, an increase in thread breaks and a decrease in weaving can be observed.

The pupal stage is characterized by deep metamorphosis processes in the worm's body. After spinning the cocoon, the worm's body shortens, the distance between the joints decreases, and its weight decreases. Later, some organs are destroyed or remodeled, and the pupal organs are formed. The pupal period can last 2–3 weeks, depending on the temperature regime. Although this process is necessary for the change of generation from a biological point of view, from a production point of view it is important to determine the timing of timely collection, drying, and preparation of the cocoon for washing [1].

The pupal stage is the reproductive stage of the mulberry silkworm. When the pupa becomes a butterfly, it uses an alkaline liquid secreted from the mouth to soften the sericin and break the cocoon shell to emerge from the cocoon. If the purpose of breeding is not pursued, this process in industrial cocoon production negatively affects the quality of raw silk, because the continuous thread of the cocoon is broken. Therefore, knowing the development period of the pupa inside the cocoon is necessary for processing the cocoon at the right time.

The external characteristics of the cocoon – color, shape, size, and texture of the shell surface – are important indicators in the primary assessment of quality. Cocoons can be pure white, yellow, green, white-yellow, or pink; the color is associated with the coloring matter in the sericin. According to their shape, cocoons are divided into round, oval, oval-shaped, cylindrical, elongated cylindrical, and pointed at one or both ends. These characteristics are closely related to the breed of the worm, its hybridity, sexual differences, and rearing conditions [2].

Determining the geometric dimensions of the cocoon is important in technological planning of the spinning process. The length of the cocoon is usually 24–40 mm and more, and the cross-sectional diameter can be 12–22 mm and more. The cocoon volume is shown to be around 5.5–12.7 cm³, the live cocoon weight is 1.2–3.2 g, and the dry cocoon weight is 0.32–1.25 g [2]. These indicators are used in cocoon storage, transportation, calibration, and forming spinning batches.



For a numerical assessment of the cocoon shape, it is appropriate to use the concepts of thinning and waisting. The thinning is interpreted as the ratio of the cocoon length to the average diameter of the hemispheres, and the waisting is interpreted as the ratio of the average diameter of the hemispheres to the waist diameter. In practical calculations, the assessment in the form of $K_i = D / ((d_1+d_2)/2)$, $K_\beta = ((d_1+d_2)/2) / d_{\text{pel}}$ allows us to compare the cylindricity of the cocoon, the expressiveness of the waist, and the stability of the cocoon during washing.

The granularity of the cocoon shell is expressed by the fine structure of the shell surface. The source indicates that the number of grains per 1 cm², depending on the breed and hybrid of the cocoon, can be up to 50–150. Cocoons with small and clearly visible grains usually have a dense and hard shell, good silkiness and spinnability [2]. Therefore, granularity is not only an aesthetic external characteristic, but also a technological indicator related to the internal layering of the cocoon shell and the continuity of the thread.

The hardness of the cocoon shell is characterized by its resistance to compression or crushing. The hardness index depends on the density of the shell, its thickness, the shape of the cocoon and the location of the internal layers. The thickness of the shell is not uniform throughout the cocoon: in some cocoons, the shell may be thinner at the tips of the head and base hemispheres and thicker at the waist. In cocoons with insufficient shell hardness, deformation increases during transportation and storage, and in cocoons with excessively hard or uneven shells, there is an increased likelihood of thread breakage during the spinning process.

Cocoon thread is biologically composed of a fibroin stream released from the silk-secreting glands and a layer of sericin covering it. Cocoon thread consists of two fibers that are glued together with the help of sericin to form a shell. In terms of chemical composition, cocoon thread has been shown to contain 70–80 percent fibroin, 20–30 percent sericin, as well as small amounts of ether, alcohol, and minerals [2]. Fibroin provides the main mechanical support, while sericin provides the adhesive layer that binds the fibers together.

The total length of a cocoon thread is the length of the thread spun from the beginning to the end of a single cocoon, which can be 1200–1500 meters. The continuous length is the distance from the beginning of the thread to the first break. In practical analysis, the total length can be estimated by the formula $L = n \cdot l + l_1$, and the continuous length can be estimated by taking into account the number of breaks using the expression $l_{\text{uu}} = L / (O+1)$. A higher continuous length increases the stability of the raw silk yield during the cocoon spinning process.

One of the most important quality indicators of cocoon yarn is its fineness or linear density. In the traditional number system, the length corresponding to 1 g of yarn is taken into account, while in modern textiles, the tex indicator is widely used. The source notes that, depending on the cocoon breed, the number of cocoon yarn is in the range of 2500–3600, which corresponds to 0.28–0.40 tex [2]. The stability of linear density affects the evenness of the yarn in weaving and knitting processes, the smoothness of the fabric surface, and the quality of the product.

The mechanical properties of silk fiber, in particular its strength and elongation, are of crucial importance for the textile industry. According to the source, silk fiber can be stretched up to 24% of its original length without breaking; its density is on average around 1.33–1.34 mg/mm³, it retains its basic properties when heated to 140 °C, it is practically non-conductive, and it can absorb up to 30% of the moisture in the air [2]. These properties determine the hygienic, aesthetic, and operational advantages of silk.

Silkiness, spinnability and specific consumption serve to assess the quality of cocoons based on industry criteria. Silkiness is determined by the ratio of the mass of the cocoon shell to the total mass of the cocoon: $I = (m_\phi / m_p) \cdot 100\%$. Spinnability is estimated by the ratio of the mass of raw silk to the mass of dry cocoon: $Ch = (m_i / m_p) \cdot 100\%$. The specific consumption expresses how much dry cocoon is consumed to obtain 1 kg of raw silk. All of these indicators depend on the correct formation of the cocoon shell, the lack of thread breaks and the efficiency of the cocoon selection system.



The relationship between biological development and cocoon thread quality can be explained as follows: incubation ensures that the worms emerge at the same time; proper care of the young ensures that the worms grow evenly; quality mulberry leaves support the normal development of the silk glands and the synthesis of fibroin-sericin; and the microclimate during the cocooning period affects the density, granularity and continuity of the shell layers. As a result, any technological error in worm breeding can be reflected in losses in cocoon spinning.

The results of the analysis show that three main areas are of priority for obtaining quality cocoons: first, achieving biological synchrony in seed revitalization and grouping of worms by age; second, controlling the quality of mulberry leaves and regulating the feeding regime of worms; third, controlling the maturity level of worms, housing density, temperature, humidity and ventilation during the cocooning period. These areas create the necessary conditions for the strength of the cocoon shell, its spinnability and raw silk yield.

In practice, assessing the quality of cocoons should not be limited to weight or color alone. A comprehensive assessment of cocoon geometry, grain size, shell thickness, hardness, silkiness, percentage of moose and worm skin, total and continuous length of the thread, linear density, and sericin-fibroin ratio is required. Such a comprehensive approach allows sorting batches of cocoons received by industrial enterprises, selecting the washing regime, and stabilizing the quality of raw silk.

Also, the voltine characteristics of the mulberry silkworm - monovoltine, bivoltine and polyvoltine forms - are important in managing the seasonality of cocoon production. The use of viable breeds and hybrids expands the possibilities of summer and autumn feeding, not limited to the spring season. However, in multi-season feeding, the decrease in the nutritional value of mulberry leaves, increased temperature and imbalance in microclimate can affect the quality of cocoon thread. Therefore, breed selection, feed base and maintenance regimen must be planned together.

Summarizing the available data, it is clear that a deep understanding of the biological development stages of the mulberry silkworm has direct practical value for cocoon spinning technology. Because the thread breaks, sliver yield, raw silk quantity and quality stability determined during the spinning process are the final result of the biological and morphological indicators formed during the worming period. Therefore, the most important condition for increasing efficiency in sericulture is the management of the stages of biological care and technological processing as a continuous system.

Conclusion

The egg, larva, pupa, and pupal stages of the mulberry silkworm constitute the biological basis for cocoon production. During the larval stage, the accumulation of nutrient reserves, the development of silk-secreting organs, and the preparation for cocooning determine the quality of the cocoon shell and cocoon thread in the future.

Of the four stages of cocooning, the third stage forms the main part of the washable shell. Therefore, the level of maturity of the worm, the density of its housing, the correct organization of the temperature, humidity and ventilation regime are crucial for the quality formation of the main washable layer of the cocoon shell, which is 70–85 percent.

In a comprehensive assessment of cocoon quality, color, shape, length, diameter, volume, weight, granularity, shell thickness, hardness, silkiness, spinnability, total and continuous length of the thread, linear density, fibroin-sericin content, and mechanical properties should be considered together.

The quality and consumption of mulberry leaves are directly related to cocoon productivity, and the fact that 1000–1200 kg of leaves are required for one box of worm seed and 15–20 kg of leaves for 1 kg of cocoon indicates the need for scientific planning of the food base.

In future studies, it is advisable to experimentally determine the effects of incubation regime, nutritional value of mulberry leaves, growth dynamics of young worms, and cocoon



winding conditions on thread continuity, spinnability, silkiness, and raw silk quality in different breeds and hybrids.

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