Revival of sericulture in Slovenia

Tatjana Rijavec[1,*], Alenka Šalej Lah[1], Rebeka Lucijana Berčič[2]
[1] University of Ljubljana, Faculty of Natural Sciences and Engineering, Ljubljana, Slovenia
[2] University of Ljubljana, Veterinary Faculty, Ljubljana, Slovenia
*Corresponding author: tatjana.rijavec@ntf.uni-lj.si
Received January 26, 2024
UDC 677.371

Original scientific paper**

Despite the extraordinary development of synthetic fibres, silk is still the most valued textile fibre, representing luxury through softness, pleasant lustre, beautiful colours, high strength, and durability. Slovenia has favourable natural conditions for growing white mulberry Morus alba L. tree, the leaves of which are fed to the silkworm Bombyx mori L. On the territory of today's Slovenia sericulture was an important economic activity, which began already in 16th century. It included rearing and breeding of silkworms, reeling of cocoons and production of silk yarns and fabrics. The spread of sericulture started in Goriška, where it was implemented also until the middle of the twentieth century. Unfortunately, the knowledge was only preserved in written sources, but the experiences of our ancestors were entirely lost. A sericulture and silk industry in Slovenia in the past is briefly presented. In the year 2018 an Institute of sericulture entilted "Inštitut za svilogojstvo in svilarstvo RLB" was established in Maribor by dr. Rebeka Lucijana Berčič. It is the only institution in Slovenia that offers professional help to silk rearers, who already practise sericulture by a large number of individuals and families from Koper to Goričko as the locally grown silk according to the guidelines of organic mulberry cultivation easily meets the criteria of a sustainable and environmentally friendly textile material. Today, it is used in a form of filament yarn for Idrija lace or for hand woven fabrics, and in a form of silk nonwovens for interior textiles. Silk mats are directly made by 2D spinning of silkworms. The process of silkworm flat spinning is shown in a digital material (video film) on the ISS_RLB website and is accessible via QR code. The process and the structure of the silk nonwoven material is described.

Keywords: *mulberry silk; raw silk; silk mat; flat spinning; decoration; digital media*

Izvorni znanstveni rad**

Unatoč izvanrednom razvoju sintetičkih vlakana, svila je i dalje najcjenjenije tekstilno vlakno, koje predstavlja luksuz zbog mekoće, ugodnog sjaja, prekrasnih boja, visoke čvrstoće i trajnosti. Slovenija ima povoljne prirodne uvjete za uzgoj bijelog duda (*Morus alba* L.), čijim se lišćem hrani svilena buba (*Bombyx mori* L.). Na području današnje Slovenije svilarstvo je bila važna gospodarska djelatnost, koja je započela već u 16. stoljeću. Uključivalo je uzgoj i razmnožavanje svilenih buba, motanje čahura te proizvodnju svilenih pređa i tkanina. Širenje svilčarstva započelo je u Goriškoj, gdje se provodilo i do sredine dvadesetog stoljeća. Nažalost, znanje je sačuvano samo u pisanim izvorima, ali iskustva naših predaka su potpuno izgubljena. Ukratko je prikazano svilarstvo i industrija svile u Sloveniji u prošlosti. Godine 2018. u Mariboru je dr. Rebeka Lucijana Berčič osnovala „Inštitut za svilogojstvo in svilarstvo RLB". To je jedina institucija u Sloveniji koja nudi stručnu pomoć uzgajivačima svile, kojima se već bavi velik broj pojedinaca i obitelji od Kopra do Goričkog, jer lokalno uzgojena svila prema smjernicama organskog uzgoja duda lako zadovoljava kriterije održivog i ekološki prihvatljivog tekstilnog materijala. Danas se koristi u obliku filamentne pređe za idrijsku čipku ili za ručno tkane tkanine, te u obliku netkanog svilenog materijala za unutarnje tekstile. Svilene prostirke izrađuju se izravno 2D predenjem svilenih buba. Proces ravnog predenja svilenih buba prikazan je u digitalnom materijalu (video film) na web stranici ISS_RLB i dostupan je putem QR koda. Opisan je proces i struktura netkanog svilenog materijala.

Ključne riječi: dudova svila, sirova svila; svilena podloga; ravno ispredanje; dekoracija; digitalni medij.

*Paper presented at the *16th Scientific-Professional Symposium Textile Science And Economy*, Jan 26, 2024, Zagreb, Croatia

1. Introduction

Today more than ever, humanity is faced with the question how to achieve prosperity for all without overtaxing the planet's natural resources [1]. The concepts of Industry 4.0 and Industry 5.0 focus on sustainable development with better resource management, reducing waste and minimising the impact of industrial processes on the environment. Industry 5.0 emphasises human well-being and job satisfaction [2]. In line with these strategies, the revival of sericulture in Slovenia took place.

Sericulture is a branch of agricultural activity encompassing rearing of silkworms and production of silk cocoons. Silk is the most valuable natural fibre and an environmentally friendly material. According to the United Nations International sericulture commission [3], global silk production in 2022 is estimated at 91,221 tonnes and accounts for only 0.2% of global textile fibre production, but its commercial value is much higher. It is a multi-billion dollar industry, with raw silk costing around twenty times as much as raw cotton [4].

China produces more than half of the world's silk, mainly fine mulberry silk used for clothing; India is the second largest silk producer in the world, with the most widespread production of wild silk; Italy is the largest silk importer in the world. The demand for silk will continue to increase due to the growing textile sector in developing countries, the increasing purchasing power of people and the user-friendly properties of silk [4].

In recent years global silk production declined [3] while prices of silk increased [4], mainly due to problems of sericulture in China, the largest producer of raw silk in the world [5]. The decline of production is mainly due to over intensified sericulture, concerning excessive use of artificial fertilizers and irrigation within cultivation of mulberry trees, abuse of antibiotics as growth promoters in the silkworm rearing, and the environmentally harmful transport of silk. The decrease of intensive Asian sericulture and silk textile industry as well as the question of the decent value of human labour contributed to the revival of this activity in Europe [6].

1.1. Sericulture in the territory of today's Slovenia in the past

Sericulture was already present in the territory of present-day Slovenia from the 16th century to the mid-20th century [7]. It was an important economic activity of our ancestors, as Slovenia has favourable natural conditions for the cultivation of the white mulberry tree *Morus alba L.*, whose leaves are the exclusive food for the silkworm *Bombyx mori L.* In Goriška, sericulture began with the rearing of silkworms, reeling of cocoons and production of silk yarns and fabrics [8, 9] and continued until the middle of the 20th century. Sericulture represented an important income for a large part of the local population of Goriška region [10]. At the end of the 19th century (1884), sericulture was abandoned in Kranjska, but continued in the Vipava Valley, Koroška and Štajerska [8]. After the First World War, when the Slovenian territory was occupied, sericulture and the silk industry in Goriška became part of the Italian economy. Italy had a highly developed mulberry silk production in Friuli. With the rise in silk prices on the world markets, sericulture in Friuli experienced a great boom, but after the Great Depression of 1929, prices for silk cocoons fell drastically on the world market. This led to the collapse of sericulture in Bovec, Kanal, Ajdovščina and the Vipava Valley. Sericulture existed in Prekmurje until 1938, when it was replaced by buckwheat cultivation and beekeeping. In order to meet the needs of the domestic market, after the Second World War there were attempts of revival of sericulture in the lower Vipava Valley in Renče, Bilje, Mirer and Vrtojba, in the immediate vicinity of Nova Gorica to Šempas, in Kras and in the valley between Lig and Kambreško.

The price of the silk always greatelly affected sericultural activity, which requiring neither large investments nor expensive equipment, but above all intensive human labour. Compared to sericulture, the situation in the silk industry is quite different, involving evaluation of the quality of silk cocoons as well as reeling of cocoons and processing of silk fibre. These processes can be carried out manually, especially in the production of unique items. The use of machines for sorting and reeling of cocoons, spinning machines for silk yarns, looms and knitting machines were already common in the 18th century. The domestic silk cocoons were reeled into threads and woven into fabrics such as velvet and ribbons, and socks were knitted. Silk fabrics were used to make colourful handkerchiefs, dresses, traditional costumes, socks and fabrics for parasols, which are part of the Gorenjska costume. The processing of silk waste into floret yarns continued in Solkan until 1965, when the last purchase of cocoons took place [10]. Artificial silk materials such as nylon for shirts and women's socks came onto the market and replaced natural silk [11]. However, significant industrial production of silk goods began in 1928 with the founding of a textile factory in Maribor under the name Mehanična tvornica svilenih izdelkov Maribor. In 1947, the Slovenian government founded the United Silk Factories, which brought together the manufacturers Thoma & Co, the Maribor silk factory

Radvanje and the Atama factory, the Maribor textile factory Košaki (1933−1947) [12]. They produced silk fabrics for loose clothing, such as crépe de Chine (fr. crépe de Chine, Chinese crepe) for women's dresses, blouses and linings, transparent georgette (fr. crepe de georgette) made of heavily twisted silk, which used to be produced in warp and weft yarns for blouses, thick, stiff and smooth taffeta for evening dresses and fine, light, shimmering satin in a satin weave. After modernization in 1978, Svila became the largest Yugoslav silk company for a few years, narrowly specializing in the production of silk fabrics, which was soon replaced by regenerated cellulose and synthetic fibers.

1.2. The beginnings of the revival of sericulture in Slovenia

The revival of sericulture in Slovenia is related to the bilateral project between Slovenia and Hungary in the period 2016–2018 [13]. Sericulture has already attractted the interest of numerous people - farmers and nonfarmers throughout Slovenia - who, with the professional support of the Institute of Sericulture RLB [14], successfully produce cocoons, hand reel cocoons and produce threads for bobbin lace [15] and hand weaving [16].

1.3. *Bombyx mori L.* silkworm cocoon formation

The development of the *Bombyx mori L.* silkworm takes 32–35 days (encompassing hatching of the larva from the egg and development-growth of the silkworm (including four moults)). After reaching full size and maturation (length of 8–10 cm and weight of 7–8 g [17]), a silkworm stops eating and starts looking for a place to spin a cocoon. The silkworm has a spinning wart on its head, squeezing out a jet of a protein fluids stored in a silk gland. The secreted protein jet quickly hardens into a very fine and strong thread consisting of two fibroin microfilaments glued together with a sericin protein cement (Fig.1a). While spinning, silkworm moves its head backwards and forwards in a shape of figure eight [18]. It attaches the silk thread to the substrate and then with long head movements forms a soft wadding, so-called silk floss. This phase is followed with forming a cocoon (Fig.1b) where the silkworm performs shorter head movements in the shape of a loop (a number 8).

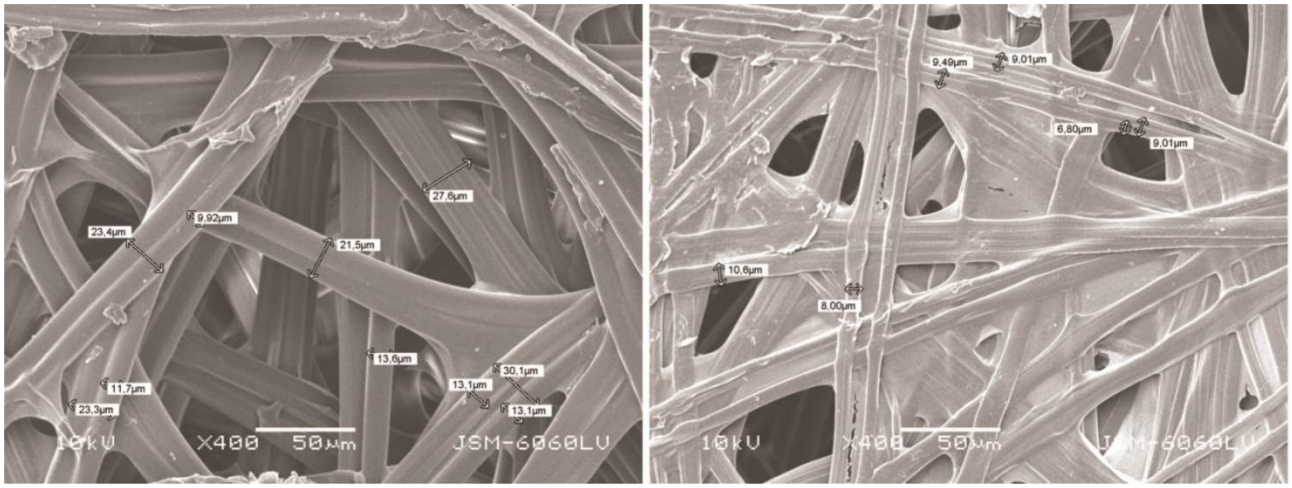
The outer layer of the cocoon (Fig.1c) is formed by placing the silk thread in compressed piles that cannot be reeled later. The middle layer of the cocoon (Fig.2a) can be reeled off. This layer is created by the rhythmic circular movements of the silkworm's head, depositing thread in the form of an irregular loop. The inner layer of the cocoon (Fig.2b) is made from finer thread from protein fluid, remained in the silk glands. This layer is loose and soft and cannot be reeled off. Formation of loops depends on a silkworm race (Figure 3a), environment temperature (Figure 3b) and the position of the layer in the cocoon (Figure 3c) [18].

Spinning of the silkworm and the formation of the cocoon strongly depend on the shape of the substrate into which the silkworm attaches the silk thread:

a) For a well-developed cocoon, the silkworm requires a fixation to three-dimensional framework. Various spatial shapes are suitable for this, from paper tubes to spiral strips to various brush-like substrates that imitate plant branches. If two silkworms are too close to each other, they can become entangled in a common twin cocoon, which is large but cannot be unwound.
b) The silkworm cannot form a cocoon on a flat surface, but lays down the silk thread two-dimensionally and forms flat structures, a kind of non-woven structure. The movement of the silkworm's head on a twodimensional surface, if there is no support from neighbouring threads, is within a range of 2–4 cm. Using the flat spinning process, designers already created an ambient mobile [19],

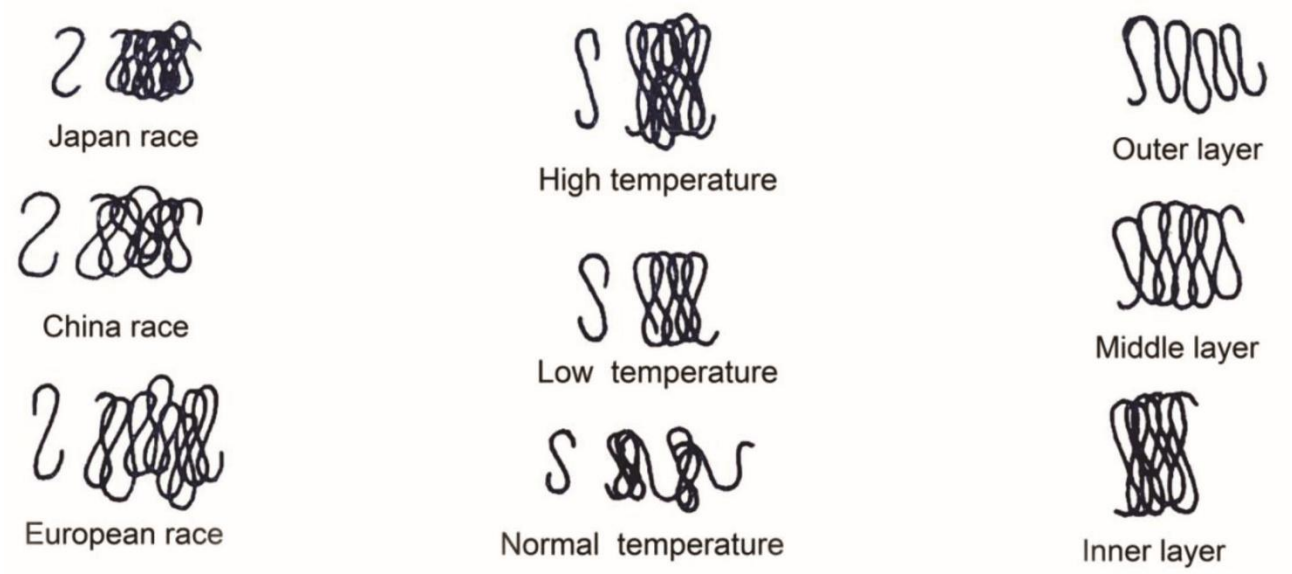
a. b. c.

Fig.1 a. Longitudinal view of extruded silk tread b. *Bombyx mori* L. cocoon; c. surface of the cocoon upper layer (*Photo: Mirjam Leskovšek*)



a. b.

Fig.2 Surfaces of the cocoon layers: a. middle layer; b. inner layer (*Photo: Mirjam Leskovšek*)



a. b. c.

Fig.3 Loop shape of deposited silk thread in cocoon: a. influence of the type of race; b. influence of the environment temperature; c. influence of the layer in the cocoon [18]

a flat silk scarf [19] and a dress [20]. The flat spinning is digitally performed on the website https://www.vickiessig.com/process-silkworms and https://svila.si/kabinet/.

Two dimensional silk mat made by a silkworms can be called a flat cocoon. Its structure is a kind of a nonwoven fabric with a potential applications in the field of technical textiles where silk is already used [21, 22]. Details of flat spinning and properties of these interesting silk mats have not yet been reported. The aim of our research was investigating the process of a two-dimensional spinning of silk mats (flat cocoons) by *Bombyx mori* L. silkworm and qualitatively evaluate their properties.

2. Methods

For the spinning silk mats nine frames were prepared on which a cross-linked surface structures were created by stretching the silk threads across the edges of the frames. The frame must be strictly two-dimensional, without corners or thicker layers in which the silkworms could insert a cocoon. The cross-linked structure served as a walking aid for the *Bombyx mori* L. silkworms. The distances between silk threads in the cross-linked structures varied from a minimum of 3 mm to a maximum of 3 cm. The frames were set up vertically and occasionally turned around for 360°, as the silkworms always prefer to move vertically up at the highest possible place.

Fig.4 Flat spinning by *Bombyx mori* L. silkworms

The mats on the frames were made by five to ten silkworms each within two days (out of four) of spinning (Fig.4). For production of a high quality silk mat, it was very important to transfer manually to a spinning net only those silkworms that have already stop eating and exterminated themselves; it was necessary to observe carefully the period when silkworms raise their heads with elongated "noses" and completely empty their intestines, becoming somewhat transparent and slightly wrinkled.

The silkworms were kept on the spinning frames for about two days, after which sufficient residual silk remained in their silk glands to allow them to complete cocoon construction on a suitable 3D surface and subsequently undergo metamorphosis into butterflies.

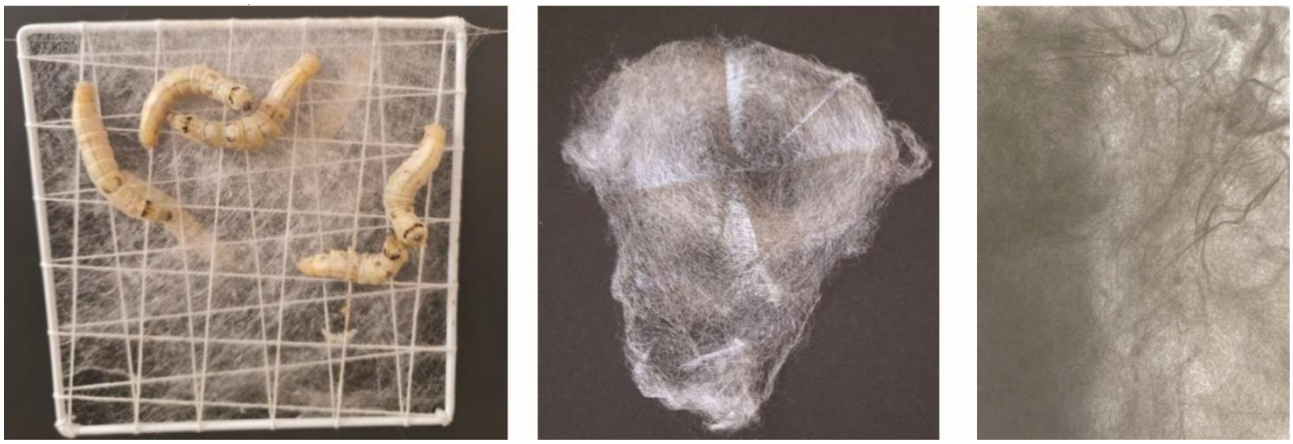
3. Results and discussion

Almost all silkworms tried to make a cocoon at the end of the fifth developmental stage. When a silkworm did not find a three-dimensional support where it could attach the silk thread and began to form the cocoon for further transformation, it secreted silk on a surface on which it was located. A silkworm on a flat substrate moved its head left and right in a diameter of 3–4 cm in the formed of a partial ellipse and forms a silk mate (Fig.5).

At flat spinning (Fig.6a) the silkworms on the frames were moved between stretched silk threads and tried to fix their silk extrudate. Sometimes they spun the mat from both sides of the frame at once. At the beginning they formed very disordered structure with many openings. In order to fill the entire surface and create the most uniform structure of the silk mat, it was necessary to control the tracks and move them from the top of the frame to lower positions and to places where there were voids. On the Fig.6b is seen a silk mat made by one silk-worm. Its surface was about 1 dm^2 and mass per unit area 45 g/m^2.

a. b. c.

Fig.5 *Bombyx mori* L. silkworm at flat spinning with a head movement: a. shown on the gray paper; b. at making silk mat on the frames with stretched silk yarns; c. structure of a flat cocoon in making



a. b. c.

Fig.6 a. *Bombyx mori* L. silkworm at flat spinning; b. Silk mat made by one silkworm; c. Morphology of raw silk mats

The elliptical formation made by the silkworm with the movement of its head is also clearly visible on the Fig.6b. Silk mats are thin and soft materials with an interesting morphology. Because of a natural moving of silkworms over the surface in different ways the structure can be partly wrinkled and transparent for light (Fig.6c). The sericin gum attached on the fibroin fibres (Fig.1a) is brittle, it breaks easily and falls off the fibres. The more sericin is shed, shinier the silk mat is.

4. Conclusion

In the experiment silk mats were successfully made and analysed. They can be used mainly for interior decoration. Care of items from silk mats should be investigated as they are made from raw silk fibre. Locally produced silk according to the guidelines of organic mulberry cultivation fulfils the criteria of a sustainable and environmentally friendly textile material with a positive ecological balance. For better understanding and comparison of silk flat spinning and silk cocoon development, websites were developed where all the digital media, with digital images and videos, are available on website https://svila.si/kabinet/

R e f e r e n c e s :

[1] Meadows, D.H.; Meadows, D.L.; Randers, J. III WWB. *The limits to growth.* New York, NY: Universe Books; **1972**. 205 p. Statistics.
[2] *From Industry 4.0 to Industry 5.0. Mapping the transitions*. Part of the book series: Studies in Systems, Decision and Control. Eds. A. Hamdan, A. Harraf, A. Buallay, P. Arora, H. Alsabatin. Springer Nature Switzerland; **2023**. https://doi.org/10.1007/978-3-031-28314-7
[3] Statistics. Global Silk Industry. *International Sericulture Commission*. Available at: https://inserco.org/en/statistics, Accessed: 10/11/2023.
[4] Silk market – global industry analysis and forecast (2023–2029). Available at: https://www.maximizemarketresearch.com/market-report/global-silk-market/26259/. Accessed: 10/11/2023.
[5] Mori, M.: The importance of assessing environmental impacts in the circular economy. *49. simpozij o novostih v tekstilstvu. Trajnost in krožno gospodarstvo v tekstilstvu. Zbornik izvlečkov*, Ljubljana, **2023**, ISBN 978961-7189-08-7. 5.
[6] Urbanek Krajnc, A.; Bakonyi, T.; Ando, I.; Kurucz, E.; Solymosi, N.; Pongrac, P.; Berčič, R.L. The Effect of Feeding with Central European Local Mulberry Genotypes on the Development and Health Status of Silkworms and Quality Parameters of Raw Silk. *Insects* **2022,** 13, 836. https://doi.org/10.3390/insects13090836
[7] Bolle, J. Kratek navod kako razumno izrejati sviloprejke. Paternolli, Gorica, **1882**.
[8] Žontar, J. Svilogojstvo in svilarstvo na Slovenskem od 16. do 20. stoletja, Založba ZRC, ZRC SAZU, Ljubljana, **1957**.

[9] Kobe-Arzenšek, K. Tekstilna proizvodnja in njena industrializacija na Slovenskem od začetka 19. stoletja do leta 1918 (Doktorska disertacija), University of Ljubljana, Ljubljana, **1979.**
[10] Ipavec, V.M. Murve in »kavalirji«. Svilogojstvo na Goriškem, Založba ZRC SAZU, Ljubljana, **2008**.
[11] Černe, A. Tekstilna tovarna in predilnica v Sračcah v Podgori, *1001 – solkanski časopis* **2012**, 19(74), pp. 7.
[12] Poročilo o stanju svilarstva in ukrepi za njegov napredek, 1926. Available at: http://www.siranet.si/volltextsuche.aspx/. Accessed: 10/11/2023.
[13] Urbanek Krajnc, A.; Ugulin, T.; Paušič, A.; Rabensteiner, J.; Bukovac, V.; Mikulič Petkovšek, M.; Janžekovič, F.; Bakonyi, T.; Berčič, R.L.; Felicijan, M. Morphometric and biochemical screening of old mulberry trees (*Morus alba* L.) in the former sericulture region of Slovenia. *Acta Societatis Botanicorum Poloniae* **2019**, 88(1), pp. 1-22. https://doi.org/10.5586/asbp.3614
[14] Inštitut za svilogojstvo in svilarstvo Rebeka Lucijana Berčič, zasebni zavod za raziskave, Maribor, **2018**. Available at: https://svila.si/institut/. Accessed: 10/11/2023.
[15] Razstava ISS RLBa: *Sijaj svilene čipke. Festival idrijske čipke 2023*. Available at: https://www.nib.si/razstave/1747-virtualna-razstava. Accessed: 10/11/2023.
[16] Požar, C.; Roženbergar, T.; Vardjan, M. *Trienale rokodelstva. Razstava sodobnih in inovativnih izdelkov na temeljih bogate kulturne dediščine Slovenije*. 26. 9. 2023. - 19. 11. 2023: Koroška galerija likovnih umetnosti, Slovenj Gradec. Koroški pokrajinski muzej, Slovenj Gradec, **2023**.
[17] Cook, G. *Handbook of textile fibres. I., Natural fibres*. Shildon, Merrow, **2012**.
[18] Jovanović, R.S. *Nauka o vlaknima i tehnologija vlakana. 3, Prirodna i hemijska proteinska vlakna*. Beograd, Građevinska knjiga, **1989**. ISBN 8639502048
[19] Essig, V. Working with silkworms. Available at: https://www.vickiessig.com/process-silkworms. Accessed: 10/11/2023.
[20] Ekart, K. Silk thread at intersection of design and art. Master's thesis. University of Ljubljana, Ljubljana, **2023**.
[21] Moncada-Saucedo, N.; Camacho-Morales, A.; Fuentes-Mera, l. Scaffolds based on silk fibroin for osteochondral tissue engineering. *Research & Development in Material Science* **2019**, 10(3). https://doi.org/10.31031/RDMS.2019.10.000740
[22] Ning, W.; Huang, J.; Ling, X.; Linet, H. Modification of electrospun silk fibroin nanofiber mats: using an EDC/NHS ethanol solvent. *IOP Conf. Ser.: Mater. Sci. Eng*. **2018**, 423(1), pp. 1–4. https://doi.org/10.1088/1757-899X/423/1/012068
[23] Chand, S.; Chand, S.; Raula, B. Usage of Silkworm Materials in Various Ground of Science and Research. *Journal of Natural Fibers* **2022**, 20(1), pp. 1–14. https://doi.org/10.1080/15440478.2022.2139328