

NUTRITIVE VALUE, USE AND IMPORTANCE OF MULBERRY LEAF FOR THE SILKWORM *BOMBYX MORI L.*

VALOAREA NUTRITIVĂ, UTILIZAREA ȘI IMPORTANȚA FRUNZEI DE DUD PENTRU VIERMII DE MĂTASE *Bombyx mori L.*

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Abstract

*If the silkworm is the main interest point of sericulture, the mulberry is the beginning point since it produces leaves, the only feed supply for silkworm species *Bombyx mori L.* Due to the production of silk fibre, on the one hand, and the secondary products produced by the sector (pupae with specific by-products, respectively cakes, oils etc.), on the other hand, the breeding of silkworms is of great economic importance. The mulberry, specifically the quality of the mulberry leaves, is one of the most important factors in determining silkworm growth, production, and health status. The mulberry (*Morus sp.*) is widely distributed in various climate zones, from tropical to temperate areas. The mulberry leaves have an excellent nutritional composition (proteins and amino acids, lipids and fatty acids, carbohydrates, vitamins and minerals, flavonoids etc.). Some volatile compounds contribute to the mulberry leaf's attractiveness, and one of the silkworm antennae receptors reacts significantly to cis-jasmone, which is thought to be the most alluring volatile component, even though it is naturally found in only trace amounts in the mulberry leaf. The digestive system and enzymatic equipment of the larva associated with the fermentative substances contained by mulberry leaves enable digestion and absorption of nutritive substances from the leaves, which are then converted into nutrients required for growth within the proper ranges and the production for obtaining a high-quality of silk fibres and valuable nutritional by-products. Given the crucial importance of the mulberries, new measures are necessary to grow and promote *Bombyx mori* silkworms, especially in rural regions.*

Keywords: mulberry, leaves, nutrients, silkworms, metabolism, applications

Rezumat

*Dacă viermele de mătase reprezintă punctul central de interes în sericultură, dudul, prin producția de frunze, reprezintă punctul de plecare, ca unica sursă de hrană pentru viermii de mătase din specia *Bombyx mori L.* Creșterea viermilor de mătase are o importanță economică deosebită dată, pe de o parte, de producția de fibră de mătase, iar pe de altă parte de produsele secundare generate de sector (pupe cu subproduse specifice, respectiv turte, uleiuri etc). Creșterea, producția și starea de sănătate a viermilor de mătase, sunt aspecte care depind de o serie de factori, dintre care primordial este dudul, și anume calitatea frunzei de dud. Dudul (*Morus sp.*) este dispersat extensiv în diverse suprafețe climatice, de la zone tropicale la temperate. Frunza are o compoziție excelentă în substanțe nutritive (proteine și aminoacizi, lipide și acizi grași, carbohidrați, vitamine și minerale, flavonoizi etc.). Atractivitatea spre frunza de dud este dată de o serie de compuși volatili, iar unul din receptorii din antene, răspunde puternic la cis-jasmone, considerat compusul volatil cel mai puternic atractant, deși este prezent natural în cantități mici în frunza de dud. Sistemul digestiv al larvei și echipamentul enzimatic specific, asociat cu fermenții din frunza de dud, permit digestia și absorbția substanțelor nutritive din frunză, ce sunt convertite mai departe în nutrienți necesari pentru creșterea în parametrii corespunzători și obținerea unor fibre de mătase de calitate și a unor sub-produse valoroase nutrițional. Dată fiind importanța crucială a dudului pentru sector, se impun noi măsuri de extindere a suprafețelor cultivate cu dud și de promovare a creșterii viermilor de mătase, cu precădere în zone rurale.*

Cuvinte cheie: dud, frunza, nutrienți, vierme de mătase, metabolism, aplicații

INTRODUCTION

Sericulture is a complex science that combines art and science to obtain silk fibre (as the main product) and secondary by-products (e.g., pupae with their waste cakes and oils), with multiple applications in various economic sectors (Jasmine and Mandal, 2014; Oduor et al., 2021). The economic value of sericulture depends on several ways of valorising products and by-products in the industry sector (Sharma et al., 2022).

The starting point of sericulture is the mulberry tree which belongs to the *Morus* genus and *Moraceae* family and has a wide geographic distribution in tropical and temperate regions. *Moraceae* is a family of plants from more than 64 species, subspecies, and a minimum of 100 varieties identified. The *Morus* word comes from Latinus "mora" and means, most probably, *delay* due to the slow development of its buds.

M. alba is the dominant species (Jan et al., 2021). The leaves are very important from the ecological point of view and as feed for silkworms being the single diet for *Bombyx mori* (*B. mori*). The pupae are directed principally to obtain silk production.

Greeks and Romans have cultivated mulberry since ancient times. Since 220 D.H., Emperor Elagabal was wearing a silk coat. The clergy members in England have worn silk robes since the 1500s. Mulberry and silk industry play a major role in Virginia (Tang et al., 2016; www.wikipedia.com).

Mulberry (*Morus sp.*) is a fast-growing plant adapted to temperate, tropical, and subtropical climates. In Romania, sericulture first developed in Transylvania and Banat in the 14th century (1348). In the 18th century, the Turks introduced sericulture practices in Moldova and Muntenian. For supporting sericulture, 60000 mulberry saplings were distributed for free in Moldova in 1845, for being cultivated in the South of the region. In Banat, mulberry is regarded as a symbol. In the 18th century, the Habsburgs introduced mulberry to feed silkworms. Sericulture developed in this area, such as Banat becoming the first silk exporter (Doliş, 2008). Leaves were considered the single feed for silkworm *Bombyx mori* L. (Sanchez, 2000; Thaipitakwonga et al., 2018).

Due to the essential oils, flavonoids, terpenes, and flavonoids used by silkworms for digesting processes, along with the nutritional content of the leaves, there may be an unpleasant odour. Palatability issues can be due to this odour (Finke, 2002; www.feedpedia.com). The ability to obtain high-quality cocoons depends on how effectively the nutritional components of the mulberry leaf are used. Pupae represent approximately 60% of the dry cocoon (Tassoni et al., 2022).

1. NUTRITIONAL VALUE OF MULBERRY LEAVES

The studies show that mulberry leaves contain toxic substances and have higher palatability than other vegetable leaves (Srivastava et al., 2006). The composition depends on variety, age, harvest time, and environmental conditions. The primary nutrients from the mulberry tree are proteins, carbohydrates, vitamins, sterols, and minerals (Raghuvanshi et al., 2019; Alipanah et al., 2020). Such as Srivastava et al., (2006) mentioned, the powder of mulberry leaves has a content in water ranging between 5.11–7.24%, crude protein (CP) between 15.31–30.91%, ash 14.59–17.24%, neutral detergent fibre 27.60–36.66%, fat 2.09–4.93%, carbohydrates 9.70–29.64%, and energy between 113–224 kcal/100 g.

Generally, the CP composition is comparable to that of most legumes. Several authors (Sanchez, 2000; Raghuvanshi et al., 2019) determined a CP level ranging from 15–28%, while Sanchez-Salcedo et al. (2017) found a level of 13.4–19.4%, Iqbal et al. (2012) a level of 18.41–24.63%, and Adeduntan and Oyerinde (2010) reported a level of 21.24–21.66%.

Compared with other plants, the fibre level is lower, although it depends on many factors such as season, age, etc. Calcium concentration is about 0.14–0.24%, and phosphorus is 1.8–2.4% (Sanchez, 2000). In 2000, Liu et al. specified that the leaves have a higher nutritional value in spring than in autumn.

Furthermore, Srivastava et al. (2006) highlighted that mulberry leaves contain important quantities of beta-carotene (14.688 mg/100 g) vs other plant leaves consumed usually (spinach, amaranth, fenugreek). Furthermore, iron and zinc, acid ascorbic and antioxidants are contained in mulberry leaves.

Two new flavonoids were also identified in leaves (Wang et al., 2009). Phytochemical components isolated from leaves and fruit extract from mulberry *Morus rubra* were reported by Sharma (2010). Recently, the antioxidant potential of extracts from different parts of mulberry plants leaves, roots, and fruits have been investigated by many authors (Andallu and Varadacharyulu, 2002; Arfan, 2012).

As perennial plants, the mulberry tree is characterised by a deep root system, high biomass production and remarkable adaptability. The mulberry leaf has a strong absorption capacity that is believed to be helpful in controlling air pollution. It has demonstrated an encouraging result for stabilizing the adverse effects of heavy metals in various polluted soils (Ghosh et al., 2017).

The attractivity of silkworms for mulberry leaves intake can be explained by 20 volatile compounds. From a neutral fraction of essential oil of old mulberry leaves, B- γ hexanol and α -B hexenal compounds attract the larvae. Twenty olfactive receptors are active in the antennae of silkworm larvae. From these receptors, one named *cis-jasmone* is considered the most strong and most attractive volatile, although it is in small quantities in leaves (0.3–300 ng). When the olfactive receptor is triggered to become active, insects move to the odour source. Citral also attracts silkworms when administrated within 30-300 ng, but not in small amounts. Linalol, hexenal, hexyl acetate and acetate 2-hexenyl presented an attractive activity at 30 ng, or 3 ng (Tanaka et al., 2009).

2. PROCESSES OF DIGESTION AND ABSORPTION IN SILKWORMS

The digestion and absorption of nutritional compounds from mulberry leaves present particularities due to the specificity of the digestive system described below.

It is essential to the fact that throughout the life cycle of the silkworm, only in the larval period does the silkworm consume feed based exclusively on mulberry leaves. In this phase, silkworms use nutritive compounds for growing and development and accumulate reserves for successive periods of growth.

2.1. The digestive tract of the silkworm

In the silkworm's body structure, such as seen by the larva's dissection, immediately under the skin at the median line of the dorsal surface of the larva, there is a dorsal vessel that surrounds many muscles and fat. Along the inside of the body is the digestive tube in the form of a straight tube with the trachea on both sides, and its dorsal side is the sericogenic gland. Beneath these organs are muscles.

Three main parts characterize the larva: the foregut (stomodeum), where feed is fragmented and stored; the middle intestine (mesenteric), where take place the digestion and absorption processes and the posterior intestine (proctodaeum), where waste is collected and decomposed substances are excreted or reabsorbed.

The foregut has the oral cavity, oral cavity, pharynx and oesophagus. At the end of the foregut, there is a cardiac valve that retain for a while, shredded leaves, to avoid regurgitation. The middle intestine (stomach) is the most significant part of the digestive tube. Goblet cells (intraepithelial, unicellular, scattered mucin secretors in simple epithelia) secrete the digestive fluid, and the cylindrical cell absorbs the digesta. The foregut and hindgut have a chitinous lining, and the peritrophic membrane in the midgut protects the epithelium from damage caused by feed particles. The posterior intestine has three components, the small intestine, cecum and rectum; a pyloric valve placed at the end of the small intestine protects and regulates the passage of feed particles from the middle to the posterior intestine. At the posterior segment of the digestive tube, the water is absorbed (a part re-enters the circuit), and the

undigested substances are eliminated. The rectal muscles exert mechanical pressure on the excreta (<https://hbmahesh.weebly.com>; Doliş, 2008).

2.2. Enzymatic equipment of silkworm

The enzyme involved in the digestion process is secreted in saliva and the middle intestine, the last having a vital role in digestion and absorption. The intestinal microorganisms can facilitate digestion. In other words, digestion consists of converting insoluble substances into soluble ones, while the impermeable substances become permeable. The most intense digestion process is in the middle intestine, where enzymes are secreted.

The digestive juice includes salivary and gastric juice. Saliva is a solution weakly alkaline and contains amylase. The gastric juice is strongly alkaline, pH of 9.2–10.3. The main enzymes contained in it is tyrosine (protease enzyme), lipase (the enzyme that acts on lipids), amylase, maltase and glycogenase (enzyme for decomposition of carbohydrates), oxidase, peroxidase, catalase, tyrosinase (enzymes oxidative). Amylase breaks down starch into destrins and maltose.

2.3. Digestion and absorption of silkworm

2.3.1. Digestion

The digestive system of the larva is well developed, while at pupae and moth are vestigial and non-functional.

Larva uses the digestive system to digest and absorb nutrients and other substances from consumed leaves. Macromolecules and other complex substances, such as proteins, polysaccharides, fats, nucleus acids etc., are taken over from mulberry leaves and subjected to a metabolic process. These substances must be beaked down by catabolic reactions in the small molecules, such as amino acids, fatty acids, and simple sugars, for passing into tissues and are used by own body cells for energy, growth, reproduction and, on the other hand, as substances required for body tissue synthesis. This process is named digestion (https://drive.google.com/file/d/1_H4Nps4-pkOX_K31Ni1QGgKy4BscnBiq/view).

The silkworms have considerable variation in the digestion, absorption and conversion capacity of the nutritive substance into body substances, depending on leaves quantity, climate variations, and feed (Rahmathulla and Suresh, 2012).

It is generally accepted that nutritive parameters are correlated with feed intake and silk production. The conversion of mulberry leaves into silk is highly correlated with the digestion capacity of the silkworm. A more accurate economic indicator for producing cocoons is the effectiveness of the conversion of mulberry leaves intake in silk or the conversion rate of active substances from leaves (Rahmathulla and Suresh, 2012). Only 620.70 kg of 2472.80 kg mulberry leaves produced/ha cultivated with mulberry plants are digested by silkworms and converted to 211.20 kg silk (Priyadharshini et al., 2017).

At *Bombyx mori* silkworm the haemolymph composition consists of 24–30 mg/mL protein and more than 1500 mg/mL lipids, while pupae have a weight that ranges between 705–885 mg (Mahmoud, 2017).

2.3.2. Absorption

The absorption of nutritional substances implies the passages from the digestive tube into the blood directly or indirectly through the lymph. Among the leaves' components, certain elements, such as glucose, soluble salts in the water etc., are absorbed directly by epithelial-specific cells in the middle intestine. Still, proteins and other macromolecules of large size can't penetrate through the cell wall. In this regard, by the decomposition into simple particles must be easily assimilable.

There are differences between the protein in mulberry leaf and the protein from the silkworm body. The specific protein of mulberry leaves is broken down by an enzyme in amino acids and peptones

and then is absorbed in the middle epithelial intestine and transported to organs through haemolymph. Into organs, the amino acids and peptones are re-synthesised in animal protein, a process named assimilation. The fat is re-synthesised in fatty acids and glycerol. Behind this synthesis, the fat can be synthesized from carbohydrates. An important part of mulberry leaf carbohydrate is synthesised in fat into the larva body.

3. EFFECTIVENESS OF FEED UTILISATION

Appropriate feeding is a critical indicator of the economic value of silkworm development and a factor in determining the superiority of specific breeds or hybrids' productive characteristics (growth, development, and silk production (Rahmathulla et al., 2005). The efficacy of digestion implies a superior conversion of nutrients from silkworm into silk.

The conversion efficacy of ingesta (ECI) represents an important economic indicator of the assessment of cocoon production. The digestion and absorption process depend on hybrid/breed, the environmental factors, sex and quantity of feed.

Several methods to improve the rate of conversion in silk were highlighted by many authors (Benjamin et al., 1984; Chandrakala et al., 1999; Rahmathulla et al., 2005). The methods focus on respecting specific environmental conditions are the, growing the variety/ hybrids with superior characteristics, appropriate mulberry variety, diets according to qualitative and quantitative requirements, and respect for specific growing procedures. A high feed intake in larval phase 5 positively influences body weight and silk production. Females consume more feed than males, and monovoltine breeds ingest and digest a higher quantity of feed. The digestibility of leaves is higher in monovoltine species, although in polyvoltine breeds, diet digestibility is significantly higher (Tzenov et al., 1999).

A positive correlation is found between leaves intake and the protein level in silk fibre. The leaves' intake influences as well the reproduction activity and quantity of biomass accumulated. The newly created hybrids valorise the feed better compared to the traditional one.

In the larvae phase, digestibility remains more or less constant from the first day up to the middle of the growing phase; after that, a decline is registered up to the spinning process. The efficacy with which the feed is digested is converted to body mass decreases with age (Rahmathulla et al., 2005). The quantity of dry matter consumed and digested, ECI, the final weight of the larva and the weight of the cocoon increase significantly, being correlated with water quantity from leaves. A less water content extends larval phases.

The mean of parameters relies on ingesta and digesta of silkworm feed with three varieties of mulberry Kenmochi (*Morus bombycis* Kodiz), black mulberry (*Morus nigra* L.), and native mulberry (*Morus alba* L.) on the entire larval period, and they were presented by Alipanah et al., (2020), respectively 34% DM, leaves ingested 5.16 g, excreta 2.20 g, leaves digested 2.42 g, digestibility 44.2%.

Figure 1 shows the biological cycle of silkworm growing, production and health, and potential industry application.



Figure 1. Biological cycle, nutritional quality and applications of the silkworm growth / Ciclul biologic, calitate nutrițională și aplicații ale creșterii viermilor de mătase

4. IMPORTANCE OF MULBERRY CULTIVATION

All those described above highlight mulberry leaves' primary role in the silkworm diet. Of crucial importance is that leaves are stocked with all the nutrients the larva needs for body functions (growing, reproduction, silk production). In addition, the positive involved for health through the conversion of nutrients in compounds beneficial to the insect's health is also important. From an economic point of view, silkworms also have an important role. However, this species cannot survive without mulberry plants.

The valuable components from leaves and fruits make these plants a suitable functional food for human health besides the primary nutritional value (Kadam, 2019).

Practically, the protein contained in mulberry leaves is transformed into silk that includes 2 types of protein (fibroin and sericin). This means that the silk produced in this way can be used commercially for silk-coats. It is estimated that silk obtained from silkworms greatly contributes to the global production of silk (approx. 90%) and is a very attractive economic activity, especially for the rural population, significantly contributing to several social groups. Behind these aspects, many nutritional and medicinal benefits are demonstrated by the mulberry plant. Thus, mulberry leaves are used for numerous other things besides feeding silkworms. The leaves and fruits are protein and vitamins-rich and were exploited long ago as feed to animals in many countries. Due to its high nutritional value and savoury, the mulberry fruit can be considered a valuable food.

Mulberry bark and wood are also useful for making paper and sporting goods. The evaluation of several medicinally important pharmacological compounds present in the mulberry plant has recently opened new avenues of medical science research. Furthermore, studies demonstrate antioxidant effects, antivirals, anti-inflammation, hypolipidemic, anti-hyperglycaemic, neuroprotective activities (Pan and Lou, 2008), anti-HIV, anti-hypotensive and cytotoxic of different mulberry species (Du et al., 2003). Furthermore, fruits, roots and leaves extract can be used in cosmetics, dermatological skin care products, gels, and many others due to a greater capacity for capturing free radicals.

The mulberry is very important from the economic point of view and for the environment, taking into consideration many aspects of its role as feed for animals, phytomedicine, and cleaning up contaminated soils and air etc. (Ghosh et al., 2017). Large quantities of wastes from the sericulture industry (such as parts of mulberry plants and excrement of silkworms), nutritive-rich, are generated during the growth period of silkworms fed with mulberry leaves. It is estimated that 15 tonnes of waste

(including crop and agricultural waste) are generated annually from one hectare of the mulberry farm. Identifying ways to utilize these wastes properly can open up new opportunities for income generation for sericulture farmers. However, the surface cultivated with mulberry trees recorded a significant decline in Europe, including Romania, and immediate measures must be taken to revitalize and expand cultivated areas. In this way, the Government Rules (H.G. no. 695/2022) on the management and administration of the Research Station for Sericulture Baneasa-Bucharest for the further development and restoration of the value of the sericulture sector is very important.

CONCLUSION

Besides the aspects that rely on the economic importance of growing silkworms due to silk production and valuable by-products, mulberry leaves are a central point of interest. The mulberry (genus *Morus*, family *Moraceae*) is widely dispersed in various climatic areas, from tropical to temperate zones. Mulberry leaves have become very important for sericulture, especially since they are the only feed source for the species *B. mori* L. silkworms.

The nutritional value of mulberry leaves, the protein and amino acids, lipids and fatty acids, carbohydrates, vitamins and minerals, flavonoids etc., are adequate for growth and good health status. We can mention that mulberry has economic and environmental importance, considering many aspects of their role in various sectors, such as animal feed, phytomedicine, and cleaning up the soil of pollutant substances and the atmosphere. Large quantities of sericulture wastes, such as leftover plants and excreta of silkworms rich-nutritive are generated from this industry. Identifying correct ways of waste valorisation opens new opportunities for generating income for farmers practising sericulture. In particular, during the early stages of growth, the silkworm's digestive tract possesses properties that enable it to consume the leaf and absorb nutrients in a relatively high proportion. The silkworm's enzymatic equipment and the fermentation process in mulberry leaves considerably aid in the nutritional principles' ability to be digested.

New initiatives are needed to increase the mulberry cultivation areas and encourage the development of silkworms, particularly in rural areas.

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REFERENCES

1. Adeduntan, S.A., Oyerinde, A.S. Evaluation of nutritional and antinutritional characteristics of obeche (*Triplochiton scleroxylon scleroxylon*) and several mulberry (*Morus alba*) leaves. 2010. African Journal of Biochemistry Research. 4: 175–178.
2. Alipanah M., Abedian Z., Nasiri A., and Sarjamei F. Nutritional effects of three mulberry varieties on silkworms in Torbat Heydarieh. 2020. Psyche: A Journal of Entomology. 1–4. <https://doi.org/10.1155/2020/6483427>.
3. Andallu B., Varadacharyulu N.Ch. Antioxidant role of mulberry (*Morus indica* L. cv. Anantha) leaves in streptozotocin-diabetic rats. 2003. Clinica Chimica Acta. 338(1-2): 0–10. doi:10.1016/s0009-8981(03)00322-x .
4. Arfan M., Khan R., Rybarczyk A. and Amarowicz R. Antioxydant activity of mulberry fruit extract. 2012. International Journal of Molecular Science. 13: 2472–2480.
5. Benchamin K.V., and Jolly M.S. Studies on ingestion, digestion and conversion efficiency in polyvoltine and bivoltine silkworm breeds (*Bombyx mori* L.) 1984. Proceeding of 3rd Oriental Entomology Symposium. Feb. 21-24. Trivandrum. India. 195–206.
6. Chandrakala M.V., Raghuraman R., and Rao S.K. Food and dietary water utilization in male and female silkworms (*Bombyx mori* L.) of a sex-mited bivoltine rase. 1999. Indian Journal of Sericulture. 38: 131–134.
7. Doliş M. Sericicultura. 2008. Editura Alfa. ISBN 978-973-8953-52-9.
8. Du J., He Z.D., Jiang R.W., Ye W.C. and Xu H.X. Antiviral flavonoids from the root bark of L. *Morus alba*. 2003. Journal of Phytochemistry. 62-8: 1235–1238. [https://doi.org/10.1016/S0031-9422\(02\)00753-7](https://doi.org/10.1016/S0031-9422(02)00753-7).

9. Finke M.D. Complete nutrient composition of commercially raised invertebrates used as food for insectivores. 2002. *Zoo Biology*. 21(3): 269–285. Wiley InterScience (www.interscience.wiley.com). doi:10.1002/zoo.10031.
10. Ghosh, A., Gangopadhyay D., and Chowdhury T. Economical and Environmental Importance of Mulberry: A Review. 2017. *International Journal of Plant and Environment*. 3(2): 51–58.
11. Iqbal S., Younas U., Sirajuddin Chan K. W., Sarfraz R. A., Uddin K. Proximate composition and antioxidant potential of leaves from three varieties of mulberry (*Morus* sp.): A comparative study. 2012. *International Journal of Molecular Science*. 13: 6651–6664.
12. Jan B., Parveen R., Zahiruddin S., Khan M.U., Mohapatra S., Ahmad S. Nutritional constituents of mulberry and their potential applications in food and pharmaceuticals: A review. 2021. *Saudi Journal of Biological Sciences*. 28(7): 3909–3921. <https://doi.org/10.1016/j.sjbs.2021.03.056>.
13. Jasmine S., and Mandal B.B. Types and properties of non-mulberry silk biomaterials for tissue engineering applications. 2014. *Silk Biomaterials for Tissue Engineering and Regenerative Medicine*. 275–298. doi:10.1533/9780857097064.2.275.
14. Kadam R.A., Dhuma N.D., and Khyade V.B. The mulberry *Morus alba* (L.): The medicinal herbal source for human health. 2019. *International Journal of Current Microbiology and Applied Sciences*. 8(4): 2941–2964. doi: <https://doi.org/10.20546/ijcmas.2019.804.341>
15. Liu J.X., Jun Y., Yan B.J., Shi Z.Q., Wang X.Q., Yu J.Q. Mulberry leaf supplement for sheep fed ammoniated rice straw. In: Sánchez, M. D. (Ed.), Conf. paper "Mulberry for animal production". Proc. e-conf., May-Aug. 2000. FAO Animal Prod. and Health Paper, 147: 189–201.
16. Mahesha H.B. Anatomy of silkworm *Bombyx mori*. https://hbmahesh.weebly.com/uploads/3/4/2/2/3422804/4.anatomy_of_silkworm_bombyx_mori.pdf.
17. Mahmoud K.M. Impact of nutritional composition of wild and cultivated mulberry varieties on productivity and some biochemical parameters of silkworm *Bombyx mori* L. (Bombycidae: Lepidoptera). 2017. *Journal of Applied Plant Protection; Suez Canal University*, 6 (1): 25–30.
18. Oduor E.O., Ciera L., Adolkar V., and Pido, O. Physical characterization of eri silk fibers produced in Kenya. 2019. *Journal of Natural Fibers*. 1–12. doi:10.1080/15440478.2019.1612306.
19. Pan G. and Lou C.F. Isolation of an 1-aminocyclopropane-1-carboxylate oxidase gene from mulberry (*Morus alba* L.) and analysis of the function of this gene in plant development and stresses response. 2008. *Journal of Plant Physiology*. 165 (11): 1204–1213. doi:10.1016/j.jplph.2007.02.012.
20. Priyadharshini P., Joncy M.A., Saratha M. Industrial utilization of silkworm pupae – A review. 2017. *Journal of International Academic Research for Multidisciplinary*. 5 (7): 62–70.
21. Raghuvanshi T., Bali R.K., and Bukhari R. Effect of different feeding frequencies on the commercial characters of silkworm (*Bombyx mori* L.). 2019. *International Journal of Current Microbiology and Applied Sciences*, 8(6): 3193–3203. <https://doi.org/10.20546/ijcmas.2019.806.381>.
22. Rahmathulla V.K., Haque Ruffae S.Z., Himantharaj M.T., Vindya G.S and Rajan R.K. Food ingestion, assimilation and conversion efficiency of mulberry silkworm, *Bombyx mori* L. 2005. *International Journal of Industrial Entomology*. 11 (1): 1–12.
23. Rahmathulla V.K., Suresh H.M. Seasonal variation in food consumption, assimilation, and conversion efficiency of Indian bivoltine hybrid silkworm, *Bombyx mori*. 2012. *Journal of Insect Science*. 12: 82 available online: insectscience.org/12.82.
24. Sanchez M.D. Mulberry: an exceptional forage available almost worldwide! 2000. *World Animal Review*. 93: 1–21.
25. Sanchez-Salcedo E. M, Amoros A., Hernandez F., Martinez J.J. Physicochemical properties of white (*Morus alba*) and black (*Morus nigra*) mulberry leaves, a new food supplement. 2017. *Journal of Food Nutrition and Research*, 5: 253–261.
26. Sharma S.B., Tanwar R.S., Rini A., Singh U.R., Gupta S. And Shukla S.K. Protective effect of *Morus rubra* L leaf extract on det-induced atherosclerosis in diabetic rats. 2010. *Indian Journal of Biochemistry and Biophysics*. 47(1): 26–31.
27. Sharma V., Rattan M., and Chauhan S.K. Potential use of sericultural by products: A review. 2022. *The Pharma Innovation Journal*. SP-11(8): 1154–1158.
28. Srivastava S., Kapoor, R., Thathola A., and Srivastava R.P. Nutritional quality of leaves of some genotypes of mulberry (*Morus alba*). 2006. *International Journal of Food Sciences and Nutrition*. 57(5/6), 305–313.
29. Tanaka K., Uda Y., Ono Y., Nakagawa T., Suwa M., Yamaoka R., and Touhara K. Highly selective tuning of a silkworm olfactory receptor to a key mulberry leaf volatile. 2009. *Current Biology*. 19: 881–890, doi:10.1016/j.cub.2009.04.035.
30. Tang R., Zhang F., and Zhang Z.N. Electrophysiological responses and reproductive behavior of fall webworm moths (*Hyphantria Cunea Drury*) are influenced by volatile compounds from its mulberry host (*Morus alba* L.). 2016. *Insects*. 7, 19. doi:10.3390/insects7020019.

31. Tassoni L., Cappellozza S., Zotte A.D., Belluco S., Antonelli P., Marzoli F., and Saviane A. Nutritional composition of *Bombyx mori* pupae: A systematic review. 2022. *Insects*. 13, 644. <https://doi.org/10.3390/insects1307064>.
32. Thaipitakwong T., Numhom, S., and Aram, P. Mulberry leaves and their potential effects against cardiometabolic risks: a review of chemical compositions, biological properties and clinical efficacy. 2018. *Pharmaceutical Biology*. 56(1): 109–118. <https://doi.org/10.1080/13880209.2018.1424210>.
33. Tzenov P., Petkov N., and Natcheva Y. Study on the inheritance of food ingestion and digestion in hybrids between univoltine and multivoltine silkworms *Bombyx mori* L. races. 1999. *Sericologie*. 39: 171–177.
34. Wang L., Gong T. and Chen R.Y. Two new prenylflavonoids from *L. Morus nigra*. 2009. *Journal of Chinese Chemistry*. 1469–1471.
35. e-curs https://drive.google.com/file/d/1_H4Nps4-pkOX_K31Ni1QGgKy4BscnBiq/view
36. www.feedpedia.com
37. www.wikipedia.com