The world of Silk

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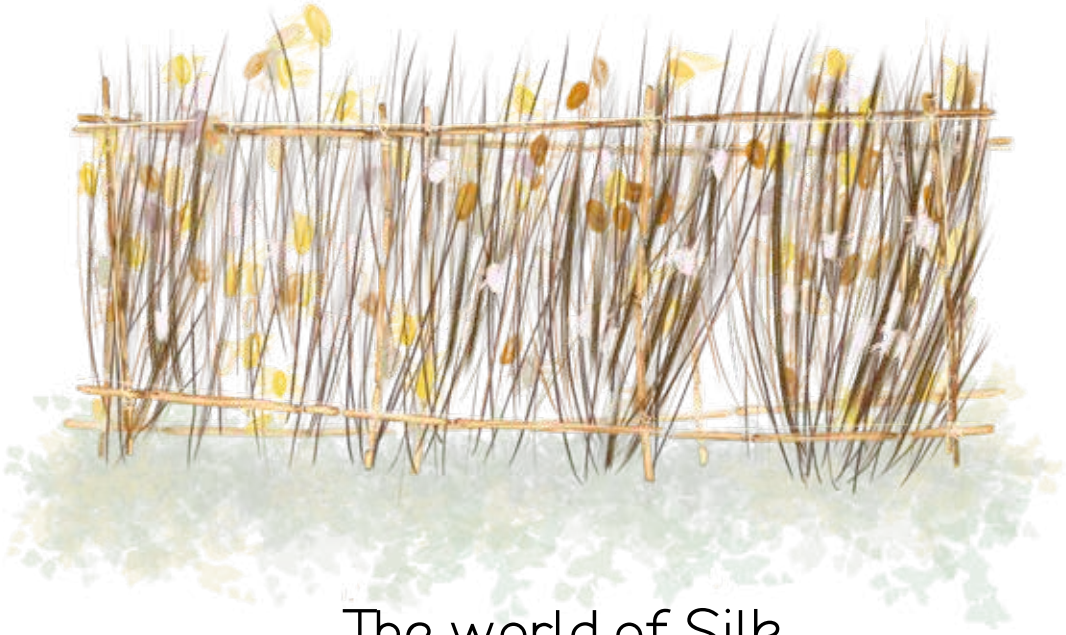


The world of Silk

A learning guide to the history, mythology, science and technology of sericulture.

The art and craft that encompasses the cultivation of mulberry trees, the silkworm rearing, and the subsequent processing of this fibre, an activity that has remained connected to humans since the Neolithic period.

The silkworm *Bombyx mori*

Its scientific name comes from Latin and Greek. The prefix "*Bombyx*" means silkworm, and "*mori*" refers to the mulberry tree it feeds on.

It belongs to the lepidopteran group of insects because it has scaly wings and undergoes metamorphosis. It is classified in the *Bombicidae* family within this group.

History of silk

The earliest evidence of sericulture appears in China. These are textile remnants and tools involved with this activity, found in archaeological excavations at Jiahu, dating back 8,500 years. In this site, silk appears woven or sewn into other textiles.

The first written records documenting domesticated silkworm rearing are attributed to Confucius and date to around 2,700 BCE. These accounts relate the legend of Empress Leizu's discovery of silk.

For 3,000 years, sericulture was kept a secret by imperial order, under penalty of death for anyone who revealed the knowledge. During this time, silk became the emperor's most common diplomatic gift to neighbours or vassals—it was even used as a tribute to secure peace with the Huns.

Experts believe that by the 2nd century BCE, the Chinese had already established a commercial network to export this fibre to the West: the vast and dangerous Silk Road.

History of silk

In 552 CE, Emperor Justinian received the first silkworm eggs from Persian monks who had hidden them inside bamboo canes. He then established imperial factories renowned for the quality of their fabrics.

During the 7th century, the Arabs who invaded Persia transmitted this knowledge to North Africa and Southern Europe, where a major silk industry gradually began to flourish—an industry that remained significant until quite recently.

Even today, you can find people who remember this industry and raised silkworms at home. This family endeavour helped cover significant expenses, including medical care and dowries.

The Silk Road

Myths and legends of silk

Since the Neolithic era, the fate of this species has been closely interwoven with that of humans by means of a delicate thread of silk.
For centuries, its origins were shrouded in mystery, leading the civilizations along the Silk Road to create many legends about it.
In Persia, it was believed that the first pair of silkworms emerged from the body of Job.

According to the writings attributed to Confucius, in the 17th century BCE, the fourteen-year-old Empress Leizu discovered how to reel the silk from a cocoon when one accidentally fell into her tea cup. She then conceived the idea of weaving the silk. At the suggestion of her husband, Emperor Huang Di, she observed the silkworms' life cycle and taught her court how to raise them. Since then, she has been revered as the goddess of silk in Chinese mythology.

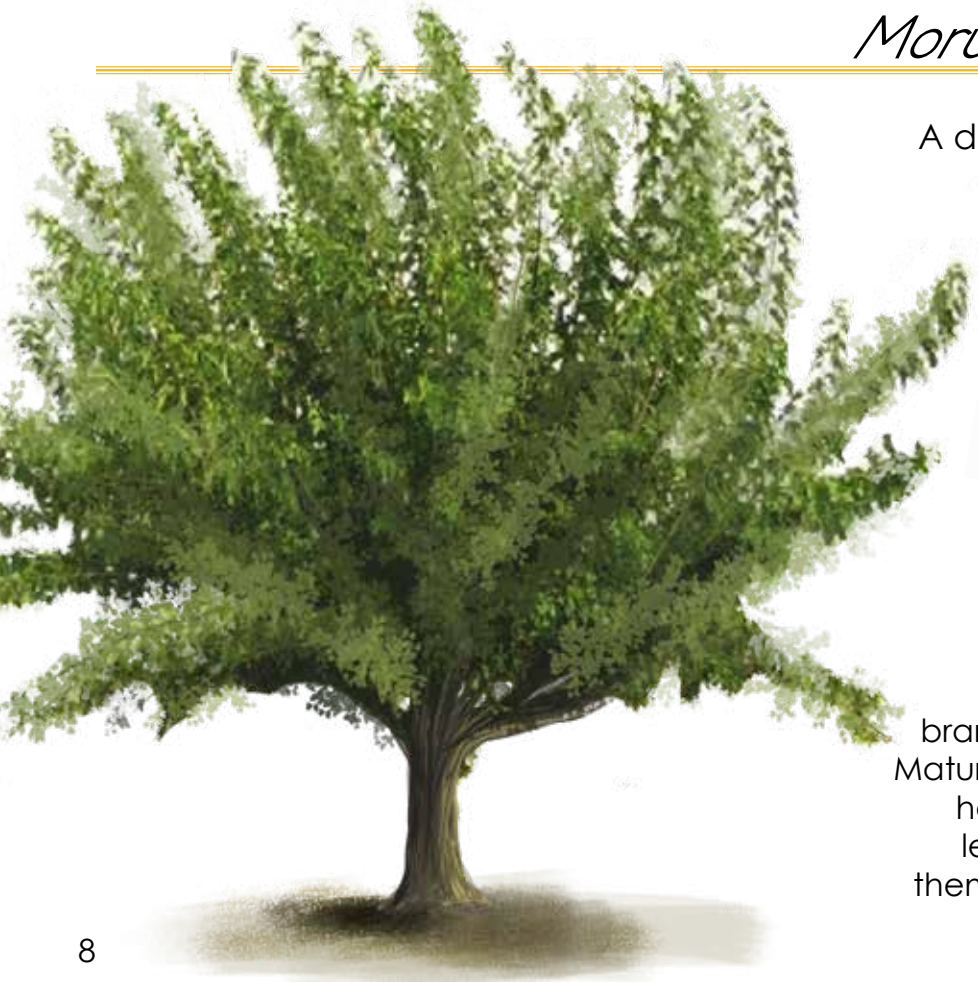
Although silk began to be exported very early to other countries, sericulture was a closely guarded secret of the Chinese. Other nations had to come up with various explanations for this marvellous fabric.

Thus, the Romans believed that silk came from trees that grew wool in Seres, an unknown people from a distant and mysterious land.

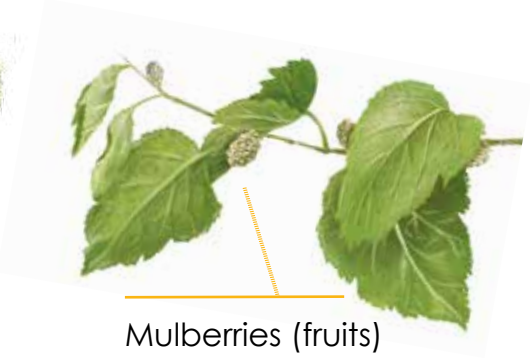
According to another legend silk travelled from China to India hidden in the hair of a princess who was betrothed to the prince of Khotan. This young woman defied the imperial ban on exporting silkworms, refusing to part with her beloved fabric.

HARVEST OF MULBERRY LEAVES
Carried out early in the day to prevent the leaves from heating up, leaving the branches on the tree so new buds can grow.

Morus / Mulberry Tree



A deciduous tree with alternate, serrated-edge leaves.

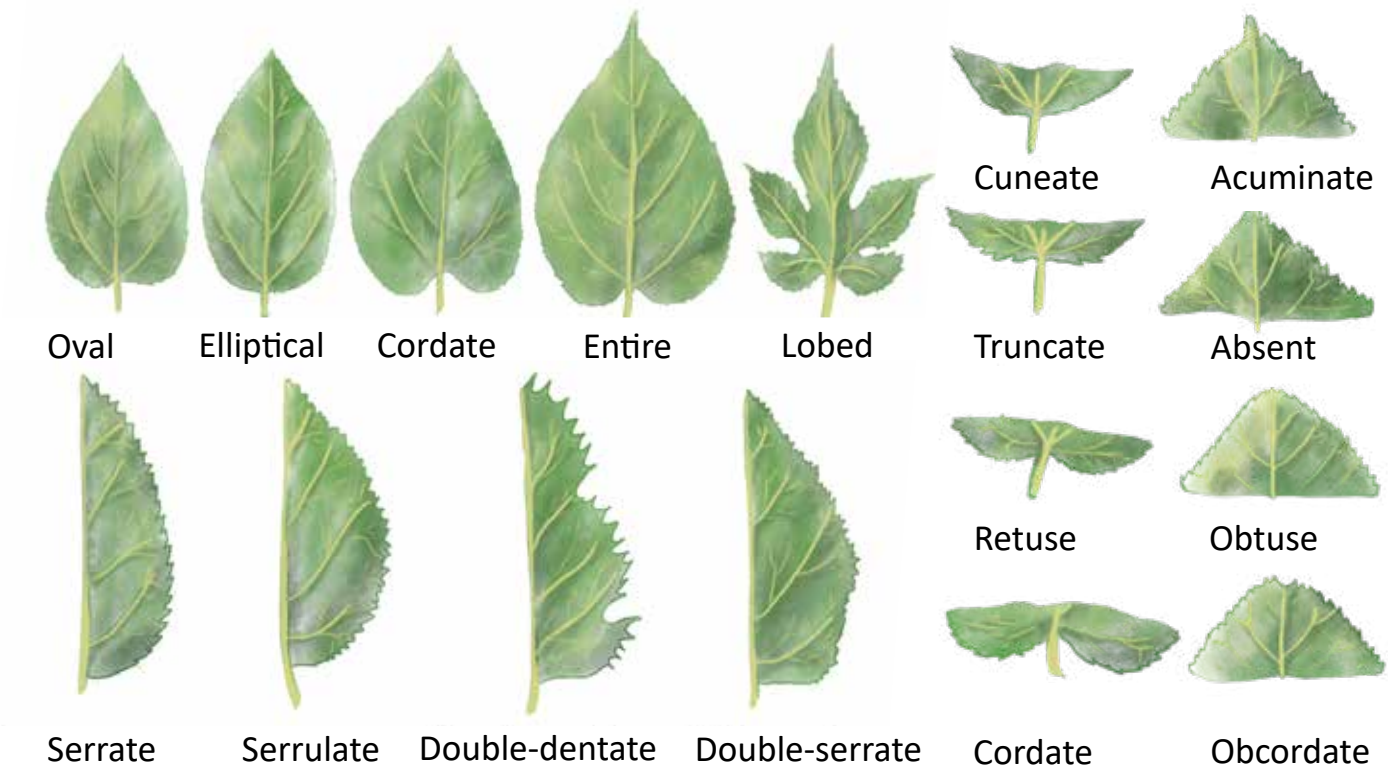


Mulberries (fruits)

Tender shoots at the tips of branches are light green in colour. Mature leaves, dark green in colour, have a rougher texture. Pick the leaves in the morning and keep them somewhere cool so they stay fresh all day.

Classification of mulberry leaves by shape

The *Morus* genus has many species, the most well-known being:
Morus alba (white mulberry), *Morus nigra* (black mulberry) and *Morus rubra* (red mulberry).



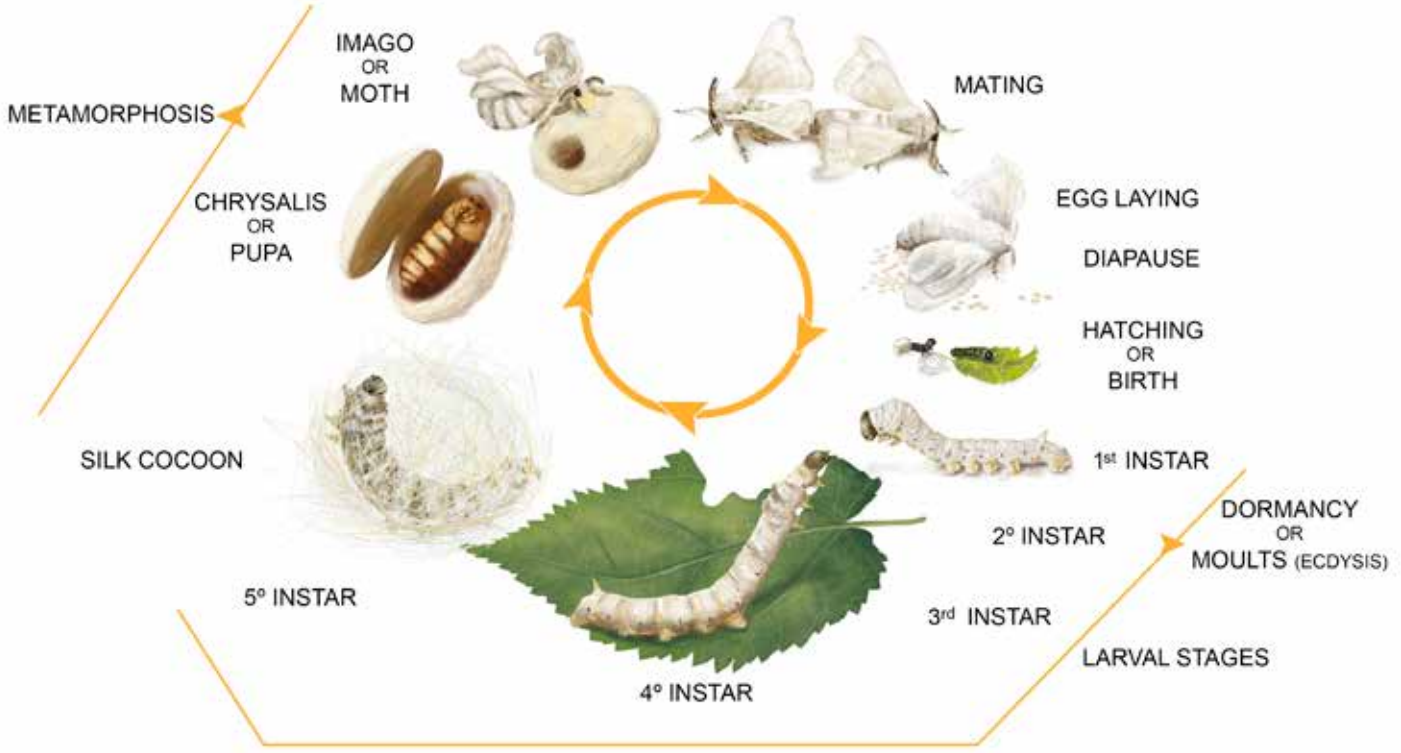
Spring

This insect is closely linked to the mulberry tree, which serves as its primary food source. Its life cycle is closely aligned with the tree's seasonal rhythms, using strategies like the notable diapause to survive and thrive. The silkworm's embryo will halt its development inside the egg, waiting for favourable external environmental conditions.

Spring, with its increase in sunlight hours and temperature, will prompt the silkworm embryos to come out of this state, which allowed them to survive while there was no food, and complete their development. They are born at the same time the mulberry trees begin to sprout. Their development is finely tuned to the seasonal cycle.
The silkworm is highly specialized to coexist with the mulberry tree; the tiny jaws of newly hatched larvae can only chew the tender young shoots.

However, they will grow in parallel with the maturing leaves, adapting their bodies to eat increasingly tougher foliage.

Life cycle



The complete life cycle of the silkworm takes approximately 65 days

Silkworm seed

In the region of Murcia, the term "simiente" (seed) has traditionally referred to silkworm eggs prepared for revival or incubation. Since 1918, the Sericultural Station of Murcia has overseen the control and distribution of these seeds, packaging them in small circular boxes containing half an ounce (approximately 15 grammes), which corresponds to around 25,000 eggs.

The eggs are revived in incubators that maintain constant temperature and humidity levels. By carefully controlling lighting and temperature during the final stages of development, it is possible to synchronise the hatching of all the eggs.

Upon hatching, a silkworm larva measures about 2 millimetres in length and weighs approximately one-thousandth of a gramme.

"AVIVADOR" or OLD INCUBATOR
A device used to maintain constant temperature and humidity, facilitating the hatching of silkworm eggs.

DEVELOPMENT OF THE SILKWORM INSIDE THE EGG

EMBRYO

This stage lasts 36 hours.

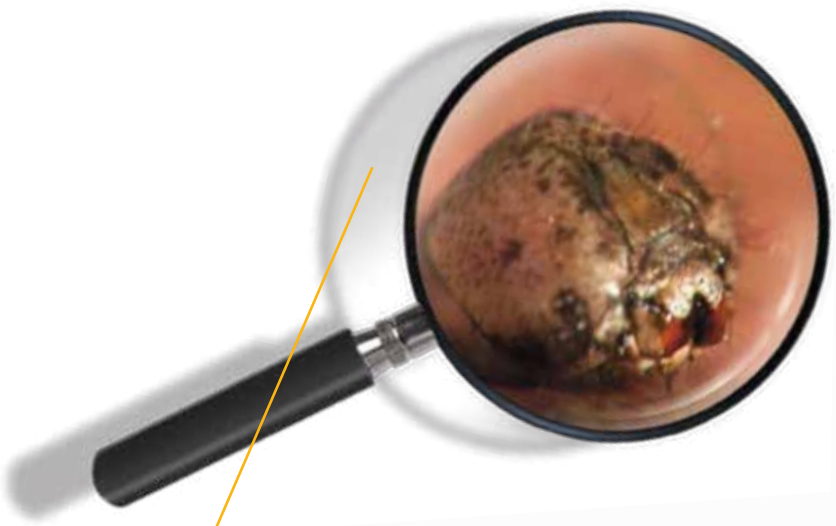
INCUBATION

This phase lasts from 16 to 20 days.

Moults or "dormidas" (lethargic phases)

From the moment the silkworm hatches until it becomes a moth, approximately 45 days elapse. During this period, by continuously feeding on mulberry leaves, the silkworm increases its weight by about 12,000 times, growing from 1 mm to 8 cm in length.
This rapid growth requires the silkworm to undergo four moults. During each moult, the larva sheds its skin and the hard shell of its head to accommodate further growth and enhance its feeding capacity.
In Murcia, these moulting phases have traditionally been called "dormidas".
To moult successfully, the silkworm anchors itself with silk threads, raises its head and thorax, and stops feeding for approximately two days until ecdysis the shedding of the old skin is complete.
It is crucial not to disturb silkworms during moulting, as handling them can break the silk threads they rely on for anchorage. These threads are essential for a successful moult and the proper shedding of the old skin (also called exuviae).

Moults or "dormidas" (lethargic phases)



Larval stages

The stages between each moult are called larval instars:

- 1st instar: lasts 5 days, and the worms eat very tender leaves.
- 2nd instar: lasts 6 days, they eat slightly more mature leaves.
- 3rd instar: lasts 6 days, they eat mature leaves.
- 4th instar: lasts 7 days.
- 5th instar: lasts 8 days and ends with the construction of the cocoon.

The fourth and fifth stages are known as “freza.” During these stages, the silkworm will consume an astonishing amount of leaves 85% of the total leaves it will eat throughout its life.

Larval stages

1st instar

2nd instar

3rd and 4th instar

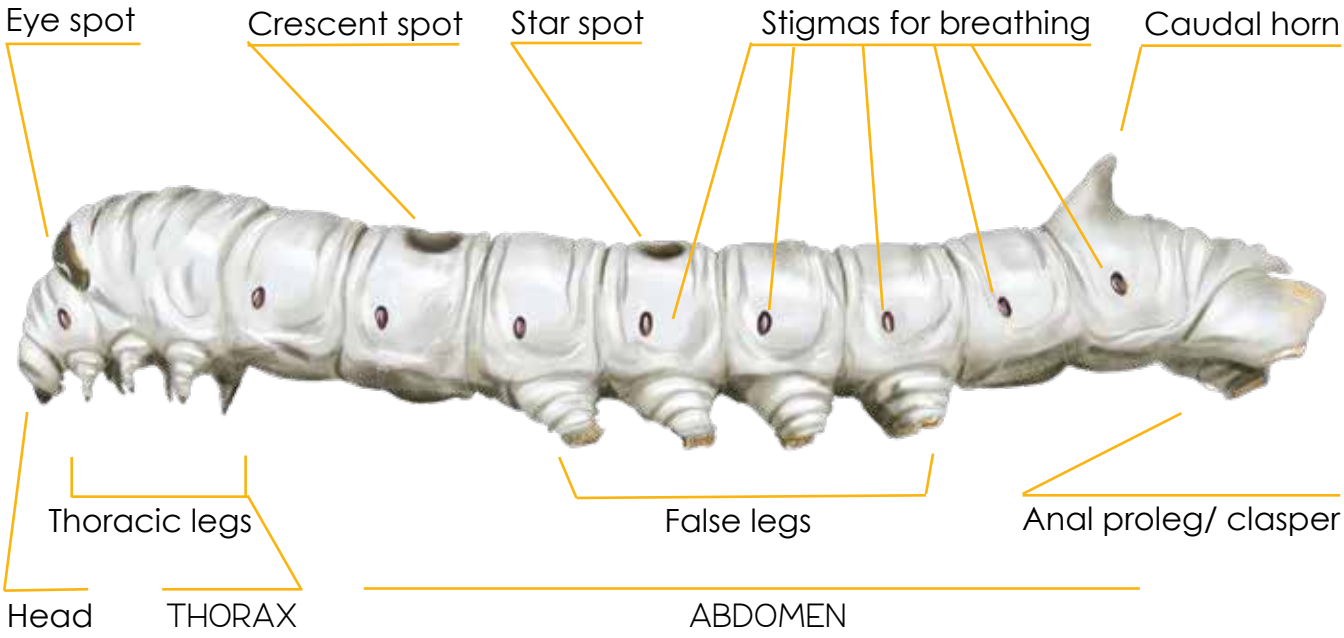
5th instar

Morphology of *Bombyx mori* in the fifth instar

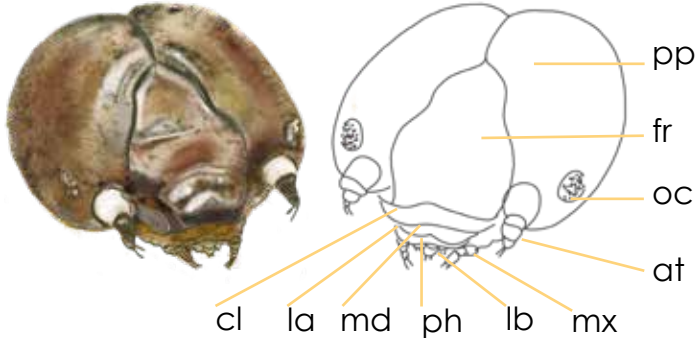
The silkworm's head is covered by a hard shell made of chitin and contains small, feathery antennae, twelve eyes, and two jaws that move sideways with the mouth located between them. At the base of the head is the silk producing organ (spinneret), through which silk is released, along with palps used to manipulate the thread.

The body is made up of twelve segments. The first three segments form the thorax, and each has a pair of conical true legs. The sixth, seventh, eighth, ninth, and twelfth segments have false legs. The black spots along the sides are called stigmas, these are breathing openings protected by a thin membrane.
Inside the body, the stomach is located between the second and ninth segments.
The circulatory system includes a large vessel running along the back of the body.
Silk is produced in two long glands located beneath the stomach, which connect to the spinneret.

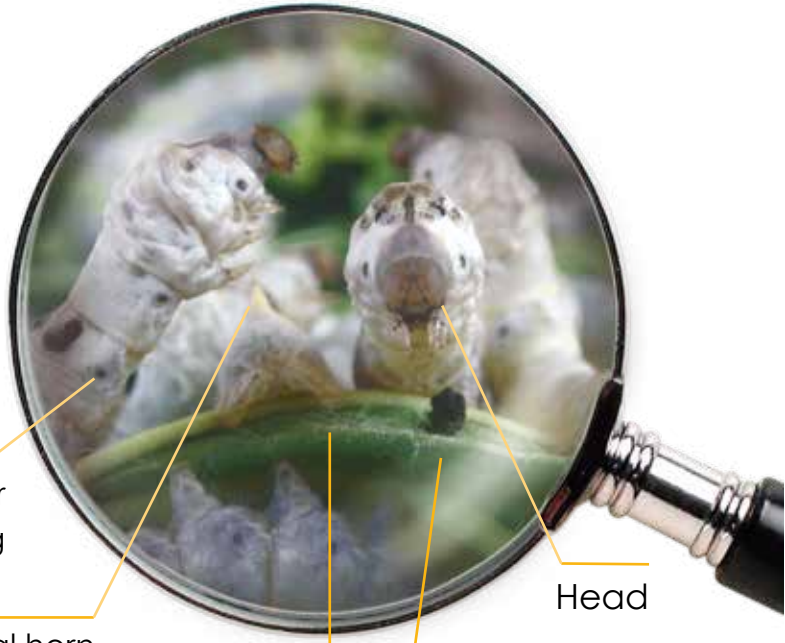
Morphology of *Bombyx mori* in the fifth instar



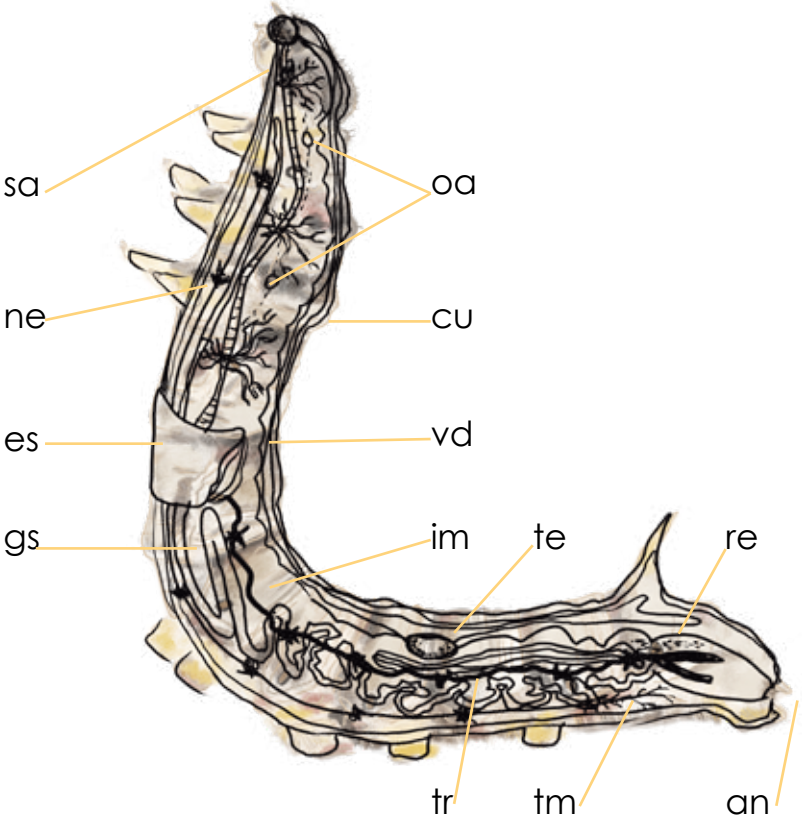
Head anatomy of the larva and details



pp: parietal plate
fr: frontal
oc: ocelli (simple eyes)
at: antenna
mx: maxilla
lb: labium (lower lip)
ph: spinneret (silk gland)
md: mandible
la: labrum (upper lip)
cl: clypeus (part of the head)



Internal anatomy of the larva



an: anus
cu: cuticle
es: spiracle
gs: silk gland
im: midgut
ne: nerve
oa: wing origin
re: rectum
sa: salivary gland
te: testicle
tm: Malpighian tubule
tr: trachea
vd: dorsal vessel

Cocooning

To build its cocoon, the silkworm needs several anchor points for its silk threads. Sericulturists provide branches of artemisia, Albaida broom, or esparto grass as structures for the silkworm to attach its threads.

This cocoon-building process coincides with the silkworm's final feeding stage. At the end of the fifth instar, the silkworm stops eating and searches for a safe, usually elevated, spot to construct its cocoon.

The silkworm begins by creating a thread structure called the "borra" (blaze or floss) which secures the cocoon and uses about 6% of the total silk that will form the cocoon.

By compressing its body segments, the silkworm expels a secretion through the spinneret that hardens when stretched to form silk.

Cocooning

It moves its head in a figure-of-eight pattern, weaving a uniform structure around itself. After 4 to 5 days, it finishes spinning all the silk stored inside its body. The final layers form a very fine silk called the bed of the pupa.

The entire cocoon is made from a single continuous silk thread that can measure between 600 and 1,600 metres, depending on the breed.

Metamorphosis or pupation

Metamorphosis is the transformation from caterpillar to pupa and then to moth, all taking place inside the cocoon. This process lasts between 15 and 20 days.

Two days after finishing the cocoon, the silkworm undergoes its fifth moult. During this moult, its appearance changes completely as it becomes a pupa, protected by a tougher, more rigid chitinous covering than in previous moults. Inside the cocoon, the pupa continues to develop and transform into a moth.

Once the transformation is complete, the moth breaks open the pupal covering by twisting its body and secretes a liquid from its mouth that softens the cocoon. It then pushes through the softened opening using its head and legs to emerge.

Metamorphosis or pupation

Moth or imago

Moths emerge ready to mate immediately. Their lifespan varies depending on ambient temperature and humidity, ranging from 3 to 15 days.
Although these moths have lost the ability to fly, they still move their wings as if trying to do so. This wing movement helps spread pheromones, which attract potential mates. The moths detect these pheromones using their antennae.

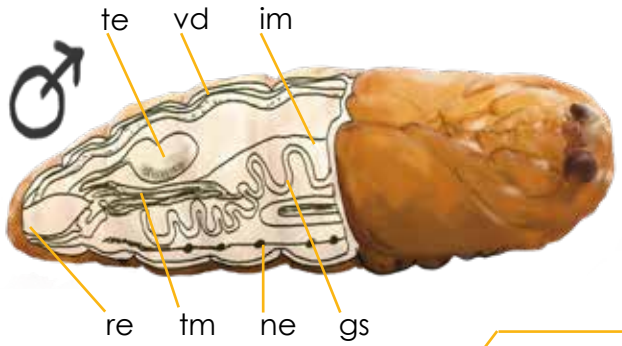
During mating, the male grips the female at the end of her abdomen using two movable chitinous hooks and fertilises her eggs internally.

Moth or imago

Whether fertilized or not, females begin laying eggs at dusk and continue throughout the night. Each female lays between 300 and 500 eggs. The eggs are lens-shaped and about one millimetre in diameter.

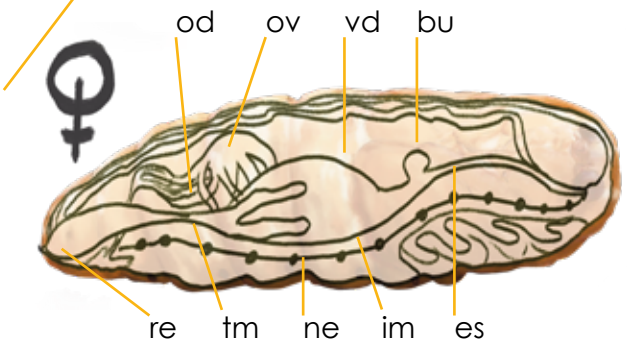
When freshly laid, the eggs are yellow. If fertilized, they change to a dark grey colour within 3 to 4 days.
This colour change occurs as the embryo develops and enters diapause a period of dormancy triggered once it can detect changes in light and temperature.
To properly preserve the eggs, they must be stored in darkness at temperatures between 5 and 10 °C year-round, until the mulberry trees sprout again the following spring.

Internal anatomy of the pupa



MALES

FEMALES

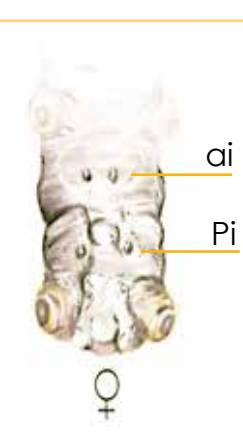


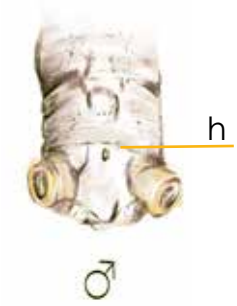
bu: crop
es: esophagus
gs: sericigenous gland
im: midgut
od: oviduct
ov: ovary
ne: nerve
te: testis
tm: Malpighian tubule
vd: dorsal vessel

Gender throughout the life cycle

FEMALES

ai: Ishiwata's fore gland
Pi: Ishiwata's hind gland





h: Herold's gland

MALES

"Hijuela"

At the end of the 19th century, breeders in the San Juan neighbourhood of Murcia began using diseased silkworms for a special process. These silkworms were soaked in a solution of water, vinegar, and salt. Afterward, they were opened, and their two silk glands were carefully stretched by hand.
Through several steps including boiling, bleaching, polishing, and ironing the fibres obtained were white, transparent in water, and very strong. These silk filaments were used as surgical sutures or fishing lines.

This industry was very important in the region of Murcia. By 1926, approximately 20 tons of "hijuela" were exported worldwide.

However, the rise of synthetic materials, especially nylon, led to the decline and eventual end of "hijuela" production.

“Hijuela”

Silk gland stretching process

Research and innovation

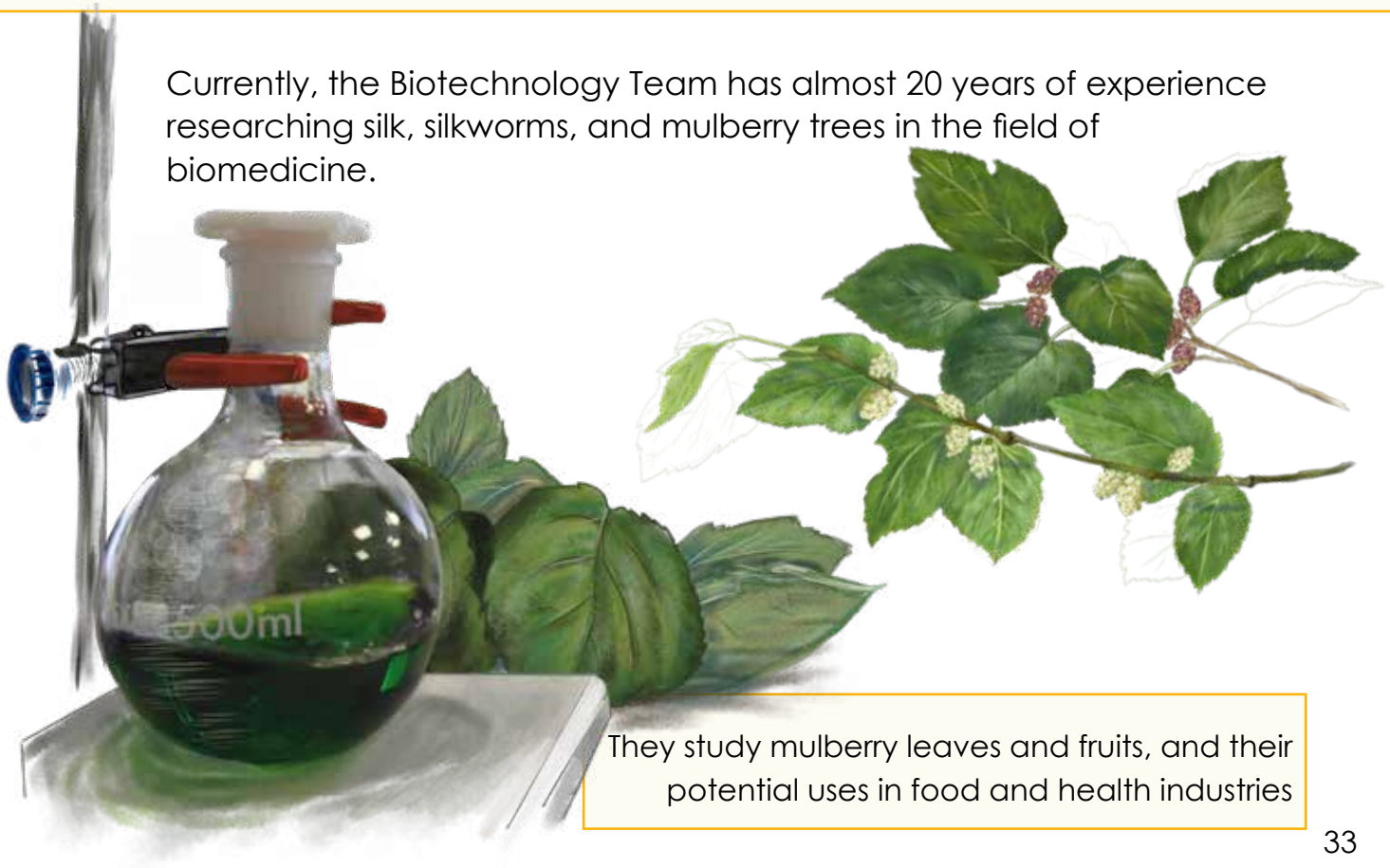
IMIDA

Murcia Institute of Agricultural and Environmental Research and Development.

The IMIDA Biotechnology Team is researching new applications for silk, particularly in regenerative medicine and tissue engineering.
In this way, the former Sericultural Station has resumed silkworm breeding with innovative applications beyond the traditional textile use, reviving an activity that was once a major economic driver in the Murcia region, in the same location where it was carried out over 100 years ago.

IMIDA

Currently, the Biotechnology Team has almost 20 years of experience researching silk, silkworms, and mulberry trees in the field of biomedicine.



They study mulberry leaves and fruits, and their potential uses in food and health industries

Silk fibres are made up of two proteins: fibroin and sericin.
Fibroin is the main component; it gives structure to silk and has characteristics ideal for use as a biomaterial. It is biocompatible, biodegradable, and has exceptional mechanical properties found in nature.

High-mechanical-strength silkworm gut fibre braids for tendon and ligament regeneration

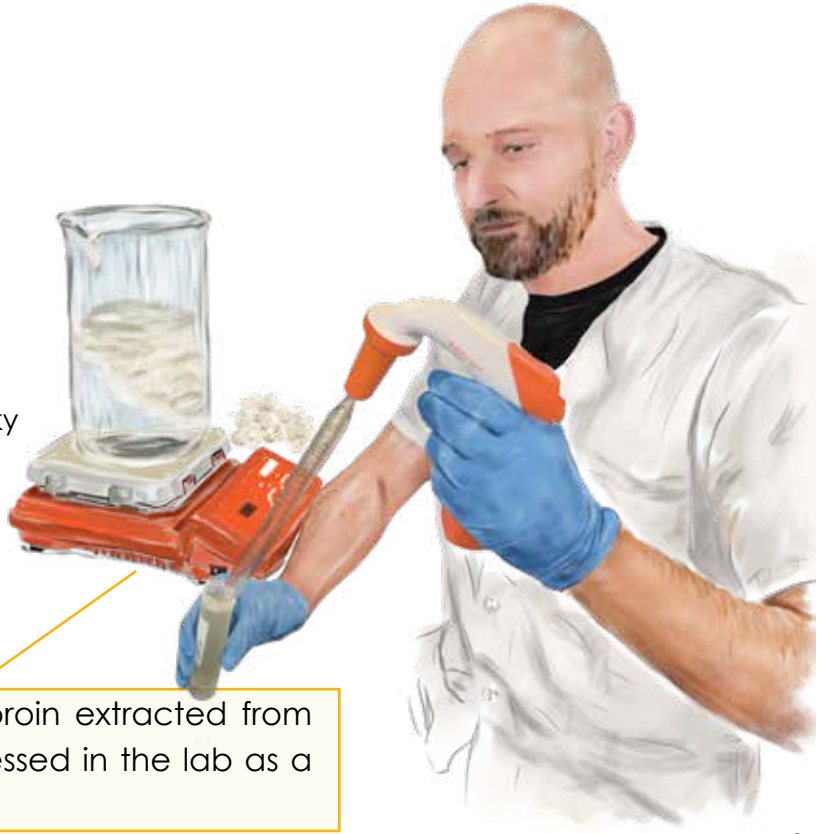
Research and innovation with silk

Silk cocoon

The silk thread

Sericin (the sticky coating)

Fibroin (the silk thread)



As well as developing silk fibroin extracted from silkworm cocoons and processed in the lab as a versatile biomaterial

IMIDA

IMIDA develops a variety of silk fibroin biomaterials which, when combined with cells and biologically active molecules, can create functional tissues and stimulate the body's ability to heal and regenerate damaged tissue. These materials include transparent films for ocular tissue regeneration, electrospun silk meshes, porous silk "sponges" for bone tissue regeneration, and high-strength fibres obtained from braided filaments of "hijuela".

Bone

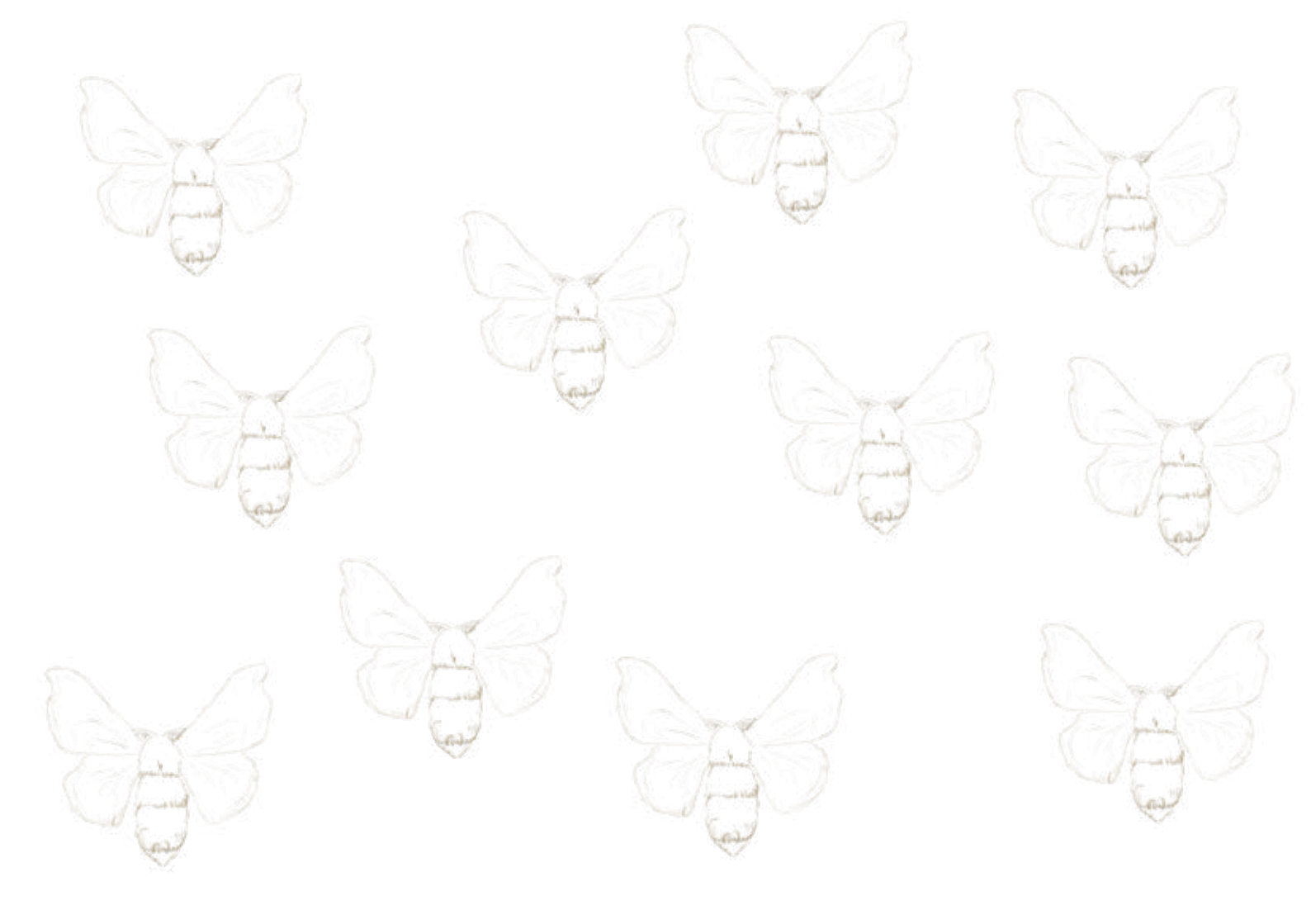
Porous "sponge"

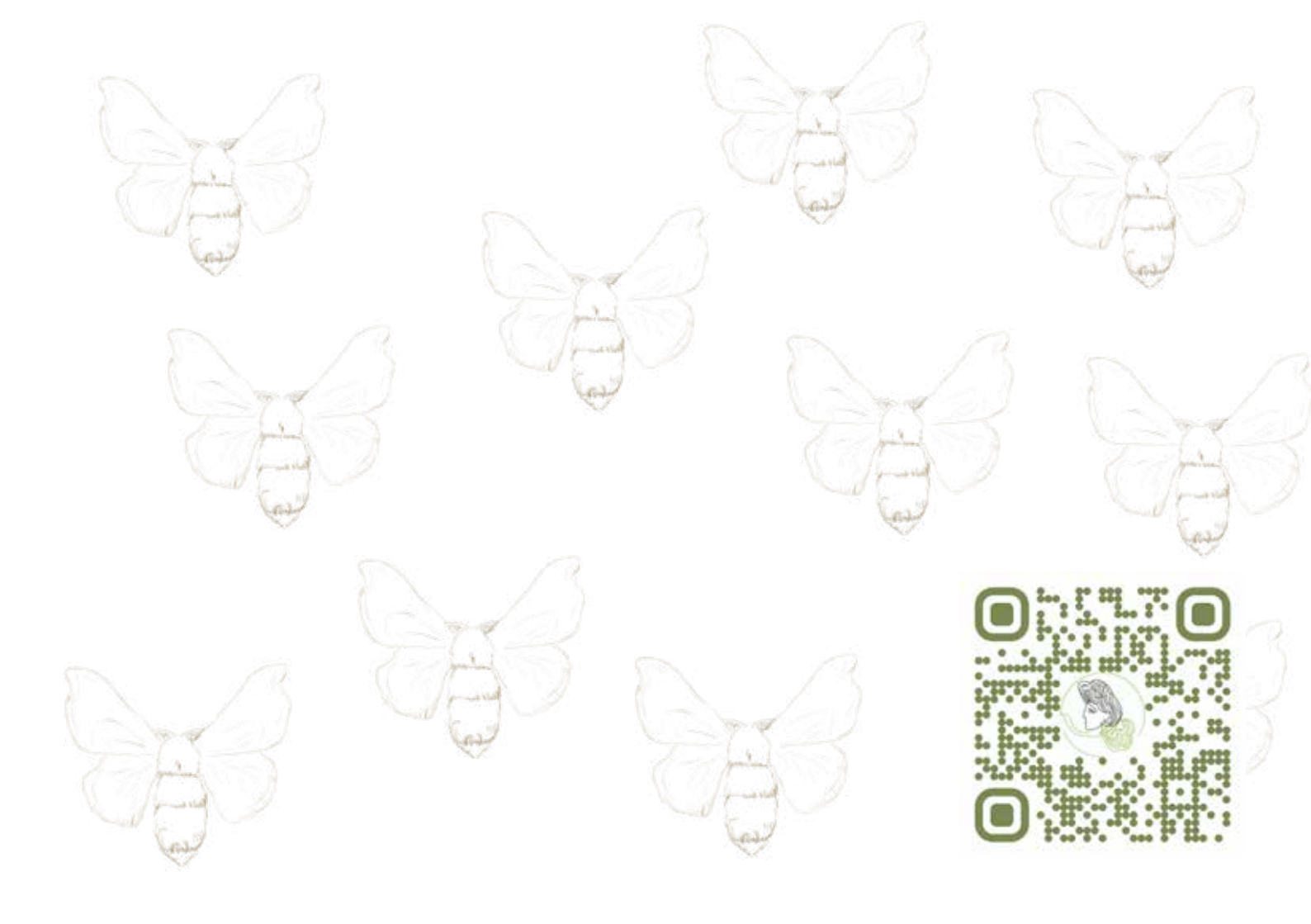
Porous "sponges" of silk for bone tissue regeneration

The transparency of fibroin films and their flat formation makes them ideal for ocular and skin tissue engineering

Research and innovation

Silk mesh with fibroblasts for skin tissue engineering





Silk Farming Learning Guide.

Discover the world of silk and the *Bombyx mori* insect through a historical, biological, and scientific journey, exploring its life cycle and the art of sericulture.

The HORIZON ARACNE project is a European initiative aimed at recovering, preserving, and promoting the silk heritage as a mark of cultural identity and a valuable legacy.
It connects culture, art, tradition, and innovations in production and scientific research at both the international and European levels.

aracne
ADVOCATING THE ROLE OF SILK ART AND CULTURAL HERITAGE AT NATIONAL AND EUROPEAN SCALE

imida
Instituto Murciano de Investigación y Desarrollo Agrario y Medioambiental

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