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Can Climate Decide Gender? The Curious Case of Silkworms

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The biology of the silkworm (*Bombyx mori*), a fully domesticated insect of immense economic value, is intricately influenced by environmental factors, especially during its embryonic development. Emerging studies reveal that rearing temperature and humidity during incubation of silkworm eggs can subtly influence the sex ratio of emerging larvae. This phenomenon, known as temperature-induced sex ratio variation, has profound implications for sericulture productivity, cocoon yield and breeding programs. This article explores the physiological mechanisms behind this phenomenon, experimental evidence, the role of temperature-sensitive genes, implications for commercial rearing and also future perspectives in climate-responsive silkworm management. It bridges classical entomology, molecular biology and environmental science to investigate the question: Can climate influence gender in insects like *Bombyx mori*?

Keywords: Silkworm, *Bombyx mori*, sex ratio, temperature, incubation, embryogenesis, sericulture, environmental influence, climate change and rearing conditions

Introduction

The silkworm (*Bombyx mori*), the primary species used in global sericulture, is not only valued for its production of silk but also for its relevance in genetics, physiology and insect development studies. Traditionally, the sex of silkworms has been understood as genetically determined-female as heterogametic (ZW) and male as homogametic (ZZ). However, several rearing and breeding experiments suggest that environmental parameters during incubation, especially temperature and humidity, may have a role in influencing sex ratios in certain rearing conditions (Kavitha *et al*., 2011). This phenomenon holds significant interest for sericulturists and entomologists, as female silkworms tend to spin heavier cocoons and lay more eggs, making them economically favourable. Understanding and possibly managing environmental factors to favour female-biased sex ratios could improve yield and efficiency in sericulture.

This article examines the scientific basis of environmentally influenced sex ratio variation in *Bombyx mori*, reviews relevant experiments, discusses the molecular and physiological mechanisms involved and evaluates implications for climate-resilient sericulture practices.

1. Sex Determination in *Bombyx mori*: A Genetic Baseline

Sex determination in *B. mori* is chromosomally based:

- Females are ZW and males are ZZ, a system opposite to mammals.
- The "Fem piRNA" (female-determining piRNA) discovered by Kiuchi *et al*. (2014) regulates sex differentiation by suppressing male-determining genes.
- The gene Masc (Masculinizer) is required for male development; Fem piRNA suppresses it to allow female development.
- This genetic determinism seems absolute. However, real-world rearing conditions sometimes show statistical deviations from the expected 1:1 sex ratio.

2. Evidence for Environmental Influence on Sex Ratio

2.1 Observational Studies

Many sericulture farms have reported seasonal variations in sex ratios:

- ✓ Summer batches (warmer conditions) often show higher proportions of males.
- ✓ Winter batches (cooler conditions) sometimes yield more females.

Humidity also correlates: low humidity favours male-biased ratios and moderate-to-high humidity appears to support female-biased ratios (Kavitha *et al*., 2011).

2.2 Experimental Evidence

A landmark study by Bhargava and Goyal (1991) demonstrated:

- ✓ Eggs incubated at 28-29°C with approximately 85% RH produced a female-biased sex ratio (≈60:40).
- ✓ Eggs exposed to ≥31°C during incubation yielded a male-biased ratio.
- ✓ Longer exposure to high temperatures during early embryogenesis led to embryonic mortality, especially in female embryos.

3. Mechanism of Environmental Influence

How can a genetically determined system exhibit environmental modulation? Several hypotheses have been proposed.

3.1 Differential Thermal Sensitivity

- ➢ Female embryos (ZW) may be more susceptible to temperature-induced stress.
- ➢ Heat shock proteins (HSPs) play a role in embryonic development. Overexpression at higher temperatures might interfere with ZW chromosome expression (Xu *et al*., 2004).

3.2 Epigenetic Regulation

- ✓ Temperature stress may cause epigenetic modifications, especially in early-stage embryos, affecting genes responsible for sexual differentiation.
- ✓ Histone modification and DNA methylation can alter expression of Masc or Fem piRNA in thermally stressed conditions (Kiuchi *et al*., 2014).

3.3 Hormonal Influence

Environmental factors might influence the juvenile hormone (JH) or ecdysteroid pathways, indirectly impacting sex-specific development pathways. Early exposure to extreme heat could inhibit pathways essential for female development.

4. Influence of Humidity and Oxygen Tension

Humidity works alongside temperature:

- ✓ Low humidity (<65%) tends to desiccate ZW embryos more than ZZ.
- ✓ Optimal humidity (75-85%) supports balanced development (Matsumoto *et al*., 1995).
- ✓ Fluctuating humidity, especially during gastrulation, results in skewed ratios.
- ✓ In sealed incubation environments, oxygen tension and CO_2 build-up have also been linked to increased male-biased mortality, though research here is limited.

5. Field-Level Observations and Practical Challenges

In commercial settings:

- ➢ Temperature-controlled rearing is practiced in developed sericulture centres (e.g., Japan, China and South Korea).
- ➢ India and Southeast Asia, with ambient-temperature incubation, often report inconsistent sex ratios seasonally.

Sericulturists often observe:

- ➢ Spring and autumn batches yield higher female ratios.
- ➢ Monsoon and summer batches, especially in non-AC facilities, yield male-biased ratios and lower cocoon quality.

However, these observations are confounded by other variables like:

- ❖ Hybrid strain susceptibility
- ❖ Mulberry leaf quality
- ❖ Incubator design and ventilation

6. Economic Implications of Sex Ratio Skew

Female silkworms are preferred in commercial rearing due to:

1. Heavier cocoons (by 10-15%)
2. Higher silk yield
3. Greater fecundity for seed production
4. Male-biased generations can result in:
5. Reduced cocoon production per batch
6. Lower egg yields from breeding programs
7. Economic losses in seed production centres

Thus, regulating incubation conditions for sex ratio optimization is both a scientific and economic concern (Ramesh *et al*., 2013).

7. Climate Change and Future Risks

As global temperatures rise, there is an increased risk of:

- Prolonged exposure of silkworm eggs to elevated temperatures in open or semi-open incubation systems
- Frequent heat waves, leading to male-dominant populations and increased embryonic mortality
- Impacts on silk quality and rural sericulture livelihoods

These concerns are particularly urgent for:

- ✓ Tropical countries without mechanized incubation
- ✓ Open egg-laying systems
- ✓ Small-scale rearers

8. Mitigation and Management Strategies

To address these risks, researchers and policymakers propose:

8.1 Temperature and Humidity Regulation

- Use of low-cost incubation chambers with passive or solar cooling
- Rural training on critical temperature/humidity thresholds

8.2 Thermo-Tolerant Strain Development

- Breeding and gene editing for strains that withstand broader temperature ranges (Ramesh *et al*., 2013)

8.3 Epigenetic and Molecular Studies

- Further research into the Masc-Fem pathway and how temperature affects gene regulation
- Development of molecular markers to predict thermal sex bias

Conclusion

While *Bombyx mori* exhibits chromosomal sex determination, accumulating evidence suggests that environmental factors, especially incubation temperature and humidity can mainly influence the sex ratio of emerging larvae. These variations, though not overriding genetic determination, reflect a complex interaction between environmental cues, developmental physiology and possibly epigenetic regulation. In the context of commercial sericulture, this has significant economic implications, especially in warmer climates and under climate change scenarios. Understanding and managing these environmental factors can help optimize cocoon yield, improve breeding outcomes and sustain rural livelihoods dependent on silk farming. Future research must focus on the molecular basis of thermal sensitivity and breed selection to ensure climate-resilient sericulture.

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