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Harnessing Sexual Selection and Sexually Selected Weapons for Sustainable Insect Pest Management

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Sexual selection is a critical evolutionary force shaping insect morphology and behavior, leading to the development of exaggerated traits known as sexually selected weapons. These structures, including enlarged mandibles, spiny hind femora, horns, and sclerotized cerci, enhance male reproductive success through competition for mates but often impose significant survival costs. Insects provide striking examples of such adaptations, from stag beetles and rhinoceros beetles to coreid bugs and earwigs, where these traits are central to male-male combat, mate guarding, or female choice. Beyond their evolutionary significance, these traits present novel opportunities for pest management. By exploiting the costs of weapon development and fighting, manipulating host plant traits such as silicon accumulation or volatile organic compounds, and intensifying competition through traps or sterile insect releases, it is possible to disrupt reproduction—the most sensitive stage of pest population growth. Such strategies represent an eco-evolutionary approach to pest control, reducing pest pressure at the plant level while aligning with sustainable and environmentally friendly agricultural practices.

Keywords : Sexual selection, sexually selected weapons, Insects, Pest management, Reproductive interference, Sustainable agriculture, Eco-evolutionary strategy

INTRODUCTION**1. Sexual selection**

Sexual selection, a concept elucidated by Charles Darwin in his seminal work "The Descent of Man, and Selection in Relation to Sex," represents a specific form of natural selection that operates on traits related to mating success and reproductive fitness. Unlike natural selection, which primarily focuses on traits that enhance survival in the environment, sexual selection centres on characteristics that increase an individual's ability to secure mates and successfully reproduce. This phenomenon leads to the evolution of traits that may not necessarily improve survival but confer advantages in

competition for mates or attractiveness to potential partners.

Sexual selection encompasses two main mechanisms: intrasexual selection and intersexual selection. Intrasexual selection involves competition between members of the same sex for access to mates. This competition can manifest in various forms, such as direct combat, displays of strength or dominance, or contests over territories or resources. The winners of these competitions often gain preferential access to mates and higher reproductive success, leading to the evolution of traits associated with competitive ability, such as larger body size, weaponry, or elaborate courtship displays.

Intersexual selection, on the other hand, involves the choice of mates by members of the opposite sex. In many species, females are the choosier sex, evaluating potential mates based on various traits that signal genetic quality, health, or parental investment. These traits, which may include bright plumage, intricate mating displays, or elaborate courtship behaviours, are often referred to as "ornaments" or "secondary sexual characteristics." Individuals possessing these traits are more likely to attract mates and successfully reproduce, leading to their increased representation in subsequent generations. While sexual selection operates independently of natural selection in many cases, the two processes are intricately linked. Traits favoured by sexual selection often have underlying genetic or physiological components that influence an individual's overall fitness and survival. For example, traits that enhance mating success may also indirectly confer benefits in terms of foraging efficiency, predator avoidance, or resistance to environmental stressors. Additionally, sexual selection can sometimes lead to trade-offs between reproductive success and survival, as individuals invest resources in costly mating displays or behaviours at the expense of other fitness-related activities. Overall, sexual selection and natural selection are complementary forces that jointly shape the evolution of organisms. By driving the development of traits related to mating success and reproductive fitness, sexual selection contributes to the overall fitness and adaptation of populations to their environments, thereby influencing the course of evolution.

1.1 IMPORTANCE OF SEXUAL SELECTION IN INSECTS

Sexual selection plays a crucial role in shaping the behaviours, physical characteristics, and reproductive strategies of insects. It leads to the evolution various aspect in the insect it includes,

Diversity of Mating Strategies

Male insects employ a wide variety of tactics to secure mates, ranging from lekking and territory defense to direct physical contests and alternative "sneaker" behaviors. For example, males of many species gather in leks where females select among displaying individuals, while in species like the dung beetle *Onthophagus taurus*, access to breeding tunnels is determined by vigorous combat between rival males. Unique strategies also occur in social insects such as honey bees, where only a fraction of males achieve mating success with queens during swarms.

Morphological Adaptations Under Sexual Selection

Sexual selection is responsible for the development of remarkable morphological features, especially in males. Exaggerated traits such as horns in beetles, elongated mandibles in stag beetles, and vibrant wing patterns in butterflies function as weapons for combat or as displays to attract mates.

These adaptations are often energetically costly but confer significant advantages in reproductive competition, reinforcing selection for larger size, weaponry, or specialized appendages.

Female Mate Choice and Resource Transfer

Females often exert strong selective pressures on males through discriminating mate choice, favoring those with superior displays, resources, or genetic quality. Insects demonstrate an array of courtship behaviors, including visual, auditory, and chemical signals. Nutritional donations—such as nutrient-rich ejaculates, prey gifts, or even bodily sacrifice as observed in mantids—directly augment female fecundity and longevity, making these traits highly desirable and reinforcing both intrasexual competition and intersexual selection.

Sexual Dimorphism in Form and Function

The interplay of sexual selection pressures leads to striking differences between males and females—sexual dimorphism. Females may be larger and better-equipped for egg production, while males frequently evolve conspicuous ornaments, enhanced mobility, or specialized copulatory structures. In some insects, female-biased size dimorphism is common, contributing to higher fecundity, while males develop physical attributes that increase their chances of mating success in a competitive environment.

Role of Chemical Communication in Mating

Chemical communication via pheromones is central to mate attraction and recognition in many insects. Both sexes may produce species-specific sexual pheromones that trigger behavioral responses, promote mate finding, and enable females to discriminate among potential partners. In some butterflies and moths, the chemical signature of a male is essential for acceptance by the female, ensuring that courtship pheromones and chemosensory adaptations remain under strong sexual selection.

Ecological and Evolutionary Implications

Sexual selection contributes substantially to the extraordinary diversity of insect life histories, shapes ecological interactions, and sometimes determines evolutionary trajectories. The interaction between sexual selection, ecological context such as host plant associations, and environmental change can influence the dynamics of mating systems and affect speciation processes. In this way, sexual selection remains a powerful and creative evolutionary force in the insect world.

1.2 FACTOR AFFECTING SEXUAL SELECTION

Environmental factors play a significant role in shaping sexual selection among insects, influencing various aspects of their behavior, physiology, and reproductive strategies.

i. Resource availability: The abundance or scarcity of resources such as food, nesting sites, or territories can significantly influence mate choice and sexual competition. For instance, in environments where resources are plentiful, females might prefer males who can provide them with the best resources or the best territories. Conversely, in resource-poor environments, traits that indicate physical vigour or the ability to survive in harsh conditions might be more valued.

ii. Predation pressure: The presence and intensity of predation can influence mating behaviors and

preferences. Bright colors or elaborate displays might attract not only potential mates but also predators. In high-predation environments, there might be a preference for more subdued displays or behaviors that reduce the risk of predation.

iii. Climate and temperature: Temperature can influence the development, behavior, and distribution of insects, thereby affecting sexual selection. For example, temperature can affect the size of insects, their reproductive timing, and their ability to perform mating displays or rituals. Climate changes can shift these dynamics, potentially favoring different traits over time.

iv. Population density: The density of a population can influence mating strategies and sexual selection pressures. In high-density populations, there might be more competition among males for access to females, potentially favoring traits like aggression or elaborate displays. In contrast, in low-density populations, the ability to locate mates might be more critical, favoring traits like increased mobility or pheromone production.

v. Disease and parasite prevalence: The presence of diseases and parasites can shape sexual selection by making certain traits more desirable. Traits that indicate health and genetic resistance to diseases can become more attractive, as they increase the likelihood of producing healthy offspring. This can lead to a preference for certain physical or behavioral traits that are perceived as indicators of good health.

vi. Light pollution: For nocturnal insects, artificial light can disrupt mating signals and behaviors, such as the ability of fireflies to find mates based on their bioluminescent signals. This interference can alter natural selection pressures and potentially favour traits that are less susceptible to disruption by artificial light.

vii. Host plant structure and complexity: The physical environment itself, including the availability of hiding spots, mating sites, and environmental complexity, can influence sexual selection. Traits that enable better navigation or success in specific habitats can become more desirable, influencing mate choice and competitive success.

2. Sexually Selected Weapons in Insects

Sexual selection is a powerful evolutionary force that drives the development of exaggerated traits in animals, particularly in males. Among insects, this has resulted in the evolution of **sexually selected weapons**—specialized structures used during **male–male competition** for access to females. Unlike adaptations that improve survival (e.g., camouflage or defensive spines), sexually selected weapons are primarily shaped by reproductive success.

These weapons often appear as **enlarged mandibles, spines, horns, or cerci** that males use in combat, to control access to females, or to defend territories where females aggregate. While such traits often impose survival costs (reduced mobility, higher energy demand, increased predation risk), they persist because males who wield them successfully achieve disproportionately higher mating success.

Evolutionary Background

Charles Darwin (1871) first proposed the concept of **sexual selection**, recognizing that some traits

evolve not for survival but for reproductive competition. In insects, this occurs in two main ways:

1. **Intrasexual Selection (Male–Male Competition):**

- ❖ Males directly fight rivals using weapons.
- ❖ Winners gain access to females or defend critical resources (sap sites, oviposition sites).

2. **Intersexual Selection (Female Choice):**

In some cases, females prefer males with larger or more elaborate weapons, interpreting them as indicators of genetic quality, strength, or dominance.

The balance of these forces creates remarkable diversity in insect morphology. Often, weapon size scales disproportionately with body size (allometric growth), producing dimorphism between "major" and "minor" males—where majors invest in fighting and minors adopt sneaky or alternative mating strategies.

Examples of Sexually Selected Weapons in Insects

A. Enlarged Mandibles – Stag Beetles (Lucanidae)

❖ Male stag beetles possess **huge, antler-like mandibles** that can exceed the length of their heads.

Function:

These mandibles are used in **combat with rival males**, where they grapple and attempt to lift or throw opponents off branches, particularly in areas where females are present (e.g., tree sap sites).

Significance: Winning males secure prime mating positions, while losers are excluded.

❖ Trade-offs:

- **Costs:** Large mandibles reduce agility and make flight less efficient.
- **Benefits:** Successful males achieve high reproductive output.

Example: *Lucanus cervus*, the European stag beetle, where mandible size is a key determinant of fighting success.

B. Spiny, Enlarged Hind Femora – Coreid Bugs (Coreidae)

❖ In coreid bugs, males exhibit **massively thickened hind legs**, often armed with spines.

Function: These legs are used in **leg-wrestling contests**, kicking or squeezing rivals during battles for access to females or feeding resources (such as fruits).

- ❖ **Significance:** Males with larger femora generally dominate, as they can inflict damage or dislodge rivals.
- ❖ Trade-offs:
 - **Costs:** Enlarged legs are heavy and reduce overall agility.
 - **Benefits:** Stronger legs increase combat success and reproductive opportunities.

Example: *Narnia femorata*—males use spiny hind legs in prolonged fights.

C. Enlarged Horns – Rhinoceros Beetles (Dynastinae, Scarabaeidae)

- ❖ Male rhinoceros beetles develop spectacular **cephalic or thoracic horns** that can vary greatly in shape and length.

Function: Males use horns to **push, pry, and flip rivals off perches** when competing for females, usually at feeding sites such as tree sap flows.

Morphs:

- ❖ **Major males:** Possess large horns, engage in head-to-head battles.
- ❖ **Minor males:** Have smaller horns or none, and often rely on **sneaky copulations** by avoiding direct combat.

Significance: Horn length and shape strongly predict combat outcomes, making them crucial for reproductive success.

❖ Trade-offs:

- ✓ Horn growth requires large energetic investment.
- ✓ Large horns may reduce maneuverability and make beetles more vulnerable to predators.

Example: *Trypoxylus dichotomus* (Japanese rhinoceros beetle) and *Oryctes nasicornis* (European rhinoceros beetle).

D. Sclerotized Cerci – Earwigs (Dermaptera)

- ❖ Male earwigs develop **forceps-like cerci**, which are longer, more curved, and more sclerotized than in females.

Function: Used in **male–male combat**, where rivals grapple and pinch one another to gain dominance. Cerci are also used in mating, helping males position themselves and sometimes guard females against rivals.

Significance: Males with larger, more curved cerci usually win contests, increasing mating chances.

❖ Trade-offs:

- ✓ Developing large cerci demands resources.
- ✓ Extremely large cerci may hinder other movements or survival activities.

Example: *Forficula auricularia* (European earwig).

Ecological and Evolutionary Significance

Sexually selected weapons in insects provide key insights into **evolutionary trade-offs and behavioral ecology**:

- ✓ **Sexual Dimorphism:** Weapons are often expressed only in males, leading to distinct morphological differences between sexes.
- ✓ **Allometric Growth:** Larger males disproportionately develop larger weapons, demonstrating strong condition-dependent trait expression.

- ✓ **Alternative Mating Strategies:** Presence of weapon dimorphism fosters multiple tactics. "Fighters" rely on weapons, while "sneakers" avoid combat.
- ✓ **Reproductive Advantage vs. Survival Costs:** These traits highlight how evolution prioritizes reproductive success over long-term survival.

Sexually selected weapons in insects—whether mandibles, hind femora, horns, or cerci—are striking examples of how competition for mates drives morphological innovation. Despite imposing costs in terms of energy investment, agility, or survival risk, these structures persist because they provide significant advantages in securing mates. They not only shape insect diversity but also serve as living models to study sexual selection, trade-offs, and the evolution of alternative reproductive strategies.

3. Application of Sexual Selection and Sexually Selected Weapons in Pest Management

1. Conceptual Basis

The concept of sexual selection is centered on traits that enhance male reproductive success, such as horns, mandibles, or specialized fighting abilities. While these traits provide an advantage in securing mates, they are also energetically costly and often compromise other survival functions, making males more vulnerable to predation or reducing their efficiency in essential tasks like feeding and flight. At the plant level, this principle can be harnessed by creating conditions that amplify the costs associated with weapon development or fighting. By strategically manipulating factors such as mating systems, competition intensity, or sexual dimorphism, pest management approaches can effectively target reproduction, which represents the most sensitive stage in population growth.

2. Potential Approaches and Examples

A. Exploiting Male–Male Competition

- ❖ Since sexually selected weapons are mainly used in **male–male combat**, manipulating environments to **increase fighting intensity** can reduce mating opportunities.

Example: In **rhinoceros beetles (*Oryctes rhinoceros*)**, males use horns to fight over females near coconut/palm trees. If plant management practices (like sticky traps or pheromone lures) artificially **increase male aggregation**, fights become more frequent, and many males die or exhaust themselves before mating.

- ❖ **Application:** Pheromone traps (Oryctalure) already exploit male aggregation; coupling them with artificial arenas where males fight could reduce successful matings.

B. Handicap Principle – Increasing Costs of Weapons

- ❖ Large weapons (horns, mandibles) are costly to maintain, especially under **resource limitation**.
- ❖ By **manipulating plant nutrition or secondary metabolites**, the host plant can make it harder for males to grow and sustain such weapons.

Example: In **stalk-boring beetles or rice stem borers**, if rice varieties are bred to accumulate **silicon**, insect growth is stunted. Males cannot develop large horns or strong mandibles, reducing

fighting success and reproductive output.

- ❖ **Application: Silicon-enriched rice plants** already reduce pest feeding efficiency; they could also indirectly suppress sexually selected traits.

C. Disrupting Female Choice

- ❖ In some insects, females choose males with larger weapons as indicators of fitness.
- ❖ If host plants are engineered or bred to release **volatile organic compounds (VOCs)** that interfere with male signaling or **mask weapon-related traits**, female mate choice may be disrupted.

Example: In **spotted cucumber beetles (*Diabrotica undecimpunctata*)**, females prefer larger males with strong fighting ability. Plant-derived **kairomones** could divert males away, reducing encounters and successful matings.

D. Sterile Insect Technique (SIT) + Sexual Selection

- ❖ Releasing sterile males into populations is a proven method (e.g., fruit flies, pink bollworm).
- ❖ If sterile males are engineered to have **exaggerated weapons or dominant fighting ability**, they could **win fights**, monopolize females, and reduce fertile matings.

Example:

- ❖ **Pink bollworm (*Pectinophora gossypiella*)** – though males don't have horns, releasing sterile, aggressive males could outcompete wild fertile males at the plant level.
- ❖ **Mediterranean fruit fly (*Ceratitis capitata*)** – enhanced male competitiveness in SIT programs already relies on sexual selection principles.

E. Behavioral Manipulation at Plant Level

- ❖ Plants or traps can be designed to **simulate mating arenas** (lekking or fighting sites).

Example:

- ❖ **Stag beetles (Lucanidae)** and **scarab beetles (Dynastinae)** fight on tree trunks or sap sites. Artificial "decoy sap sites" on trees can attract males, triggering combat where males exhaust themselves or can be trapped.
- ❖ Such strategies could be applied in **orchards** (mango, cashew, palm), where male beetles aggregate naturally.

3. Ecological and Evolutionary Rationale

- ❖ Sexually selected weapons involve **trade-offs**:
- ❖ Larger weapons = higher reproductive success **but lower survival**.
- ❖ In stressful environments (low nutrition, resistant plants), investment in weapons further weakens the male.

By **pushing populations toward costly investment in weapons**, pest populations may naturally decline due to:

- ✓ Reduced survival.
- ✓ Fewer successful matings.
- ✓ Greater predation risk (predators often target conspicuous males with large weapons).

4. Specific Case Examples

1. *Oryctes rhinoceros* (Coconut rhinoceros beetle):

- ❖ Males fight with horns at coconut palms.
- ❖ Pheromone-baited traps could be enhanced with **decoy males or fighting arenas** to exploit their aggression and reduce mating.

2. Rice stem borers (e.g., *Scirpophaga incertulas*):

Resistant rice with **high silicon content** reduces larval growth, preventing males from developing large competitive body structures.

- ❖ This indirectly reduces sexual competitiveness at the adult stage.

3. Fruit flies (*Tephritidae*):

- ❖ SIT programs release sterile males. If these males are **competitively superior in mating arenas**, they exploit sexual selection directly to suppress populations.

4. Earwigs (*Forficula auricularia*):

- ❖ Male–male fighting via cerci occurs around females.
- ❖ Artificial aggregation sites or traps could manipulate these contests to reduce successful mating.

The concept of sexual selection and sexually selected weapons can be effectively applied in pest management by intensifying male–male competition through traps and lures, manipulating host plant traits such as nutrient levels, silicon content, or volatile organic compounds (VOCs), disrupting female mate choice and signaling pathways, and enhancing sterile insect release programs to favor competitive males. Together, these approaches form an eco-evolutionary pest control strategy that targets reproduction rather than direct killing, thereby reducing pest pressure at the plant level while promoting sustainability and eco-friendly management practices.

CONCLUSION

Sexual selection and the evolution of sexually selected weapons highlight the trade-offs between reproductive success and survival in insects. These exaggerated traits, while enhancing male competitiveness, also impose significant energetic and ecological costs that can be strategically exploited for pest control. By intensifying male–male competition with lures and traps, manipulating host plant traits such as silicon or volatile organic compounds, disrupting female mate choice, and strengthening sterile insect release programs, pest populations can be effectively suppressed through reproductive interference rather than direct lethality. This eco-evolutionary approach offers a sustainable alternative to chemical control, targeting the reproductive capacity of pests while minimizing ecological disruption and promoting long-term crop protection.

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