The intriguing adaptation of moth: with special reference to camouflage and defence

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Abstract

Animals have evolved different mechanisms for survival like camouflage, defence mechanisms. These characteristics behaviour of moths is essential for developing adaptation in a critical environment. Camouflage can affect behaviour, possibly influencing the selection of suitable resting backgrounds, body positions, and orientations, as well as the concealment of essential features like shadows and the ability to remain hidden while moving and altering bodies, structures, and the environment. Moths adapted themselves in many ways for their survival like camouflage, defence, foraging behaviour, and developing navigation mechanisms in search of food. Here, we explained the adaptation in moths with reference to various camouflage and defence mechanisms. Here we elaborate on the mechanism of how moths ignored and survived predators with the help of various adaptations. Survival of moths is essential because they balance the ecosystem. This study also helps in the evolution of prey defence diversity.

Keywords: Antipredator, camouflage, Chemical defence, natural selection.

Introduction

Order Lepidoptera is the largest phylum Arthropoda order, including butterflies and moths. Generally, moths are polyphagous agricultural pests, worldwide distributed, nocturnal pollinators, and natural bio-indicator[1]. In previous studies, there are approx. 1,65,000 moths have been reported worldwide of which 12,000 species are from India[2,3]. The moth's life cycle is completed in four stages: egg, larva, pupa, and adult. The agricultural fields are attacked by the larval stage of many moths, like *Helicoverpa armigera*, *Spodoptera frugiperda*, *Spodoptera litura*, *Spodoptera littoralis*, *Helicoverpa zea*, etc. Adult female deposits their eggs on leaves and hatched larvae start consuming leaves. After completing the larval stage larva undergo pupation or diapause in the soil and emerges as adult stages. The adult stage of the moth takes nectar as food. In the ecosystem, they are primary consumers of plants and help in balancing the ecosystem. Many moths participate in ecosystem functioning like the formation of the food web, and nutrient cycling, moth insect sometimes slows down the cycling process which results from plant abundance in the ecosystem decreasing, but sometimes the cycling process speed up by which plant abundance increases[4]. Moths adapted themselves in many ways for their survival like camouflage, defence, foraging behaviour, and developing navigation mechanisms in search of food. In this Chapter different adaptation mechanisms in moths with special references to camouflage, defence, and navigation.

1.1 Camouflage

The core hypothesis in biology is the development of adaptations through natural selection, and the crypticity of moths is the symbol of morphological modification to ignore predation across the history of evolutionary biology[5-7]. Camouflage is an example of natural selection; it is the most common and simple form of antipredator behaviour of moths. In several ways, animals can control their camouflage behaviour at a significant level[8]. The cryptic nature of moths helps them in background selection which matches with their colour[9,10]. This adaptation process was seen in an experiment conducted on peppered moths (Fig. 1). Postural camouflage is the key element of peppered moths to provide antipredator behaviour of larvae from chicks. They hide in a branch as arresting state.

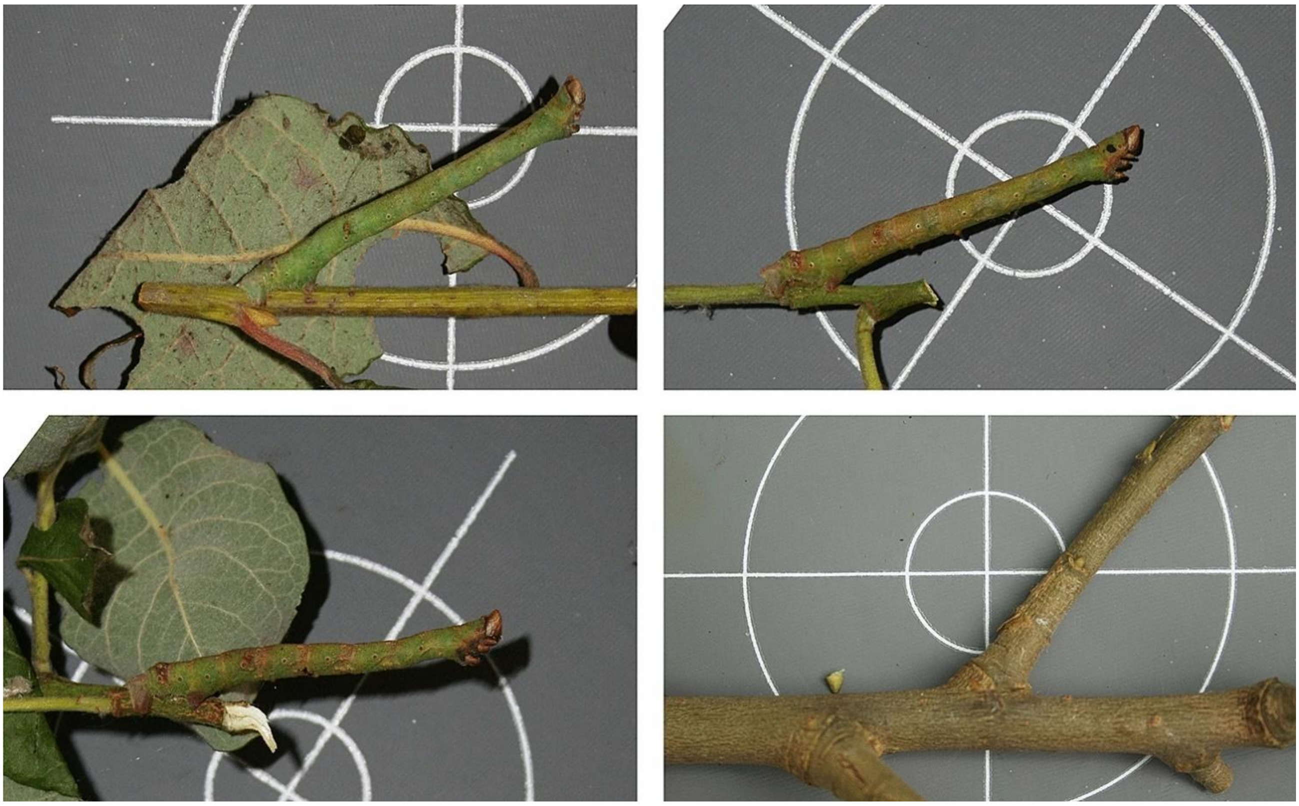

Fig.1 Camouflage behaviour in peppered moth[11].

Observing camouflage behaviour in moth experiment were done on two species of moth *H. roboraria* and *J. fuscaria*[12]. These two moths are known as bark-resting moths. In this experiment, results suggested that both species enhance their crypticity by matching surrounding and disruptive coloring. Most of the time moths rest on the background matching their wings, which helps them to avoid predation. When larvae are resting in an unusual posture for prey, predators may mistake them for non-prey things. Crypsis may also be aided by twig-like positions. While it may appear counter-intuitive that exposing more of a larva's body to view might improve crypsis, evidence supports this theory. To sense an item, an animal's neural system must link the characteristics of that thing into a cohesive representation. Regardless of whether the behaviour involves a new body orientation or not, body placement considerably boosts the camouflage effect offered by the moth's cryptic colour pattern.

Fig 2. Camouflage behaviour in *Tyria jacobaeae*[13]

It has been proposed that the cinnabar caterpillar's orange-and-black stripes enable both aposematism (warning) and camouflage. Aposematic patterns usually comprise bright colours and high contrast patterning, which have been associated with faster and more accurate predator avoidance learning and are thought to promote signal saliency across varied backgrounds[14-16]. These warning signs are often composed of prominent, high-contrast stripes, which have been proposed to accelerate and improve predator avoidance learning. When the experiment was done on the cinnabar caterpillar it has been observed that, while the caterpillar's orange-and-black stripes are visible up close, when viewed from a distance, the colours merge together to nearly resemble those of the background. Cinnabar caterpillars create a distance-dependent signal that combines conspicuous aposematism with targeted backdrop-matching camouflage, without sacrificing the magnitude or saturation of their aposematic signal. It has also been hypothesized that the swallowtail (*Papilio machaon,* Papilionidae) and apollo (*Parnassius apollo*, Papilionidae) butterfly caterpillars develop distance-dependent designs that are neither optimized for concealment nor optimized for conspicuousness[17,18].

2.1 Defence

The main mechanism of natural selection in prey species is predation. Animals have developed several defence measures that varied in their nature and efficiency in relation to predator sensory capabilities and assault tactics in order to live in a world with multiple predators[19-21]. The advantages received and the associated expenses determine which defence tactic, or collection of tactics, is employed. The goal of the utilized method must be to halt the completion of a predation event as early as feasible in the predation sequence (i.e., detection, identification, approach, subjugation, and eating).

Generally, moths are nocturnal and they form hearing organs. It was believed that moth hearing served only as a protection against bats. Within the moth group, there are many kinds of sound and vibration-receiving mechanisms. Several of these hearing mechanisms fail to pick up on the bat’s ultrasonic echolocation screams. For instance, certain moth larvae have sensitive acoustic hairs on their thorax that can pick up flying wasps, and both larval and adult moths are able to pick up vibrations from the surface they are sitting on. However, it is only concerned with moths' tympanic hearing organs, or "ears," which appear to have evolved in response to pressure from echolocating bats.

2.1.1 Ear of moth

Most moths belonging to the Noctuoidea superfamily have bilateral tympanic hearing organs on the metathorax. Several publications have characterized the noctuid ear's morphology. Each ear's tympanum is a portion of the anterior wall of a hollow with no scales that open to the environment. The tracheal air chamber is backed by the tympanum, which divides the cavity from the tracheal air chamber and is connected to the outside via a spiracle. Noctuid ears can detect sounds at a variety of frequencies. According to Roeder, this range extends from 3 to more than 150 kHz. The ear is thought to be receptive to higher human vocal sounds because of the lower limit of 3 kHz. Subsequent audiograms have revealed sensitivity spectra that are very comparable to Roeder's recordings. Yet, the sensitivity of moths varies depending on their origin. Moth hearing sensitivity often tends to match the regional frequencies and intensities of bat noises, apart from moths on islands free of bats.

2.1.2 Mechanism

Flying moths nearly commonly use their ears as defence against bats that hunt insects. Roeder identified a variety of arctiid, geometrid, and noctuid moths' surprising loops, dives, rolls, and turns as a means of avoiding bats. The moth often flies straight away from the bat when it hears a low-intensity sound signal suggesting that the bat is still some distance away. This strategy may move the moth far enough from the bat's flight path that it may continue without being noticed since the moth senses the bat before the bat can do so. Moths may make a quick scan in the right direction before choosing an alternative flying course. According to this habit, moths may purposefully compare the signals that each of their bilateral ears receives. In lab tests, noctuid moths stood still despite trying to move away from low-intensity noises that represented the bat's hunting phase. This proved that the initial line of behavioural protection was negative phonotaxis. Even if the sound was coming from the same direction, a moth turned towards the injured ear when one of its tympanums was destroyed. A moth would so go towards the sound with the lowest perceived intensity. A flying moth that has one of its tympanums damaged finds it difficult to get away from an approaching bat and instead prefers to circle it.

Moths with either one or two intact ears employ heightened movements to avoid capture up close as opposed to flying away from the bat sound. A moth can often sense an approaching bat from up to 30 to 45 meters away. A bat might not see the moth until it is 5 m away. A moth can only find safety by landing in an area where the bat's sonar is unlikely to pick it up. As a result, many moths plunge or loop downward. The moth will land if the looping puts it close to a surface. Another defensive strategy some moths employ at the last second is the sound generation in an effort to disrupt the bat's sonar system**[22]**. Arctiid moths, such as the Ctenuchinae family, make high-frequency noises that appear to be used in defence against advancing bats and maybe other predators**[23-25]**. Each metepisternum has a striated tymbal (each stria is one microtymbal) that produces the sound, which is frequently in reaction to bat echolocation noises**[26]**. Male geometrid winter moths (*Agriopis* and *Erannis* spp.; Ennominae, and *Alsophila aescularia*; Oenochrominae), which have large wings and a slow flight, have good, broadly tuned ultrasonic hearing with the best frequencies at 25-40 kHz, coinciding with the frequencies used by the majority sympatric aerial-hawking bats, according to audiograms and behavioural responses to ultrasound**[27]**.

2.1.3 Chemical defence

Chemical defences are sometimes known as secondary defence strategies for the survival of moths. Considering that these defences are often successful during the predation sequence's stages of subjection and/or consumption**[19]**. They can prevent predators in several ways, such as by being irritating, unpleasant, or even poisonous. Many factors, such as volatile irritation, disgust, or even poison, might repel predators**[28]**. Chemical defences can be expensive since they entail steps such as the sequestration of active chemicals, either with or without further modification, and their production from scratch**[29]**. Hence, it is anticipated that these defences would only develop when necessary and that they will be efficient against a variety of predators[30-32].

In a previous study, the chemical defence was observed in tiger moth *Arctia plantaginis*. It is a widespread aposematic arctiid species in the Holarctic[33]. Males have either white or yellow hind wings, but females have hindwing colorations that range continually from yellow to red. Together with this warning hue, the organism also produces two other kinds of chemical secretions that look repulsive[34,35]. The secretion of one type of secretion referred to as "neck fluids," is secreted from prothoracic (cervical) glands while the abdominal tract releases the other type, referred to as "fluids”. Wood tiger moths' defensive fluids contain specific chemicals that have not yet been fully characterized, although many other arctiid species are widely recognized for having chemical defences that include, among other things, pyrrolizidine alkaloids, methoxypyrazines, and iridoid glycosides. It is interesting that wood tiger moths can afford to use two distinct fluids given the potential expense of insect chemical defences. The occurrence of enemy-specific chemical defences in a single prey animal raises questions about the role that predator communities played in determining the evolution of prey and raises the possibility that selection for chemical defences may be far more complicated than previously thought.

3.1 Conclusion

It has long been recognized that camouflage can affect behaviour, possibly influencing the selection of suitable resting backgrounds, body positions, and orientations, as well as the concealment of essential features like shadows and the ability to remain hidden while moving and altering bodies, structures, and the environment. The examples and experiments presented in this chapter suggested that moths are adapted different mechanisms for their survival. The study of camouflage behaviour provides us with a new direction to the evolutionary category. Moths distinguish between mating calls and bat screams by utilizing their exceptional hearing ability to recognize sound-pulse strength, repetition rates, and time intervals between pulses. A range of distinctive defence and communication behaviours among moths have evolved as a result of adaptation to specific environmental challenges.

Many animals fall prey to many species that belong to various groups. Because various species have varying sensory capacities, tolerances, and hunting techniques, this diversity of predators offers a serious challenge to the efficacy of anti-predator defences. So, various predator types might result in various selection pressures on the same prey, which could account for why defence mechanisms range so drastically between and within species. Tiger moths create two different forms of protective fluids, each with a unique purpose and makeup. Although belly fluids effectively repel ants, neck fluids successfully prevent birds. In both instances, yellow people's chemical defences generated a higher resistance than those of white males. The occurrence of enemy-specific chemical defences in a single prey animal raises questions about the role of predator communities in determining prey evolution and raises the possibility that selection for chemical defences may be far more complicated than previously thought.

References

1. Ahmad, A., Jamal, K., Alhazmi, A., El-sharnouby, M., Salah, M., & Sayed, S. (2021). Saudi Journal of Biological Sciences Moth diversity , species composition , and distributional pattern in Aravalli Hill Range of Rajasthan , India. *Saudi Journal of Biological Sciences*, *28*(9), 4884–4890. https://doi.org/10.1016/j.sjbs.2021.06.018
2. Khan, H., & Perveen, F. (2015). Distribution of butterflies (family: Nymphalidae) in union council Koaz Bahram Dheri, Khyber Pakhtunkhwa, Pakistan. *Social and basic sciences research review*, *31*, 52-57.
3. Chandra, K. A. I. L. A. S. H., & Nema, D. K. (2007). Insecta: Lepidoptera: Heterocera (Moths). *Fauna of Madhya Pradesh (including Chhattisgarh), State Fauna Series. Zoological Survey of India*, *15*(1), 347-418.
4. Belovsky, G. E., & Slade, J. B. (2000). Insect herbivory accelerates nutrient cycling and increases plant production. *Proceedings of the National Academy of Sciences*, *97*(26), 14412-14417.
5. Thayer, G. H. (1918). Concealing-coloration in the animal kingdom: an exposition of the laws of disguise through color and pattern. *Macmillan Company*.
6. Cott, H.B. (1940). Adaptive Coloration in Animals. Meuthuen, London, UK
7. Endler, J. A. (1984). Progressive background in moths, and a quantitative measure of crypsis. *Biological Journal of the Linnean Society*, *22*(3), 187-231.
8. Rowland, H. M., Burriss, R. P., & Skelhorn, J. (2020). The antipredator benefits of postural camouflage in peppered moth caterpillars. *Scientific Reports*, 1–8. https://doi.org/10.1038/s41598-020-78686-4
9. Stevens, M., Troscianko, J., Wilson-aggarwal, J. K., & Spottiswoode, C. N. (2017).

background choice in ground-nesting birds. *Nature Ecology & Evolution*. https://doi.org/10.1038/s41559-017-0256-x

10. Stevens, M., & Ruxton, G. D. (2019). The key role of behaviour in animal camouflage. *Biological Reviews*, *94*(1), 116-134.
11. Rowland, H. M., Burriss, R. P., & Skelhorn, J. (2020). The antipredator benefits of postural camouflage in peppered moth caterpillars. *Scientific Reports*, *10*(1), 21654.
12. Kang, C., Stevens, M., Moon, J. Y., Lee, S. I., & Jablonski, P. G. (2015). Camouflage through behavior in moths: the role of background matching and disruptive coloration. *Behavioral Ecology*, *26*(1), 45-54.
13. Barnett, J. B., Cuthill, I. C., & Scott-Samuel, N. E. (2018). Distance-dependent aposematism and camouflage in the cinnabar moth caterpillar (Tyria jacobaeae, Erebidae). *Royal Society Open Science*, *5*(2), 171396.
14. Stevens, M., & Ruxton, G. D. (2012). Linking the evolution and form of warning coloration in nature. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1728), 417-426.
15. Gamberale-Stille, G. (2001). Benefit by contrast: an experiment with live aposematic prey. *Behavioral Ecology*, *12*(6), 768-772.
16. Prudic, K. L., Skemp, A. K., & Papaj, D. R. (2007). Aposematic coloration, luminance contrast, and the benefits of conspicuousness. *Behavioral Ecology*, *18*(1), 41-46.
17. Bohlin, T., Tullberg, B. S., & Merilaita, S. (2008). The effect of signal appearance and distance on detection risk in an aposematic butterfly larva (Parnassius apollo). *Animal Behaviour*, *76*(3), 577-584.
18. Tullberg, B. S., Merilaita, S., & Wiklund, C. (2005). Aposematism and crypsis combined as a result of distance dependence: functional versatility of the colour pattern in the swallowtail butterfly larva. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1570), 1315-1321.
19. Endler, J. A. (1986). Defense against predators. In Predator prey relationships. Perspectives and approaches from the study of lower vertebrates (ed. MELGV Feder), pp. 109– 134. Chicago, IL: University of Chicago Press
20. Hoverman, J. T., & Relyea, R. A. (2007). The rules of engagement: how to defend against combinations of predators. *Oecologia*, *154*, 551-560.
21. Sih, A., Englund, G., & Wooster, D. (1998). Emergent impacts of multiple predators on prey. *Trends in ecology & evolution*, *13*(9), 350-355.
22. Spangler, H. G. (1988). Moth hearing, defense, and communication. *Annual review of*

entomology, *33*(1), 59-81.

23. Blest, A. D., Collett, T. S., & Pye, J. D. (1963). The generation of ultrasonic signals by a New World arctiid moth. *Proceedings of the Royal Society of London. Series B. Biological Sciences*, *158*(971), 196-207.
24. Blest, A. D. (1964). Protective display and sound production in some New World arctiid and ctenuchid moths. *Zoologica*, *49*, 161-181.
25. Dahm, K. H., Meyer, D., Finn, W. E., Reinhold, V., & Röller, H. (1971). The olfactory and auditory mediated sex attraction in Achroia grisella (Fabr.). *Die Naturwissenschaften*, *58*(5), 265-266.
26. Fullard, J. H. (1977). Variability and absence of sexual dimorphism in the sounds of Cycnia tenera Hübner (Lepidoptera: Arctiidae). *Journal of the New York Entomological Society*, 21-25.
27. Building, E. (1997). Hearing and bat defence in geometrid winter moths.
28. Bowers, M. D. (1992). The Evolution of Unpalatability and the Cost of Chemical Defense in Insects M. Deane Bowers University of Colorado, Boulder. *Insect chemical ecology: an evolutionary approach*, 216.
29. Rojas, B., Burdfield-Steel, E., Pakkanen, H., Suisto, K., Maczka, M., Schulz, S., & Mappes, J. (2017). How to fight multiple enemies: target-specific chemical defences in an aposematic moth. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1863), 20171424.
30. Reudler, J. H., Lindstedt, C., Pakkanen, H., Lehtinen, I., & Mappes, J. (2015). Costs and benefits of plant allelochemicals in herbivore diet in a multi enemy world. *Oecologia*, *179*, 1147-1158.
31. Skelhorn, J., & Ruxton, G. D. (2008). Ecological factors influencing the evolution of insects' chemical defenses. *Behavioral Ecology*, *19*(1), 146-153.
32. Zvereva, E. L., & Kozlov, M. V. (2016). The costs and effectiveness of chemical defenses in herbivorous insects: A meta-analysis. *Ecological Monographs*, *86*(1), 107-124.
33. Hegna, R. H., Galarza, J. A., & Mappes, J. (2015). Global phylogeography and geographical variation in warning coloration of the wood tiger moth (Parasemia plantaginis). *Journal of Biogeography*, *42*(8), 1469-1481.
34. Lindstedt, C., Eager, H., Ihalainen, E., Kahilainen, A., Stevens, M., & Mappes, J. (2011). Direction and strength of selection by predators for the color of the aposematic wood tiger moth. *Behavioral Ecology*, *22*(3), 580-587.
35. Nokelainen, O., Hegna, R. H., Reudler, J. H., Lindstedt, C., & Mappes, J. (2012). Trade-

off between warning signal efficacy and mating success in the wood tiger moth. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1727), 257-265.