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TRADE- OFF IN COCCINELLIDAE: A COMPREHENSIVE REVIEW OF ECOLOGICAL CONSTRAINTS AND LIFE- HISTORY

Deepa Arya[1], Ahmad Pervez[2*], Noorin Saifi[1] and Mamtesh Kumari[1]
[1]Department of Zoology, Radhey Hari Govt P.G. College, Kashipur-244713, Uttarakhand, India.
Author's email: deepa262402@gmail.com
[2]Biocontrol Laboratory, Department of Zoology, Pt. L.M.S. Campus, Sri Dev Suman Uttarakhand University, Rishikesh-249201, Uttarakhand, India

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ABSTRACT

The Coccinellidae family of ladybird beetles exhibits a range of physiological and ecological trade-offs that influence their ability to reproduce, survive, and function as biological control agents. These trade-offs occur when resources and energy devoted to one activity, such protection, reproduction, or foraging, cannot be used for another. In warmer climates, bright aposematic colouring may impair thermoregulation, but it further enhances predator deterrence. In the same manner, more foraging increases nutrient intake but increases the risk of predation. Chemical defence increases survival but at the expense of growth rate and fertility, primarily through the generation of alkaloids and reflex bleeding. A balance between increased resource requirements and predation efficiency is also reflected in body size. The distribution of energy between survival and reproduction is further altered by environmental stressors including fluctuating temperatures and a lack of prey. Understanding these life-history trade-offs offers significant insights into the ecology of ladybirds, their evolutionary techniques, and their useful application in integrated pest management.

Keywords- Ladybird beetles, trade-offs, foraging, prey-predation, environment stress, invasiveness, colouration, body size, balance, biocontrol.

INTRODUCTION

In agricultural ecosystems, ladybirds (Coleoptera: Coccinellidae) are essential natural predators and biological control agents (Omkar and Pervez, 2016; Pervez et al., 2020). Predatory ladybirds are crucial elements of Integrated Pest Management (IPM) methods because they are very successful at reducing populations of aphids, whiteflies, scale insects, mites, and other soft-bodied pests (Bahlai et al. 2013; Sloggett and Zeilstra 2020). Life-history evolution is really about optimization, not maximization. Numerous characteristics that affect fitness are linked both physically and genetically. As a result, as one trait's fitness value rises, another trait's fitness value may fall in proportion. There are two distinct scales at which trade-offs might take place: physiological and evolutionary. In coleopterans, melanism is directly linked to body colour, temperature regulation, resistance to solar radiation, endurance under drought conditions, and durability against abrasion (Hodek et al. 2012). Through crypsis, imitation, and camouflage, melanism protects *Biston betularia* (L.) against predators (Majerus, 1998; Rowland et al. 2022). Low temperatures are advantageous to *Adalia bipunctata* (Linnaeus) ladybirds because their darker colour facilitates faster UV absorption, which boosts foraging activity and reproduction rate (Okuda et al. 1997). Polymorphisms in ladybird colour patterns are likely to be supported by a wide range of factors that could alter trends related to climate change. While the yellowish/orange liquid is expelled from dorsal glands in larvae, reflex bleeding occurs on the tibiofemoral joints in adults (Holloway et al. 1991, 1993). Defence chemicals range in quantity and quality depending on the stage of development (Camarano et al. 2006). Additionally, the mature beetle can simultaneously or separately produce reflex blood in each of its six legs.

Important defence chemicals are typically produced at high energy costs (Majerus, 2016).

Ladybird populations are impacted both directly and indirectly by the added complexity brought about by climate change. Extreme weather events including droughts, floods, and storms have harmed ladybird habitats and prey availability, while rising temperatures have changed ladybird metabolic rates, foraging efficiency, and reproductive cycles (Filazzola et al. 2021). At higher temperatures, *H. axyridis* ability to forage may be diminished (Han et al. 2017). Additionally, native ladybird species have been displaced and predator-prey dynamics have been disrupted by the introduction of exotic species, especially *Harmonia axyridis*, which has increased competition for resources (Bahlai et al. 2013). The long-term impacts of various environmental stresses on ladybird survival, reproduction, and ecological interactions are discussed in this article. Like other creatures, ladybirds must make several trade-offs, where investing in one feature limits the investment available for another. Their ecological success, reproduction, defence, and survival are all influenced by these trade-offs. Ecology, evolution, and their application in biological pest management all depend on an understanding of these parameters.

1. Colouration vs. Thermoregulation trade-off- Ladybirds (Coleoptera: Coccinellidae) include a diverse assemblage of beetles, typically exhibiting vibrant coloration, which is generally acknowledged to play a significant role in deterring predators (Blount et al. 2012). Furthermore, toxic substances are frequently produced endogenously by ladybirds (Blount et al. 2012; Bezzerides et al. 2007 and Blount et al. 2009). These compounds have been linked to the region of background elytra coloration in the Asian ladybird *Harmonia axyridis* (Bezzerides, 2007) and carotenoid abundance in the seven-spot ladybird *Coccinella septempunctata* (Blount et al. 2012). Ladybirds in the Coccinellidae family exhibit remarkable colour variation, ranging from red, orange, and yellow to brown and almost white species. The patterns on the elytra are very diverse (Hodek et al. 2012). Several pigment compound groups and structural elements work together to give Coccinellidae their vivid coloration, which is frequently referred to as their first line of defence (Majerus, 2016; Carrada et al. 2025; Shawkey & Hill, 2005). Carotenoids and melanin’s are the pigments that cause red and black, respectively (Sloggett and Honěk, 2012; Svensson and Wong, 2011). However, new studies reveal that the optical characteristics of the ladybird's elytra are made up of pigment compounds only when combined inside a structural matrix. Pigments interact with the second ingredient, the structural matrix, and change physical characteristics like the refractive index, even though they do produce colour by absorbing wavelengths (Carrada et al. 2025). Additionally, a variety of ladybird beetle species coexist, which likely forces predators to learn and identify a wide range of colours and patterns to accurately decide whether to attack them.

According to the thermal melanism hypothesis (Clusella-Trullas et al. 2007), dark people have an advantage over light people at low temperatures because they warm up more quickly at any given level of sun energy. Numerous researchers have focused on how colour patterns affect ladybird thermoregulation (Sibilia et al. 2018; Rosa & Saastamoinen, 2020). Although a variety of factors have been linked to this variation in colour patterns, climate factors including humidity, temperature, and sun radiation have a significant influence (Roulin, 2014). A warmer climate in Japan was thought to be linked to a rise in melanics and a decrease in non-melanics in the highly polymorphic ladybird *Harmonia axyridis* (Pallas) (Murakami et al. 2019). Low temperatures are advantageous to *Adalia bipunctata* (Linnaeus, 1758) ladybirds because their darker colour facilitates faster UV absorption, which boosts foraging activity and reproduction rate (Okuda et al. 1997).

Ladybirds must manage a balance between warning colouring and ideal body temperature.
Trade-off: Darker morphs are more likely to overheat in warm climates but heat up more quickly in cold climates. Although lighter variants are better managing heat, but they have less effective in deterring predators.

2. Chemical defence Vs. Growth and Reproduction Trade off- For generations, scientists have been captivated by the well-known phenomena of reflex bleeding, sometimes known as "autohaemorrhaging" (Crénot, 1896). In many insects with effective toxins in their bodies, the discharge of hemolymph is a frequent defence behaviour when individuals are threatened or exposed to direct physical attack. Because some of the insects' hemolymph is lost and must be replaced, the externalization of hemolymph can have a substantial physiological cost. The scant data that is now available suggests that reflex bleeding results in the loss of not

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only nutrients but also other important components of hemolymph, such as hemocytes and alkaloids (Holloway et al. 1991; Karystinou et al. 2004 & Knapp et al. 2018). Reflex bleeding during the larval stage may cause the adult to be smaller or take longer to mature (Grill et al. 1998; Rowell-Rahier et al. 1986; Sato et al. 2009). According to Knapp et al. 2018, the composition of reflex blood in ladybirds is identical to that of the hemolymph that comes from the body cavity. As a result, elements essential to immune system function—such as alkaloids, hemocytes, or antimicrobial peptides—are lost and must be replaced. According to (Holloway et al. 1991and de Jong et al. 1991), ladybirds that had reflex bleeding only once a week were unable to manufacture enough alkaloids to make up for their loss. The substantial association between harmonine concentration and antibacterial activity revealed by (Schmidtberg et al. 2013) indicates that the immune system of H. axyridis is highly dependent on harmonine, an alkaloid with potent antimicrobial activity. The immune system would become weaker and less capable of fending off infections and parasitoids if the component loss was not compensated for. According to (Bayoumy et al. 2020), non-reproducing individuals may be more prone to stronger reflex bleeding (if they can afford it), and eggs from bled females have lower fertility. However, for those who bleed a lot, hemolymph loss in and of itself can delay reproductive processes. According to (Bayoumy et al. 2020), Transgenerational effects on the progeny of stressed ladybirds may be more significant than the direct fitness limitation seen in bled individuals, this matter merits further consideration. However, frequent reflex bleeding affects the immune system and delays reproduction in a ladybird beetle, according to (Knapp et al. 2020). **Trade-off**: Ladybirds with extensive chemical defences typically exhibit slower development, immune system, or decreased fecundity.

3. Foraging behaviour Vs. Predation risk Trade off- To locate new food supplies and the best places to deposit their eggs, adult ladybirds can fly great distances. They identify prey patches using both visual and olfactory cues, and whenever prey becomes rare, they are known to migrate. However, compared to adult ladybirds, ladybird larvae are typically thought to search for and eat food more energetically and voraciously. Their quick development into the pupal and adult phases depends on this fast rate of eating. Most reports of ladybird predation likely employ mature beetles (e.g., see Frost, 1924; Kirkland, 1897; & Çiçek and Mermer 2007), which are easier to identify in stomach samples due to their tougher and less easily destroyed cuticle. In areas where larval predation is documented, it may be greater than that of adult ladybirds. According to Whitaker (1977), dietary inventories may overlook a significant portion of ladybird predation (i.e., the soft-bodied larvae). The huge, vividly colourful members of the aphid-eating tribe Coccinellini (subfamily Coccinellinae) are often the species or genera of ladybirds that are documented. This is probably because the colour patterns make it simpler to recognize the insect remains in the stomach. Accordingly, the *Hippodamia parenthesis* (Say), *Coccinella transversoguttata* Faldermann, *Adalia bipunctata* (L.), and most likely *Ceratomegilla fuscilabris* (Mulsant) were identified from 10 years (1915–1924) of examining the stomach contents of numerous North American frogs (Frost, 1924). Alkaloid defences have been found in this and allied species (Daloze et al. 1995; King and Meinwald, 1996; Sloggett, 2007), and all of these species have bright coloration (Gordon, 1985), which is likely warning coloration.

However, in order to meet their energy needs, particularly during reproduction, ladybirds must actively look for aphids. **Trade-off:** While increased foraging increases energy, it also increases exposure to predators including larger beetles, ants, and birds.

4. Body size vs. Resource requirement Trade off- There are two parameters that determine the link between coccinellid body size and prey density. A coccinellid's body weight or mass determines how much food it needs to survive or reproduce (Dixon, 2007). However, bigger ladybird, also move more quickly and have a bigger field of vision; as a result, they search a larger area per unit of time, scaling as (Dixon & Stewart, 1991; Dixon, 2007). Smaller aphid species or the smaller, early stages of larger aphids are typically the focus of smaller ladybirds. Due to size limitations, they are less effective at capturing larger, more energetic prey, yet they can survive in settings with low concentrations of small prey. Due to their better physical ability to capture larger prey, huge ladybirds may consume enormous aphids at both low and high densities. However, because of their greater absolute feeding need, they cannot be supported by low concentrations of small aphids (Sloggett John J, 2008). Compared to smaller species, larger ladybird species are able to lay eggs at higher aphid population densities.

Larger ladybirds do have advantages, such as increased fecundity and predation capacity, but they also have higher metabolic costs and feeding requirements. Smaller species are better able to survive during periods of food scarcity since they demand fewer resources. Therefore, the availability of food in the environment balances body size.

5. Invasive success vs. Ecological cost Trade off- The harlequin ladybird, or H. axyridis, was first used as a biological control agent in the twentieth century. However, because of its aggressive behavior, faster rates of reproduction, and wider feeding preferences, this species has become invasive in many areas, displacing local ladybird species (Roy et al. 2012). H. axyridis has been shown to displace native species including C. septempunctata and Adalia bipunctata in North America and Europe, decreasing biodiversity and changing ecosystem dynamics (Bahlai et al. 2013). Because native ladybirds, who frequently have more specific prey and habitat preferences, find it difficult to compete with this generalist predator, H. axyridis invasions have far-reaching ecological effects. H. axyridis has an advantage over local species that depend on certain prey or habitats since it can eat a wider range of aphid species and other pests (Grez Villarroel et al. 2016). Additionally, H. axyridis is known to harbor a microsporidian parasite that is deadly to local ladybirds but harmless to itself, offering an alternative means of displacement through disease transfer (Vilcinskas et al. 2013). **Trade-off** Although Harmonia axyridis has a strong chemical defence and a rapid rate of reproduction, these invasive species frequently outcompete native species for resources, which causes native biodiversity diminished and the environment to be disrupted.

6. Environment stress vs. Resource allocation Trade off- By decreasing food, nesting places, and overwintering refuges, habitat loss, degradation, severe temperatures, chemical pesticides, and fragmentation endanger ladybird populations (Dirzo et al. 2014; Foley et al. 2005; Habel et al. 2019). For instance, oral treatment to glyphosate resulted in increased motility in *Chrysoperla carnea* larvae, indicating acute physiological distress (Awad et al. 2024; Defarge et al. 2023), but adult C. septempunctata exposed to abamectin within three hours demonstrated 100% mortality (Rabbi et al. 2021). In the same direction, research has shown that ladybirds that feed on aphids treated with neonicotinoids like imidacloprid and thiamethoxam have high mortality rates (Scarpellini & Andrade 2011). According to studies, ladybird longevity, development, and reproductive success can all be negatively impacted by sub-lethal pesticide exposure. Imidacloprid exposure dramatically reduced fertility and shortened oviposition time in C. septempunctata, with reductions in adult longevity of 23.97% and 28.68%, depending on exposure level, according to (Xiao et al. 2016). By influencing their prey, pesticides can also have an indirect effect on ladybird numbers. Pesticide use directly affects aphids, which are the main food source for many species of ladybirds. Ladybirds have less access to food when pesticides like thiamethoxam, imidacloprid, and dimethoate interfere with aphid life cycles (Cheng et al. 2022; Sánchez-Bayo 2021). Ladybirds experience food shortages when aphid populations decline or their life cycles are disturbed, which may result in lower survival rates, particularly for larvae.

Trade off- Ladybirds must allocate more energy to stress resistance than to growth or reproduction when faced with severe temperatures, pesticide exposure, or a lack of prey. Thus, the distribution of energy is altered by environmental stress.

Conclusion: Most of this review has been on how competition between two physiological processes for a restricted resource can result in a trade-off, with some consideration given to the mechanics of how that resource might be allocated. The ecological success and potential for biological control of ladybird beetles are influenced by a number of interrelated trade-offs. Scientists can forecast population dynamics, improve biological control techniques, and investigate evolutionary adaptation by having a better understanding of these limitations. Colouration–thermoregulation, foraging–predation threat, defence–reproduction, body size–energy requirements, and survival–reproduction are some significant trade-offs. These compromises demonstrate how ladybirds must balance scarce resources in order to achieve optimal fitness.

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