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MORPHOLOGICAL INSIGHTS: ANATOMICAL VARIATIONS AMONG THREE BUTTERFLY FAMILIES (PIERIDAE, NYMPHALIDAE, AND PAPILIONIDAE) FROM NEMALIGUNDLA–A.P.-INDIA

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Abstract
With an emphasis on morphological variations that have developed in response to environmental stresses, feeding patterns, and ecological niches, this study investigates the anatomical divergence seen among the several butterfly families Pieridae, Nymphalidae, and Papilionidaein the area Nemaligundla, a dense black forest area in the Giddaluru Zone of the Prakasam District. We examined the head, antennae, proboscis, and wing measurements of a few butterfly families using a comparative method. Our research shows how structural modifications let butterflies survive and diversify in a variety of environments. In contrast to other butterfly families, the Papilionidae family has distinctive physical characteristics, most notably the greatest average head size (0.60), which may indicate special adaptations or behaviours. The Papilionidae has the greatest average for sensory adaptations (1.58), however their antennae mean values are also in close agreement with those of other families. A notable observation is that the Papilionidae have the longest proboscis (2.68),compared to the shorter averages of the Pieridae (1.7) and Nymphalidae (2.11), suggesting specialization for accessing a variety of floral resources; additionally, the family has the largest average widths for both forewings (5.2) and hindwings (3.1), which may improve mobility, flight, or visual displays during mating; these morphological traits demonstrate the evolutionary adaptations of the Papilionidae family in response to ecological niches.

Keywords: Butterflies, Anatomical divergence, Morphology, Evolutionary adaptation, Comparative anatomy.

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Introduction
Butterflies (Order: Lepidoptera) represent a fascinating group of insects characterized by their striking diversity and complex behaviours. Understanding anatomical divergence within butterfly families provides insights into evolutionary processes and ecological adaptations. This paper aims to highlight key anatomical features among selected butterfly families, including Nymphalidae, Papilionoidae, and Pieridae.

The diversity of butterfly morphology provides insight into their evolutionary adaptations to different environmental niches. There are more than 28,000 species of butterflies, with about 80 percent found in tropical regions. India hosts about 1,501 species of butterflies out of which peninsular India hosts 350 species [1, 2]. While all three families share certain Lepidopteran characteristics, they also display unique traits that facilitate their survival and reproductive strategies. Understanding these anatomical variations offers a glimpse into the evolutionary processes that shape biodiversity [3].

The family Nymphalidae is the most diverse within the butterflies, both objectively in terms of species numbers (>6000 worldwide) and more subjectively in terms of morphological and biological diversity [4, 5].

Pieridae is known for having species adapted to extreme cold or dry conditions, such as high montane habitats, the Arctic and deserts [6, 7]. The family is sensitive to ambient temperature, and morphological adaptations for regulating temperature have been identified in several lineages [8, 9].

Members of the Papilionidae family are typically found near their larval feeding plants and at the same elevation. Because no species of the host plant, Aristolochia, is found at low elevation in the western Himalaya, batwings, windmills, and birdwings are found at higher elevations than in the eastern Himalaya [10].

Methodology

Study Area

Nemaligundla, a dense black forest area in the Giddaluru Zone of the Prakasam District, is renowned for its waterfalls, Nemaligundla Falls, and is situated in the center of the dense Nallamala forest. Latitude 15° 45' 19.9944'' N and longitude 79° 57' 55.854'' E are where the study area was situated. The natural environment of this study region is a dry deciduous woodland. Large trees cannot develop when there is insufficient water, and the typical vegetation is a dry deciduous forest with an abundance of *Terminalia, Hardwickia* and *Pterocarpus* trees. Except for small areas close to villages where subsistence farming is done, agriculture is essentially non-existent. It is distinguished by different sections of grasses, climbers, shrubs, and herbs. The distribution of sunlight in this habitat is uneven, and it is somewhat disturbed. Because of the shades created by different tree species, this ecosystem is somewhat disturbed and the distribution of sunlight is inconsistent.

Morphological analysis

Physical specimens from study area were analysed, focusing on wing structure, head, antennae and proboscis. Collection of butterfly species of 3 families (Pieridae, Nymphalidae and Papilionidae) from Museum.

Wing structure

Shape, size, and venation patterns.

Coloration

Patterns, pigmentation, and their relevance to camouflage and mating.

The field rearing was done according to the day light and length from April 2024 to December 2024. There are some butterflies that are easily observed in early sun rise while majority of the others are found during whole day. The collection of samples was done with the help of net and few were done with bare hands directly. After collecting them we have preserved them in specimen bottles in a dry form. Later on, pictures were taken for those samples again so that if further verification is required then we can do that to have perfect identification.

They were then transferred to the insectary for identification using standard manual by [11, 12]. Butterflies were pinned in insect boxes stuffed with naphthalene balls which served as protection against insect attacks [13].

Forewing length is measured from where it attaches to the thorax to the tip, or apex, of the wing. Vernier callipers are the most accurate way to do this, but it is fine to use a small clear ruler that measures in millimetres.

Hindwing length-To make the second measurement, find the discal cell (the mitten-shaped cell on the hindwing). Finally, measure the distance between the beginning of the discal cell and the point where the vein meets the hindwing margin.

Results

Family descriptions

Pieridae (Whites and yellows)

Morphological characteristics

Smaller body size and lighter coloration for effective thermoregulation in open habitats. Generally, less varied, with broad, flat wings that facilitate gliding. Predominantly white, yellow, or orange with black spots that serve as camouflage or warning signals. Shorter proboscis adaptable for different feeding strategies, including feeding on nectar from short-tubed flowers. Pierids often engage in migratory behavior, with their wing morphology facilitating flight over long distances. Their coloration plays a crucial role in both foraging and mate attraction.

1) *Catopsilia pomona*

Broad wings with a typical Pieridae shape; elongated and slightly pointed. Venation shows a prominent pattern that's often simple and straightforward. Broad, somewhat triangular wings. Medium-sized with a wingspan of approximately 5-7 cm. Distinctive venation with robust forewings featuring a clear pattern of radial and cubital veins. Hindwings typically have fewer veins. Bright yellow with black tips; coloration aids in signalling to potential mates.

2) *Delias eucharis*

Wing structure: Irregular wing edges with a slightly broader expanse; venation is moderately complex. White wings with black markings; provides some camouflage among flowers. Slightly elongated wings with pointed tips. Small to medium size, wingspan ranging from 5-6 cm. Characteristic venation, often exhibiting a combination of short and long veins, with potential for colourful patterns on the upper surface.

3) *Ixias pyrene*

Substantial wings with rounded edges; venation pattern is intricate and helps in flight dynamics. Yellow with black margins; coloration aids in mating displays and can blend with a variety of floral backgrounds. Broad forewings and rounded hindwings. Small, with a wingspan of about 4-5 cm. Dense network of veins, particularly noticeable on the forewings. Typically, ground color with bright patterning.

4) *Catopsilia pyranthae*

Broad wings with smooth venation, similar in style to *C. pomona.* Pale yellow with distinct purplish accents; coloration aids in attracting mates. Similar to *Catopsilia pomona* but often exhibiting more pronounced apex. Medium-sized, around 5-7 cm wingspan. Prominent venation with a clear pattern that often shows light and dark contrast.

5) *Cepora nerissa*

Wings are large and slightly pointed, with clear venation. Variable shades of white and yellow; adaptive for camouflage in natural settings. Angular, with hindwings often lobed. Medium-sized, around 4-6 cm wingspan. Characteristic venation pattern with distinct dark lines; forewings have a prominent radial vein pattern.

6) *Colotis danae*

Moderate in size with exquisite venation patterns. Bright orange and black; coloration enhance visibility to mates. Slightly elongated and narrow with rounded hindwings. Small to medium, with a wingspan of about 4-6 cm. Broad network of veins, usually with distinct coloration and patterning that varies between individuals.

7) *Appias olferna*

Characteristic white wings with angular shapes. White and black patterns assist in camouflage among white flowers. Triangular forewings, often more pointed than rounded. Medium-sized, around 5-7 cm wingspan. Complex venation with thickened subcostal veins and distinct block of radial veins.

8) *Eurema alitha*

Delicate shape with short wings; simple venation pattern. Bright yellow with light undersides; adapted for visibility during mating. Generally, modestly shaped, with less pronounced angles. Small, with wingspans of about 3-5 cm. Simple venation with relatively few cross veins, broad space between veins.

9) Pieris rapae

Standard white wing shape with simple venation. White with black tips; provides limited camouflage among various habitats. Broad, rounded forewings and hindwings. Larger than some of the others listed, with a wingspan of about 4-6 cm. Well-defined non-specialized venation, with a clear network on forewings; usually white with dark tips.

Nymphalidae (Brush-footed butterflies)

Nymphalidae are known for their diverse wing shapes and patterns. Adaptations such as larger surface areas for gliding in forest habitats and striking color patterns for mimicry and mate attraction. Dark coloured wings mostly, often broader and rounded, providing stability in flight. Reduced proboscis suitable for feeding on fermenting fruits rather than flowering plants, reflecting their ecological niche. Dull to bright coloration with intricate patterns that serve both camouflage and mimicry. Nymphalids often exhibit behaviours such as basking and displaying to predators, employing their wing patterns for both thermoregulation and deterrent strategies.

1) *Mycalesis visala*

Substantial wings with soft edges; typically, has rounded wings with a somewhat broad appearance. Brownish with eyespots to mimic leaves; contributes to camouflage. Shorter proboscis, feeding primarily on tree sap and rotten fruit. Medium-sized; wingspan generally around 60-70 mm.

2) *Junonia almana* (Peacock Pansy)

Rich blue-orange hues with dark spots; visually striking for mate attraction. Round to broad wings with pronounced eye spots. Medium; wingspan around 50-60 mm. Long proboscis adapted for nectar feeding, Access to a range of deep-flowering plants is made possible by long proboscis that is suited for nectar eating. big animals have long tails that improve flight stability and particularly on flowers. Displays typical Nymphalid venation, with distinct cell structures and veins that are prominent, especially near the margins.

3) *Junonia lemonias* (Lemon Pansy)

Long proboscis for foraging nectar. Similar to *Junonia almana*, rounded and broad wings. Bright orange-yellow with black markings; used in mating displays. Medium-size; wingspan around 50-60 mm. Exhibits Nymphalid venation; eye spots may vary in intensity.

4) *Athyma perius*

Wings are broad and slightly rounded, with distinctive rings on the forewings. Dark brown with white patterns; helps in blending with surrounding flora. Medium-sized, wingspan around 50-60 mm. Nymphalid venation with clear dark veins and a pattern of rings that are characteristic of the species. Adequate for various feeding habits.

5) *Euploea core* (Common Crow)

Strong and broad wings; complex venation. Medium to large; wingspan up to 90 mm. Dark brown with white spots; camouflage adaptation. Long and functional for nectar feeding. Exhibits strong Nymphalid vein structures, with a dark coloration that helps in mimicry.

6) *Acraea terpsicore*

Usually, elongated wings with a more triangular shape compared to Nymphalids. Medium; wingspan around 40-50 mm. A unique pattern that may include additional cross-veins, consistent with the subfamily Acraeinae. Distinct orange and black patterns with a larger wing structure. Bright orange; aposematic coloration as a warning to predators. Functional for nectar feeding habits from various plants.

7) *Junonia iphita*

Round wings with somewhat variable coloration and patterns. Similar to other Junonia species, wingspan around 50-60 mm. Nymphalid characteristic with distinct vein patterns. Similar to *J. almana* but slightly smaller. Bright colors with complex patterns; provides a striking appearance during courtship. Long proboscis, generally feeding on nectar.

8) *Byblia ilithyia*

Irregular edges with modest venation. Dark body with spot patterns; enhances camouflage. Adapted for efficient nectar extraction. Rounded wings with notable coloration variation. Medium; wingspan about 60-70 mm. Nymphalid venation with clear cell structures.

9) *Danaus limniacea* (Mexican Monarch)

Broad and slightly elongated wings, similar to other Danaus species. Medium to large; wingspan can reach up to 100 mm. Strong Nymphalid venation; known for its vibrant colors and strong, heavy veins.

Papilionoidae (Swallowtail butterflies)

Papilionoidae have distinctive characteristics that help them survive:

can deceive predators. Designs that are bold and eye-catching, frequently aposematic (warning colors) to indicate poison to possible predators. Swallowtails' vivid

colors attract mates while discouraging predators, demonstrating the importance of visual cues in predator-prey relationships.

1) *Pachliopta aristolochiae*

Large wings that resemble a swallowtail. Sexual dimorphism is frequently visible; dark with red highlights. Wings are broad and slightly rounded. Size range: medium to big (wing span: 70-90 mm). Typical lepidopteran pattern with intricate vein networks and noticeable forewings, frequently accompanied with extra discal cell occurrences.

2) *Papilio crino*

Strong venation and broad wings with distinct patterns. Black and green; signalling and imitation during mating. extended hindwings that frequently have a tail-like protrusion and triangular forewings. Medium size, with a wing span of roughly 60 to 80 mm. Strong veins that are characterized by a complex pattern with huge cells and branching, especially in the forewings.

3) *Princeps demoleus*

It is medium in size and has characteristic tail extensions. Black and yellow serve as warning colors to ward off predators. Wide, rounded wings that are distinctly coloured. Wing span: around 70-90 mm, medium size. Well-defined veins with a somewhat dense vein network; the border of the hindwings may be darker.

4) *Papilio demodocus*

Sturdy body with distinct wings. Adaptable for camouflage and mating, black with blue and yellow patterns. Wide hindwings and triangular forewings. Medium size (about 90–120 mm across the wings). Complex, with a combination of delicate and heavy vein structures; vein chambers in the forewings are usually well delineated.

5) *Graphium doson*

Graphium is known for its elongated, slim wings, which allow for agile flight. For mating displays, the color is dark with blue and green accents. Slender wings with forewings that are pointed. Somewhat smaller (approximately 50–70 mm in wing span). Dense veins with observable cell formations that generate a pattern unique to the Graphium genus.

6) *Papilio polytes*

Significant tail; distinctive swallowtail form. Black with blue and red patterns; varies depending on the people. Broad hindwings and wide forewings, frequently with tail extensions. Medium to large (about 70–100 mm wing span). Robust and substantial, with noticeable dichotomous branching.

7) *Graphium agamemnon*

Narrow wings with distinctive veining. During courting, black with blue and white stripes is visually appealing. The forewings are pointed and the wings are long and thin. Medium (about 60–80 mm in wing span). Characterized by complex vein networks and a robust, developed appearance, particularly on the forewings.

8) *Triodes helena*

Distinctive tail-equipped wings that enable nimble flight. Vibrant black and yellow; serves as a warning to predators and attracts mates. Rounded wings that have a hint of wave to them. Medium to large (wing span usually between 70 and 90 mm). Remarkably intricate, with numerous veins and folds that display a range of linkages.

9) *Pachliopta hector*

Though slightly different in size and shape, they are similar to *P. aristolochiae*. Aposematic signals for predators; dark with orange or red. It has a wide look, much like *Pachliopta aristolochiae*. Medium (about 70–80 mm in wing span). Intricate veining that has a classic lepidopteran appearance.

Family comparisons

White butterflies, or Pieridae, have the lowest averages of any family. This is especially noticeable in the forewings (2.98) and hindwings (2.26). Given that many species in the Pieridae family rely on certain host plants and require fewer extensive wing structures, these characteristics might be indicative of their ecological niche.

The family Nymphalidae, which includes brush-footed butterflies, has a range of ecological responsibilities and generally has intermediate values. Compared to Pieridae, the forewing dimensions (3.57) and hindwing widths (2.49), which may be adaptations for improved flying maneuverability or alternative feeding techniques, are noticeably larger.

Swallowtail butterflies, or Papilionidae, are the obvious outlier with the biggest physical features, suggesting a distinct evolutionary trajectory. Their higher average values may be a result of their longer wings and proboscis, which enable them to take advantage of a greater variety of food sources or habitats.

Table1. Anatomical traits of the collected butterfly species of 3 families.

S/N	Name of the butterfly	Head in cm	Antennae in cm(L)	Proboscis in cm(L)	Forewing in cm (L)	Hindwing in cm (L)
	FAMILY**: PIERIDAE**					
A.	*Catopsilia pomona*	0.5	1.3	2.2	4.0	3.2
B.	*Delias eucharis*	0.6	1.4	2.3	4.5	3.2
C.	*Ixias pyrene*	0.4	1.3	1.6	2.6	2.0
D.	*Catopsilia pyranthae*	0.5	1.2	2.2	3.7	3.1
E.	*Cepora nerissa*	0.3	1.2	2.0	2.7	1.9
F.	*Colotis danae*	0.2	0.9	1.7	2.3	1.7
G.	*Appias olferna*	0.4	1.3	1.9	2.4	1.9

H.	*Eurema alitha*	0.2	0.9	0.7	1.8	1.3
I.	*Pieris rapae*	0.25	1.3	1.0	2.9	2.1
	FAMILY: NYMPHALIDAE					
A.	*Mycalesis visala*	0.4	1.3	2.1	3.6	2.3
B.	*Junonia almana*	0.2	1.4	2.0	3.4	2.4
C.	*Junonia lemonias*	0.3	1.3	2.2	3.6	2.6
D.	*Athyma perius*	0.4	1.4	2.3	2.2	1.5
E.	*Euploea core*	0.4	1.7	2.5	4.7	2.9
F.	*Acraea terpsicore*	0.4	1.4	2.1	3.0	2.1
G.	*Junonia iphita*	0.3	1.4	2.2	3.3	2.6
H.	*Byblia ilithyia*	0.3	1.2	1.5	3.7	2.5
I.	*Danaus limniacea*	0.5	1.6	2.1	4.6	3.4
	FAMILY: PAPILIONIDAE					
A.	*Pachliopta aristolochiae*	0.7	1.6	2.6	5.8	3.4
B.	*Papilio crino*	0.6	1.4	2.8	4.5	3.5
C.	*Princeps demoleus*	0.5	1.2	2.6	4.1	2.7
D.	*Papilio demodocus*	0.6	1.4	2.3	4.0	3.0
E.	*Graphium doson*	0.4	1.3	2.5	3.8	2.2
F.	*Papilio polytes*	0.6	1.9	2.7	4.7	2.4
G.	*Graphium agamemnon*	0.57	1.7	2.5	4.4	2.9
H.	*Triodes helena*	0.8	2.0	3.4	8.3	4.9
I.	*Pachliopta hector*	0.6	1.7	2.7	5.6	3.1

Table 2. Average of the anatomical traits of the collected butterfly species of 3 families. The table presents mean values ($\bar{x}$) for various morphological traits across three butterfly families: Pieridae, Nymphalidae, and Papilionidae. Each family is characterized by specific averages for the head, antennae, proboscis, forewing, and hindwing measurements.

S/N	Name of the family	$\bar{x}$ of the values of Head	$\bar{x}$ of the values of Antennae	$\bar{x}$ of the values of Proboscis	$\bar{x}$ of the values of Forewing	$\bar{x}$ of the values of Hindwing
1.	Pieridae	0.37	1.2	1.7	2.98	2.26
2.	Nymphalidae	0.35	1.41	2.11	3.57	2.49
3.	Papilionidae	0.60	1.58	2.68	5.2	3.1

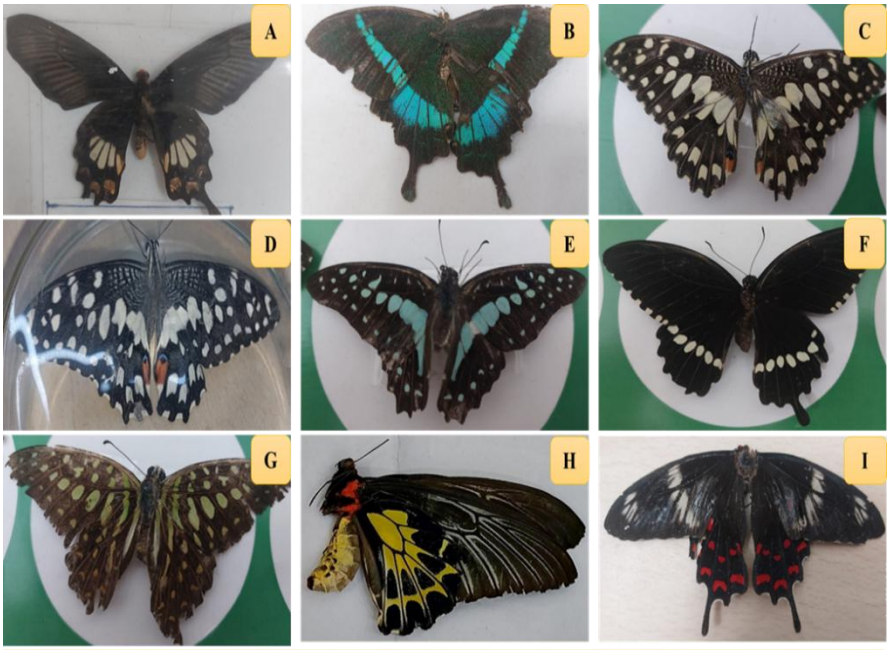
FAMILY: PIERIDAE
A. *Catopsilia pomona*, **B.** *Delias eucharis*, **C.** *Ixias pyrene*, **D.** *Catopsilia pyranthae*,
E. *Cepora nerissa*, **F.** *Colotis danae*, **G.** *Appias olferna*, **H.** *Eurema alitha*, **I.** *Pieris rapae*

Figure 1. Butterflies belonging to family Pieridae.

FAMILY: NYMPHALIDAE

A. Mycalesis visala, B. *Junonia almana*, C. *Junonia lemonias*, D. *Athyma perius*, E. *Euploea core*, F. *Acraea terpsicore*, G. *Junonia iphita*, H. *Byblia ilithyia*, I. *Danaus limniacea*

Figure 2. Butterflies belonging to family Nymphalidae.



FAMILY:PAPILIONIDAE

A. Pachliopta aristolochiae, B. *Papilio crino*, C. *Princeps demoleus*, D. *Papilio demodocus*, E. *Graphium doson*, F. *Papilio polytes*, G. *Graphium agamemnon*, H. *Triodes helena*, I. *Pachliopta hector*

Figure 3. Butterflies belonging to family Papilionidae.

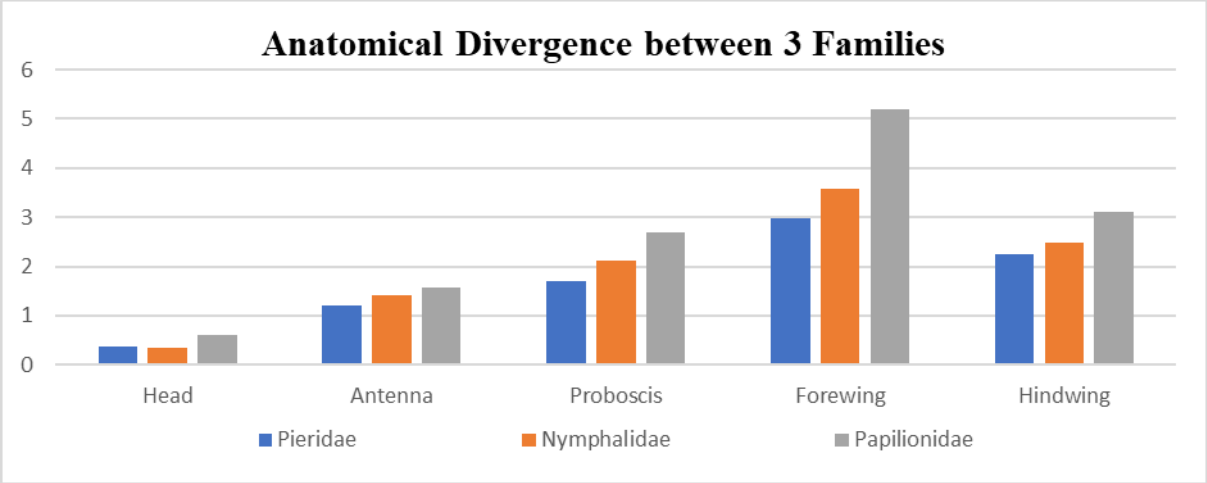


Figure 4. Graphs representing the anatomical traits difference between 3 families.

Discussion

In comparison to the other two families, the Papilionidae family has the biggest average head size (0.60), which points to the possibility that its members have developed unique traits or behaviours that call for a larger head. The Papilionidae have the highest average (1.58), which may be a sign of sensory adaptations. The antennae mean values within the families are closely clustered. In comparison to the other families, which have smaller proboscis averages (1.7 for Pieridae and 2.11 for Nymphalidae), the Papilionidae family has a noticeably longer proboscis (2.68), which may indicate that they are specialized for accessing distinct floral resources. Forewings (5.2) and hindwings (3.1) have the biggest average widths in the Papilionidae family [10]. This characteristic may have to do with mobility, flight ability, or even display during mating rituals.

Ecological Implications

These species' physical variations may be related to their preferred habitats, dietary habits, and methods of reproduction. For example:

Proboscis length: While shorter proboscises in the Pieridae family may reflect a preference for more accessible floral sources, longer proboscises in the Papilionidae family suggest an adaptation for getting nectar from deeper flowers.

Wing size: Papilionidae have larger wings, which can let them fly more steadily and maneuverably-two qualities that are crucial for avoiding predators. It may also be related to their territorial or migration tendencies.

Conclusion

According to the research, variations in the three butterfly groups' average morphological characteristics may have important ecological ramifications that affect how they feed, choose their habitats, and mate. Gaining knowledge of these differences can help one better understand their ecological niches and evolutionary adaptations. To completely understand these families' adaptations and interactions with their habitats, more research might examine their ecological roles and behavioral traits.

The relationship between morphological characteristics and environmental adaptation is highlighted by the anatomical differences between the butterfly families Pieridae, Nymphalidae, and Papilionidae. Evolutionary responses to preferred environments and eating habits are shown in variations in wing shape and mouthpart morphology.

Future studies should focus on the genetic basis of these physical features in order to better understand evolutionary biology in Lepidoptera. These results could be further developed to shed more light on the genetic underpinnings and evolutionary links of butterfly morphological features by integrating molecular investigations.

Author Contributions

All authors are contributed equally

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Declaration of Competing Interest

The Authors have no Conflicts of Interest to Declare.

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