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Short Communication

Morphological Variation of Butterfly Wing Scales (Lepidoptera) in the Taman Gading Ecotourism Area, Ledokombo, Jember, East Java

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ABSTRACT
This study provides the first detailed characterisation of wing scale variation in butterflies from Taman Gading Ecotourism, East Java. Thirty-three species representing Lycaenidae, Nymphalidae, Papilionidae, and Pieridae were sampled within a 1-hectare plot using insect nets during peak activity periods. The scales were examined under light microscopy, and morphometric measurements (length, width, and serration) were analyzed using ImageJ and PAST to assess morphological variation. Darkly pigmented scales were predominantly elongated, whereas lighter or translucent scales were mostly rounded, indicating adaptive, structural, and chemical differentiation. These findings support species identification, biodiversity assessment, and the development of bioinspired materials.

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Butterflies (Lepidoptera) are ecologically important as herbivores, pollinators, parasitoid hosts, and preys (Kawahara et al. 2019; López-Vázquez et al. 2024). Due to their high sensitivity to environmental changes, butterflies are widely used as bioindicators of habitat quality (Ndandika et al. 2025). As cosmopolitan insects, butterflies occur in a wide range of habitats, provided that host plants, nectar resources, and suitable shelter are available (Tzortzakaki et al. 2019). Butterfly abundance and distribution are influenced by both biotic and abiotic factors, including vegetation structure, temperature, humidity, and rainfall (Koneri et al. 2019).

One of the most distinctive characteristics of butterflies is the intricate patterns and vibrant colours of their wings. Butterfly wings are covered with microscopic scales arranged in an overlapping pattern resembling roof tiles, producing diverse patterns and colours that function in communication, species recognition, thermoregulation, and predator defence (Vértesy et al. 2006; Stavenga et al. 2023; Dharmaraaj et al. 2024). Aposematic patterns serve as warning signals to predators, indicating toxicity or unpalatability (Vallin et al. 2006). Butterfly wing coloration arises either from pigments such as melanin and pterin (Vértesy et al. 2006), or from scale microstructures that generate structural colour through light refraction and reflection (Han et al. 2009).

Although butterfly diversity has been extensively documented, studies focusing on the microscopic variation of wing scales remain limited. Early studies identified two primary wing scale shapes, namely rectangular and triangular forms (Efendi 2009). Subsequent research by Sumah (2019) reported that *Papilio demoleus*, *Ideopsis juventa*, and *Arhopala araxes* possess uniformly rectangular wing scales, whereas *Catopsilia scylla* exhibits both rectangular and triangular scales, with serration numbers ranging from one to four. Analyses of wing scale morphology provide valuable insights into taxonomy, structural colouration, thermoregulation, and ecological adaptation (Sijina & Evans 2022; Tang 2024).

Taman Gading, in Sumber Bulus Village, Ledokombo, is ecologically heterogeneous and supports diverse host plants and nectar resources for butterflies (Maisyaroh et al. 2021; Nuruzzaman et al. 2025). Despite its ecological significance, the surrounding landscape is increasingly threatened by anthropogenic disturbances, including stone and sand extraction and the conversion of natural habitats into monoculture plantations (Mubarok et al. 2023). While butterfly diversity in Taman Gading has been previously documented, studies addressing the microscopic variation in wing scale morphology are still lacking. This knowledge gap is particularly important given the role of wing scale structures in taxonomy, functional adaptation, and structural coloration. Therefore, this study aims to provide the first detailed characterisation of microscopic wing scale variation in butterflies from the Taman Gading Ecotourism area. The results can be used to enrich taxonomic reference data, support biodiversity conservation strategies, and contribute to educational and bioinspired research.

Sampling was conducted from January to March 2025 in the Taman Gading Ecotourism Area, Sumber Bulus Village, Ledokombo District, Jember, East Java, Indonesia (8°08′58.7″ S, 113°54′05.0″ E). All research activities were authorized by the management of the Taman Gading Ecotourism Area (Permit No. B-10484/In.20/3.a/PP.009/02/2025). The research site map is presented in Figure 1.

An exploratory survey was conducted within a 1-hectare plot, which was purposively selected based on vegetation heterogeneity and its location within the core zone frequently utilised by butterflies across the broader Taman Gading landscape. The high availability of plant resources indicates that the habitat provides suitable ecological conditions for supporting multiple pollinator species (Tiedge & Lohaus 2017). During data collection, microclimatic parameters, including temperature, relative humidity, and light intensi-

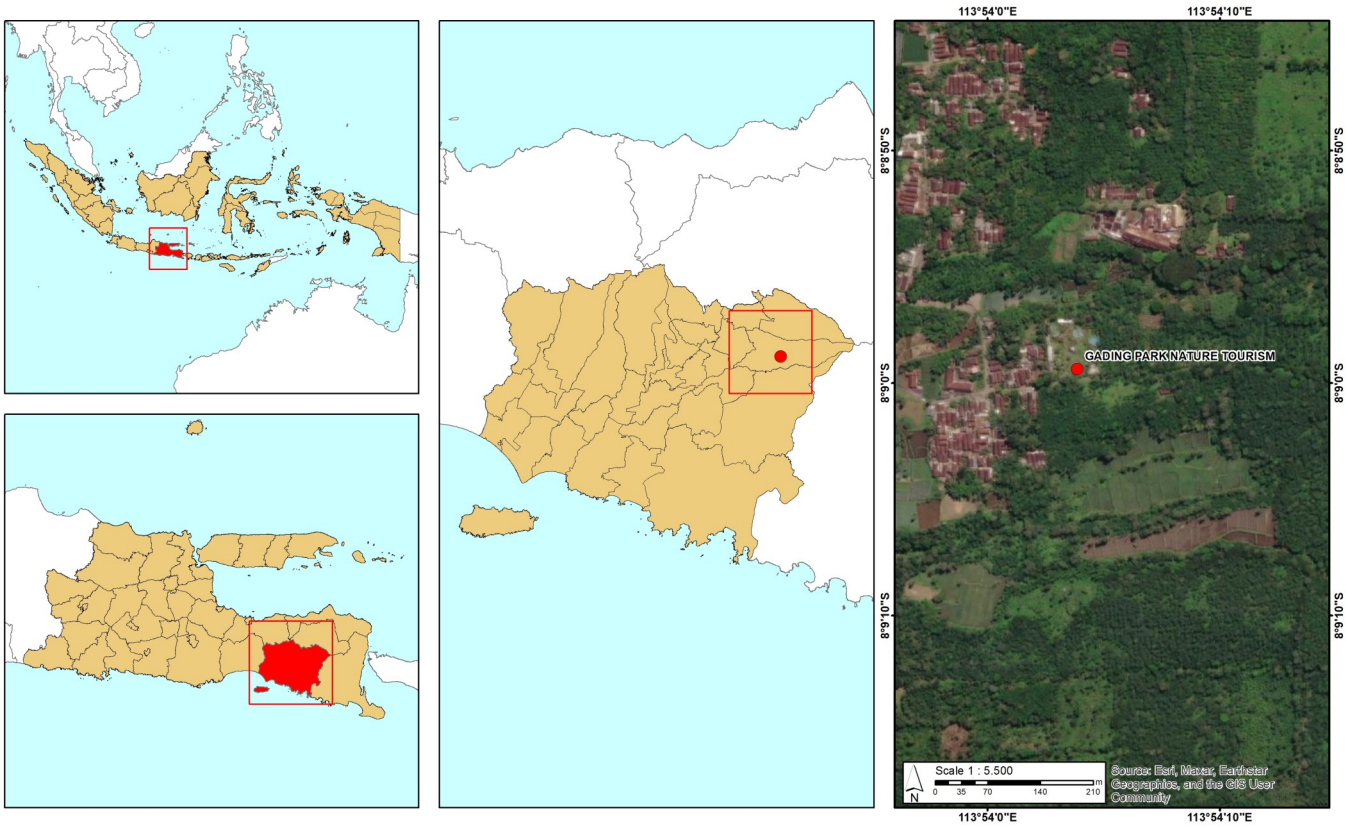


Figure 1. Research location.

ty, were recorded to characterise the environmental conditions that may influence butterfly presence and activity within the study area.

Sampling was conducted during peak butterfly activity periods, specifically from 07:00–11:00 and 13:00–17:00 (Peggie 2014). Butterflies were captured using an insect net and euthanised ethically by gentle thoracic compression using the thumb and forefinger (Vieira-Silva et al. 2024). Each specimen was placed in a labelled triangular paper envelope indicating the date and time of collection and transported to the Laboratorium Terpadu FTIK UIN Kiai Haji Achmad Siddiq Jember for further identification. Species were identified using Peggie and Amir (2006), Ruslan (2015), Panjaitan et al. (2021) as well as the Kupunesia application (https://play.google.com/store/apps/details?id=org.kupunesia). Species validation was carried out by Agmal Qodri, M.Si., an entomologist from the National Research and Innovation Agency (BRIN).

Butterfly wing scale observations were performed by gently scraping a small section of the wing surface using fine tweezers. The detached scales were transferred onto a glass slide, covered with a cover slip, and examined under a light microscope. Scales were selected from both dark and light wing regions, including areas exhibiting colour variation within a single wing (Giraldo 2008). Wing scales were classified into two main morphological types: elongated and rounded. Elongated scales exhibited a pronounced disparity between length and width, whereas rounded scales showed relatively similar dimensions along both axes (Rani et al. 2023). Morphometric measurements (length, width, serrations) were obtained using ImageJ (Ferreira & Rasband 2012) and analysed using PAST ver. 4.09 (Hammer et al. 2001).

Microclimatic measurements averaged 29.5 °C, 68 % humidity, and 4,803 lux (Table 1). These values fall within the optimal range for supporting butterfly daily activities, including feeding, basking, and flight behaviour (Koneri et al. 2019; Mahata et al. 2023). Microclimatic conditions are important determinants of wing scale microstructure, as variations in light in-

tensity, temperature, and humidity can influence scale morphology at micro- and nanoscales. Recent studies have shown that wing scale nanostructures vary across forest strata (canopy, mid-story, and understory), with each layer exhibiting distinct structural adaptations to local microclimatic conditions (López et al. 2024). In addition, hierarchical variation in wing scale micro- and nanostructures has been demonstrated to affect emissivity and radiative cooling efficiency, as observed in *Tirumala limniace*, where thermal properties are different among wing regions but remain consistent between sexes (Tang et al. 2022).

Table 1. Microclimatic parameters measured in the Taman Gading study area.

Parameter	Mean Value	Unit
Air temperature	29.5	°C
Air humidity	68	%
Light intensity	4.803	Lux

A total of 33 butterfly species belonging to four families Lycaenidae, Nymphalidae, Papilionidae, and Pieridae were recorded at the research site (Figure 2). Species documentation and subsequent analyses were based on a single individual per species, without differentiation between male and female butterflies. Nymphalidae exhibited the highest species richness, comprising 18 species, followed by Papilionidae and Pieridae with six species each, and Lycaenidae with three species. The predominance of Nymphalidae is consistent with previous studies and is likely attributable to their broad ecological tolerance and versatile feeding strategies (Mubarok et al. 2023; Qodri et al. 2023; Millah et al. 2023). Many nymphalid butterflies are polyphagous, utilising multiple host plant species during the larval stage, which enhances their persistence across heterogeneous habitats (Gao et al. 2025). In addition, adult Nymphalidae are not exclusively dependent on floral nectar but frequently exploit alternative nutrient sources, such as fermenting fruits, decaying plant material, and animal excreta (Millah et al. 2023).

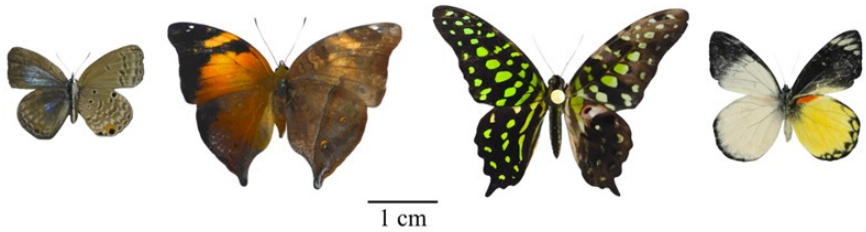


Figure 2. Representative butterfly species from each family found in Taman Gading, from left to right: *C. strabo* (Lycaenidae), *D. polibete* (Nymphalidae), *G. agamemnon* (Papilionidae), *D. belisama* (Pieridae). Scale bar = 1 cm.

Microscopic observations revealed that wing scales across all examined species are arranged in an overlapping pattern resembling roof tiles, a characteristic feature of Lepidoptera. This arrangement was consistent among all families studied, indicating a conserved structural organisation. Variations in scale shape and size are largely governed by microstructural features on the scale surface, particularly the ridges and cross ribs. Differences in ridge density, cross rib arrangement, and the number of serrations along the scale margins contribute substantially to interspecific and interfamilial morphological diversity (Giraldo 2008). Such structural heterogeneity underlies functional differences in colouration, light manipulation, and thermal performance (Sijina & Evans 2022; Tang 2024). Variations in butterfly wing scale shapes among families are shown in Figures 3–6.

Species within Lycaenidae predominantly exhibited elongated wing scales, particularly in darker or semi-transparent wing regions (Figure 3). For example, *Miletus symethus* displayed distinctly elongated, darkly pigmented scales with relatively simple ridge arrangements. Consistent with observations by Sun et al. (2024), lycaenid scales are generally characterised by parallel ridges with modest serration, resulting in a relatively uniform and less complex surface structure compared to other butterfly families. Elongated and densely arranged scales are commonly associated with enhanced solar radiation absorption, potentially facilitating thermoregulation in small-bodied butterflies (Vértesy et al. 2006).

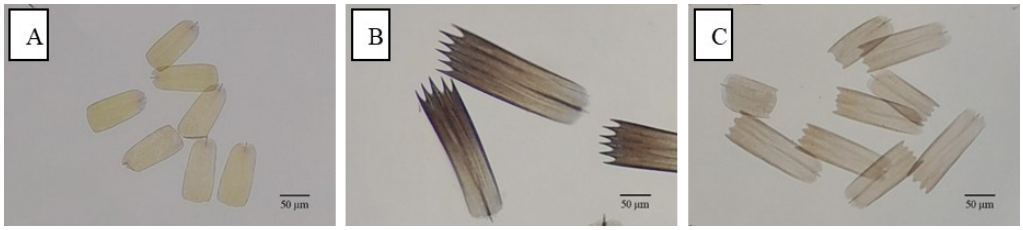


Figure 3. Variation in wing scale morphology of Lycaenidae: A.) *C. strabo*, B.) *F. apidanus*, and C.) *M. symethus*. Scale bar = 50 µm.

Nymphalidae exhibited the greatest diversity in wing scale morphology among the four families studied (Figure 4). Both elongated and rounded scales frequently co-occurred within individual species, such as *Discophora sondaica*, *Elymnias hypermnestra*, and *Euploea climena*. Darkly coloured wing regions, typically black or deep brown, were dominated by elongated scales, whereas lighter or brightly coloured regions showed a higher proportion of rounded scales. These findings are consistent with Rani et al. (2023), who reported that dark-coloured scales tend to have a greater number of ridges, whereas lighter-coloured scales in this family are generally broader.

The morphological diversity observed in Nymphalidae is closely linked to pigmentation and functional colouration. The structure of wing scales influences both pigment-based and structural coloration, which in turn plays a critical role in thermoregulation and predator avoidance (Vértesy et al. 2006; Giraldo 2008). Recent field-based evidence further supports this mechanism, as Vieira-Silva et al. (2024) demonstrated that flash colouration in *Morpho* butterflies significantly reduces avian predation in tropical rainforest environments.

Papilionidae displayed a combination of elongated and rounded scales, generally larger in size than those of the other families (Figure 5). Species such as *Papilio polytes* exhibited pronounced morphological variation corresponding to their intricate wing color patterns (Lim et al. 2024). The presence of mixed scale morphologies in Papilionidae is strongly associated with visual signaling functions, including mimicry, aposematism, and mate recognition (Stavenga et al. 2015). Structural complexity within the scales enhances color vibrancy and contrast, reinforcing the striking wing patterns for which this family is renowned. Sexual dimorphism, commonly observed in Papilionidae, further emphasises the role of scale morphology in visual communication and reproductive behaviour.

Pieridae were characterised by a predominance of rounded wing scales, particularly in species exhibiting white, yellow, or translucent wing coloration, such as *Eurema blanda* and *Delias hyparete* (Figure 6). This contrasts with Rani et al. (2023), who suggested that Pieridae butterflies generally possess elongated scales with broadened basal regions. The rounded scales observed in this study typically exhibited lower ridge density and smoother surface structures, which facilitate efficient and diffuse light reflection. In Pieridae, white and yellow coloration arises from a combination

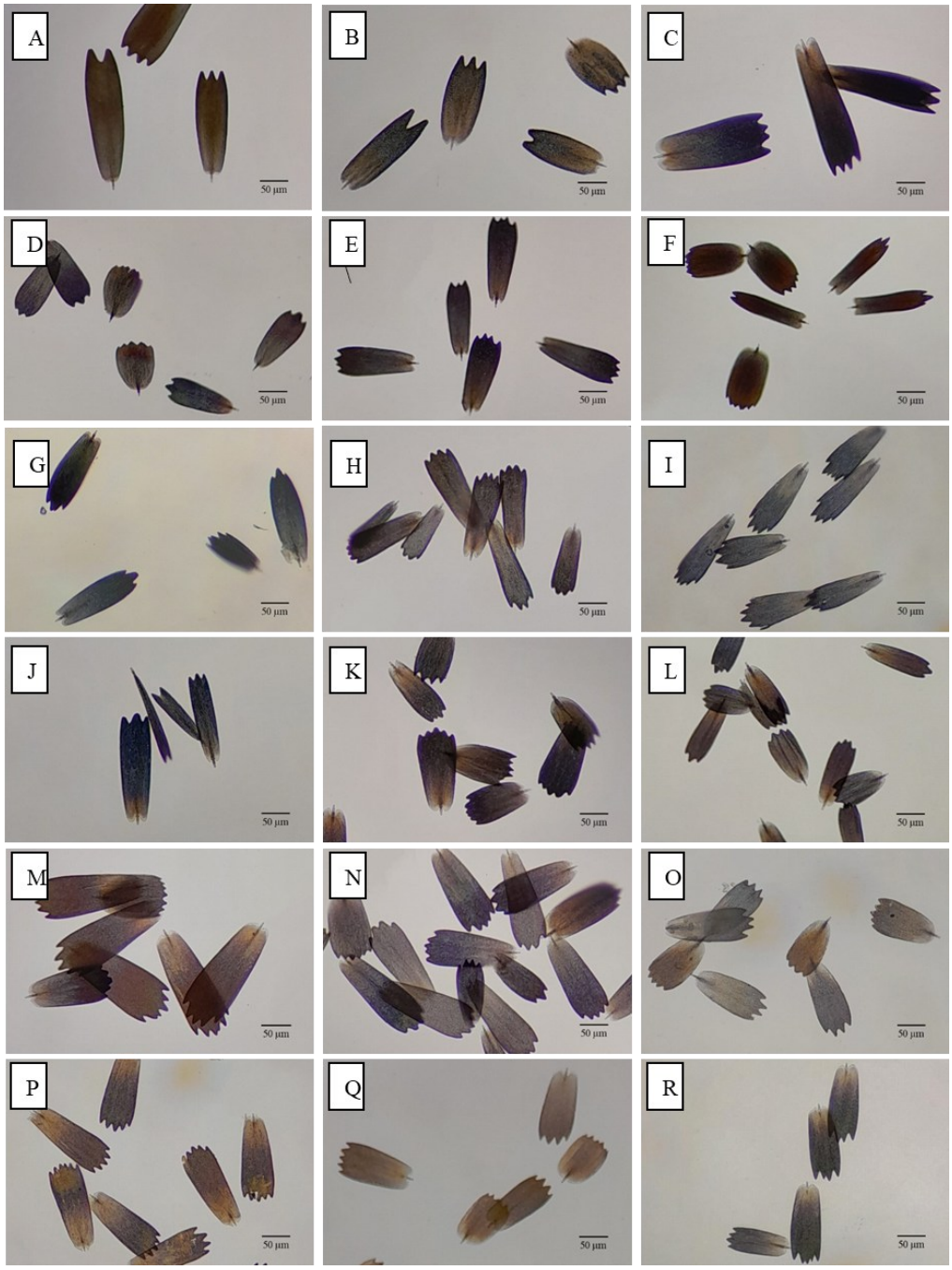


Figure 4. Variation in wing scale morphology of Nymphalidae: A.) *A. phidippus*, B.) *D. sondaica*, C.) *D. polibete*, D.) *E. hypermnestra*, E.) *E. nesaea*, F.) *E. climena*, G.) *E. eunice*, H.) *E. anosia*, I.) *E. monina*, J.) *H. bolina*, K.) *H. misippus*, L.) *J. almana*, M.) *J. hedonia*, N.) *J. iphita*, O.) *L. europa*, P.) *N. hylas*, Q.) *P. phalantha*, R.) *S. hypselis*. Scale bar = 50 µm.

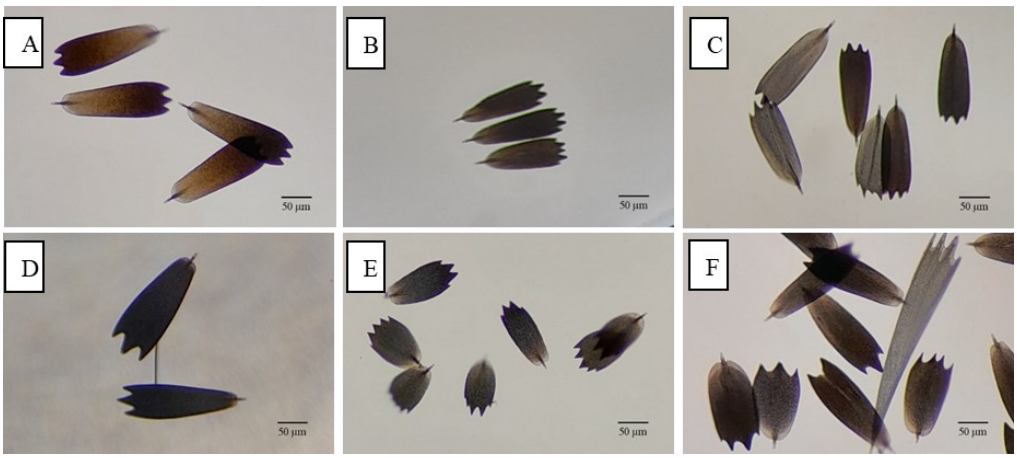


Figure 5. Variation in wing scale morphology of Papilionidae: A.) *G. agamemnon*, B.) *G. doson*, C.) *G. sarpedon*, D.) *P. memnon*, E.) *P. polytes*, F.) *T. helena*. Scale bar = 50 µm.

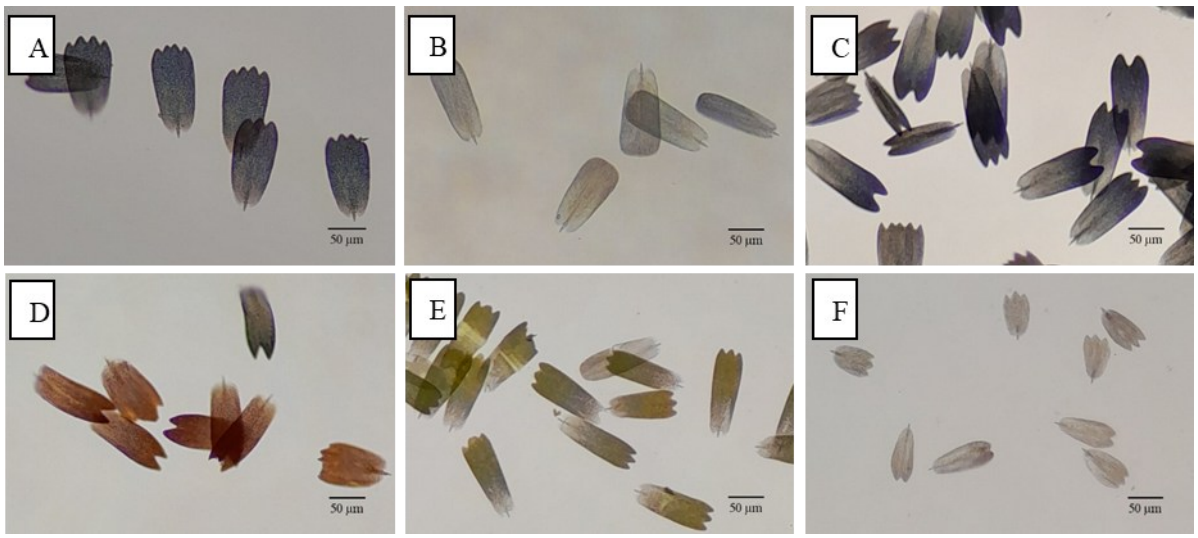


Figure 6. Variation in wing scale morphology of Pieridae: A.) *A. olferna*, B.) *C. pomona*, C.) *D. belisama*, D.) *D. hyparete*, E.) *E. blanda*, F.) *L. nina*. Scale bar = 50 µm.

of pigment deposition, primarily pterins and carotenoids and scale microstructures that maximise light scattering, resulting in high reflectance and visual brightness (Giraldo et al. 2008; Thayer & Patel 2023). Ecologically, this trait is advantageous for species inhabiting open or semi-open habitats with high light intensity, as rounded scales may contribute to thermal regulation by reducing excessive heat absorption under strong solar radiation (Kingsolver 1985; Neha & Kumar 2025).

The shape of the scales and the number of serrations on each scale also varied, while the width remained relatively constant in specific wing regions. Butterfly species observed in this study even exhibited scale shape variation within a single wing, including differences in serration number (see Table 2).

Based on Table 2, the number of serrations observed along scale margins ranged from 1 to 7 per scale. In general, scale length and width exhibited a positive correlation, whereby increases in length were accompanied by proportional increases in width. Scales with broader basal regions tended to possess a higher number of serrations than narrower forms, consistent with previous findings that tapered scales show reduced serration variability (Rani et al. 2023).

In this study, *Flos apidanus* (Lycaenidae) exhibited the largest average scale size (266 ± 60 µm in length; 68 ± 6 µm in width), whereas *Leptosia nina* (Pieridae) had the smallest scales (73 ± 13 µm in length; 35 ± 1 µm in width). These measurements generally fall within the reported range for butterfly wing scales, which typically measure 100–200 µm in length and 50–75 µm in width, with densities of approximately 200–600 scales per mm² (Preston-Mafham & Preston-Mafham 2004).

Scatter plot analysis of scale length and width showed no distinct clustering by family (Figure 7). Although Pieridae showed a tendency toward a more compact grouping, the overall distribution remained overlapping across families. This pattern indicates substantial intra-family and interspecific variation, suggesting that scale morphometry alone is insufficient for reliable family-level discrimination. Nevertheless, Nymphalidae displayed the widest range of variation, with scale lengths spanning 100–200 µm and widths ranging from 40–95 µm, a pattern consistent with their high species richness in this study. Papilionidae occupied an intermediate to large size range (120–180 µm in length; 35–70 µm in width), whereas Pieridae formed a relatively compact cluster with smaller and more homogeneous scales. Lycaenidae generally showed small to medium-sized scales, with *Flos apidanus* representing a notable outlier due to its exceptionally large scale dimensions.

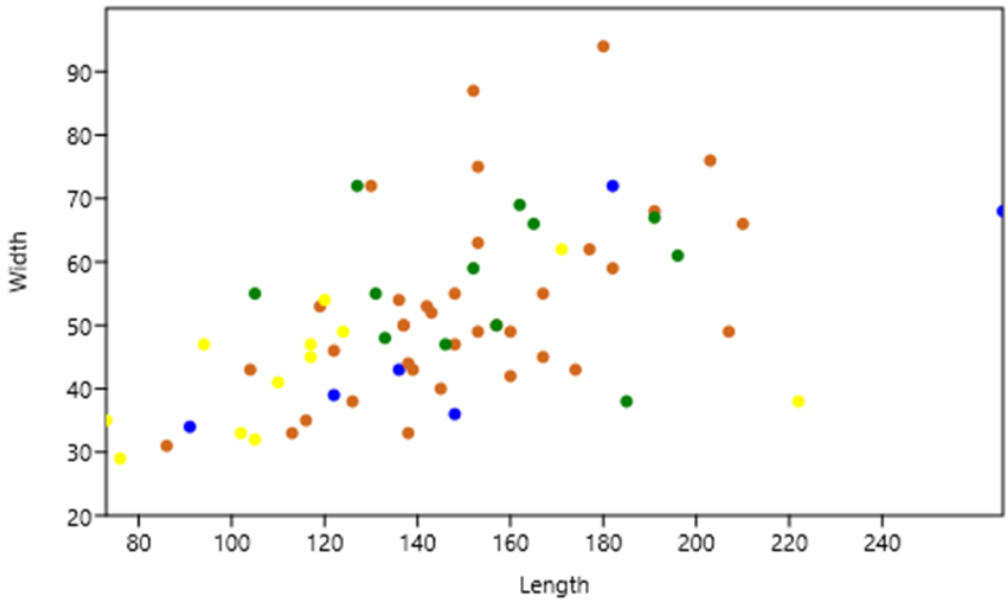


Figure 7. Scatter plot of butterfly wing scale length versus width across four families: Lycaenidae (blue), Nymphalidae (brown), Papilionidae (green), and Pieridae (yellow). Data analysed using PAST ver. 4.09.

Previous morphometric studies indicate that wing scale dimensions vary significantly across Lepidoptera and correlate with overall wing size, supporting the observed differences in scale length and width among families in this study (Kusaba & Otaki 2009; Sumah 2019; Rani et al. 2023; Sun et al. 2024). Additionally, comparative morphological investigations reveal species-dependent variation in scale size and shape, consistent with our findings of larger, more heterogeneous scale dimensions in Nymphalidae and Papilionidae versus more compact scales in Pieridae and small-to-medium scales in Lycaenidae (Sijina & Evans 2022).

Table 2. Morphological variation of wing scales across species.

	Family and species	Scale colour	Scale shape	Scale size (n = 3) (Mean ± standard deviation)		Number of serrations
				Length (µm)	Width (µm)	
	Lycaenidae					
1	*Catochrysops strabo*	Gray	Elongated	148 ± 16	36 ± 3	3
		Grayish purple	Elongated	91 ± 5	34 ± 2	1-3
2	*Flos apidanus*	Dark brown	Elongated	266 ± 60	68 ± 6	5
		Light brown	Elongated	182 ± 3	72 ± 3	1
3	*Miletus symethus*	Brown	Elongated	122 ± 13	39 ± 6	3-5
		White	Elongated	136 ± 20	43 ± 1	3-5
	Nymphalidae					
4	*Amathusia phidippus*	Brown	Elongated	207 ± 19	49 ± 4	2-4
		Cream	Elongated and rounded	148 ± 5	47 ± 5	3-4
5	*Discophora sondaica*	Black	Elongated	153 ± 15	63 ± 11	2-4
		Dark brown	Rounded	130 ± 5	72 ± 1	2-4
6	*Doleschallia polibete*	Black	Elongated	210 ± 19	66 ± 10	3-5
		Brown	Elongated	180 ± 14	94 ± 12	3-4

Table 2. Contd.

	Family and species	Scale colour	Scale shape	Scale size (n = 3) (Mean ± standard deviation)		Number of serrations
				Length (µm)	Width (µm)	
7	*Elymnias hypermnestra*	Black	Elongated and rounded	119 ± 23	53 ± 9	3-5
		Reddish brown	Elongated	160 ± 2	49 ± 3	4-5
8	*Elymnias nesaea*	Black	Elongated	145 ± 8	40 ± 3	3-4
		Green	Elongated	126 ± 1	38 ± 2	2-3
9	*Euploea climena*	Dark brown	Elongated and rounded	138 ± 5	33 ± 1	3-5
		White	Elongated	139 ± 1	43 ± 0	1
10	*Euploea eunice*	Blackish blue	Elongated	167 ± 1	45 ± 2	2-4
		White	Rounded	152 ± 31	87 ± 12	4-7
11	*Euthalia anosia*	Dark brown	Elongated	153 ± 5	49 ± 3	4-5
		Cream	Elongated and rounded	177 ± 43	62 ± 2	2-6
12	*Euthalia monina*	Brown	Elongated	160 ± 3	42 ± 5	4-5
		White	Elongated and rounded	138 ± 8	44 ± 4	2-5
13	*Hypolimnas bolina*	Black	Elongated	174 ± 11	43 ± 7	2-3
		White	Elongated	153 ± 3	75 ± 2	1-5
14	*Hypolimnas misippus*	Black	Elongated	148 ± 7	55 ± 0	3-7
		Orange	Elongated	136 ± 5	54 ± 2	1-4
15	*Junonia almana*	Dark brown	Elongated	116 ± 12	35 ± 4	3-4
		Orange	Elongated and rounded	137 ± 14	50 ± 2	2-5
16	*Junonia hedonia*	Reddish brown	Elongated	191 ± 26	68 ± 4	4-6
		Orange	Elongated	203 ± 12	76 ± 4	5-6
17	*Junonia iphita*	Dark brown	Elongated	167 ± 4	55 ± 2	3-5
		Brown	Elongated	182 ± 26	59 ± 4	4-5
18	*Lethe europa*	Brown	Elongated and rounded	143 ± 9	52 ± 3	4-5
		Cream	Elongated and rounded	142 ± 19	53 ± 4	4
19	*Neptis hylas*	Black	Elongated and rounded	157 ± 3	50 ± 1	4-5
		White	Elongated and rounded	122 ± 18	46 ± 7	4-5
20	*Phalanta phalantha*	Black	Elongated	86 ± 10	31 ± 4	3-5
		Orange	Elongated and rounded	104 ± 12	43 ± 11	1-6
21	*Symbrenthia hypselis*	Black	Elongated	113 ± 15	33 ± 3	3-4
		Orange	Elongated	137 ± 4	50 ± 7	4

Table 2. Contd.

	Family and species	Scale colour	Scale shape	Scale size (n = 3) (Mean ± standard deviation)		Number of serrations
				Length (µm)	Width (µm)	
	Papilionidae					
22	*Graphium agamemnon*	Black	Elongated	165 ± 10	66 ± 11	1-7
		Green	Rounded	127 ± 9	72 ± 5	1
23	*Graphium doson*	Black	Elongated	146 ± 15	47 ± 12	3-6
		Greenish blue	Elongated	162 ± 2	69 ± 6	1
24	*Graphium sarpedon*	Black	Elongated	131 ± 15	55 ± 10	3-6
		Greenish blue	Elongated and rounded	133 ± 4	48 ± 11	1
25	*Papilio memnon*	Black	Elongated	196 ± 24	61 ± 8	3-5
		Red	Elongated	185 ± 8	38 ± 4	2
26	*Papilio polytes*	Black	Elongated and rounded	105 ± 14	55 ± 9	4-5
		White	Elongated and rounded	152 ± 25	59 ± 7	3-4
27	*Troides helena*	Black	Elongated	191 ± 17	67 ± 9	2-5
		Yellow	Elongated	157 ± 16	50 ± 7	1
	Pieridae					
28	*Appias olferna*	Black	Elongated	120 ± 2	54 ± 1	3-4
		White	Elongated and rounded	94 ± 4	47 ± 5	3-4
29	*Catopsilia pomona*	Yellow	Elongated	171 ± 3	62 ± 4	3-5
		Greenish white	Elongated	124 ± 5	49 ± 2	1
30	*Delias belisama*	Black	Elongated	117 ± 13	47 ± 8	2-5
		White	Elongated	222 ± 2	38 ± 5	1-3
31	*Delias hyparete*	Red	Elongated and rounded	117 ± 3	45 ± 8	2-5
		Yellowish white	Elongated	110 ± 8	41 ± 2	2
32	*Eurema blanda*	Black	Elongated	102 ± 14	33 ± 11	2-3
		Yellow	Elongated and rounded	105 ± 6	32 ± 0	2-4
33	*Leptosia nina*	Black	Elongated and rounded	76 ± 13	29 ± 4	2-3
		White	Elongated and rounded	73 ± 13	35 ± 1	2-3

* n = number of scales measured.

Although wing scale morphology may not serve as a definitive taxonomic character at the family level, the observed variations remain critical for understanding structural colouration, thermal regulation, and ecological adaptation (Tang 2024). Furthermore, scale diversity reflects aspects of functional evolution, highlighting how microstructural traits contribute to survival strategies across butterfly lineages (Sijina & Evans

2022).

In conclusion, a total of thirty-three butterfly species from four families (Lycaenidae, Nymphalidae, Papilionidae, and Pieridae) were recorded. The results revealed distinct variations the number of serrations observed ranged from 1 to 7 per scale. In general, scales with broader basal regions tended to have a higher number of serrations compared to those with narrower bases. The structural and pigmentation characteristics of the scales demonstrated a strong correlation with wing coloration, which plays a vital role in thermoregulation and defence against predators. Darkly pigmented scales were predominantly elongated in form, while lighter or transparent scales exhibited a more rounded shape. Morphometric analysis further indicated size variation among species, with *Flos apidanus* possessing the largest scales and *Leptosia nina* the smallest. Future studies are recommended to include a larger sample size, to utilise scanning electron microscopy (SEM) for more detailed structural examination, and to investigate developmental processes related to scale formation and pigmentation.

AUTHORS CONTRIBUTION

H.M. conceptualised, collected the data, analysed, and supervised the study. A.N. carried out data collection and analysis. A.Q. validated and analysed the data. All authors contributed equally to the preparation and writing of the manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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